Las Cruces, New Mexico, U.S.A., October 14-19, 1990

6th International Conference on the Conservation of Earthen Architecture

Adobe 90 Preprints

A Note on the Cover

Historic photograph of Fort Selden courtesy of Museum of New Mexico State Monuments.

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Under the aegis of US/ICOMOS

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The Getty Conservation Institute
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—Neville Agnew
Conference Co-Chair for Publications

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Introduction

Neville Agnew and Michael Taylor

The 6th International Conference on the Conservation of Earthen Architecture is convening at a time of growing awareness worldwide of the need to protect our earthen architectural heritage. The collective body of knowledge developed since the first international meeting on this subject in Yazd, Iran in 1972 has contributed to a new appreciation of earth as a viable and appropriate building material, historically a medium of choice rather than necessity. This improved understanding has, in turn, helped to generate needed funds to support new frontiers of conservation research as exemplified in many of the papers presented for this conference.

This meeting has been dubbed "Adobe 90" informally, in recognition of the importance of earth as a building material in the Americas and, in particular, in the American Southwest where the conference is taking place. Organized under the auspices of US/ICOMOS, Adobe 90 offers a forum for the exchange of ideas, methods, techniques, and research findings among scientists and practitioners specializing in the preservation of this ancient building material. The thirty countries represented at the conference and the nearly eighty papers accepted for presentation and prepublication testify to the expanding interest in preserving earthen architecture as well as to the wealth of new work being undertaken worldwide.

Adobe 90 bears witness in many ways to the strides that have been taken since the last international meeting held in Rome in 1987. Two of that meeting's objectives were to promote greater collaboration among institutions on related research projects and to recommend future research directions in the preservation of earthen structures. The GAIA Project, the subject of a plenary address, illustrates the joint efforts of ICCROM and CRATerre-EAG to promote an integrated program of training, research, documentation, development of standards and technical cooperation at international, national, and regional levels. The mandate of the 1987 meeting also inspired the collaboration between the Museum of New Mexico State Monuments and the Getty Conservation Institute to study chemical consolidants and physical protective measures for historic adobes through field evaluation of test walls. This involvement was extended recently to include the United States National Park Service, Southwest Region. The progress of this testing program and preliminary results are documented in the Fort Selden papers published here. This project represents the kind of interagency cooperation that is necessary to bring large, multi-phased research projects to fruition. During the half-day session at Fort Selden, 25 km northwest of the conference site in Las Cruces, New Mexico, delegates have the opportunity to view the results of the project firsthand and to exchange insights and experiences with the researchers who designed the two test wall projects adjacent to the historic ruins.

The largest number of papers submitted concerns the history and traditions of earthen architecture. It is encouraging to see that almost every country represented at the conference has presented a paper on its regional and historical architecture. The picture that emerges here, more clearly than ever before, is the ubiquitous use of earth over the broad span of history and throughout the world, in Europe—England, France, Germany, and Italy—as well as in parts of North America such as New York State and the Dakotas, where the use of earth as a building material has not been fully recognized nor appreciated.

The papers concerned with history and traditions also contribute greatly to our awareness of the connections that can and do exist between present-day living communities and their earthen structures. These cultures are to be found in many parts of the world, including our host state of New Mexico, where the maintenance of earthen buildings is often a community activity that fosters cohesiveness and cultural identity. The parallels that exist with other communities on other continents—Zambia, Tanzania, Kashmir, for example, as portrayed in these papers—will surely lead to productive discussions among delegates. The continuity between ancient usage of earth as a building material and its importance in present times will be illustrated further by the acclaimed photographic exhibition "Spectacular Vernacular," which presents magnificent African ceremonial structures—initiation houses, kasbas, mosques—made of earth. This exhibition is displayed at the conference on loan from the Smithsonian Institution.

It is also important to highlight here the progress of seismic stabilization studies, particularly in South America, which includes both examination of traditional stabilization methods used on historic adobes and research into modern methods. The vulnerable condition of historic adobe buildings in California, which are damaged or destroyed with every seismic event, underscores the urgent need for retrofitting these structures—in ways that are affordable, sensitive, and minimally invasive—against further damage by earthquakes. In other parts of the world—Kashmir and Macedonia, for example—earthen buildings have demonstrated remarkable resistance to seismic effects, achieved through trial-and-error evolution of building practice, materials, and techniques.

The active debate concerning the benefits versus disadvantages of chemical consolidants applied to historic and archaeological earthen structures is also represented among the Adobe 90 papers. This debate has arisen, in part, because of the relatively short evaluation period for a variety of different chemical treatments under different circumstances and on earthen types with different mineralogical composition. Among the papers presented is a review of chemical treatments implemented at field sites up to twenty years ago. This developing body of information, together with continuing consolidation studies also documented here, will facilitate future decision making concerning the benefits, or otherwise, of chemical consolidants.

The susceptibility of earth and clay to the effects of weathering will continue to pose difficult technical problems in our mission to prevent deterioration. It can be expected that answers and solutions to these problems will be found over time. However, as borne out by the range of papers contained in these proceedings, the dimensions to be addressed also extend beyond the reach of technical expertise. It is our hope that the collaboration and contacts established at this conference, together with the new findings presented, will go a long way to further the knowledge of the conservation needs of our earthen architectural heritage.

Introduccion

Neville Agnew y Michael Taylor

La Sexta Conferencia Internacional sobre la Conservación de la Arquitectura de Tierra se lleva a cabo en un momento de creciente conciencia sobre la importancia de proteger nuestro patrimonio arquitectónico de tierra. Los nuevos conocimientos obtenidos desde la primera reunión internacional efectuada en Yazd, Irán, en 1972, han contribuido en gran medida a apreciar la tierra como material de construcción viable y apropiado y a dilucidar que históricamente, su uso responde a una elección deliberada y no a la necesidad. A su vez, la comprensión de este concepto ha generado el apoyo requerido para llevar a cabo nuevas investigaciones en materia de conservación tal como lo demuestran los numerosos estudios presentados en esta conferencia.

Informalmente, se ha denominado a esta reunión "Adobe 90", reconociendo la importancia de la tierra como material de construcción en las Américas y en particular en el Sudoeste de los Estados Unidos, sede de esta conferencia. Contando con el auspicio del US/ICOMOS, Adobe 90 proporciona el marco ideal para el intercambio de ideas, métodos, técnicas y descubrimientos de investigación entre científicos y especialistas dedicados a la preservación de este antiguo material de construcción. Los treinta países asistentes y los casi ochenta trabajos de investigación aceptados para su presentación y publicación confirman el creciente interés mundial por la preservación de la arquitectura de tierra y dan fé de la importancia de los nuevos trabajos emprendidos en el mundo entero.

En gran medida, Adobe 90 sirve como testimonio de los grandes logros obtenidos desde la última reunión internacional llevada a cabo en Roma, en 1987. Dos de los objetivos principales de dicha reunión eran promover una colaboración más estrecha entre las diversas instituciones involucradas en proyectos de investigación relacionados y recomendar directivas e instrucciones claras para la preservación de las estructuras de tierra existentes. El Proyecto GAIA, objeto de una sesión plenaria, ilustra los esfuerzos conjuntos de las organizaciones ICCROM y CRATerre-EAG con el fin de promover un programa integrado de capacitación, investigación, documentación y desarrollo de normas para la cooperación técnica a nivel internacional, nacional y regional. El objetivo de la reunión de 1987 sirvió de inspiración para la colaboración entre el Museum of New Mexico State Monuments y el Getty Conservation Institute a fines de estudiar consolidantes químicos y medidas de protección para las construcciones históricas de adobe a través de la evaluación "in situ" de muros de prueba. Recientemente, este esfuerzo conjunto se ha ampliado incluyendo la participación del National Park Service, Región Sudoeste de los Estados Unidos. El progreso logrado en este programa de experimentos y sus resultados preliminares se documentan en los trabajos de investigación de Fort Selden que se publican aquí. Este proyecto representa el tipo de cooperación entre los diferentes entes que resulta imprescindible a fines de lograr el éxito en toda actividad de investigación de múltiples etapas. Durante la sesión de medio día que se llevará a cabo en Fort Selden, a 25 kilómetros al noroeste de la sede de la conferencia en Las Cruces, Nuevo México, los delegados tendrán la oportunidad de apreciar los resultados del proyecto e intercambiar sus impresiones y experiencias con los investigadores que diseñaron los dos muros de prueba adyacentes a las ruinas históricas.

La mayoría de los trabajos presentados tratan sobre la historia y las tradiciones de la arquitectura de tierra. Resulta alentador observar que casi todos los países representados en la conferencia han presentado un trabajo sobre su propia arquitectura histórica regional. De esto se desprende más claramente que nunca, el concepto de que la tierra ha sido utilizada casi constantemente durante la historia de la humanidad y en todo el mundo, en Europa - Inglaterra, Francia, Alemania e Italia - y en varias partes de América del Norte, como los estados de Nueva York, y las Dakotas del Norte y del Sur, donde el uso de la tierra como material de construcción no ha sido apreciado ni reconocido en toda su plenitud.

Los trabajos presentados relativos a la historia y a las tradiciones contribuyen en gran medida a nuestro conocimiento sobre la relación, probable o real, entre la vida actual de ciertas comunidades y sus estructuras de tierra. Estas culturas existen en la actualidad en numerosas partes del mundo, incluyendo el estado anfitrión, Nuevo México, donde el mantenimiento de los edificios de tierra constituye frecuentemente una actividad comunitaria que fomenta la unión y la identidad cultural. Los paralelos trazados con comunidades de otros continentes - Zambia, Tanzania, Cachemira, por ejemplo - descritos en los trabajos presentados - provocarán sin lugar a dudas, discusiones productivas entre los delegados. La continuidad entre el uso de la tierra como material de construcción en épocas anteriores y su importancia en los tiempos actuales se ilustrará con mayor detalle en la exhibición fotográfica "Spectacular Vernacular" que presenta magníficas estructuras ceremoniales africanas - construcciones para ritos de iniciación, kasbas, mezquitas - construidas en tierra. Esta muestra se exhibirá durante la conferencia gracias a la gentileza de la Smithsonian Institution.

Es importante, también, recalcar el progreso logrado en los estudios de estabilización antisísmica, particularmente en América del Sur, que incluye el examen de los métodos tradicionales de estabilización utilizados en estructuras de adobe históricas y la investigación de nuevos métodos. El precario estado de las construcciones históricas de adobe del estado de California, constantemente dañadas o destruidas por la actividad sísmica, subraya la necesidad urgente de reforzarlas - en forma económica, prudente y con el mínimo de alteraciones posibles - a fines de protegerlas contra futuros terremotos. En otras partes del mundo - Cachemira y Macedonia, por ejemplo - las construcciones de tierra han demostrado una resistencia notable ante los movimientos telúricos, lograda aplicando el método de prueba y error a las prácticas, materiales y técnicas de construcción.

Entre los trabajos presentados en Adobe 90 algunos tratan la controversia entre los beneficios y desventajas de aplicar consolidantes químicos a las estructuras de barro arqueológicas e históricas. En parte, este debate ha surgido a consecuencia del relativamente corto período de evaluación de una variedad de tratamientos químicos, que bajo distintas circunstancias, fueron aplicados a tipos de tierra con diferente composición mineral. Entre los trabajos presentados hay una revisión de los tratamientos químicos implementados en diversos emplazamientos, algunos de ellos con hasta 20 años de antigüedad. La compilación de esta información, conjuntamente con los estudios de consolidación que también se documentan aquí, facilitarán las decisiones futuras relativas a los beneficios o desventajas de los consolidantes químicos.

La vulnerabilidad de la tierra y la arcilla frente a los agentes climáticos continuará presentando graves y difíciles problemas técnicos en nuestra misión de prevenir el deterioro de las estructuras de tierra. Con el correr del tiempo, hallaremos soluciones y respuestas a estos problemas. Sin embargo, como se desprende de la gama de trabajos presentados, los temas a tratar sobrepasan nuestra capacidad técnica. Esperamos que la colaboración y los contactos logrados en esta conferencia, conjuntamente con los nuevos descubrimientos presentados, logren ampliar nuestros conocimientos sobre las necesidades de conservación de nuestro importante patrimonio arquitectónico de tierra.

Introduction

Neville Agnew et Michael Taylor

La Sixième Conférence Internationale sur la Conservation des Architectures en Terre se réunit dans un climat de prise de conscience mondiale sur la nécessité de protéger notre héritage architectural en terre. La masse de connaissances accumulées depuis la première réunion internationale sur ce sujet, qui prit place à Yazd (Iran) en 1972, a contribué à une nouvelle appréciation de la terre comme matériau de construction viable et approprié qui, au cours de l'histoire, fut utilisé non pas par nécessité mais par choix. Cette meilleure compréhension a, à son tour, facilité la collecte des fonds nécessaires au financement de ces avant-postes de la recherche en conservation comme le prouvent les nombreuses communications soumises pour cette conférence.

Cette réunion a été familièrement surnommée "Adobe 90", en reconnaissance de l'importance de la terre comme matériau de construction aux Amériques, et plus particulièrement dans le Sud-Ouest américain où va se tenir cette conférence. Organisée sous les auspices de l'US/ICOMOS, Adobe 90 offre une tribune propice aux échanges d'idées, méthodes, techniques et résultats de recherches entre chercheurs et praticiens spécialisés dans la préservation de cet ancien matériau de construction. Le fait que trente pays y sont représentés et que presque quatre-vingts communications ont été acceptées pour leur présentation et pré-publication témoigne de l'intérêt grandissant porté à la préservation de l'architecture en terre, ainsi que de l'abondance des travaux nouvellement entrepris de par le monde.

Adobe 90 atteste amplement des progrès importants réalisés depuis la dernière réunion internationale de Rome en 1987. Deux des objectifs de cette réunion étaient de promouvoir une collaboration accrue entre les institutions travaillant sur des sujets de recherche apparentés et de recommander des directions futures pour la préservation des structures en terre. Le Projet GAIA, qui fera l'objet d'un communiqué en séance plénière, illustre les efforts concertés de l'ICCROM et de CRATerre-EAG en vue de la promotion d'un programme comprenant la formation, la recherche, la documentation, le développement de normes et la coopération technique aux niveaux internationaux, nationaux et régionaux. Le mandat de la réunion de 1987 inspira également la collaboration entre le Musée des Monuments de l'Etat du Nouveau-Mexique et l'Institut Getty de la Conservation en vue de l'étude des consolidants chimiques et des mesures protectrices physiques pour les adobes historiques par évaluation sur place de murs de test. Le Service des Parcs Nationaux des Etats-Unis, région Sud-Ouest, s'est récemment joint à cette association. Les progrès réalisés au cours de ce programme d'essais et certains résultats préliminaires sont documentés dans les rapports sur Fort Selden publiés ici. L'ampleur et le nombre des étapes nécessaires pour mener à bien de tels projets de recherche illustrent le type de coopération nécessaire entre les différents organismes intéressés. Lors de la demi-journée de travail à Fort Selden (à une distance de 25 km et au nord-ouest de Las Cruces, Nouveau-Mexique, lieu de la conférence), les délégués pourront se rendre compte d'eux-mêmes des résultats et auront l'occasion d'échanger idées et expériences personnelles avec les chercheurs ayant réalisé les deux murs de test adjacents à ces ruines historiques.

La majorité des présentations nous ayant été soumises portent sur l'histoire et les traditions de l'architecture en terre. Il est encourageant de voir que presque tous les pays représentés à la conférence ont fourni un article portant sur leur architecture régionale et historique. Il est de plus en plus clair qu'au cours des siècles la terre fut utilisée non seulement en Europe (Angleterre, France, Allemagne et Italie), mais également dans certaines régions de l'Amérique du Nord telles que l'Etat de New York et ceux des Dakotas, sans que ce fait ait été pleinement reconnu ou apprécié.

Il est également certain que les communications ayant trait à l'histoire et aux traditions contribuent grandement à notre prise de conscience sur les rapports étroits qui existent de fait entre les communautés contemporaines et leurs constructions en terre. De telles cultures existent dans de nombreuses parties du monde, y compris au Nouveau-Mexique, notre hôte, où l'entretien de bâtiments en terre constitue souvent une activité communale qui stimule l'esprit de corps et l'identité culturelle. Les parallèles existant avec des communautés situées sur d'autres continents (en Zambie, en Tanzanie et au Cachemire par exemple, tels que décrits dans ces articles) susciteront sans aucun doute des discussions productives entre délégués. La continuité qui existe entre l'utilisation de la terre comme matériau de construction dans les temps anciens et son importance actuelle sera en outre illustrée par l'exposition photographique renommée "Spectacular Vernacular", une magnifique présentation de structures cérémoniales africaines (maisons d'initiation, casbahs, mosquées) construites en terre. Cette exposition fut gracieusement prêtée à la conférence par la Smithsonian Institution.

Nous devons également mentionner les progrès réalisés dans les études de stabilisation sismique, particulièrement en Amérique du Sud, études qui portent aussi bien sur l'examen des méthodes traditionnelles utilisées pour les constructions historiques en adobe que sur la recherche de méthodes modernes. La vulnérabilité des bâtiments californiens historiques en adobe, endommagés ou détruits lors de chaque secousse sismique, souligne le besoin urgent de protéger ces structures contre tous dégâts additionnels par tremblements de terre d'une manière à la fois abordable, pratique et présentant un minimum d'interférence. Dans d'autres parties du monde (comme le Cachemire et la Macédoine), les constructions en terre ont fait preuve d'une résistance aux effets sismiques remarquable, résultat de l'évolution empirique de la pratique, des matériaux et des techniques de construction.

Plusieurs présentations d'Adobe 90 illustrent également le débat animé sur les avantages et les inconvénients des consolidants chimiques pour le traitement des structures historiques et archéologiques en terre. Ce débat est en partie dû au fait que la période d'évaluation des divers traitements chimiques dans des circonstances différentes et sur des types de terre de compositions minéralogiques variées a été relativement courte. L'un des articles présentés passe en revue les traitements chimiques mis en uvre sur place au cours de ces vingt dernières années. Les décisions futures relatives aux bénéfices éventuels des consolidants chimiques seront facilitées par l'accumulation continue des informations sur ce sujet et par la poursuite des études sur la consolidation qui sont documentées ici.

La susceptibilité de la terre et de l'argile aux intempéries continuera à poser des problèmes techniques ardus pour nos travaux de prévention de la détérioration. Des réponses et solutions à ces problèmes seront éventuellement trouvées. La variété des articles rassemblés dans ces comptes rendus prouve cependant que le domaine de ce débat s'étend au delà de la poursuite de l'expertise technique seule. Nous espérons que la collaboration et les contacts établis lors de cette conférence, ainsi que les résultats récents qui y seront présentés, favoriseront une prise de conscience accrue sur la nécessité de préserver notre héritage architectural en terre.

History and Traditions

ABSTRACT

This paper presents the first case study dealing with a type of house built with earth, called "casoni," that is found in northeastern Italy.

The topics discussed in this paper include typological and technological research, inventory methods, observation and classification of deterioration, and initial programs in conservation on buildings of this type.

KEYWORDS

Inventory methods, typological research, technological research, cultural heritage, restoration, adobe, Italy.

CONSERVATION DE L'ARCHITECTURE EN BRIQUE CRUE:LA RECHERCHE SUR LES"CASONI" DU NORD-EST D'ITALIE

Mauro Bertagnin
Faculté d'Ingegnierie
Université de Udine
Via Larga 42 33100 Udine /Italie
CRATerre

1.Introduction

Après le Colloque de Rome,suite à une série des"recommandations" parues dans les Comptes Rendus,s'est formé un groupe italien(1) pour coordonner recherches et action dans le domaine de la connaissance et conservation de l'architecture de terre en Italie soit au niveau archéologique soit du patrimoine bâti encore habité ou en voie de disparition suite à l'abandon des habitants. Durant ces deux années le groupe a mis au point une strategie d'action qui se déroule dans les secteurs suivants:

-Méthodes d'inventaire et recherches typologique et technologique du patrimoine existant,

-Histoire et évolution de la construction en terre en Italie et recherches sur les traités d'architecture en terre italiens(2)

-Observation et classement des pathologies des bâtiments ,analyses chimiques sur les terres et sur les enduits des maisons en terre et premiers programmes de conservation sur les typologies d'échantillons.

Parmi ces actions est présenté ici un premier cas d'étude qui concerne une typologie,le "casone",qui correspond à la totalité de la maison en terre au nord-est d'Italie.
En abordant la recherche,on a suivi la démarche méthodologique résumée dans les trois secteurs de la stratégie d'action envisagée pour une approche globale.

2.Une typologie archétype:histoire et données anthropogéographiques

Dans les études sur les types anthropogéographiques de la basse plaine de la Padanie(3),on reconnaît le "casone" de la plaine entre Padoue et Venise comme la plus ancienne forme de maison rurale,type hybride entre hutte et maison,que des peintres tels que Giovanni Bellini,Giorgione et Tiziano fixent dans leurs paysages(4).
L'intégration au site est assurée par l'utilisation du matériau même qui compose le site,la terre,et des autres matériaux tels que le bois de chêne pour la structure du toit et la paille ou la roseau des lagunes vénitiennes pour la surface extérieure des couvertures.
Cette forme archétype de maison dégage dans les plaines du nord-est d'Italie trois modèles de base:

-Le premier type est caractérisé par un plan qui naît du contact de deux parties de la maison,dont la plus petite contient la cuisine avec la cheminée.La forme et la volumétrie sont particulières,approchant celle d'une tente.
Ce premier type se retrouve dans la basse plaine de la région de Venise et quelques exemplaires existent aussi dans la province de Treviso,tout près de la plaine du fleuve Tagliamento.
Normalement ce type comporte un rez-de-chausée qui représente la partie habitée et l'étage correspondant à la grange.

-Le deuxième type présente une forme strictement rectangulaire, avec les pièces aux surfaces régulières.La pente du toit est inférieure à celle du premier type.

Ce deuxième type se situe dans l'aire ouest de la basse plaine du Friuli.
Le logis ne comprend, le plus souvent, qu'un rez-de-chaussée habitable, recouvert d'une toiture régulière à deux versants. La grange en bois peut correspondre à l'étage ou être réunie sur le côté nord du "casone".

-Un troisième type, n'étant pas bâti en briques de terre crue, mais homogène au point de vue typologique et morphologique aux deux autres a été considéré dans la recherche seulement comme extension architecturale et géoanthropique de l'habitat ancien dont les "casoni" représentent les exemples les plus intéressants.

L'ensemble de ces constructions rurales analysées présente plusieurs caractères communs. Effectivement il s'agit de maisons rurales d'assez petite taille, l'étage correspondant souvent à la grange, le plan général très simple, plus souvent rectangulaire avec des adjonctions (granges ou abris pour les outils).
Le toit joue un rôle de grande importance, soit pour la détermination de la volumétrie et par conséquent de la forme du "casone", soit pour la structuration du logis. On retrouve aussi une utilisation fréquente des mêmes matériaux tels que la terre crue pour les murs, le bois (chêne, sapin ou orme), pour les planchers et l'ossature primaire et secondaire du toit et poutres éventuelles, tuiles pleines et roseaux pour la couverture.

3. Inventaire et recherches typologique et technologique

Le patrimoine bâti des "casoni" ayant déjà fait l'objet d'une série de publications (5), on a pu aborder le problème de l'inventaire de tous les exemplaires aujourd'hui encore existants à partir des données déjà partiellement acquises et ensuite on a pu établir une démarche d'analyse raisonnée devant servir à la définition d'un premier niveau de stratégie de conservation à proposer.
Les relevés ponctuels sur le terrain et la construction de fiches typo-technologiques a permis d'identifier et classer tous les "casoni" encore existants et bâtis en brique de terre crue (adobe) correspondants à la totalité des bâtiments en terre du nord-est d'Italie.
Une fois vérifiés du point de vue quantitatif, les exemplaires encore existants appartenant aux deux premiers types et correspondant aux "casoni" bâtis en briques de terre crue (adobe), on a pu organiser un inventaire complet de l'existant et essayer de retrouver des analogies même au niveau technologique.
En effet pour la plupart des "casoni" du premier et second types, le troisième étant exclu de l'inventaire, on a pu vérifier une technologie du bâti constante, expression du savoir-faire local, fixée dans l'architecture vernaculaire locale.
Dans la plupart des "casoni" analysés, les fondations sont traditionnellement inexistantes. Pour bâtir les murs en "adobe" des "casoni", on a vérifié qu'une fois fixé l'emplacement où le sol était jugé stable, on tassait tout simplement le sol à l'emplacement du futur "casone".
Ce choix technologique a signifié, par conséquent, la création des soubassements, dont le rôle était celui de répartir les efforts de la charpente et des murs tout en les transmettant au sol.
Ce choix de réaliser des soubassements a aussi conditionné l'adoption d'une série d'autres matériaux tels que galets, pierres ou briques cuites nécessaires pour éviter aux murs en "adobe" d'être détériorés par les eaux de ruissellement ou par le rejaillissement des eaux de pluies tombant des toits sans gouttières.
Pour les "casoni" de la plaine vénitienne, on a vérifié l'adoption des briques cuites tandis que la pierre et les galets constituent la plupart des soubassements des "casoni" de la plaine frioulaine du fleuve Tagliamento.
Dans les deux types, on retrouve une variation de hauteur des

soubassements entre 80 et 120 centimètres.
L'adoption de murs d'une hauteur réduite(2 mètres ou 2,25 maximum) et l'utilisation d'un grand débord sont plus marqués dans les "casoni" du premier type.L'adobe étant très sensible à l'humidité et à l'érosion de la pluie battante et aux eaux dont le vent rabat quelquefois des toitures sans gouttières,ces choix de la technologie vernaculaire ont été très valables pour la durabilité des bâtiments en "adobe" analysés.
Les "adobes" utilisés dans la basse plaine vénitienne et frioulaine ont des dimensions peu variables la plupart étant faits avec un moule en bois,souvent le même utilisé dans les briqueteries de l'aire du "casone".Les épaisseurs des briques crues varient donc de 7 à 10 centimètres,la largeur de 13 à 16 et la longueur de 26 à 32 centimètres.
Par conséquent les murs analysés ont en général 40/45/50 cm.
Pour les murs extérieurs et les murs de refend peuvent,selon le cas,varier de 13 à 16 cm.,de 26 à 32 cm. et de 40 à 50 cm. selon les choix du bâtisseur. Les points d'appui de la charpente et les angles sont quelquefois faits avec des matériaux plus résistants,pierre et briques cuites dans la majorité des cas.
Des pièces de bois reposant sur les murs d'angle pour soutenir la poutre en bois d'arête ou une sablière pour répartir l'effort de la charpente sont d'autres éléments constructifs vérifiés dans la recherche.
Dans les couvertures on retrouve,au contraire,une différence entre le premier et le second types.
Le premier type étant conçu pour une couverture en roseaux et le second pour une en tuiles pleines,les deux pentes étant différentes,la structure en bois de la charpente est differente.
Pour les deux structures de la charpente,on a fait une étude approfondie sur le savoir-faire traditionnel concernant l'utilisation du roseau dans le premier type et sur les chevrons caractérisant le deuxième type.Pour ce dernier,le recouvrement de tuiles sur le faîtage présente une particularité due à une orientation particulière qui évite le soulèvement des tuiles par le vent.
Les bois employés pour l'ossature primaire du premier type sont normalement le chêne et le lattis varie entre le chêne,le châtaignier et le sapin.
Pour les mortiers et les enduits employés dans les deux aires où se situent les deux types analysés on utilise toujours un mélange de terre et de chaux,ou moins souvent de chaux et de sable.
En ce qui concerne la mise en oeuvre de la maçonnerie en "adobe", dans la plupart des cas,on a pu vérifier partout une régularité des lits successifs de briques et par conséquent une horizontalité généralisée qui témoigne dans le deux aires d'une bonne exécution et donc d'un art de la maçonnerie même de ces habitations pauvres dans le domaine rural.

4.Classement des pathologies

Le travail engagé à l'échelle régionale du Veneto et du Friuli, doit aboutir selon les objectifs des chercheurs à des plans d'action de conservation de ces derniers exemplaires(dans les deux régions ils ne sont qu'une vingtaine encore) d'une typologie et technologie en voie de disparition.
L'étude des pathologies de ces bâtiments et les solutions techniques pour un programme compatible de conservation représentent une autre démarche opérationnelle de la recherche.
On peut grouper les pathologies rencontrées au cours de la recherche par classes homogènes.
On a vu que les "casoni" sont situés dans des zones humides de la basse plaine du nord-est de l'Italie caractérisée par une remarquable pluviosité,ce qui signifie que ces bâtiments sont dans la plupart des cas affectés par la pluie et par l'humidité.On a déjà rappelé que la structure typo-technologique des "casoni" est conçue pour une défense contre les pluies (pentes et débord de la toiture, murs extérieurs bas etc.)mais malgré cela on doit enregister plusieurs dégâts à cause des

eaux ,des pluies et de l'humidité.
La pluie et le vent ont souvent provoqué l'érosion des façades et en même têmps créé des dégâts dans la structure en bois dus à son infiltration dans la couverture.
L'absence de gouttières est responsable d'un rejaillissement marqué sur le sol,qui cause,malgré les soubassements,des dégâts aux enduits comme aux murs.
C'est un processus progressif entamé par la pluie qui est responsable de la destruction de deux "casoni" dans l'aire frioulaine.
Cloques et décollements visibles sur les surfaces des façades, sont liés à des remontées capillaires dans les murs et surtout pour les "casoni" de la plaine frioulaine pendant les cycles de gel-dégel.
Une autre pathologie relevée dans l'analyse des deux typologies concerne les dégâts produits dans plusieurs "casoni" par le manque des chaînages puisque même dans le cas où les angles on été bâtis en brique cuite ou en pierre,ils sont désolidarisés du reste du bâti.
Des fissures dans la façade correspondant au point d'appui des chevrons sur le murs sont d'autres pathologies liées à la non adoption de la sablière pour l'appui des chevrons le long du mur et qu'on a pu vérifier dans certains cas.
En ce qui concerne la dégradation des enduits,on peut établir après la première partie de la recherche, que la plupart des dégâts signalés sont liés à deux genres de causes:viellissement des enduits par manque d'entretien ou mauvais dosage des enduits.
Dans la deuxième classe des pathologies on trouve surtout les essais d'entretien utilisant des matériaux tels que le ciment qui créent une dégradation de retour,causée par une mauvaise connaissance des réactions entre matériaux traditionnels et actuels.
Pour compléter les volets analytiques des pathologies,on doit aussi rappeler la dégradation des "casoni" non habités due surtout au manque d'entretien et à la perte de savoir-faire à construire des toitures en roseaux de la lagune, qui ne sont connues désormais que de quelques anciens artisans locaux(6).

5. Programmes de conservation

Les "casoni" comme on l'a déjà souligné représentent aujourd'hui les derniers types d'habitat en briques de terre crue existant au nord-est d'Italie et sont un petit nombre de bâtiments encore utilisés mais de toute façon en voie d'extinction.
Ils peuvent être sauvegardés avec un peu d'effort du point de vue économique et socio-culturel.
La plupart des"casoni" ont été améliorés et réhabilités par les habitants qui ont dans la majorité des cas gardés les caractères typo-architecturaux des "casoni",favorisant la conservation de ces bâtiments traditionnels dans le paysage rural.
C'est un devoir social que de conserver ces bâtiments sans les dépersonnaliser,d'aider à l'entretien approprié aux caractères architecturaux et technologiques de ces typologies archétypes de la plaine du nord-est italien.
On a déjà essayé de sensibiliser les institutions à l'aide au développement d'actions au niveau local et au financement par les organismes publics(Régions,Gouvernement etc.).
L'introduction de ce patrimoine architectural vernaculaire dans le registre des"architectures à sauvegarder",la création de deux petits parcs régionaux pour le "casoni",une série d'actions pour la valorisation du savoir-faire artisanal local et une parfaite connaissance de la technologie et de l'art de bâtir concernant les"casoni" sont les programmes d'action envisagés.
Pour ce qui concerne les solutions techniques appropriées pour la conservation de ces bâtiments,à côté des relevés complets de tous les "casoni" existants(soit à travers l'utilisation des relevés dejà publiés dans les livres concernant ces architectures ou par la réalisation de relevés manquants),on on a fait démarrer d'autres actions aujourd'hui en cours.
Les analyses chimiques des"adobes" des différents bâtiments

et des enduits utilisés dans les différents types,les analyses des sols,les inventaires des matériaux locaux employés et les premiers essais de conservation typo-technologiques d'un échantillon de chacun de deux types étudiés sont les actions programmées pour la sauvegarde d'un témoignage encore vivant de l'habitat en terre en Italie.

6.Conclusions

Les bâtiments en "adobe" analysés représentent un patrimoine architectural dont la sauvegarde est indispensable pour préserver les derniers exemples de maisons en terre dans le nord-est de l' Italie.
La méthode suivie est, à notre avis, extensible à d'autres cas et peùt contribuer à la sauvegarde réelle du patrimoine architectural en terre italien.
Une fois démarrées les actions envisagées on pourra effectivement compter sur une série d'expériences de référence valables pour une approche plus efficace à la conservation du patrimoine en terre italien.

NOTES

(1)Alva A.,Bertagnin M.(coordinateur),Bisconti G.,Chiari G., Galdieri E.,Laureano P.

(2)Voir Bertagnin M.,"L'architecture de terre en Italie:connaissance et réhabilitation d'un patrimoine typologique méconnu" et Galdieri E.,"Etat et futur des bâtiments italiens en terre:le cas du Piémont et de la Sardaigne" in Le patrimoine européen construit en terre et sa réhabilitation ,ENTPE,Vaulx en Velin, Comptes Rendus,1987

(3)Il s'agit de la plaine du fleuve Po,le plus grand fleuve italien

(4)Regardant les paysages des"Crocefissione"(Correr,Venezia) et "Allegoria sacra"(Uffizi,Firenze)de Giovanni Bellini,de la "Venere dormiente"(Gemalde Galerie ,Dresden)de Giorgione et "L'amor sacro e l'amor profano"(Galleria Borghese,Roma) de Tiziano on peut reconnaître le "casone" comme typologie dominant le paysage agricole du XVe Siècle,dans la plaine de la région de Venise

(5)cfr.Tieto P. I casoni veneti,Panda editeur,Padoue ,1979

(6)cfr. note 2

ABSTRACT

It is in the earthen architecture of the Chilean central region where we can find the values of a real vernacular architecture which displays a unique spatial and cultural quality.

Space and matter thus determine a specific architectural form constituting a valuable heritage which ought to be preserved as a genuine model of representation and extension over time.

It provides us with the architectural "type" springing from a set of formal variables and becoming a basic form which in being applied to a new project should keep its distinctive spatial features and values immutable.

The typology and language observable in the models under analysis would enable the proposal of a contemporany architecture based on the values typical of such vernacular architecture.

PALABRAS CLAVES

Historia y Tradición
Arquitectura Vernácular
Tipología y Modelos Espaciales reconocibles
Vigencia del Tipo
Propuesta de Preservación del Modelo
Propuesta de Proyección del Tipo

KEYWORDS

History and tradition, Vernacular architecture, Typology and spatially recognizable models, Validity of the type, Proposal for preservation of the model, Proposal for projection of the type.

ARQUITECTURA VERNACULAR DEL VALLE CENTRAL DE CHILE

Edwin Binda Compton
Martín de Zamora 4247
Las Condes - Santiago
Chile.

INTRODUCCION

El presente trabajo constituye el inicio de una amplia investigación que pretende demostrar la perfecta validez y contemporaneidad del modelo espacial que adoptó la arquitectura rural de tierra en el Valle Central de Chile desde las primeras manifestaciones de ocupación territorial pasando por los diversos siglos, desde la Conquista a la República.

El valiosísimo aporte que representa la tipología arquitectónica del modelo propuesto, se encuentra íntimamente ligada a la definición de "tipo" que da Quatrèmere de Quincy en su "Dizcionario Storico" (1): "la palabra "tipo" no representa tanto la imagen de una cosa que debe ser copiada o imitada perfectamente cuanto la idea de un elemento que debe servir, él mismo, de regla al modelo. ...El modelo entendido según la ejecución práctica del arte, es un objeto que se debe repetir tal cual es; el tipo es, al contrario, un objeto, según el cual cada uno puede concebir obras que no se parecerán en absoluto entre ellas. Todo es preciso y dado en el modelo; todo es más o menos vago en el tipo..."

Esta forma arquitectónica tradicional vernacular, se convierte así en elementos espaciales permanentes que definen de hecho, un valor patrimonial. La técnica y el material constructivo, tendrán sin duda un papel primordial que jugar, ligado lo anterior a los valores arquitectónicos que define formas en espacio y tiempo. "En la arquitectura actual, muchas ramas de su desarrollo se han apartado de las raíces primitivas. La falta de comprensión de los problemas fundamentales y la adopción de soluciones superficiales han conducido a la probreza de la construcción arquitectónica... Hasta el siglo actual el hombre construyó su hábitat, con materiales locales y de forma sencilla, natural y resistente. Las plantas eran directas e inequívocas, se basaban en exigencias y funciones, haciendo que el hombre se sintiera orgulloso de su ambiente." (2)

El surgimiento, por así decir espontáneo de las viviendas que se levantaban sin tener tras ellas ninguna especulación, siguiendo solamente los dictados de la tradición, la limitación o riqueza del material, las funciones que debían cumplir, produjo expresiones arquitectónicas locales que asombran por su variedad. En cambio, la vivienda producto de la especulación ha unificado las expresiones, perdiéndose ese gran atractivo que significa encontrar la manifestación genuina. Es por esto que nuestra arquitectura vernacular debe ser objeto de reflexión. Ella es la manifestación de una quizás no muy rica variedad de formas, pero es sabia en tanto corresponde a la expresión auténtica de un entorno y de un modo de vida particular.

"La Arquitectura del Valle Central de Chile ha recurrido como en toda civilización a condicionamientos espaciales que la han caracterizado, reflejando en sus formas y elementos, cualidades propias que la identifican. En ella no sólo hay una respuesta adecuada al medio geográfico natural, sino también al uso adecuado del material. El uso del adobe tratado tanto constructivamente, como en su distribución geométrica y espacial, nos permite sostener que su forma y calidad, obedecen a una condicionante espacial propia que la distingue y la define. Variados ejemplos podemos recoger en diversos autores y épocas, encontrando en ellos siempre un nexo que la identificará plenamente con nuestra idiosincrasia y estilo de vida". (3)

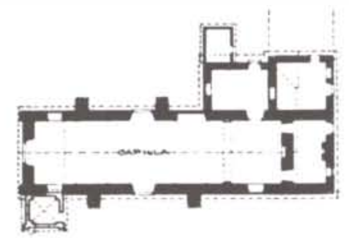
ARQUITECTURA RURAL DE LA ZONA CENTRAL DE CHILE

Tal vez las manifestaciones más interesantes de la arquitectura en Chile, por su sincera realidad local, sean los conjuntos rurales de la Zona Central.

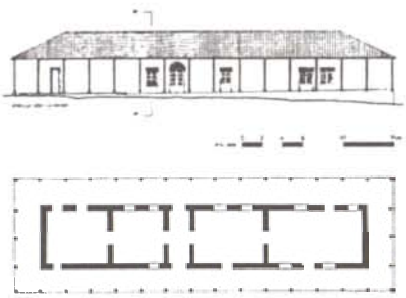
"Durante más de un siglo de soledad indiana, en un país casi sin núcleos urbanos, la única verdadera estructura caminera y territorial fue la rural que buscaba desesperadamente lograr un orden agrario, ocupando paulatinamente y en medida muy reducida, los valles transversales y costeros. Faltando aún ciudades y villas, casas patronales, caseríos y algunas aldeas, se ocupó este inmenso espacio, sólo en forma esporádica. Fue solamente en la segunda mitad del siglo XVIII que con la fundación de una larga serie de villas y ciudades alrededor del camino central, se creó una estructura agraria continua, permitiendo una colonización y explotación del Valle Central. Las casas rurales fueron adquiriendo siempre mayor importancia, manteniendo como una constante los conceptos formales y organizativos originales". (4)

Estos conjuntos rurales conformando haciendas son citados por destacados tratadistas extranjeros, como Angulo Iñiguez, Marco Dorta, Buschiazzo, Kluber, Wethey y Kelemen. Todos concuerdan en calificarla como el más interesante y completo exponente iberoamericano en su género, "conformando estos un capítulo fundamental de la historia de la arquitectura americana. Efectivamente, ningún otro

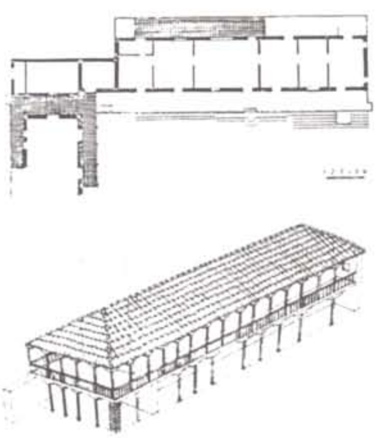
A. IGLESIA DE LA COMPAÑIA DE GRANEROS(20)



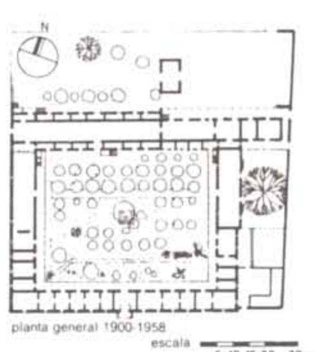
B. CASAS DE LAS AZULES DEL TABON (21)



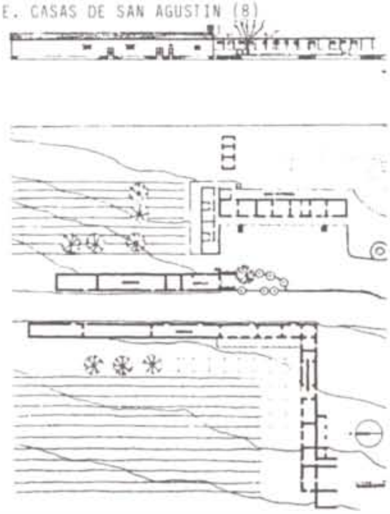
C. CASA DE LO MATTA (17)



D. CASAS DE LO CONTADOR (21)



E. CASAS DE SAN AGUSTIN (8)



país del continente presenta el caso de estas construcciones que se suceden contínua e ininterrumpidamente a lo largo de todo el territorio". (5)

En este Chile rural, las casas son un conjunto de edificios de apoyo a la faena rural, los caseríos y las aldeas se constituyeron los elementos reales de la ocupación territorial, y sucesivamente de su incipiente explotación.

Muchas de estas casas se iniciaron en plena Colonia y fueron centro de importantes núcleos agrícolas, conformando los principales hitos de nuestros primeros asentamientos desde Copiapó al Bío-Bío. "Una larga vivencia en una geografía a la que se van adaptando hombres y medios, donde se define un arte de vivir y permite concebir al pasado como origen de un saber habitar." (6)

La planta cuadrada fue el módulo básico y, por lo tanto, la más comúnmente empleada desde el siglo XVI hasta nuestros días, especialmente en aquellas regiones sureñas donde la frontera con las poblaciones indígenas se mantuvo hasta muy avanzado el siglo XIX. Otro tipo de planta usado desde el siglo XVIII, fue la "alquería", edificio de un solo cuerpo, pero en dos pisos, ocupando las bodegas el primero y las habitaciones el segundo, permitiendo con ésta conquistada altura, el dominio visual de las faenas agrícolas.

Una nueva tipología de arquitectura del Valle Central de Chile, surgirá a mediados del siglo XVIII para extenderse en el siglo XX. Serán las casas de enormes proporciones como San Vicente de Tagua-Tagua, Quinta de Tilcoco o San José del Carmen de Colchagua (El Huique), en las cuales casas y patios (algunas de ellas incluyen hasta quince de éstos) han conformado una extensión de unidades de adobe y tejas, formando llenos y vacíos que adquieren el aspecto de verdaderas casas-pueblos.

El profesor Romulo Trebbi del Trevigiano en su libro:"Desarrollo y tipología de los Conjuntos Rurales de la Zona Central de Chile, siglos XVI - XIX, (7) nos describe los tres conceptos formales y organizativos iniciales:

EL RELIGIOSO, en cuanto a su distribución pareciera originarse en la de un claustro o convento (b) EL MILITAR que se manifiesta en la solidez de los muros exteriores casi sin ventanas en la planta cerrada y en el uso de cuerpos altos y torreones, y finalmente (c) EL AGRARIO con el empleo de pórticos para las faenas, la importancia dada a las bodegas y corrales y la anexión de vastas explanadas para los trabajos.

La forma del complejo arquitectónico estará dada fundamentalmente por la explotación propia del Valle Central donde se emplean pórticos para protegerse del clima y para cobijar faenas de distinta naturaleza. Bodegas, corrales, llaverías, casas de inquilinos, capilla, se reunirán junto al patio o los patios de trabajo; sólidos muros de adobe cubiertos por grandes mantos de teja, serán los elementos que le darán el carácter de unidad espacial al conjunto.

DESARROLLO ESPACIAL

La casa tradicional de campo adopta desde su inicio hasta fines del siglo XIX diversas formas que explicaremos más adelante.

"Cada propietario o administrador principal, asumirá en su oportunidad la responsabilidad del arquitecto, utilizando espontáneamente (o quizás con determinantes establecidos por el lugar o las necesidades), tres tipos de espacios diferentes con los que organizaba el total del conjunto: las habitaciones, los corredores y los patios". (8)

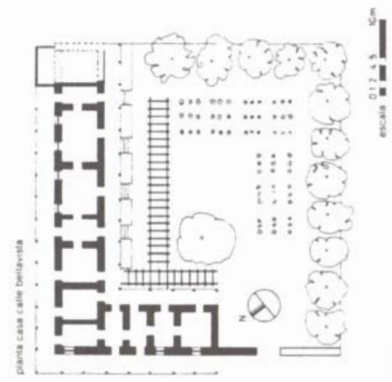
Los volúmenes presentan una rígida ortogonalidad, alternando espacios llenos y vacíos, representado por los sucesivos patios, ordenados casi siempre en cuadrículas, conectando todo lo anterior por amplios y largos corredores que permiten anexar todo el conjunto, solucionando así una alternativa de vinculación con características de espacio intermedio cubierto, pero abierto en uno de sus costados.

"En contraste con la variedad de dimensiones y ocupaciones de los patios de la Casa, sus espacios interiores son regulares, repetidos, salvo (si los hay) la capilla y las bodegas con recintos más amplios... los espacios interiores resultan muy semejantes entre sí, con anchos, largos y altos que no superan los 5 o 6 metros. Estas medidas establecen en cada Casa, una especie de módulo estructural que se respeta en toda la edificación, con raras excepciones, como en el comedor, en el salón, o en la sala de juegos, donde la longitud es mayor por ser estos lugares más representativos. Los dormitorios en cambio... tienen las mismas características y son multifuncionales" (9) admitiéndose con ello su calidad de diversidad de uso tanto en el espacio como en el tiempo.

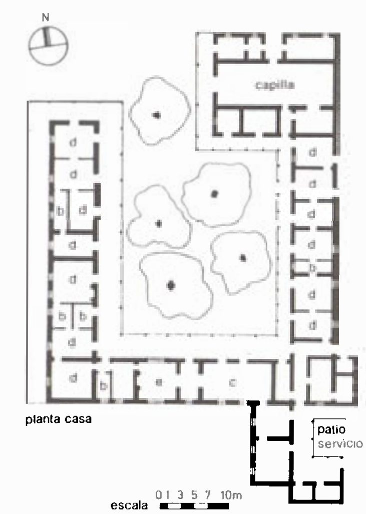
Lo esencial de la ordinación espacial de los conjuntos se expresa casi siempre en las siguientes constantes:

Un sentido del orden a partir de la ortogonalidad de la casa, se prolonga a la regularidad en los patios, los cuadros del jardín, el dibujo del huevillo en el suelo, los parrones, las calles y los caminos que llevan hasta los potreros cercados de árboles; formas claras que producen una gran armonía de conjunto dentro del marco general del Valle Central.

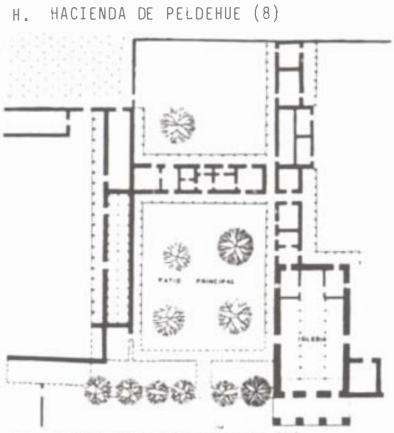
F. CASA EN PUEBLO DE MAIPO (21)



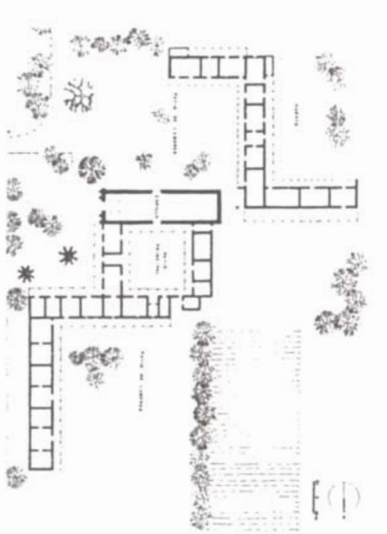
G. HACIENDA LOS LINGUES (21)



H. HACIENDA DE PELDEHUE (8)



I. HACIENDA QUERCHEREGUAS (8)



"Espacios interiores de la casa que no han sido creados para un fin determinado, semejantes en proporciones, iluminación y tamaño, la función que acogen les es indiferente, ora comedor, sala, habitación u oficina". (10)

Repetición longitudinal de un módulo que formando conjunto recto, es capaz de resistir en los dos sentidos los esfuerzos principales. Estructura racional de muros y contrafuertes para un territorio sometido continuamente a sismos. (45° constante en el cambio de giro de los muros).

"En una tierra de temblores constantes, serán necesarios muros anchos y de poca altura la mayor de las veces con contrafuertes laterales en aquellos cuyo largo es excesivo. Estas edificaciones se sostienen, más que por resistencia, por la estabilidad de sus apoyos; será frecuente que coincidan los muros transversales de los recintos para colaborar en el amarre y contraventación de las murallas longitudinales. Esta condición estructural sumada al concepto de casa fortaleza, se verán especialmente expresadas en líneas continuas de muros cerrados en los cuales se abrirán de trecho en trecho algunas ventanas y uno que otro portón principal; la greda cocida que se amoldará originalmente sobre el muslo de los operarios, serán a la postre los grandes mantos de teja que cubrirán finalmente la totalidad de la estructura". (11)

"Formas primarias de proporciones simples, fácilmente reconocibles. Volúmenes regulares, planos verticales e inclinados; llenos que predominan sobre los vacios, sucesión de pilares y de vanos. La luz anima la obra, los muros se iluminan, el sol marca la huella de la mano en el revoque de barro, textura que adorna la simplicidad de las superficies. La sombra se aisla en los vanos, en los aleros protectores y en la profundidad de los corredores". (12)

La homogeneidad del color en los muros donde predomina el blanco hace resaltar la masa del techo de tejas sobre la casa, el cual mantiene casi siempre la misma altura. Ocasionalmente presentará diversas alturas que no alterarán la homogeneidad del conjunto.

La repetición de vanos en los muros, la sucesión de pilares y vigas en los corredores; crean un ritmo ordenado que recorre toda la casa. El construir con adobe, teja de arcilla no impide que haya ligereza del conjunto, el gran peso del techo descansa en pilares delgados; junto a la macisez del muro trabaja la esbeltez de la madera.

Un paso gradual del interior al exterior a través de los corredores, patios, parrones y arboledas van abriendo progresivamente la intimidad de las piezas. Espacios intermedios que relacionan la pequeña escala de la casa con la gran escala del paisaje.

La conexión de los espacios interiores se produce normalmente en el centro de las habitaciones relacionando virtualmente todo el conjunto a través del eje central.

CONSTRUCCION Y MATERIALES

La característica constructiva de los volúmenes que componen las casas son estructuras de crujía simple con corredores a lo largo de sus costados en una u otra orientación, de preferencia norte y sur. Su cubierta de teja cocida a dos aguas sobrepasa con generosidad los bordes construidos.

Los materiales provienen en su mayor parte de la propia hacienda, son sencillos y familiares, son trabajados con herramientas tradicionales de poca elaboración.

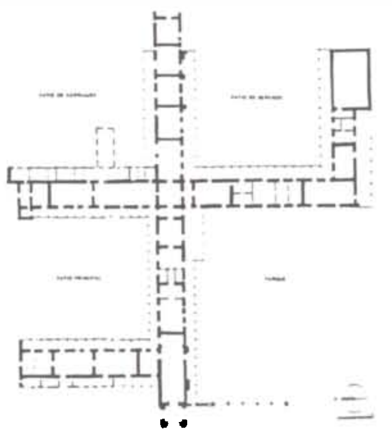
Piedra de bolón para los cimientos; muros de barro y paja; (adobe amoldado en el mismo sitio y el adobón que se construye al mismo tiempo que se fabrica el muro); madera para labrar vigas, costaneras, dinteles, soleras, pilares, canes sopandas y también para los centros de puertas y ventanas.

La arcilla cocida, es empleada en las tejas y ladrillo para los pisos. El polvillo, mezcla de arcilla fina, recubre el adobe tanto en el interior como en el exterior de los muros. Finalmente éstos son recubiertos por una capa de cal tiñendo de blanco los edificios, dándoles así unidad y buena apariencia al conjunto, todo ello dentro de una expresión sencilla, sin ornamentación que la identifique en tiempo y estilo.

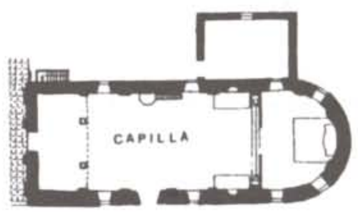
"Los muros de adobe periférico y los de refuerzo interior varían entre 0.80m. y 1.20 m., lo que asegura una excelente aislación térmica y acústica, generando un peso propio suficiente para resistir los esfuerzos sísmicos a condición de rigidizarlos a intervalos regulares con muros transversales y que la pesada carga del envigado, tijerales, ensordinado y tejas de la cubierta, no los desestabilicen" (13). Vanos pequeños, simétricos y no profusos en los muros, ayudan a los esfuerzos de tracción que pudiesen estar en algún momento sometidos.

Las técnicas empleadas para la construcción por los constructores anónimos, se encuentran sólo condicionadas por la tradición legada de generación en generación, así como también por el uso probado y popularmente aceptado de aquello que es útil y eficaz, sin vaguedad y que permite calidades probadas.

J. CHACRA LO VALDIVIESO (8)

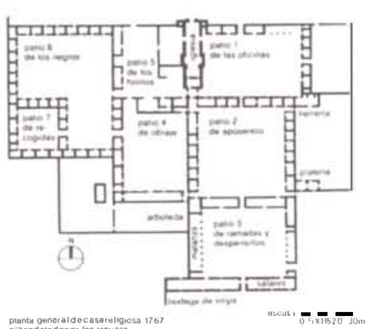


K I CAPILLA DE LO ARCAYA (8)

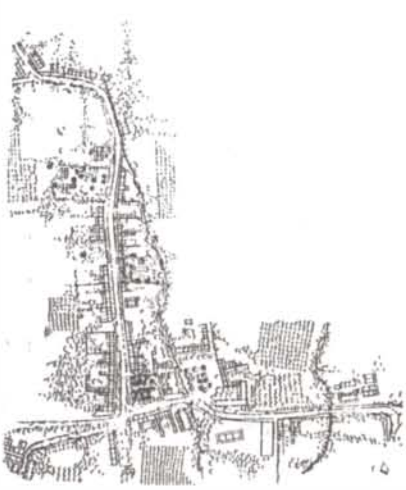


K II CABALLERIZAS DE ALCONES (18)

L. HACIENDA CALERA DE TANGO (21)



M. PUEBLO DE GUACARGUE (19)



SIGNIFICADO Y EXISTENCIA

Una de las características propias de la arquitectura vernácular es la persistencia en el transcurso y paso del tiempo, entendiendo todo ello como un espacio arquitectónico que conforma un ámbito de vida, de una sociedad determinada y que frente a las inevitables transformaciones cíclicas de la historia, pareciera querer brotar inesperadamente para controlar el destino.

"En su versión latina el término "VERNACULUS" significa, doméstico-nativo. A su vez doméstico nos lleva a la palabra DOMUS, casa residencia patriarcal y que nos recuerda el "dominicus", el señor de la casa, (el "PATER FAMILIAS") el usuario por derecho de tradición". (14)

Así la tradición vernácular nos transporta a la casa que encierra valores constantes de permanencia en el tiempo y en el espacio, en la cual, Señor, familia, propiedad, tierra y tradición se confunden con el habitar, donde todo aquello permanece inalterable y transmisible.

Una "FORMA" en el espacio que se traslada en el tiempo manteniendo el valor del espacio arquitectónico permanente; valores que hablan del momento del espacio como cualidad intrínsica de este "tipo" de arquitectura.

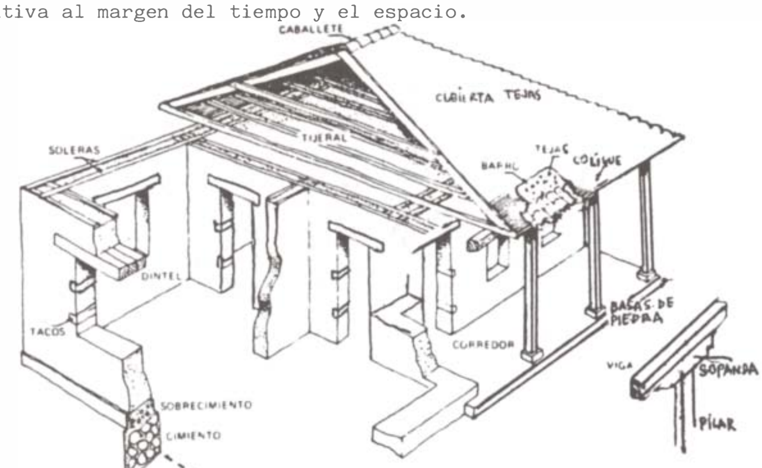
"Podemos considerar a nuestra arquitectura vernácula como una manifestación al parecer sencilla, generalmente simple en sus soluciones estructurales (y espaciales) y que sin embargo, se desarrolla sobre bases formales y conceptuales, ricas en soluciones diversificadas y hasta insospechadas que adquieren siempre una especial importancia histórica por ser el resultado de una tradición viva". (15) De esta manera su fuerza principal y vitalidad de persistencia arquitectónica pareciera ser entonces "la de preservar la memoria de los "tipos" lo que no es poco si pensamos que el principal problema arquitectónico es justamente aquello del génesis de las formas y de la relación forma-contenido" (16)

La lectura de la arquitectura vernácular constituirá un medio de reconocimiento de un panorama cultural que ha estado siempre presente como lo cotidiano; lo doméstico, aquello que tiene que ver con el uso diario y permanente, inmutable al tiempo y que permanece en la memoria de los hombres sin alteración y por lo tanto merece la permanencia en el espacio y aportando al hombre su "ser" cultural permanente.

La arquitectura vernácular, más allá de sus expresiones propias, nos llama a reflexionar acerca de los valores que el hombre contemporáneo va continuamente y sistemáticamente marginando, avanzando rápidamente a un desequilibrio cada vez más dramático entre el rítmo del progreso tecnológico y esa inevitable ansiedad de incorporarlo en la integración de una nueva personalidad de ser humano.

Es así que estas expresiones que llamamos vernaculares, espacios arquitectónicos, estructuras simples, materiales tradicionales, herramientas directas, parecen invitarlo a toda clase de esfuerzos para retomar el control de nuestro propio destino. En la casa tradicional de la Zona Central encontramos reunidas todas las consideraciones propias de lo vernácular que permitiría con las mismas formas espaciales, materiales y técnicas artesanales proponer un tipo de arquitectura que recogiendo valores patrimoniales proyecte la permanencia de estos valores, hoy.

En síntesis debemos reconocer que sin espectacularidades, el material de tierra, planteado con las características antes señaladas, tiene conferida una nobleza que se remonta al mismo origen de la habitabilidad y la ocupación del Valle Central, haciéndose por tanto merecedora de lograr su más genuina identidad en todo momento. Es más, es posible sostener que es allí, en esa determinada relación espacial-estructural, queda planteada una perspectiva de soluciones arquitectónicas diversificadas y hasta insospechadas, en una potencialidad creativa al margen del tiempo y el espacio.



N. PARTES CONSTRUCTIVAS PRINCIPALES DE UNA ANTIGUA VIVIENDA TIPICA DE ADOBE (23)

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TIPOLOGIA Y LENGUAJE DE LOS VALORES EXISTENTES (16)

A VOLUMEN UNICO — Ver plano A (20)

1) ESPACIO Un solo espacio rotundo, estanco. Entrada jerarquizada por un eje de simetría. Simetría y equilibrio otorgados por el eje central.

2) VOLUMEN Volúmen único, como portador de toda la concepción.

B VOLUMEN UNICO PERIPTERO — Ver plano B (21)

1) ESPACIO Espacio interior centralizado, eje central perforado, presencia del perímetro en toda su extensión que impide la anexión de nuevos espacios.

2) VOLUMEN Estructura períptera con volúmen único central. La primera definida por los pilares y la segunda por la masa.

C VOLUMEN DE ALQUERIA — Ver plano C (17)

1) ESPACIO Dos niveles; espacios interiores rotundos y estancos. Ordenación de "Alqueria". El espacio intermedio exterior está conectado en el 2º nivel.

2) VOLUMEN Unico en dos niveles escalera exterior conecta primero y segundo nivel. Sistema volumétrico permite una extensión orgánica.

D PLANTA CUADRANGULAR EN — Ver plano D (21)

1) ESPACIO Planta octogonal, cuadrado riguroso. Predominio de la linealidad en el orden del cuadrado y sus extensiones. Módulo básico y cerrado.

2) VOLUMEN Compuesto y orgánico permite su extensión en diversas orientaciones. Espacio definido por una estructura perimetral definida exterior y períptera interior.

E PLANTA RECTANGULAR LINEAL EN — Ver plano E (8)

1) ESPACIO La ley del desarrollo total está en la línea demarcando límite interior y exterior.

2) VOLUMEN Unico de simetría axial de ley de desarrollo formal en línea.

F PLANTA EN — Ver plano F (21)

1) ESPACIO Espacio exterior; no conforma cerramento; planta en "L" con un lado dominante.

2) VOLUMEN La disposición volumétrica formula dos espacios definidos, norte-sur; este-oeste. Sistema de circulación paralela privada y pública exterior. Sistema en "L" crea un espacio rotular estanco.

G PLANTA EN — Ver plano G (21)

1) ESPACIO Espacio interior rotundo, estanco. Espacio intermedio se propone como estructurador de la idea casa.

2) VOLUMEN El partido general es una "U" elemental enriquecida por la incorporación de la topografía. Perspectiva visual en apertura.

H PLANTA EN — Ver plano H (8)

1) ESPACIO El partido es una "H" con adosamientos de volúmenes varios y que genera todo el conjunto.

2) VOLUMEN Volumen compuesto; el patio central; permite el crecimiento orgánico en toda su extensión.

I PLANTA EN — Ver plano I (8)

1) ESPACIO Planta dinámica con un centro ortogonal que define el giro. La capilla y los volúmenes que conforman el nodo, permiten un patio interior.

2) VOLUMEN Volumen compuesto y tensional en diagonal.

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J PLANTA EN + Ver plano J (8)

1) ESPACIO Espacio de característica lineal; lo interior dentro de la casa y lo exterior abierto fuera de ella, creando patios abiertos.

VOLUMEN La disposición volumétrica formula dos espacios definidos, norte-sur, este-oeste con un encuentro en su eje central. Volúmenes adicionales a las alas principales, producen patios abiertos. Circulación del eje principal es periférica.

K PLANTA CURVA

I COMO OBRA INDIVIDUAL Ver plano K I(8)

1) ESPACIO Uno solo, rotundo, estanco.
Entrada jerarquizada que remata en el abside curvo.

2) VOLUMEN Volumen aislado que participa de un conjunto complejo y total.
Abside circular (semi-círculo) como remate del total del volumen

II COMO OBRA DE CONJUNTO Ver plano K II (18)

1) ESPACIO Un solo espacio central trazado en círculo; insinúa la "trilla" o el "rodeo", ambas fiestas de trabajo con animal.

2) VOLUMEN Circular formando un amplio patio central. Altura significativa volumen único lineal de vanos pequeños, ingresos e iluminación (caballerizas)

L PLANTA MULTIPLE (CASA PUEBLO) Ver plano L (21)

1) ESPACIO Conformación de infinidad de espacios abiertos que definen su propia especialidad con los mismos elementos tradicionales.

2) VOLUMEN Volumen complejo. El muro y la suma de patios interiores conforman el volumen total.

M PLANTA DE PUEBLO (CONJUNTO MULTIPLE) Ver plano M (19)

1) ESPACIO Conjunto que insinúa una unidad lineal. Se entiende como un todo conformado a través de dos ejes principales, norte-sur y este-oeste.

2) VOLUMEN Conjunto de volúmenes de características similares a los anteriores mencionados.
Se caracterizan por su angulación y reunión en angulo de 90º; Corredores y volúmenes que forman espacios abiertos y cerrados.

CONCLUSIONES

Humberto Eco sostiene en su "Introducción a la Semiótica" (22) "que el objeto arquitectónico puede demostrar la función o connotar determinada ideología de la función. El objeto de uso es, desde el punto de vista comunicativo, el significante del significado, denotando exacta y convencionalmente que es su "función", (el objeto arquitectónico denota una función).

La casa patronal que hablamos, reconoce en si misma un contexto de signos referibles a un código conocido con lo cual ella puede representar sin incomodar o innovar un habitat agradable y funcional.

Podríamos añadir que la forma arquitectónica puede también connotar otras cosas, en el caso de la casa patronal, connota la función "habitar" y que luego con el tiempo connotó además: "Familia", "Núcleo comunitario", "Núcleo de trabajo", "seguridad", "comunidad agrícola", "centro de la vida familiar", "núcleo de autosustento", etc. Siendo que la casa denota "utilitas" a los fines de la vida asociativa, no es menos cierto y de importancia que la valoración de connotación, que implica intimidad y familiaridad unidos a los valores simbólicos y existenciales y por lo tanto espaciales, son de notable importancia.

De este modo la casa campesina tradicional, que evidencia estas connotaciones simbólicas, se consideran funcionales no solamente en sentido metafórico, sino porque también comunican una utilidad social que no se identifica inmediatamente con la "función" en sentido estricto.

Cabe señalar finalmente que en los casos arriba analizados, encontramos bases espaciales y conceptuales ricas en soluciones diversificadas y hasta insospechadas que adquirirán siempre una especial importancia histórica y arquitectónicas dado el resultado de una tradición vigente.

ABSTRACT

In England adobe buildings are found only in East Anglia and were introduced around 1800. The distribution of the buildings and the possible geological influence are illustrated and the processes of manufacture and construction are outlined. The range of building types and the properties of the material are described as well as the present trends in conservation.

KEYWORDS

Earthen architecture, adobe, strength, conservation.

CLAY-LUMP THE ENGLISH ADOBE

Dirk Bouwens F.R.I.C.S.
Paperhouse
West Harling
Norfolk
NR16 2SF
United Kingdom

Introduction

The topography of the British Isles is remarkably varied. Changes occur every 70 km and in many places more frequently. The vernacular architecture changes in style and construction with the landscape.

There are clay buildings in several regions. These are of monolithic construction formed either by placing a mixture of clay and straw on the wall and paring the face level after the mixture has partly dried, or by placing the mixture between boards. The former method is known as 'cob' or 'wichert' and the latter 'shuttered or puddled' clay.[1] Adobe mud-brick construction is confined to the region of East Anglia in parts of the counties of Norfolk, Suffolk, Cambridgeshire, Essex and Hertfordshire[2] where it is loosely related to the superficial glacial deposits of chalky boulder clays (see Fig.1). These are up to 60 m thick over chalk sub-strata.[3] These clays vary in composition from chalk mud with pieces of chalk mixed in to clay with pieces of chalk varying in size from 1 mm diameter to over 25 mm diameter to clay containing a high proportion of sand with little chalk. Commonly the clay content varies around 15 percent of the total volume.[4] Suitable clays for making adobe occur elsewhere; why clay-lump, as this type of adobe is called locally, should be confined to one region is not known.

Fig 1
The areas of chalky boulder clay.

The main area where clay-lump buildings occur measures approximately 60 km square and straddles the Norfolk Suffolk border. Further west is another area about 45 x 15 km around the city of Cambridge. This area extends east into Essex. Further south are other areas in Essex (see Fig 2). Much work has still to be done in preparing the distribution map which is based on the writer's actual sightings and reports from several sources. The density of clay-lump buildings is highest in the centre of the main area, as is illustrated by the maps of the village of East Harling (see Fig 3) and the small town of Attleborough (see Fig 4).

Clay-lump was used in the construction of every type of building, from boundary walls and the smallest outbuildings to small houses and at Bridgham Hall Farm, (Ordnance Survey TL957 268) a large farmhouse. In between are thousands of small- and medium-sized houses built detached, in pairs and in terraces. All types of agricultural buildings were built of clay-lump, and farmers are still using barns 50 m long by 7 m wide. Shops and public houses built of clay lump are common. Clay-lump was used for schools like the one at Thompson (O.S. TL 923 966) and for vicarages and parsonages such as at Hepworth (O.S. 983 752). There were two tower windmills known to have been built of clay. At Carleton Rode (OS TM 099 945) the solid clay mill was 15 m high and

Fig 2
The general areas where clay-lump buildings are found.

Fig 3
East Harling (Population 2071) clay-lump houses shown shaded.

had five floors. It collapsed in 1958, one hundred years after it was built.[5] The clay-lump windmill at Attleborough (O.S. TM 053 949) collapsed in 1911.[6] Hingham watermill (O.S. TG 033 088) still stands and has been converted to a dwelling. The steam traction engine shed at East Harling (O.S. TM 995 882) was 30 m long 7.5 m wide and had walls 300 mm thick and 4.8 m high and was demolished in 1989.

In the centre of the main region of clay-lump construction, it is rare to find any buildings built between 1850 and 1900 which are not of clay-lump. Indeed for about 100 years clay-lump was the major walling material in this region and was still being used in the 1920s for public housing in a number of villages.[7] Clay-lump lost its supremacy to cheap mass-produced materials which were more durable and became more available as the motor lorry replaced horse-drawn transport.

Beginnings

John McCann has convincingly argued that clay-lump was introduced just before 1800.[8] He points out that whereas there are examples of buildings in other clay construction techniques from all periods, no clay-lump buildings before the early nineteenth century have been found. He also cites numerous writers who, in the first half of the nineteenth century, wrote in a way suggesting that clay-lump was an innovation. John McCann lists the reasons for the adoption of clay lump and expands on them:

> "1. The cottage movement stimulated an interest in low-cost construction combined with presentable appearance.
>
> 2. The rising price of timber provided an incentive to use alternative materials.

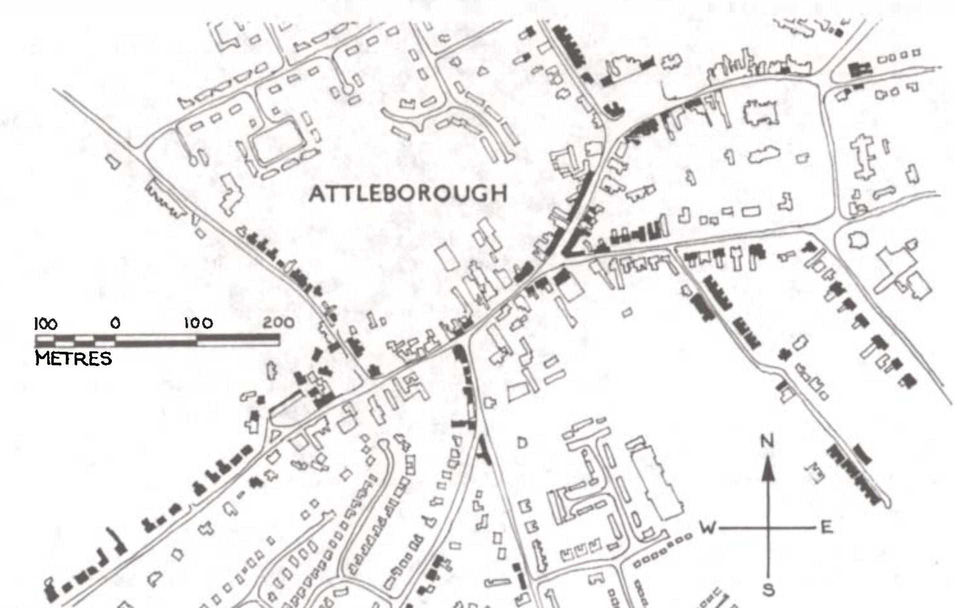

Fig 4
Attleborough (Population 7230) clay-lump houses shown shaded.

3. The tax on fired bricks introduced in 1784 provided an incentive to seek tax-free materials.

4. Technical literature on building with unfired earth was available in 1790 and in wide circulation by 1797.

5. Foreign and classical influences.

6. Agricultural improvements of the time required many new buildings in an area where other materials were expensive owing to poor transport facilities."[9]

Manufacture

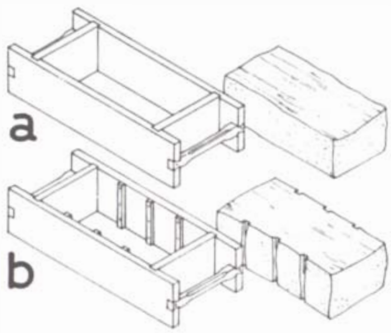

Fig 5
a. Clay-lump and mould

b. Keyed clay-lump and mould

The clay was dug as near to the building as practical. The clay for the council houses at Garboldisham and Attleborough was dug from what became the back gardens of the houses.[10] The clay for the council houses at East Harling was quarried a short way from the site just over the brow of a slight rise. Instead of following the road the tumbrils took the direct route across the fields.[11] The clay was often dug in winter to allow the frost to break it up, to let water get into it and to take advantage of cheaper labour.

The clay was laid on a bed of chaff or straw to a depth of about 225 mm.[12] It was covered with straw and 'trodden' by a horse, pony or donkey until the clay and straw were thoroughly mixed. Ray Shinfield who was a building worker until he retired seven years ago was sometimes employed to make a few clay-lumps for repair work by R Hogg and Sons, a firm of builders, of Coney Weston and to do this an octagonal banker of scaffold boards was filled with clay and straw and the horse was led by a man outside the banker while another man threw water on to the mixture. The clay was ready if it did not fall through the tines of a fork when lifted.[13]

The straw mixed with the clay was usually barley straw, although Mr Claude H Thompson who was over 90 and had seen clay-lumps made said dried spear grass (Agropyron repens) was considered best.[14] Other fibrous materials are also found but these probably got there by accident. The more chalk in the clay the less straw was used and the more sand present the more straw was used. Barley straw was cheap because the beard from the ears made it unsuitable for bedding animals. Harriet Sprigg, who during the 1970s largely rebuilt her clay-lump house and made the lumps that she needed, noted that the larger the proportion of straw in clay-lump the better it lasted when exposed to the weather. The straw may give some tensile strength to the clay-lumps when they are handled.

Moulding the clay was done close to the the treading bed. The moulds were bottomless wooden boxes with handles at both ends and could be made without nails (see Fig 5a). Some moulds were reinforced with iron straps fixed to the edges. If a key were required on the blocks, battens of wood were fixed inside the mould (see Fig 5b). The mould was placed on the ground, and the clay was placed inside the box, and packed into the corners with a shovel or fork, and scraped level with the mould which was immediately removed. Ray Shinfield dusted the inside of the mould with sand to prevent the clay sticking. Harriet Sprigg floated the moulds in water and used them alternately. The mould to be filled was placed close to the last clay-lump made. When the moulding was finished and the lumps had dried sufficiently they were turned on to their sides to prevent the blocks from distorting as the upper side dried. The clay-lumps would be turned again on to their ends and as soon as they were dry enough to be handled the blocks were stacked in open formation under cover to dry completely. Harriet Sprigg noticed that the lumps were most vulnerable from rain for about two days after they had been made. After that moderate falls of rain had no harmful effect.

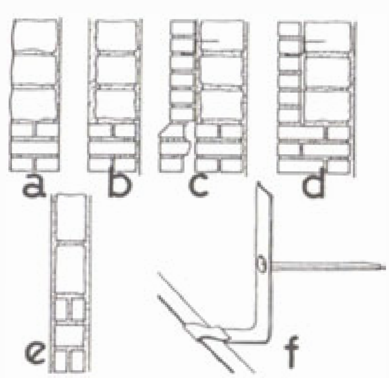

Fig 6
a. Tarred clay-lump wall plastered one side (section)

b. Clay-lump wall rendered externally, plastered internally (section)

c. Clay-lump wall with added brick facing (section)

d. Clay-lump wall built with brick facing (section)

e. 150 mm thick clay-lump internal wall (section)

f. Hoop iron tie (sketch view)

Construction

All external walls have a plinth between 150 mm and 1200 mm high (See Fig 6). The plinths are of brickwork or flint rubble and sometimes have a split flint facing. The purpose of the plinth is to check rising damp, however, its height seems to have been purely a matter of choice. The thickness of the plinth was equal to the wall or if there was a course of splay bricks at the top about 50 mm thicker. Load-bearing internal walls sometimes have no plinths. Partitions of blocks laid on edge have plinths of brick on edge tied together with cut bricks (see Fig 6e).

The mortar in which the clay-lumps were laid was usually composed of the same clay as the lumps, but with the stones removed. Mortar joints were between 12 mm to 20 mm thick. Hydrated lime ($Ca(OH)_2$) was sometimes added to the clay. Edward Skipper used a lime mortar for the council houses at Garboldisham because the blocks were not completely dried.[15] The blocks must be dry if clay mortar is used so as to absorb the moisture from the clay and prevent it from being squeezed out.

Openings were formed as work progressed, with door frames placed in position against which to build the lumps. Lintels were of wood and were between 300 mm and 600 mm longer than the width of the opening. In some houses it is clear that the windows were put in after the walls were complete, possibly to take into account any shrinkage in the clay.

Floor joists were built into the wall and bore directly on the clay-lump or on a timber plate or on a single brick. The wall plate at the top of the wall on which the roof framing bears is usually substantial - 150 x 100 mm is a common section.

Hearths on the ground floor are always of brickwork. On upper floors the openings are often of clay where a cast iron fireplace was fitted. Brick flues were always lined with clay because the condensates from the flue gasses attack mortar, and some flues were entirely of clay-lump. Above roof level, chimneys were always of brick.

Clay-lump requires a covering to protect it from the weather. Exposed clay-lumps gradually disintegrate at each frost. Water alone has little effect as the clay will absorb considerable amounts of water without damage, provided it can dry out. The most common surface treatment was tar, either coal tar (a by-product of gas and coke ovens) or hot bitumen. Both will craze as the oil in them evaporates, and these cracks allow moisture to escape. Although it is not used often on houses, tar is common on agricultural buildings and out-buildings and can be painted or rendered if sand is stuck to it while it is still wet (see Fig 6a).[16] Renders were originally made of the same clay as the clay-lump, with short straw and other fibres added. The clay is put on in two 9 mm thick layers inside and thicker externally. The first coat is scratched to form a key for the second coat and lime putty was used as a finishing coat inside and sometimes outside. Corners and reveals sometimes have wood beads. Lime-tallow paint provides a durable water-resistant finish which was applied directly to the lumps and over sanded tar as well as to renders. Nowadays cement renders laid on wire mesh fixed to the walls are used with modern waterproof paints instead of clay renders and limewash.

Many clay-lump buildings are faced with brickwork which was added to existing clay-lump houses over the original render (see Fig 6c). Hoop-iron ties fixed with 100 mm nails secured the brickwork to the clay-lump. The ties were bent over horizontal hoop-iron bands which were built into joints in the brickwork (see Fig 6f). Some houses were designed to be faced with brick immediately and have the facing brickwork bonded to the plinth (See Fig 6d). On the public housing in Attleborough (O.S. TM 038 947) the swan-necks of the cast-iron rainwater pipes are built into the brickwork which shows that the roof and gutters must have been completed before the brickwork facing was finished. Flint rubble with brick dressings was also used as facings. Research is hampered by the apparent similarity of such walls to walls constructed of solid flintwork.

A small number of clay-lump buildings still have roofs of thatch. Thatch was often replaced with fired clay pantiles which together with natural stone slates are the most common roof covering. Roofs on clay-lump buildings usually project over the walls and, because clay-lump gables are difficult to make stable, are often of low pitch or of hipped construction.

Properties

Clay-lumps were made in a number of sizes:

A. 65 x 90 x 215 mm
Similar to unburnt bricks except that the chalk in the clay would prevent its being fired.
Used on chimney stacks and as backing bricks to facing brickwork.

B. 140 x 140 x 295 mm
Found in a chimney stack.

C. 140 x 140 x 440 mm
Used to make internal load-bearing partitions at the public housing at Garboldisham and by Harriet Sprigg who could not lift larger blocks.

D. 140 x 215 x 440 mm
The universal block used to make walls 215, 140 and 440 mm thick.

E. 140 x 295 x 440 mm
Used to make walls 140, 295 and 440 mm thick.

F. 215 x 215 x 440 mm
Although this size has often been reported[17] The author has never seen one.

One clay-lump measuring 140 x 215 x 440 mm weighs about 25 kg or 1576 kg/m^3. That clay-lump can be used on edge or on bed suggests that there is no compression in the manufacture of the block.

The Department of Scientific and Industrial Research, Building Research Board recommends "a maximum compressive strength of 1.08 - 1.30 N/mm^2 ("10 to 12 tons per sq ft")".[18] Tests carried out at Norwich City College of Further and Higher Education on 5 October 1987 on four clay-lumps taken from an internal wall resulted in failure at an average pressure of 1.58 N/mm^2 (14.6 tons per sq ft). In order to obtain the samples which were tested two workmen working from both sides of the wall with 1.8 kg hammers and bolsters took 6 minutes to fragment one clay-lump. Nails driven into clay-lump like those which secure the hoop iron ties require a pull of at least 30 kg to remove them.

Lime was burnt locally from chalk which produced a mortar with a safe crushing strength of 0.5 N/mm^2 [X] clay-lump was therefore as strong as brickwork built with this mortar.

Conservation

The cob and wichert buildings of the southwest and the midlands are thoroughly surveyed and protected. The same cannot be said of clay-lump. Its conservation is a sorry tale of ignorance and neglect, although this situation is being changed through the work of a small number of people by means of lectures and the publication of articles. In the United Kingdom buildings are legally protected when included on the list of "Buildings of Special Architectural and Historic Interest".[20] A small number of clay-lump buildings are on the list but this is chiefly because of their architectural interest; very few are listed soley because of their structure. The demolition of the public housing at Garboldisham in 1987 and the traction engine shed in East Harling before they could be listed has resulted in other clay-lump buildings being listed. The authorities now seem much more responsive to the protection of such buildings.

The attitude of the mortgage companies has changed in recent years so now clay-lump houses are regarded as good security. This has helped change the commonly held view that clay-lump is an inferior material since public perception is based on the few dramatic collapses which do occur. In every case water had got into the clay and in several recent cases structural alterations were being made. Portland cement based renders crack and let water in but not out. Similar less marked effects are caused by modern waterproof paints.

In the case of brick faced buildings the hoop iron ties eventually rust and fail. The traditional repair is to replace the brick veneer. The patent devices for repairing similar defects in modern walls of cavity construction are effective on clay-lump walls.

The Society for the Preservation of Ancient Buildings set out the principles of the proper repair of clay buildings in 1929[21] but is only now in the process of preparing a leaflet on the subject. Cambridgeshire County Council has such a leaflet; other authorities expect to follow. The universities of Bristol, York and East Anglia have all included clay-lump buildings in conservation conferences.

Conclusion

The author's own work in preparing the distribution map is far from complete and only identifies the range of clay-lump buildings. Conservation can only be hit or miss until the number and density of the buildings is known. Nearly all clay-lump houses are lived in and the vast majority are owner occupied and will have a secure future when the public understands the different requirements by way of maintenance and repair. Agricultural buildings have a less certain outlook. The success of clay-lump as a building material in what might seem a hostile climate should encourage those concerned about the high cost of modern walling materials in terms of the energy consumed in their manufacture and distribution.

Acknowledgements

The author's research would be impossible without the kindness of many who let me into their houses and provided valuable information: Harriet Sprigg of Bridgham, Roper Reeve of East Harling, Roy Shinfield of Barningham, R V Ramm of Attleborough, Robert Hogg of Coney Weston, Claud Thompson of Besthorpe, Harry Apling of East Dereham.

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INSOLITA TRADICION DE TAPIAL EN CUBA

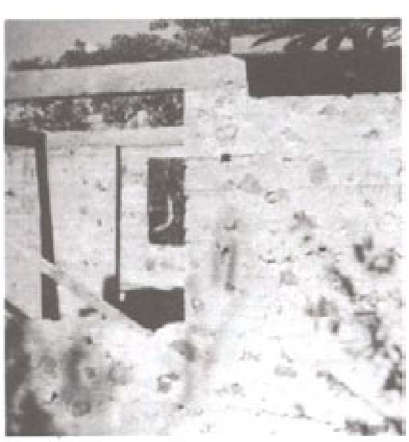
Arq. Francisco T. Casal Iglesias
Unión de Arquitectos e Ingenieros de la Construcción
Humbolt 104 Esq. A Infanta, Vedado
Ciudad de la Habana
Cuba

ABSTRACT

The paper deals with a carbonate-soil-based traditional building technique frequently used in one of the easternmost regions of the Republic of Cuba, its historical evolution, present situation, construction mistakes most commonly encountered and the most rational solutions for both buildings and maintenance. Emphasis is made on the economical and environmental benefits of this building technique for different kinds of architectural programs. The need to disregard certain subjective barriers regarding its use is also underlined, since weather proofing solves earthen architecture's most commonly signaled drawback. Recommendations for the extended use of this technique within and beyond Cuba are also included.

KEYWORDS

Compaction, crystalization, calcium carbonate "coco soil," blocks, manual press, earth, pisé, tamped earth



VIVIENDA DE "COCO"

Introducción

En la región de Puerto Padre, al norte de la provincia Las Tunas, al este de la Repúplica de Cuba, se construyen viviendas económicas y otras construcciones con una insólita técnica denominada localmente como obras de "cocó" o de mampuestos. Esta solución es similar al tapial ("pisé de terre") y consiste en la compactación de un material calizo, convenientemente humedecido, en forma directa en el muro con el auxilio de guarderas de madera o metálicas (Fotos 1 y 2). Determinados suelos calizos de la región, conocidos como "cocó", ofrecen un buen comportamiento constructivo, ya que sin ningún aditivo logran alcanzar después de diez semanas resistencias superiores a 26 Kg/cm2. Este endurecimiento se origina en la cristalización del carbonato húmedo consolidado en un proceso similar al de la formación natural de algunas rocas. Una vigorosa compactación es la condición básica para obtener la resistencia requerida capaz de garantizar un buen comportamiento ante el severo régimen de lluvias tropicales sin acudir a terminaciones como resanos y pinturas. Estas obras de "cocó" resuelven uno de los mayores inconveñientes para el uso de la tierra en construcciones que radica en su limitada resistencia ante los agentes atmosféricos. Es éste, el manido argumento que se le ha señalado casi a nivel ecuménico para limitar o rechazar el uso del más abundate y económico material de construcción: el suelo.

Características del Suelo Apto

Internacionalmente se conocen por suelos calizos los que presentan una alta concentración de carbonato de calcio ($CaCO_3$) en todo el perfil. Generalmente se trata de suelos jóvenes formados sobre calizas blandas y margas que han retenido un alto por ciento del carbonato de calcio, en algunos casos como partículas y fragmentos de rocas calizas, pero principalmente como carbonato de calcio gredoso o blando, más o menos disperso en la masa del suelo. En la zona en cuestión, los suelos pertenecen a la era geológica del neógeno. El "cocó" es un eluvio de caliza con igual o más del 70% de carbonato de calcio en su composición, libre de materias orgánicas, color blanco y olor característico cuando se humedece. En la región aparece como bolsones por debajo de la capa vegetal, y, en algunos casos, bajo formaciones rocosas calizas superficiales conocidas como "diente de perro" por su textura muy afilada.

Origen y Evolución

La incorrecta denominación de mampuesto nos ayuda a develar el hilo de su origen. Los legendarios muros de mampuestos han sido ejecutados con piedras irregulares unidas con un mortero de arena y cal. En Puerto Padre el más notable ejemplo de su uso el es

VIVIENDA DE "COCO" CON COLUMNITAS PREFABRICADAS

BOHIO

MAMPUESTO CON RESANO

Fuerte de la Loma (Fotos 3 y 4) construído por los españoles el siglo pasado como parte del sistema defensivo costero. El mismo fue recientemente restaurado y ostenta la distinción de Monumento Arquitectónico Nacional. Originalmente en él se empleó el "cocó" como elemento de unión de las piedras calizas lográndrose un hermoso efecto de color y textural rugosa uniformes (Fotos 5 y 6). Su curiosa volumetría exalta la fuerza contínua de los muros cilíndricos, con una expresión muy orgánica, a la vez sólida y desenfadada, como brotada de la loma, pues en su concepción general se emparenta más a las vanguardias del diseño contemporáneo, que al academicismo imperante en la época. También en el casco histórico del poblado abundan las construcciones de mampuestos, aunque siempre con las superficies resanadas y pintadas. Sin embargo el nuevo aporte constructivo aparece en las zonas campesinas. Allí se modificó la vivienda típica conocida con su nombre indígena: "bohío". Este se construía a lo largo de la isla aprovechando integralmente determinadas palmáceas, principalmente la palma real. El bohío se construía a partir de un esqueleto de palos redondos (varas) enterrados en el suelo, con una cubierta muy inclinada de hojas de palma (guano) y paredes con la corteza endurecida de su tronco (tablas de palma) o la resistente prolongación de la hoja que la fija al tronco (yagua). ¿Cuál tecnología apropiada desarrollaron los constructores campesinos? Tomaban el "cocó" que extraían de los pozos para el agua y la letrina sanitaria y con él levantaban los muros de su bohío con un espesor de unos 25cm, invirtiendo las proporciones del mampuesto, es decir, aumentando el aglomerante y disminuyendo las piedras que generalmente aparecían mezcladas en el suelo. Se introducen las guarderas de madera para conformar los muros. En algunos casos se combina con el esqueleto de palos redondos. Surgen los primeros bohíos de "cocó". La cubierta continua siendo el típico guano. Sus ventajas son sus mejores condiciones sanitarias y su adecuación climática, pues es tan fresco en verano como el bohío tradicional, pero resulta mucho más confortable térmicamente en el invierno. El "cocó" también es utilizado para consolidar los pisos de tierra.

Deficiencias y Mantenimiento

Su eficiente resistencia al intemperismo, como ya se ha señalado, depende de la compactación. En el año 1962, cuando un ciclón tropical de gran intensidad asoló la zona durante varios días con fuertes lluvias, pocos fueron los casos de colapso de estas construcciones. Sin embargo la acción combinada del agua y el viento debilitó las aristas de las ventanas y las esquinas, erosionó algunas secciones de los muros donde dejó la piedra a vista y sólo en muy pocos casos produjo ahuecamiento. Este comportamiento refleja sus dos puntos débiles; la falta de un diseño redondeado en las aristas y la dificultad en obtener una compactación manual uniforme debido a la técnica tan primitiva al uso, que no ha introducido pisones sino un madero corto. Véase erosionada una vivienda construída hace 20 años (Foto 7) con muros de 25cm de "cocó" sin resanar y techo de hormigón armado. El proceso de mantenimiento (Foto 8) acude a un simple mortero de

TEXTURA DEL MAMPUESTO

FUERTE DE LA LOMA EN PUERTO PADRE

arena y cemento que se adhiere sin dificuldad y recupera la forma perdida. Lo mas importante es que en ningún caso existen fallas de orden estructural que puedan provocar derrumbes. Esta es una vivienda atípica, pues ya es práctica generalizada proteger los muros con resanos o emplear una pintura cementosa.

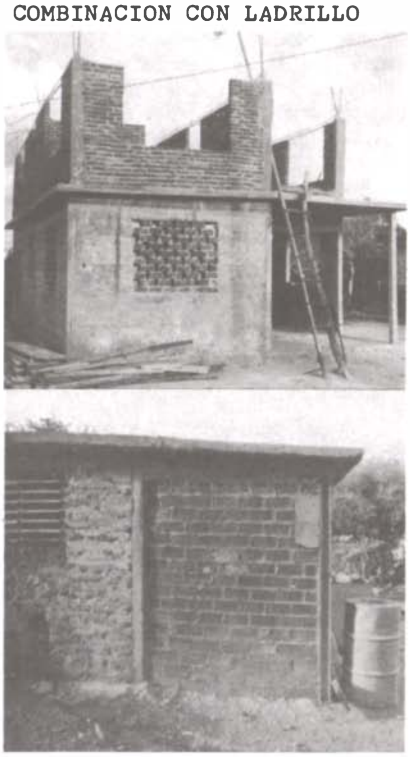
COMPACTACIONES DEFICIENTES

Un Nuevo Enfoque

En los últimos años se ha modoficado el uso de este material que consiste en su combinación con otros, principalmente columnas de 11 X 11cm producidas regionalmente según un catálogo nacional. Estas columinitas están concebidas para un prefabricado ligero donde se combinan con paneles de pequeña dimensión sin refuerzo para estructurar muros, cercas y similares. Ellas son colocadas en la esquinas (Foto 1 y 2) y en otras posiciones estratégicas. Las guarderas se sustentan sobre ellas manteniendo el espesor de 11cm. Una cuidadosa compactación permite inclusive mantenerlo a vista. Una variante de esta solución le añade una pequeña cantidad de cemento (3 a 4%) para aumentar su dureza. Con este nuevo enfoque, si bien se superan sus deficiencias mayores, continúa siendo un procedimiento sumamente agotador para el hombre. Por ejemplo, la compactación con pisones en la parte alta y final del muro después de varias horas de labor produce una gran fatiga física que atenta contra la calidad de la terminación. Aún así, se están construyendo numerosas viviendas en cooperativas y comunidades campesinas.

Otro enfoque muy curioso es la combinación aparentemente arbitraria con muros de ladrillos (Fotos 9 y 10). Siempre se mantienen las columnitas como elemento de transición y refuerzo de las esquinas. En el ejemplo de la biplanta donde emplearon el "cocó" en los bajos y el ladrillo en los altos; a contrapelo de la lógica constructiva, la solución es todavía más insólita. El constructor argumenta con la disponibilidad coyuntural de materiales, ya que tanto el "cocó" como el ladrillo debe trasladarse en camiones al lugar, y el resano final unificará el conjunto.

COMBINACION CON LADRILLO



Continuar Perfeccionando

Recientemente se ha experimentado con la fabricación de bloques compactos de "cocó" con muy satisfactorios resultados. Para su ejecución se emplea un modelo experimental de prensa mecánica de diseño cubano. Esta comprime con doble acción y su cofre es intercambiable lo que facilita ejecutar piezas de formas diferentes tanto compactas como ahuecadas. Se han obtenido resistencias siempre superiores a 30 Kg/cm2 después de las diez semanas. Su mayor ventaja radica en una major garantía de calidad, eliminación de las columnas armadas y la humanización de trabajo a pie de obra. También puede completarse su uso integral, pues la cubierta puede construírse con una bóveda de bloques convenientemente impermeabilizada. La cimentación con ciclópeo de "cocó" (mampuestos) completaría el esquema constructivo que obvia la viga de zapata y reduce el uso del hormigón armado sólo a la viga de cerramento superior.

EROSION EXTERIOR Y REPARACION CON MORTERO

Actualmente se ejecuta una vivienda experimental con este proyecto.

BOVEDA DE BLOQUES

Otros Programas Arquitectónicos

Hasta ahora su uso dominante se reduce a las viviendas económicas y algunos ejemplos de paradas de ómnibus y pequeños locales comerciales. No obstante, por sus indudables ventajas económicas recomendamos extender su empleo a otros programas afines como cabañas turísticas, pequeños moteles, locales, sociales y además en otras construcciones que demanda el agro: pequeños almacenes, cercas, canteros para hidropónicos, naves de cría y otros.

¿Inconvenientes?

El más peligroso inconveniente que debe enfrentar esta técnica es de orden subjetivo: es el prejuicio generalizado que asocia las obras de prestigio y calidad con las técnicas y materiales tradicionales, y considera las construcciones con suelo como precarias y, por tanto, sin prestigio. Razonamiento equivocado, ya que sus posibilidades constructivas permiten diseños de la mejor calidad tan imperecederos y válidos como el logrado con mampuestos en el Fuerte de la Loma. Por suerte en la región, ésta inercia subjetiva esta declinando, pero el "cocó" abunda en muchas otras regiones el país y resulta necesaria una inteligente campaña divulgativa para introducir su uso como una de las tantas soluciones constructivas disponibles.

Valoración Económica

Aventaja a las otras técnicas en uso por la sensible disminución de los costos provocada por los ínfimos consumos energéticos, la mejora del confort témrico de los espacios y la prácticamente inexistente afectación al medio natural. El costo de una vivienda de "cocó" se estima que es un 40% menor que una de columnitas y paneles. Quiere decir que con el presupuesto de tres viviendas se pueden ejecutar cinco de mejor calidad. Pero si la obra se realiza por autoesfuerzo las ventajas son superiores ya que el costo de materiales es reducido y si se emplea la cubierta en bóveda, la cantidad de cemento y acero es mínima.

Conclusiones

Continuar perfeccionando las técnicas en uso, insistiendo principalmente en la fabricación de bloques, las soluciones de cubierta y la disponibilidad de suelos aptos.

Generalizar estas experiencias a otras regiones del país que cuenten con suelos adecuados, estableciendo una inteligente campaña de divulgación.

También puede ser posible que estas técnicas sean del interés de otros países tropicales con los que estamos dispuestos a co-laborar.

UNA TECNICA ADECUADA AL TROPICO Y MUY ECONOMICA

ABSTRACT

1. Objectives:

   a. Collect the knowledge on "Earth Based" construction technology that exist in Antigua Guatemala as part of the culture inherited from generation to generation.

   b. Use this knowledge in current investigations.

   c. Combine and apply the knowledge to the restauration of colonial adobe buildings in Antigua Guatemala.

2. Methodology:

   a. Consult authors of previous "earth" architecture investigations.

   b. Contribute with personal experience from 10 years of field work in the restauration of the cultural heritage of Antigua Guatemala.

   c. Tests and essays on Granulometric Composition and general characteristics of earth materials.

3. Summary:

Adobe used in Antigua Guatemala Granulometric composition, general characteristics of earth material, construction systems, adobe in colonial buildings, deterioration agents.

4. Conclusions:

Intervention, preservation, consolidation, conservation, restauration, maintenance of adobe colonial buildings.

KEYWORDS

Mound of earth, adobe, wattle and daub, rammed earth wall.

RESTAURACION DE ADOBE EN EDIFICIOS COLONIALES DE ANTIGUA GUATEMALA

Mario Ceballos
Maestría en Restauración de Monumentos
Facultad de Arquitectura, Universidad de San Carlos
Ciudad Universitaria, Zona 12. Guatemala City.

1. Introducción

1.1 Justificación

La construcción de tierra sin cocer en Guatemala y en general en América data de épocas muy lejanas, incluso pre-hispánicas, existiendo hasta ahora vestigios arqueológicos muy importantes entre los que cabe señalar particularmente Kaminal Juyú en Guatemala, Chan-Chan, en Trujillo, Perú, Taos y Las Cruces en Nuevo Mexico y otras. Con la conquista del territorio por parte de los españoles, se incorpora a la técnica constructiva del viejo mundo, el uso del adobe y tierra sin cocer en edificios con las características propias de la cultura occidental como los del Manierismo y el Barroco.

Es por ello que consideramos sumamente necesario aportar todo conocimiento adquirido en los cursos de la maestría en Restauración de Monumentos de la Facultad de Arquitectura, de la USAC, a la restauración de un material que había sido utilizado tan eficazmente en Guatemala, y que continúa usandose, y se seguirá usando en el futuro por muchos años, lo cual justifica plenamente todos los esfuerzos de investigación que se hagan para mejorar la tecnología de Restauración de ese material.

1.2 Delimitación del tema

Estudiaremos en lo posible desde los tipos de suelo existente en Guatemala, su naturaleza, su composición granulométrica, así como las pruebas y ensayos para evaluar las características del suelo para hacer adobe o restaurar el ya existente.

También nos proponemos describir los sistemas de construcción de tierra sin cocer que se usan en Guatemala, como lo son el tapial, el adobe, y el bahareque.

Los materiales utilizados para construir con estos tres sistemas así como las causas de deterioro de los mismos. Y como conclusiones nos proponemos indicar cuales deben ser los procedimientos y las técnicas adecuadas para su conservación y los procesos de intervención.

1.3 Objetivos

El objetivo fundamental de esta investigación de construcción y restauración de ADOBE en edificios coloniales de la Antigua Guatemala, es recuperar en lo posible los conocimientos que sobre las tecnologias de tierra existen como acervo cultural de sus pobladores, sumando a ello los conocimientos tecnológicos modernos, para contar con técnicas mejoradas que permitan hacer intervenciones en los Bienes Culturales Inmuebles, sobre todo ante las contínuas acometidas telúricas, tan frecuentes en este país.

1.4 Metodología

La metodología a seguir esta basada en la investigación científica de varios autores, tanto nacionales como extranjeros que han dedicado horas de su vida a la Arquitectura de tierra. También aportamos de la propia experiencia en el campo ya que tenemos 10 años de ser restauradores de bienes culturales en la Antigua Guatemala y en el Interior del País, en donde hemos tomado algunos ejemplos gráficos asi como datos estadísticos.

2. Contenido:

2.1 Los sistemas constructivos de tierra sin cocer más usados en Guatemala y sus usos:

2.1.1 El tapial:

Este sistema consiste en apisonar tierra húmeda dentro de un encofrado de madera deslizante. Fue utilizado por los indígenas antes de la llegada de los españoles quienes ya lo conocían porque era utilizado con frecuencia en su tierra de origen. El tapial fue utilizado por los indígenas principalmente para muros exteriores de separación entre linderos, así como para construir murallas en algunas ciudades importantes, ya que se conocen ejemplos (Iximché, Gumarcah) en donde se alcanzan tres metros o más de altura.

En nuestros días también sigue siendo utilizado el tapial para construir paredes de colindancia. En los alrededores de Antigua Guatemala casí todas las fincas y propiedades principales estuvieron cercadas por muros de tapial que algunas veces tienen 0.80 metros de ancho por 2.00 metros de alto y con una cubierta triangular en la parte superior para protegerse del agua y que se llama "albardón". En algunos lugares de Antigua Guatemala también se conoce la utilización del tapial como relleno constructivo en muros de piedra combinada con ladrillos, donde algunas veces la estructura principal es una arquería y los muros de los rellenos son los tapiales.

2.1.2 El adobe o mampuesto:

Es probable que este sistema sea el más popular en la Antigua Guatemala y sus alrededores y el mas utilizado desde antes de la llegada de los conquistadores españoles hasta nuestros días. Consiste en la fabricación de mampuestos de tierra cruda. El nombre más popular es el de "adobe" en toda latinoamérica, aunque es de origen árabe. En el altiplano guatemalteco también se le conoció con el nombre de "chan".

La fabricación mas conocida de estos ladrillos de tierra cruda consiste en rellenar un molde de madera con barro, luego se desmolda y se deja secar durante cierto tiempo que varía de cuatro semanas a dos meses, según las condiciones atmosféricas.

En cuanto a las dimensiones más utilizadas, se han encontrado en Antigua piezas de 0.10 x 0.30 x 0.60 metros y de 0.10 x 0.20 x 0.40 metros. Su uso más frecuente es el de levantado de paredes de 2.50 a 3.00 metros de altura y se han dado casos de construcción de dos niveles.

Es de hacer notar que hasta hace algunos 10 años, el 75% de las viviendas en Antigua Guatemala y sus alrededores estaban construidas con mampostería de adobe (10).

2.1.3 El bahareque:


Casa construida con el sistema de BAHAREQUE, Chiquimula de la Sierra, Guatemala.


Casa de BAHAREQUE, Chiquimula de la Sierra, Guatemala.

El nombre de este sistema, muy conocido en Guatemala, también es de origen árabe y se popularizó mucho en la vivienda popular en las zonas de clima cálido debido a su fragilidad, ya que el techo permanece soportado por otra estructura.

En el área de Antigua Guatemala este sistema es utilizado con frecuencia para tabiques interiores de una construcción, ya que la estructura principal es por lo general un marco de madera o de caña. Existen dos variantes muy conocidas del bahareque:

1. El sistema de relleno de una estructura independiente de madera reforzada con alambres o cinchos de cuero, a la que solo se agrega el barro para formar el paramento; y

2. El sistema de una estructura de madera (piezas de 2" x 3") dentro de la cual se levanta con adobes puestos de canto (11).

2.2 Usos del adobe en edificios coloniales de Antigua Guatemala:

2.2.1 El tapial fue muy usado en los edificios coloniales en dos formas:

A. En muros de colindancia para separar propiedades en "muros de colindancia", "linderos" o "paredes medianeras" como se les conoce popularmente.

El sistema constructivo es el de apoyarlos en un cimiento de piedra, o un sobrecimiento y luego empleando moldes o formaletas rellenándolas con tierra apisonada hasta una altura aproximada de 3 varas castellanas (0.84) equivalente a unos 2.50 mts..

Actualmente se pueden ver todavía por toda la ciudad de Antigua Guatemala no solo en propiedades privadas, sino en los conventos y monasterios como por ejemplo en la Recolección.

B. Fue utilizada también como elemento de relleno en las grandes estructuras de paredes, o entre los marcos estructurales, formando un esqueleto de mampostería y rellenando con tierra apisonada, tal es el caso de la mayor parte de los edificios religiosos de la Antigua Guatemala. Contándose entre ellos la Recolección que tiene muros de 17 varas castellanas de altura (±15 mts.). Otro ejemplo muy a la vista es el de el convento del siglo XVI de San Francisco El Grande. Por abandono y falta de mantenimiento quedan al desnudo dichos tapiales.

2.3.2 Los mampuestos o adobes como se les conoce en Guatemala fueron utilizados más que todo en la construcción de muros de colindancia y en muros de carga pero en viviendas de tipo popular y también en la arquitectura vernácula.

En muchas ocasiones también se utilizó en la construcción de algunos edificios religiosos o en casas de 2 niveles pero se popularizó mucho este sistema sobre todo en el altiplano; como un ejemplo podemos citar la iglesia del cementerio de Chichicastenango dedicada al padre ROSSBACH.

2.2.3 El bahareque, más que todo fue utilizado en la arquitectura popular y vernácula para construir muros divisorios entre ambientes o bien en segundos niveles para "aligerar" la carga en el entrepiso.- También podemos decir que se extendió su uso en el altiplano aunque en el oriente y en el norte (Depto. de Chiquimula o el Petén) se utilizó como muros de exteriores de las viviendas a igual manera que los muros divisorios o de tabicación (ver fotos).

2.2.4 La Recolección de Antigua Guatemala:

Se utilizó como relleno en los esqueletos estructurales, aunque por el buen estado de conservación de los repellos es dificil distinguirlo, en los muros del convento o de la iglesia, pero su uso mas extendido fue en los muros perimetrales de la propiedad recoleta, ya que por azolvamientos continuos del río Magdales, el terreno se le ha visto constantemente inundado y los muros han sufrido muchas alteraciones causadas por las humedades y cuyo efecto ha sido la caída de los repellos afectándole directamente a los tapiales que se han visto afectados por todo tipo de agentes de deterioro.

La utilización de tapiales en la construcción colonial, Convento Franciscano del Siglo XvI, Antigua, Guatemala.

2.3.5 Agentes de deterioro:

- HUMEDAD O AGUA - POLVERULENCIAS - ESFOLIACIONES - INSECTOS - MICROORGANISMOS
- MACROFLORA - HUMANOS

3. Conclusiones:

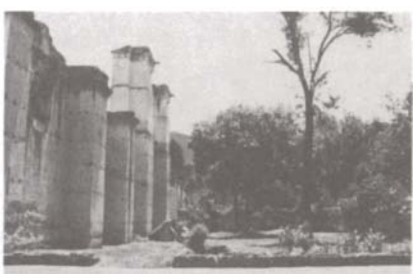
3.1 Procesos de intervención:

De acuerdo a las normas internacionales vigentes subdiviremos las intervenciones en tres grupos principales:
* PRESERVACION
* CONSOLIDACION
* CONSERVACION
* MANTENIMIENTO

La primera conclusión es detectar los deterioros, estudiando sus causas y dando un diagnóstico de que está sucediendo con el muro y por último dar su dictámen de como intervenirlo, de donde tenemos:

3.1.1 Preservación:

Es de suma importancia las labores de preservación de un edificio detectando inmediatamente cualquier alteración o deterioro y encargar al técnico adecuado o especializado para iniciar una intervención.



También en la Construcción de la Recolección, así como en muchas otras, muros de mas de 17 vrs. de alto, con Tapial.

La segunda conclusión es que una vez detectada y cortada la causa de deterioro, deberá hacerse la intervención adecuada para cada caso, mencionamos los más comunes:

a.- Repellos   b.- Muros sin albardón

a) Repellos:

1. Lo primero es establecer la proporción del repello original, es decir con que proporciones fue fabricado.

2. Se retira todo el material (repello) en mal estado o desprendido.

3. Se limpian con brocha o cepillo de fibra natural las superficies expuestas y toda la zona que va a entrar en contacto con el nuevo repello.

4. Se inicia la colocación del nuevo repello colocando una capa muy líquida que puede aplicarse con brocha como si se tratara de pintura, (se recomienda hacer esto principalmente en tapiales).

5. Se van agregando con cuchara las subsiguientes capas guardando similitud con el grosor del repello existente.

6. Se recomienda dejar alguna diferencia de textura entro lo nuevo y lo antiguo.

b) Muros sin albardón:

1. Establecer en que condiciones se encuentran las últimas hiladas de adobe, (si es tapial y existe alguna grieta, ver consolidación).

2. Si las hiladas se encuentran en mal estado, reintegrar con material fabricado en condiciones similares al existente y construirle cubierta que puede ser:
   - ALBARDON
   - DE TEJA
   - DE BALDOSA O LADRILLO

3.1.2 Consolidación:

Cuando un muro no presenta deterioros importantes o al contrario, que la ruina sea irreversible, estamos ante casos en que la tarea a realizar es una consolidación, esto quiere decir que dejaremos las casas "como están" no innovar, no arreglar, pero tampoco permitir destrucciones, es muy común usar estas técnicas en edificios que están restaurando.

La tercera conclusión es que la consolidación es posible efectuarla por medio de sistemas mecánicos y químicos; los sistemas mecánicos serán todo el aparato mecánico necesario para tener al alcance el objeto a restaurar, por ejemplo andamios, entramados, puntales, etc.

Los sistemas químicos pueden ser:

a. Productos industrializados
b. Sintéticos
c. de Laboratorio
d. Caseros (substancias naturales como: vegetales y animales)

a. Los productos industrializados:

1. Las resinas polivinílicas utilizadas desde hace ya más de 20 años en la consolidación de los pueblos indios del sur de E.E.U.U. pero que no dió muy buenos resultados.

2. Consolidantes Poliuretánicos, solubles en petroleo se han utilizado en Europa y Asia Menor, pero aún no se ha tenido un resultado 100% eficiente (12).

b. Los productos sintéticos:

1. En Mesopotamia se ha utilizado mucho en la decada de los 80 el Silicato de etilo, que penetra por capas sucesivas y va polimerizando. Es sumamente caro y se aplica en forma de fumigaciones, con bomba, (lo producen las firmas UNION CARBIDE y MONSANTO). Se recomienda tener cuidado con su uso porque altera el color de la pintura, y hay que tener mucho cuidado en presencia de pintura mural (12).


Construcción de dos niveles en el sistema de Bahareque, Santo Tomás Chichicastenango.

c. De laboratorio:

1. El profesor Giacomo Chiari del ICCROM (13) en investigaciones realizadas en el Perú llegó a la conclusión de que los adobes fabricados con caldos en vez de agua dieron como resultado piezas resistentes al agua.

d. Caseros

Es muy importante volver la vista atrás y recapacitar sobre el uso que daban en la colonia a ciertos elementos naturales que contienen substancias ligantes debido al contenido de savias y almidones, por ejemplo:

BANANA, COCO, BABA DE NOPAL O CACTUS, MAGUEY, LINO, PAPA, MIEL, LECHE Y ARROZ.

En muchos casos algunas de estas substancias producen por cementación procesos químicos ligantes, impermeabilizantes, repelentes de insectos, etc. (14).

Recomendación: Dependiendo del estudio de cada caso en especial y del material que se trate, así como del aspecto económico, se debe elegir el producto adecuado para cada intervención, dado a que en la restauración no se pueden dar recetas de cocina.

3.1.3 Restauración: Cuando haya que reponer partes caídas (Anastilosis) o deterioradas, o de integrar nuevos elementos, estamos ante una restauración de donde debemos de respetar los principios de homogeneidad y continuidad (15).

3.1.3.1 Humedades en partes bajas: Particularmente las arquitecturas de tierra son atacadas por el agua y las humedades por lo que tendremos problemas como los siguientes:

- Malas condiciones Hidrófugas: Puede ser que no exista ninguna capa aisladora o solera de humedad por lo que pueden hacerse cortes horizontales por segmentos a manera de integrar una nueva solera hidrófuga, que puede estar echa a base de materiales eficaces para el aislamiento del agua, (por ejemplo adobes impermeabilizados). En tapiales tener el cuidado de hacer el corte coincidiendo con las capas de fabricación. También pueden usarse algunas técnicas como las mencionadas en el inciso anterior (substancias químicas y sintéticas) pero tener mucho cuidado porque como ya se dijo estan en fase experimental y son demasiado onerosos.


Construcción de adobe, como arquitectura vernácula en una población del Altiplano, San Andrés Xecúl, Totonicapán.

- Humedades Interiores: Por la cubierta; cuando son provocadas por filtraciones en la cubierta, lo primero es detener esta causa reparando el techo y luego intervenir el muro haciendo las actividades que sean necesarias dependiendo del criterio del arquitecto restaurador.

- Fisuras y Grietas: a) Si es una fisura probablemente desaparecerá al detectar la causa, pero muchas de ellas siempre subsisten aunque pueden ser rellenadas con un mortero de arcilla similar al utilizado originalmente. b) Si es una grieta más profunda y atraviesa de lado a lado la pared se recomienda quitar los mampuestos que sean necesarios y reintegrarlos nuevamente pero colocándolos en la posición de punta y soga si fuera posible. c) Si es un tapial, puede remendarse con mampuestos de adobe si las dimensiones lo permiten y si no, cortar lo necesario y reintegrar con material similar en proporciones al material original.

d) Perforaciones de insectos y erosiones:

* Si es en mampostería o aparejos, retirar piezas destruidas y reintegrar nue-

vas manufacturadas en condiciones similares a originales.
* Si es en tapial cortar el espesor que sea necesario empezando de abajo hacia arriba y reintegrar con mampuestos de adobe o bien, si es posible, colar y apisonar nuevamente con material similar al original.

3.1.4 Mantenimiento: El mantenimiento es necesario para evitar que el edificio se deteriore por lo que se recomienda mantener atención entre otros a:

a) Encalar periodicamente los muros.

b) Hacer drenas en los muros cuando se notan humedades.

c) Cuidar los albardones de los muros para evitar entrada de humedades.

d) Revisar los techos sobre todo antes de cada invierno para ver si no hay tejas rotas en los tejados.

e) Fumigar contra insectos y plagas.

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EARTH USED FOR BUILDING IN THE HIMALAYAS, THE KARAKORAM, AND CENTRAL ASIA - RECENT RESEARCH AND FUTURE TRENDS

Anne Chayet, Corneille Jest* and John Sanday
23 Quai le Gallo
Boulogne 82100
FRANCE

ABSTRACT

The use of earth, as either rammed earth (pisé de terre) or sun-baked bricks (adobe), is characteristic of the Himalaya/Karakoram range and central Asia. Earth is combined with timber and stone as the major construction material used in this area. Examples from archaeological excavations dating from 7000 B.C. demonstrate the importance of this construction technology. Methods of adobe and pisé construction are described and comments made on the variations in application of techniques and their geographical distribution.

A multi-disciplinary approach involving archaeologists, historians, architects and craftsmen will help identify conservation methods for earthen structures and enable the decision makers to incorporate these methods and appropriate technical information into new construction as well as the preservation of historic monuments and sites.

KEYWORDS

Adobe; Archaeology; Central Asia; Himalaya; Karakorum; Pisé de Terre; Tibet.

Fig. 1. Map showing the region of Tibetan civilization

Introduction

The use of earth for construction either in pisé de terre (rammed earth) or adobe (sun-baked) bricks is common throughout Central Asia, especially in the provinces of West China, Xinjiang, Quinghai, Gansu, Sichuan, Xizang (the autonomous region of Tibet) and in the highest regions of the Himalaya Karakoram range, located 70 to 110 degrees east longitude and 25 to 45 degrees north latitude (1) (see fig. 1).

The absence of other suitable building materials has caused man to use earth as a means for construction over a period of many centuries. Archaeological excavations have shown structures in rammed earth dating from as early as 7000 BC (2).

The latest information concerning adobe technology can best be demonstrated by using the method of house construction in Tibet as an example. Different examples will show the diversity of technology to be found in these regions.

The principles of construction, as well as the type of material used, provide a link for the architecture of this region to that of the ancient middle eastern civilizations of the 6th century BC in the Achemenide Period around Persia, which in turn has influenced India on one side and Central Asia on the other.

Techniques of Construction for a Tibetan House.

The structural module of a Tibetan house is established by four load bearing walls, positioned at right angles to one another, which support a flat roof of rammed earth, laid over unhewn timbers. This module can be expanded both horizontally and vertically as necessary. Generally, the houses have two floors and a terraced roof (3).

Religious rituals precede all construction. Using astrological forecasts as a guide, a site is checked to see that it is not contaminated with evil spirits and is not inhabited by earth deities (4).

1. Foundations and walls

The foundation trench is excavated according to the existing conditions of the terrain and the intended height of the building. There is never a basement and the foundations are constructed of rubble stone when it is available.

As opposed to the methods of construction generally used in China where a timber structural frame is employed (5), the adobe brick walls in this example are load bearing. The wall thickness is dependent on the type of load transferred from above. As rammed earth and adobe have a tendency to compact under heavy loads, the wall bases are thicker and, wherever possible, earth

Anne Chayet
Charge de Récherche
Center National Récherche Scientifique (CNRS)
CNRS/URA 1229 "Langues et cultures de l'aire Tibetaine"

Corneille Jest*
Directeur de Récherche, CNRS
GRECO Himalaya Karakoram

John Sanday
Conservation Architect
Getty Grant Program
Architectural Conservation Grants

*Author to whom correspondence should be addressed.

Fig. 2. Bhutan, process of constructing "pisé de terre".

construction is replaced with stone. In addition, because of the mud mortar's lack of cohesion and the fragility of the adobe brick structure, vertical loads cause the structure to buckle at its base and for this reason, the lower part of Tibetan buildings are heavily buttressed. Alternatively, the walls may be battered approximately 3 to 6 degrees on the outside, thereby providing more resistance to earthquakes and producing a silhouette characteristic to all Tibetan buildings.

2. Rammed Earth

Tibetans consider this form of construction as the oldest, simplest and cheapest of building techniques. It is widely used throughout Tibet as well as in some regions on the southern slopes of the Himalaya such as in Bhutan where conditions are slightly more humid. The method of construction is similar to that used in Western Europe.

A clay-based soil is wetted and worked by foot. Aggregate is often added to the mix. Two planks are set on edge on top of the foundation and held in place by wooden poles driven into the ground. Wooden cross bars set between the planks establish the width of the wall which is usually between 60 and 90 centimeters.

Teams of women place the prepared clay between the planks and ram it with wooden rams, beating in time to the rhythm of traditional songs (see fig. 2). After two or three hours the planks are struck and reset at a higher level and the process is repeated (see fig. 3). The junction between these lifts or layers, as well as the holes created by the cross bars, becomes a decorative feature on the building.

In the meantime, carpenters prepare the timbers for the doors, windows, and floors (see fig. 4). Doors and windows are prefabricated on site, erected in position as the construction progresses and are built in place. In some regions it is customary to place one long timber lintel at the correct level in the wall and to cut the necessary doors and windows out of the walls below the lintels.

Fig. 3. Setting the planks.

3. Adobe or Sun-Baked Bricks

Adobe bricks are always made close to the building site and the matrix is prepared by trampling the mud under foot. Gravel, grass, or straw can be added to the matrix. The mold is a wooden frame that is 35 x 18 x 16 centimeters with extended sides, one of which is removable to enable the brick itself to be freed. After placement the bricks are removed from the mould and three days later placed on edge to help with the drying process. Placing the bricks on edge minimizes the bricks' exposure to the sun, slows down the drying process, and therefore prevents cracking (6). The first layer of bricks are placed as "headers" and the mortar joints between the bricks are the thickness of a finger. The next course or layer of bricks are placed as "stretchers" forming an alternating header stretcher bond often referred to as the English Bond. Thicker walls are based on two rows of headers to create double the width. When walls of a lesser thickness are prepared, adobe bricks are laid on edge in parallel similar to boards and the matrix is placed in between. This method of construction, however, is not as strong because the matrix is not compacted and it lacks the cohesion found in a properly bonded adobe brick wall.

Fig. 4. Placing the windows.

4. Floors and roofing

The ground floors of houses are usually set on virgin ground that has been levelled if required. Sometimes, a layer of rammed earth is used to provide the necessary finish.

The flat roof or terrace is constructed in the following manner. Unhewn beams are set close together and a layer of twigs from the "Caragana" shrub placed above the beams to prevent the moist earth from rotting them. A layer of rammed earth is placed over the twigs and covered with a final layer of waterproofing clay to prevent water penetration.

Fig. 5. Bhutan, Valley of Paro: Construction of a farm house using "pisé de terre" with a light timber framing for the upper floor.

5. Plastering

Occasionally, when an appropriate material with a high content of clay is available, the rammed earth or adobe walls are plastered externally. Otherwise the walls are left plain. An application of wet clay of porridge-like consistency is prepared and applied by hand. This allows for some form of decoration to be added to the exterior of the building.

Some examples earthen construction in the region

1. The Himalaya

In Dolpo, a Tibetan valley located in northwest Nepal at an altitude of 4000 meters, the different types of material described above are also in common use. The foundation as well as the back and side walls are in rubble stone and the facade is in adobe (7).

In Bhutan, located in the eastern Himalaya, where the population is of Tibetan origin, the houses follow the same model as those in the Tibetan cultural area. In addition, above the flat roof, the Bhutanese extend a light timber pitched roof structure which generously overhangs the external walls. The foundations are made of large stones and the walls are of rammed earth. The Bhutanese house is an impressive architectural achievement combining utility and technical skill with a great aesthetic sensibility (8) (see fig. 5).

In Ladakh, in the western Himalaya, the oldest constructions are always of rammed earth. Today, pisé de terre has been replaced by the adobe brick. The Palace of Leh presents an interesting example of the use of sun-baked bricks (see fig. 6). The palace was built in the early 1600's as a royal residence and is a building of great dimensions. The palace is the largest of a group of buildings crowning a seven kilometer ridge overlooking the city of Leh.

The fortress of Namgyal peak located high above the palace of Leh, was built in the 16th century out of rammed earth and adobe brick (see fig. 7).

Fig. 7. The Fortress of Namgyal.

Fig. 6. Ladakh, 17th century palace of Leh overlooking the city.

Fig. 8. Central Tibet, a fort in "pisé de terre" surviving from the 18th century

The palace is built into the rocky outcrop with the main facade measuring about 60 meters in length and 58 meters in height overlooking the city. The foundations, which are of granite, grow out of the bed rock itself and the lower part of the battered walls is formed in cut and dressed granite. As the walls rise, the structure becomes lighter and the windows in turn become wider. The upper third of the building is constructed of mud bricks with the roof terraces formed of earth and clay. The method of construction for the adobe structure is almost exactly the same as for a traditional dwelling.

The palace was abandoned and, because of the total lack of maintenance, snow and water have infiltrated the adobe walls causing damage and collapse to much of the upper structure (9).

2. Karakoram

An interesting example of reinforced adobe structure can be found in buildings such as the 15th century Baltit and Altit Forts in the region of Hunza, in northern Pakistan. Here, the use of a timber cribbage at the corners of the tower with an infill of adobe brick creates a flexible structure capable of withstanding the seismic activity which is prevalent in this region.

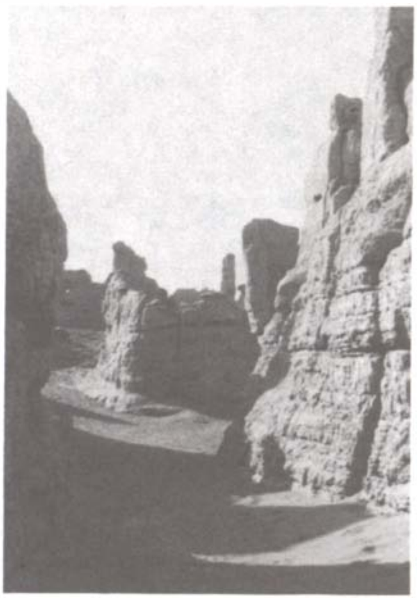

Fig. 9. Turfan, Citadel of Jiaohe, part of the main thoroughfare.

3. Central and Western Tibet

The oldest monuments to be found in Tibet are the Royal Tombs located in central Tibet, the most well known being the Tsetang (Pyong Rgyas), which are tumuli of rammed earth interlayered with slate and timber planks dating from 650-815 AD (10).

More recently, the fortifications have been built in adobe and rammed earth. For example, in Lha-artse, located in central Tibet, defense towers still remain in a state of decay and neglect. These structures therefore show the lower levels in rammed earth and the superstructure in adobe. From time to time during previous restoration efforts random stonework has been used instead of earth (see fig. 8).

In eastern Tibet, the village of Tsaparang is another particularly interesting example of the use of earth in construction. It is here that certain unusual technical details, such as the use of pebbles as a capping for the walls and the presence of forms of arches that have not been found elsewhere, can be seen. Within the cliff dwellings above Tsaparang some unique structures using adobe walls have been studied (11).

Fig. 10. Turfan, City of Gaochang, central part of a stupa.

4. Xinjiang

The architecture of the oases around Xinjiang are entirely of adobe. In Turfan, the cities founded during the Han Period (206 BC to 220 AD) demonstrate the diverse uses of earth. For example, Jiaohe was built on a limestone spur and Gaochang was built on a flat plain, both of which were undoubtedly abandoned in the Ming Period. In Jiaohe, the main thoroughfare of the town has buildings constructed of rammed earth at ground level, with large adobe blocks at mid-level and smaller adobe bricks at the upper level (see fig. 9). The monuments, including the enclosure walls, temples, and stupas in these two towns, are of sizeable dimensions (see fig. 10). Interesting architectural features such as the arch and the tiered vault can be seen in Turfan where they have been used to support several floors. Erosion, especially wind attrition, has caused major damage which is only apparent when comparing early photographs taken by such well-known explorers as Le Coq and Stein at the beginning of this century.

In the graveyard of Astana there are examples of rammed earth tumuli covering funeral chambers which have been decorated with murals. A series of monasteries carved out of cliffs, such as those at Bezeklik, were enclosed with adobe structures as the external facades. These structures have remained unchanged to this day.

The large mosque of Turfan built in the 17th century was restored in 1980. The structure is capped with a series of domes and the method of decoration for the minaret has been used as a model throughout Central Asia and Iran (13) (see figs. 11, 12).

Fig. 11. Turfan: General view of the Friday Mosque.

Fig. 12. Turfan: Detail of the minaret of the Friday Mosque.

5. Qinghai

Circa 2000 - 500 BC, earth has also been used in the areas between Tibet proper and Central Asia. Three sites from the Nuomhong Period have been discovered in the Tsaidam Region. These correspond to a nomadic civilization largely independent of the bronze period of the Qinghai-Gansu. Remnants of architecture consisting of foundations of houses, walls, and ditches using adobe and rammed earth have been found on a site which may have been a resting place for these nomads (14).

Conclusions

The above examples drawn from Central Asia and Tibet demonstrate the unique qualities of earth when used as a building material. The technology used in earth construction advances the following observations:

The house is often regarded by architects and planners as a geometric element that needs to be "rationalized" to suit the assembly of structures, voids, and spaces. In practicing architectural conservation, however, it is necessary to discover through analysis how building design has been adapted to suit specific conditions and climates. Central Asia provides an excellent example of this principle.

Today, due to the fashions fostered by the pressures of development, it is unlikely that new buildings in these regions will be permitted to evolve from traditional technology. Therefore, in order to retain these traditional structures, restorers and "conservationists" need to not only find ways of preserving traditional technology, but also convince potential clients that the traditional structure will provide suitable, if not preferable, living conditions. For obvious reasons, one cannot expect new hospitals to be built in adobe, but perhaps some of the less sophisticated structures may employ this technique in recognition of this longstanding tradition.

As many archaeological sites along the Silk Road in such places as Turfan and Khocho have been exploited, and where many of the sites are still being "mined" by farmers as a source of fertilizer for their fields, it is hoped that the Adobe 90 Conference will promote an active interest in the technology of adobe. This kind of information will help local decision makers responsible for the conservation of historical sites to protect their cultural heritage and prevent the exploitation of these ruins.

Finally, it is essential to sensitize the conservationists in this region to help them avoid the indiscriminate use of "modern" materials, such as cement, and to teach them simple but appropriate conservation techniques as well as some specific ways to preserve this unique but fragile building tradition.

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EARTHEN WALLS FROM FRANCE AND ENGLAND FOR NORTH AMERICAN FARMERS, 1806-1870

Jeffrey W. Cody
Department of City & Regional Planning
Cornell University
Ithaca, NY 14853-6701

ABSTRACT

This paper discusses the transfer of earthen wall building technology from France and England to North America during the nineteenth century, connections which have remained obscure for many reasons. Emphasis is here placed on the rationales and variations of earthen walling methods from France, where, in the context of the French Revolution, pisé (rammed earth) was heralded as a technique for the "common man," to England and America, where the virtues of using earth for rural structures were subsequently extolled. In discussing major personalities, publications, and trends, the paper argues that earthen wall construction was more widespread than has sometimes been assumed. It demonstrates that not all American "adobe" buildings are in the Southwest and that they were stylistically and technologically versatile. Protective measures taken by their builders are likewise explained. A proper historical and technological context is thus provided for understanding the significance of earthen wall structures in areas not normally associated with their existence.

KEYWORDS

PISÉ
RAMMED EARTH
UNBURNT BRICKS
TAPIA
EASTERN UNITED STATES
NINETEENTH CENTURY

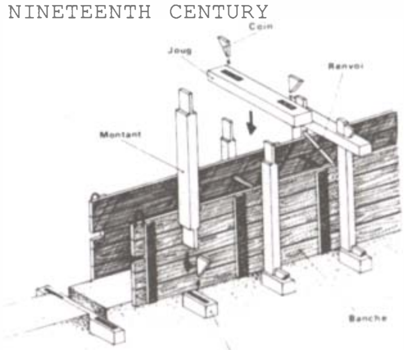

Fig. 1. Schematic assembly of a mould used in Auvergne, Source: P. Doat, et al., Construire en Terre, 16.

Introduction

In American architectural traditions the logic and viability of building with earth has been documented only superficially, hence the astonishment of most who learn of the use of rammed earth or "unburnt" bricks east of the Mississippi River as early as 1806. Although one does not normally associate New Jersey with adobe, it was in this state that some of the earliest East Coast experiments with earthen wall technology were conducted.[1] To understand how and why this occurred, it is necessary to cross the Atlantic Ocean.

Pisé, or rammed earth walls in western Europe, were erected most often on a masonry foundation. The walls were formed by pounding a mixture of sand, silt, and clay into a case, or shutter, which was characterized by moveable frames of wood held parallel by a set of supports. This set often consisted of lower and upper horizontal struts, vertical support posts, countershafts, and wedges (see Fig. 1). European traditions of ramming earth into solid walls or of drying soil mixtures in the sun to yield a suitable building material have been traced to the Phoenicians, the Romans and the cultures that came under their influence.[2] By the eighteenth century, certain regions, at least partially because of their favorable geologic conditions, were better known than others for their success in utilizing time-worn building traditions related to earthen walls. One of the most famous was the French Lyonnais, where the rich, sedimentary deposits along the Rhone River provided a useful variety of clays and sands for builders to mix into economical and fireproof building materials.[3] This paper will concentrate on this circuitous documentary link between south central France and the eastern United States, establishing that firm rationales, building methodologies and European precedents existed as American farmers in the nineteenth century began considering whether to adopt, adapt or reject these precedents under new conditions. Between 1806 and 1870 they tried all three alternatives, finally rejecting earthen walls in favor of wood or brick.

The pisé, or rammed earth, connection from Lyon to New Jersey can first be traced by examining the key publications that emerged in late-eighteenth-century France to encourage more scientific analyses and practical applications of rammed earth structures. The most important of these analyses was by François Cointeraux in 1790, but other pisé propagandists helped set the stage for him. For example, Georges-Claude Goiffon's "L'Art du Maçon Piseur" (1772) was an obscure, unsuccessful treatise written by a nonpracticing academician for practicing masons (see Fig. 2), but it represented the emergence of a rational understanding of pisé technology, briefly reflected in 1777 by Diderot in his Supplément, and more substantially nine years later by François Boulard in Abbé Rozier's popular Cours Complet d'Agriculture.[4] Boulard first focused on the coagulating qualities of soil appropriate for ramming ("strong earth," a humid mixture of clay and sand with no roots or gravel). He then emphasized construction procedure, paying particular attention to the problem of how to merge two perpendicular wall segments, and he suggested a rough-cast plastering as an exterior finish (see Fig. 3).

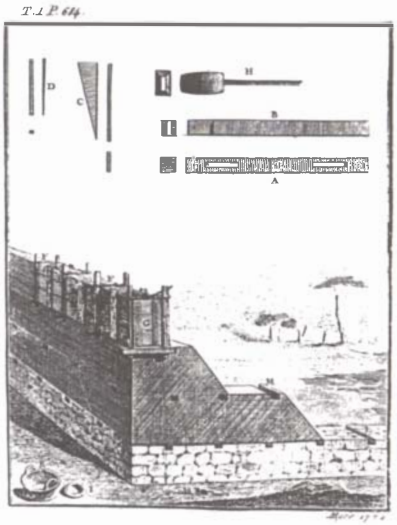

Fig. 2. Goiffon's depiction of pise construction, 1772.

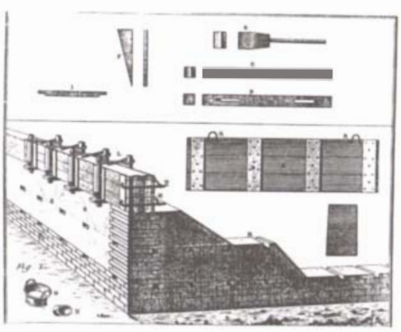

Fig. 3. Boulard's depiction of pise construction, 1786.

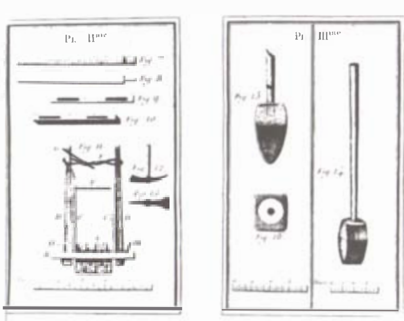

Fig. 4. Plates II and III Cointeraux's First Cahier

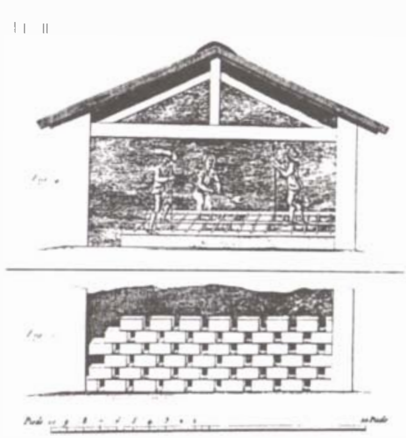

Fig. 5. Plate II from Cointeraux's Fourth Cahier

Boulard's description, although empirical, lacked zeal. Such could not be said of Francois Cointeraux, an avid Lyon builder and agriculturist, who in the 1780s began experimenting in northern France with the rammed earth technology he had learned in the south. Aided in 1788 by royal officials of the newly formed Société Royale d'Agriculture, Cointeraux moved to Paris the following year, when he inaugurated a "school for rural architecture" in order to promote the use of pisé as an economical method of erecting farm structures and as a way of building "incombustible" structures for French cities. Cointeraux, whose motto was "Theory is beautiful, but practice surpasses it," sought to make a "patriotic contribution" in the spirit of the Revolution.

Pisé became his passion. "My desire is to advance only that which is practical," he wrote. "Honor engages me to prove it by all the means within my power. My style perhaps is not brilliant, but it will be useful; I will render it clear and simple, to be within reach of everyone, particularly workers."[5] Cointeraux viewed his mission as a course of public instruction, effectively eliminating poverty by occupying beggars in "major works."[6] For Cointeraux, pisé was not simply a man-made architectural technique; rather, it was:

> a gift of Providence. . . a present which God has made to all people. If agriculture is the basis for all science, pisé is also the first of all the arts. . . . Factories will multiply with pisé and commerce will flourish. . . .One should employ this kind of building throughout the realm, for the decency of villages and the honor of the nation, to save wood, which is used in such great abundance in constructions, to avoid fires, to protect laborers from cold or excessive heat, at the same time to conserve and protect their health, and for so many other objectives, too long to list, so useful to the state and to private landowners.[7]

This rationale illustrates the connection Cointeraux made between nature and pisé construction, and the rapport he saw between an architecture for the common man and the political upheavals. Cointeraux was thus expressing, in terms of pisé's origin (the soil) and utility (for the common good), what Voltaire and Rousseau were arguing in terms of political philosophy -- that society should recognize its natural link with the soil upon which men and women tread.

Cointeraux published four cahiers, or "notebooks" between March 1790 and November 1791. The first provided construction details made more palpable by costly, copper-engraved plates (see Fig. 4), while the second (published in March 1791) was concerned with soil qualities, further construction details, and the artistic rendering of wall surfaces. The third cahier was a plea to "men of commerce" to consider incorporating some earthen walls with those of brick in order to economize factory construction. In the fourth cahier, Cointeraux extolled the "new pisé," referring to the construction of more portable and adaptable unbaked bricks of rammed earth which could be moulded indoors and used at a later date (see Fig. 5). Cointeraux's notebooks were more popular than earlier pisé publications not only because of the author's passion for his subject, but also because of the imaginative and graphic way he addressed a wider audience and the innovations in technique he espoused.

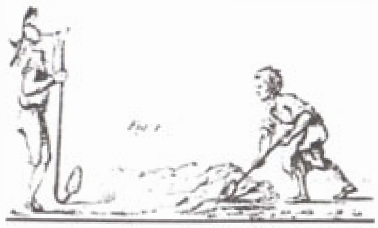

Fig. 6. Plate XII from Cointeraux's Second *Cahier*, showing workers mixing soil.

Three of those innovations are particularly noteworthy: Cointeraux's *pisé* pick, his conservation precautions, and his recommendations to adopt more than one sort of *pisé* technology (see Figs. 6, 7). The "pick" was a curved hoe, adapted for the requisite mixing of clay and sand, and the engaging way the author depicted this new tool helped make its use more understandable. Regarding conservation, Cointeraux adroitly discussed those materials -- stone or brick -- which could most effectively be used around doors and windows, where joints were more susceptible to damaging moisture intrusions and where tensile stresses led to structural weaknesses. In this regard, he suggested using more expensive lintels and sills in place of those made from wood, because the harder materials joined more solidly to the earthen wall. Furthermore, the hot lime-whiting which Cointeraux suggested applying as a coating would adhere, he asserted, more easily to the stone or brick than to the wood elements. Because Cointeraux envisioned rammed earth as a liberating technique, he was more amenable than any of his contemporaries to include variations, as well as the "standard" Lyon method, in his recommendations. Therefore, Cointeraux not only promoted the "new *pisé*," but he also lauded the sort of rammed earth technique devised in Bugey (Bresse). The Bugey method differed from that of Lyon because of the use of wood braces angled from the ground to the frame, which kept the vertical panels of the *pisé* shuttering more perpendicular to the ground, thus ensuring a flatter and more regular wall surface (see Fig. 7). By using the external braces it became unnecessary to insert lower horizontal supports at the base of the shutters. These lower supports required leaving gaps in the walls, which then had to be filled once the wall was complete. By using the Bugey method, Cointeraux observed, "All is whole from the ground level to the roof."[8] Cointeraux's inclusion of the Bugey method made a stronger case for *pise* because it demonstrated the versatility of the technology.

Through Cointeraux's persistent litanies, *pisé* became a technique for rural housing known far beyond the Lyonnais, although the author's personal success lagged behind his architectural notoriety.[9] There was an almost immediate reissuing of Cointeraux's findings, for example, in several other European countries.[10] In Britain, the initial impulse for considering rammed earth sprang from personal friendship between Cointeraux, his disciples, and British patrons rather than from French publications. Between 1791 and 1793, Cointeraux made a journey to the British estate of Philip Yorke, the third Earl of Hardwicke, a learned agriculturist who had purchased Cointeraux's *cahiers* in Paris and financed Cointeraux's trip in order to see *pisé* being implemented firsthand.[11] But even before Cointeraux's journey, two

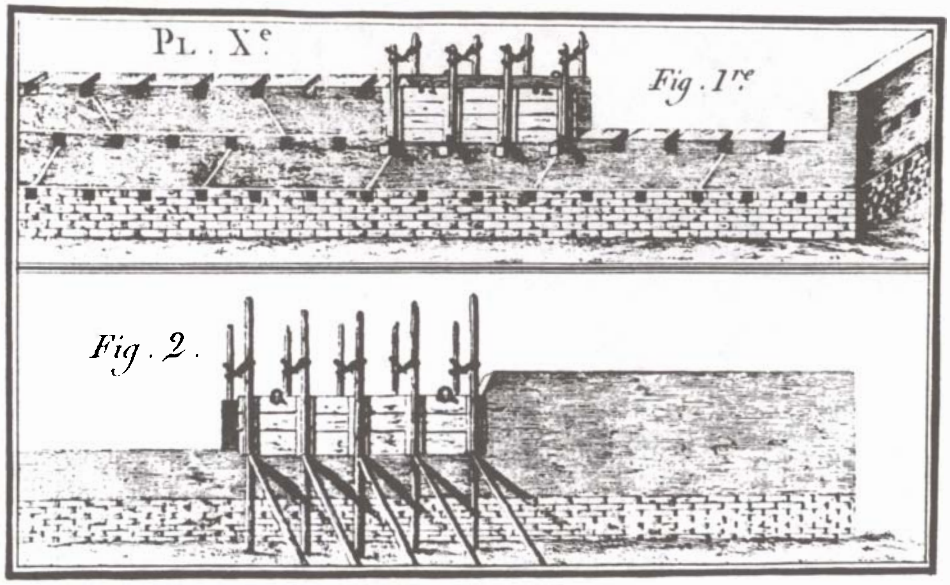

Fig. 7. Plate X from Cointeraux's First *Cahier*, 1790, comparing two, commonly-employed French methods for ramming earth: Lyon (above) and Bugey (below).

French pisé craftsmen trained by Cointeraux at his "school" in Paris were contracted in 1789 by Thomas Eccleston, of the Academy of Arts of London, to venture to Lancashire in order to erect experimental walls there.[12] British writings followed quickly on these heels of pisé experiments with, and on, English soil.

By the mid-1790s, British rural architects, seeking a cheap alternative to wood framing, began to consider pisé as a counterpart to the more common British methodology of erecting earthen walls, known as clay-lump walling or "cob," whereby clay was mixed with straw and then superimposed by layers before wall surfaces were pared down until flat.[13] John Plaw, in his Ferme Ornée (1795) was the first to acknowledge Cointeraux in print, but he was more an intermediary voice with access to a publisher than a practitioner of earthen constructions.[14] The most important British architect to give legitimacy to earthen walls was Henry Holland, who probably was introduced to the French methods by virtue of the curiosity of his patron, Francis, the fifth Duke of Bedford, a renowned agricultural promoter. The Duke's surveyor, Robert Salmon, later recalled how Francis was so interested in the Lancashire pisé experiments that he paid for a French worker to reside at his Woburn estate to build pisé walls there.[15] Holland and Salmon became immediate converts, but because Holland was enlisted to contribute to the popular Communications of the Board of Agriculture, his work, though more imitative than innovative, became more well-known than Salmon's. Salmon, for example, proposed using iron clamps to keep the shuttering taut, and at the troublesome junctures of two perpendicular wall segments he suggested using a long iron bar, connecting the shuttering of each segment, to maintain a right angle (see Fig. 8).

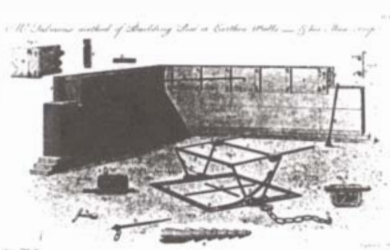

Fig. 8. Salmon's depiction of pise construction, 1809.

In praising pisé buildings, Holland simply offered a digest of Cointeraux's first two cahiers for the English practitioner. Holland emphasized Cointeraux's principal sections concerning the erection and dismantling of the wood forms, proper soil composition, and wall coverings. In most cases he even reproduced Cointeraux's graphics. But Holland omitted what he deemed less crucial to the case for pisé: Cointeraux's pisé pick, the Bugey method, the "new pisé," and the discussions about the preferred use of stone and brick lintels and sills. Either Holland knew of Cointeraux's other writings and simply chose to ignore them, or he remained in the dark concerning the later cahiers. In any event, Holland's edited translation helped lend enormous credence to the pisé technique. At the dawn of the nineteenth century, several British builders and agriculturists elaborated upon Holland's suggestions.[16]

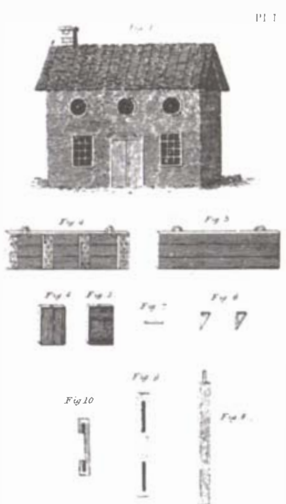

Fig. 9. Stephen Johnson's pise construction, 1806.

So, too, did some Americans. The most notable was Stephen W. Johnson, a lawyer and builder who hailed from New Brunswick, New Jersey. Precisely what drew Johnson to Holland's work is unknown. By 1804 the American had read the Communications and near Trenton he was in the midst of erecting his own pise experiment, 27 ft. long, 19 ft. wide, and 15 ft. tall (see Fig. 9). Contemporaries gawked and Johnson decided to publish his observations as part of a text concerning rural economy. Johnson's approach was to quote Holland freely without proper acknowledgment, alter the placement of whole sections of Holland's translation, and then lace these sections with his own observations, criticisms, and suggestions. Although he included depictions of his own work (along with copies of Holland's illustrations), Johnson never explained oddities such as circular window openings. Based upon his own practice, Johnson also significantly altered Holland's translation of Cointeraux. For example, he reduced optimum foundation height from 2 ft. 6 inches to 2 ft; where Holland specified a frame 10 ft. long, Johnson suggested 10 to 15 ft.; where Holland suggested using twisted rope as a means of keeping the frames parallel, Johnson recommended wood clamps; and where Holland saw the logic in battering the walls to alleviate tension at the building's base, Johnson thought this unnecessary. Johnson, then, had only a dubious faith in his pisé predecessors. Undaunted by critics who even before publication tried to vilify him, Johnson hoped to appeal to Americans who might buy a construction manual for a newly settled, soon-to-be-improved farm.

Johnson hit a responsive chord, but with regards to pisé he was not the only American to do so. John Stuart Skinner, the Baltimore-based editor and publisher of The American Farmer from 1819 to 1830, was the most notable of Johnson's contemporaries to disseminate European knowledge about earthen walls to North American farmers. He not only entirely reproduced Holland's translation, but he also publicized actual American experiments which documented the use of Johnson's book. Skinner first demonstrated an interest in earthen agricultural structures in 1820, but it was a year later before he reissued Holland's translation for an American audience.[17] By this time Skinner was intrigued with John Hartwell Cocke's experiments with rammed earth slave quarters and outbuildings at Bremo Plantation, near New Canton (Buckingham County), Virginia. Cocke admitted using Johnson's book as his guide, but he had problems with workmen becoming confused about how to erect the wood frames, and he discovered that the moisture of Virginia was more damaging to the walls than he had anticipated. Therefore, he wrote Skinner, it would be more sensible to make use of smaller shuttering systems, fortified by iron clamps instead of wood, yielding more adaptable blocks of unbaked brick. Unconsciously, by using Johnson's book Cocke had "discovered" Cointeraux's "new pisé" with the help of Salmon's suggestions about iron clamping.

As Skinner indicated for his subscribers, Cocke was not alone in his fascination with rammed earth. William Anderson's experiments in Statesborough, South Carolina were particularly noteworthy; between 1821 and 1824 this plantation owner proudly constructed five pisé structures on his land. Three of these are extant, and together with a nearby pisé church erected at Anderson's behest in the 1850s, these buildings represent the largest existing concentration of rammed earth examples in eastern North America.[18] Anderson wrote Skinner that he disagreed with Cocke's suggestions about making smaller wall sections. In South Carolina, he maintained he had experienced little difficulty in training workers to use the larger shutters, and furthermore he claimed great success with a lime stucco which, when troweled smooth, was easily marked to resemble ashlar stone.[19] In the American southeast, then, by the 1820s, two pisé methods were being adapted concurrently. This was also the case further north along the coast. In Baltimore, at least one landowner used Johnson's book to erect large wall sections in 1813, and in the state of Maine, two patents were secured in the late 1820s for devices that could fabricate "unburnt brick" blocks.[20]

By 1827 these two methods were related to a third analogous technique in the American southeast, called tapia or tabby.[21] Tapia walls differed from pisé in the quality of the soil mixture rather than in the method of moulding that mixture. Shells, small stones, and lime were crucial ingredients in tabby, which, when rammed with correct proportions of sand and water, formed a moist cementicious mix by molecular and capillary action. When dry, the mixture formed a solid mass. Pisé shared with tabby the use of wood moulds, braces, and rammers; a masonry foundation; similar wall thickness; and the common rationales of cheapness and durability. Pisé, however, was characterized by different soil components and was less moist when rammed.

Alexander Macomb and Thomas Spalding were two of the most important tabby enthusiasts in the late 1820s. Their experiments in South Carolina demonstrated that the technique of rammed earth construction was just as significant as the material being rammed. Macomb, Spalding, and those who continued using rammed earth technology in the 1830s, such as Benjamin Rivers Carroll, Nicholas Herbemont, and Philip St. George Cocke, concentrated upon the economic rationale for pisé to build factories, fences, a wide range of agrarian buildings, and even railroad ties.[22] They also obliquely indicated some of the pitfalls associated with the method. These included the damage inflicted by water if walls were not properly coped or if a wide enough overhang was not constructed, and the spalling that resulted from applying a lime-based covering to a predominantly clay wall.[23]

Once again, the intensifying interest in pisé or tabby structures in the coastal southeast during the 1830s was matched by similar curiosity in the northeast. Several letters and short articles from 1834 to 1838 in the Genesee Farmer (based in Rochester, N.Y.) attest to this popularity.[24] But it was not until the 1840s that rammed earth technologies became most accepted by American agriculturists. The figure most responsible for this acceptance was Henry L. Ellsworth, America's first Patent Commissioner, whose annual Reports between 1843 and 1845 lauded the use of "unburnt brick" as a sensible "mode of constructing houses."[25] Ellsworth based his praise upon his own experiments with rammed earth in Washington, D.C. and in Grand Prairie (Tippecanoe County), Indiana (see Fig. 10). Although not immediately apparent, Ellsworth's Reports were widely read,[26] and his opinions sparked editors of many agricultural periodicals to ask their subscribers for advice based upon empirical experience with earthen buildings on the American frontier.

Fig. 10. Henry Ellsworth's rammed earth house in Indiana.

The most supportive editor was John Stephen Wright, of Chicago's Prairie Farmer. Between 1843 and 1855 there were over forty references in this periodical which discussed earthen wall mixtures and examples, more than any other American journal. Farmers throughout the upper Midwest wrote to the Prairie Farmer with their favorable or critical comments. But by the early 1850s other cheap materials for economical houses, such as sawn lumber and fired bricks, were more popular, more abundant, easier to handle, more portable, and they more easily coincided with prevailing tastes of what constituted proper domestic architecture for those no longer poor and indigent on the prairie. Based upon the few documentary examples in the eastern U.S. of rammed earth or unburnt brick construction during the two decades after 1850, the peak period for earthen wall popularity coincided with the 1840s. After 1870, there was no articulated rationale in the American architectural or agricultural press for earthen wall construction until after World War I. However, a discussion of American interest in adobe and its affiliated technologies during the twentieth century reaches beyond the scope of this paper.

Conclusion

Eastern North American adoption of rammed earth building methods derived most significantly from Henry Holland's 1797 translation of Francois Cointeraux's first two cahiers (1790-91), as published in the Communications of the British Board of Agriculture. Cointeraux, an adventurous rural architect, promoted a method of building indigenous to his native Lyon, because he saw the need for an economical, fireproof material that "the common man" could grasp and because no one had yet adequately explained how this could be done. On the American continent, Cointeraux's ideas, filtered at first through Holland and his American imitator, Stephen Johnson, took root quickly. Rural builders were anxious for an answer to the question of how to build a cheap, durable, and easy-to-erect structure.

But in the face of biting northern frosts and abundant rainfall, prejudice about "mud houses" persisted, despite the publicized successful experiments. The economy of such houses was also undermined by the increasing cheapness of other building materials that were made more accessible by canal and railroad expansion. The ease of earthen wall construction was likewise called into question by those who wanted homes without having to wait for a proper season to dry a specially-moulded brick, formed from a special recipe of sand, gravel, clay, or loam.

The safeguards that alleviated these problems provide lessons for today's conservationists who might confront an American rammed earth structure. Building a proper foundation was almost mandatory. Constructing eaves that flared sufficiently to throw water far enough from the wall and its base to prevent intrusion was another prerequisite. Joining the bricks carefully with wood joists, sills, lintels, sash, lath and rafters was also critical, as was finding the proper coating to apply over the particular kind of earth used to make the wall.

The diversity of technique, function, style, and material that characterized European and North American earthen wall construction from the late-eighteenth to the mid-nineteenth centuries, as depicted in the remarkable range of publications surveyed above, suggests that no single formula existed for earthen homes one might build. Fuller appreciation for the unique combinations that builders employed can be gained by examining the rammed earth or unburnt brick structures themselves. The several that survive attest to the durability of this building technology, even in a climate not normally conducive to the flourishing of adobe.

ENDNOTES

[1] Stephen W. Johnson, Rural Economy: Containing a Treatise on Pise Building (New Brunswick, N.J.: William Elliott, 1806).

[2] See, e.g., Vitruvius, Ten Books on Architecture (New York: Dover, 1960), 39; Plinius Secundus, Natural History (Cambridge, Mass.: Harvard University Press, 1952), 385; Marcus Varro, On Agriculture (Cambridge, Mass.: Harvard University Press, 1967), 217; and Sheppard Frere, "Excavations at Verulamium, 1956, Second Interim Report," Antiquaries' Journal 37, nos. 1,2 (January, April 1957): 1-15.

[3] Jean Dethier, Down to Earth (New York: Facts on File, Inc., 1983), 57; P. Doat, A. Hays, et al., Construire en Terre (Paris: Editions Alternatives, 1979), 13-29; Maurice Garden, Lyon et les Lyonnais au XVIIIe Siècle (Paris: Les Belles Lettres, 1970), 6-24; and René Abrard, Geologie de la France (Paris: Payot, 1948), 322-40.

[4] Georges-Claude Goiffon, "L'Art du Maçon Piseur," Introductions Aux Observations sur la Physique, sur l'Histoire Naturelle et sur les Arts, 1 (March 1772): 682-97; Denis Diderot, Supplément aux Dictionnaires des Sciences des Arts et des Metiers, Volume IV (Paris: Chez Panckoucke, Stoupe, Brunet, 1777); and C. Francois Boulard, "Pisé," in Abbé Francois Rozier, Cours Complet d'Agriculture, Volume VII (Paris: Rue et Hotel Serpente, 1786): 722-36.

[5] François Cointeraux, Ecole d'Architecture Rurale, Premier Cahier (Paris: Chez l'auteur, 1790).

[6] François Cointeraux, Ecole d'Architecture Rurale, Deuxième Cahier (Paris: Chez l'auteur, 1791), 10.

[7] François Cointeraux, Ecole d'Architecture Rurale, Premier Cahier (Paris: Chez l'auteur, 1790), 33-4.

[8] François Cointeraux, Ecole d'Architecture Rurale, Premier Cahier (Paris: Chez l'auteur, 1790), 38.

[9] Cointeraux's lamentations about the uncooperative way politicians treated him is found in his De la Distribution des Batiments de Pisé (Paris: Chez Vezard et le Normant, 1793), 6-7, and in La Méthode Facile et Economique de Reédifier les Eglises Paroissiales (Paris: Delaunay, 1816), n.p. Cointeraux sent "many copies" of his cahiers to Prussia, Sweden, Germany, England, Italy, Russia, Holland and North America. See André Bourde, Agronômes et Agronomistes en France au XVIIIe Siècle (Paris: S.E.V.P.E.N., 1967), Vol. 11, 946.

[10] The most notable are: in Italy, Giuseppe del Rosso, Dell' Economica Costruzione delle Case di Terra, Opuscolo Diretto Agli Industriosi Possidenti e Abitatori dell' Agro Toscano (Firenze: J.A. Bouchard, 1793); and in Germany, F. Cointeraux, Schule der Landbaukünst (Hilderberghaussen: n.p., 1793).

[11] Cointeraux mentioned his British experience in Méthode Facile, n.p. For Yorke, see Leslie Stephen and Sidney Lee, eds., Dictionary of National Biography (London: Oxford University Press, 1917), Vol. 21, 1268; and G.E. Cohayne et al, eds., The Complete Peerage (London: St. Catherine Press, 1926), Vol. 6, 307.

[12] The location of these experiments, none of which survived, was probably Scarsbrick Hall. See Robert Beatson, "On Cottages," Communications of the Board of Agriculture, or Subjects Relative to the Husbandry and Internal Improvements of the Country (London: W. Bulmer & Co., 1797), I, 111.

[13] The most complete description of this methodology is in The Quarterly Review 58, no. 116 (February/April 1837): 524-40. Also see Norman Davey, A History of Building Materials (New York: Drake Publishers, 1971), 19-20, and R.J. Brown, The English Country Cottage (London: Robert Hale, 1970), 147.

[14] John Plaw, Ferme Ornée; or Rural Improvements (London: I. and J. Taylor, 1795). For a proper context of Plaw's motives, see Sandra Blutman, "Books of Designs for Country Houses, 1780-1815," Architectural History 11 (1968): 25-33; J.M. Robinson, "Model Farm Buildings in the Age of Improvement," Architectural History 19 (1976): 17-23; and Georges Teyssot, "Cottage et Pittoresque: Les Origines du Logement Ouvrier en Angleterre, 1781-1818," Architecture, Mouvements, Continuité 34 (1974): 26-37.

[15] Robert Salmon, "Method of Constructing Commodious Houses with Earthen Walls," Transactions of the Society for the Encouragement of Arts, Manufactures and Commerce 27 (1809): 185-97. For Henry Holland and the Duke of Bedford, see Dorothy Stroud, Henry Holland: His Life and Architecture (South Brunswick, N.Y.: A.S. Barnes & Co., 1966) and Charles Drury, Important Hints and Discoveries in Agriculture; or, a New System of Farming in General (4th ed.; London: Sherwood, Neely & Jones, 1818), 214.

[16] In addition to Robert Salmon, see William Barber, Farm Buildings (London: J. Tyler, 1802); Joseph M. Gandy, Designs for Cottages, Cottage Farms, and Other Rural Buildings (London: John Harding, 1805); and The Society of Arts, "Rammed Earth Buildings," in The Complete Farmer; or the General Dictionary of Agriculture and Husbandry (5th ed.; London: W. Flint,

1807), Vol. II, n.p. Holland's contributions in this regard were best articulated by John B. Papworth, in his Rural Residences (London: J. Diggens, 1818), 15.

[17] American Farmer, 2, no. 28 (October 6, 1820): 224; 2, no. 36 (December 1, 1820): 288; 3, nos. 1-5 (March 31- April 27, 1821).

[18] The plantation buildings were placed on the National Register of Historic Places on March 23, 1972. The Church of the Holy Cross was designed by E.C. Jones. See unpublished 1926 report (located at Clemson University, South Carolina) by Thomas A.H. Miller, Associate Agricultural Engineer, Bureau of Public Roads, U.S. Department of Agriculture.

[19] For Anderson, see American Farmer 3, no. 22 (August 24, 1821): 176; 6, no. 1 (March 26, 1824): 6; Southern Agriculturist, 9 (April 1836): 188.

[20] S. Chase erected a two-story, whitewashed, "very firm" pise dwelling in Baltimore, as indicated in the American Farmer 2, no. 2 (April 6, 1821): 14. For the Maine patents by E. Mayo, T. Norcross and G. Pollard, see M.D. Leggett, comp., Subject Index of Patents for Inventions Issued by the U.S. Patent Office from 1790 to 1873 (Washington, D.C.: Government Printing Office, 1874), I, 139, 148.

[21] See Janet Bigbee Gritzner, "Tabby in the Coastal Southeast: the Culture History of an American Building Material" (Ph.D. diss., The Louisiana State University and Agricultural and Mechanical College, 1978).

[22] American Farmer, 8, no. 45 (January 26, 1827): 353; no. 49 (February 23, 1827): 391; Southern Agriculturist 3, no. 12 (December 1830): 617-24; 9, no. 1 (January 1836): ii; no. 8 (August 1836): 400; and no. 12 (December 1836): 641-44.

[23] For example, Benjamin Carroll recommended using one of three, nonlime stuccos: (1) a mixture of linseed oil, litharge (water-insoluble PbO), red lead (Pb_3O_4), and lead acetate; (2) turpentine gum boiled in salt water; or (3) tar mixed with hot water and salt. Southern Agriculturist, 9, no. 8 (August 1836): 406.

[24] Genesee Farmer, 4, no. 39 (September 27, 1834): 309; no. 44 (November 1, 1834): 345; 5, no. 5 (January 31, 1835): 34; 7, no. 6 (February 11, 1837): 42; and 8, no. 3 (August 4, 1838): 244.

[25] Annual Report of the Commissioner of Patents, 1843 (Washington, D.C.: U.S. Government, Senate Document 150, 28th Congress, First Session, House Document 177), 45-6, 98-101; Ibid., 1844 (Senate Document 75, 28th Congress, Second Session, House Document 78), 239-41; Ibid., 1845 (Senate Document 307, 29th Congress, First Session, House Document 140), 450-54.

[26] The 1844 and 1845 reports were reissued by Congress in printings of 15,000 and 50,000 respectively. See the New Genesee Farmer and Gardener's Journal 5, no. 6 (June 1844): 54 and the Ohio Cultivator 1, no. 5 (March 1, 1845): 36.

EL USO DEL ADOBE EN EDIFICIOS EN EL AREA METROPOLITANA DE LA CIUDAD DE MEXICO; EL PASADO, EL PRESENTE Y LAS EXPECTATIVAS PARA EL FUTURO.

Segismundo Engelking Keeling
Saúl Alcántara Onofre
Universidad Autónoma Metropolitana-Azcapotzalco
Av. San Pablo No.180
Col. Reynosa Tamaulipas
02200 Azcapotzalco, D.F.
México.

ABSTRACT

The explosive growth of the Mexico City Metropolitan Area, and the deep changes in the lifestyles of its inhabitants, have brought the use of traditional building methods in adobe practically to an end; adobe is now seldom used, but an enormous number of buildings of all types made of this material still exist. By breaking the metropolitan area into zones relating to soil types and environmental conditions, we have found that, within a general framework of building usage applicable for the whole area, adobe and its related building methods can be studied as the result of truly regional and even local developments, responding successfully to the requirements of these localities.

KEYWORDS

Adobe, Mexico City, geography, history, characteristics existents.

Introducción

Este trabajo es parte de una primera etapa de organización de un programa de investigación académica que se está realizando dentro del marco de las actividades docentes del Departamento del Medio Ambiente de la División de Ciencias y Artes para el Diseño, Universidad Autónoma Metropolitana. Estos trabajos se originan en nuestra preocupación por la constante destrucción de edificaciones realizadas en adobe, como producto del rápido crecimiento de la Ciudad de México y el consecuente olvido de las tecnologias de construcción en este material fundamental.

No comenzar su estudio ahora, implicará una cada vez mayor dificultad para su análisis desde el punto de vista estadístico.

La meta de este programa de estudios será establecer criterios para determinar la monumentalidad que los edificios de adobe pueden alcanzar en el contexto del medio construido existente en el país, y asignar juicios de valor que no necesariamente estén vinculados a la noción de que éste material se usa sólo en construcciones paupérrimas y despreciables.

El ámbito geográfico; condiciones físicas

En esta investigación nos hemos dedicado al estudio de la construcción de adobe existente en algunos poblados absorbidos por el crecimiento de la Ciudad de México y las áreas ribereñas de los antiguos Lagos de Chalco y Texcoco, incluyendo los Municipios de Atenco, Ecatepec, Texcoco, Chimalhuacán, Ixtapaluca y Chalco, y los Municipios de Tlalmanalco y Amecameca, que muestran una sección típica de la orografía y de las variaciones climáticas de flora y fauna, así como la composición geológica y de suelos que se pueden encontrar en la mayor parte del Valle de México. Estas áreas aun cuando conservan muchas de sus características rurales, se encuentran en un proceso de transición a formas de vida urbanas, incluyendo la adopción de métodos de construcción no tradicionales.

Caracteristicas geográficas del Valle de México

En el extremo sur de la Meseta Central ó Altiplano Mexicano, se encuentra, a una altura de unos 2240 m. sobre el nivel del mar, la depresión conocida tradicionalmente como el "Valle de México". Este término, que por razones de orden histórico y de uso generalizado seguiremos utilizando, en rigor no es correcto, pues debe ser definido como cuenca, dado que se encuentra rodeada por cadenas montañosas que, por su peculiar ordenación impiden la existencia de una línea de drenaje superficial que permite la erosión o modelado, característica de un Valle.

Dicha cuenca tiene una forma aproximadamente oval, cuyo eje mayor, de Noreste a Sureste es de unos 110 km, y el menor, de Este a Oeste de unos 80 km. (ver figura 1).

La cuenca de México debe su formación a procesos volcánicos y tectónicos que se han ido desarrollando en los últimos 50 millones de años como parte de la formación de la faja volcánica transmexicana.

El valle o cuenca se encuentra rodeado al Sureste por la Sierra de Rio Frío y por la Sierra Nevada, que incluye los volcanes Popocatepetl, con 5438 m. S.N.M. y el Iztaccihuatl, con 5286m. Esta se liga por el Sur con la cadena del Chichinautzin y la del Ajusco, constituyendo parte integral de la cordillera neovolcánica. Del Suroeste al Noroeste se extienden las Sierras de Tepozotlán y de Tezontlalpan, ligándose con la serranía de Pachuca. Por el Nororiente encontramos las Sierras de Chichicuautla, del Tepozán y Calpulalpan.

*ama

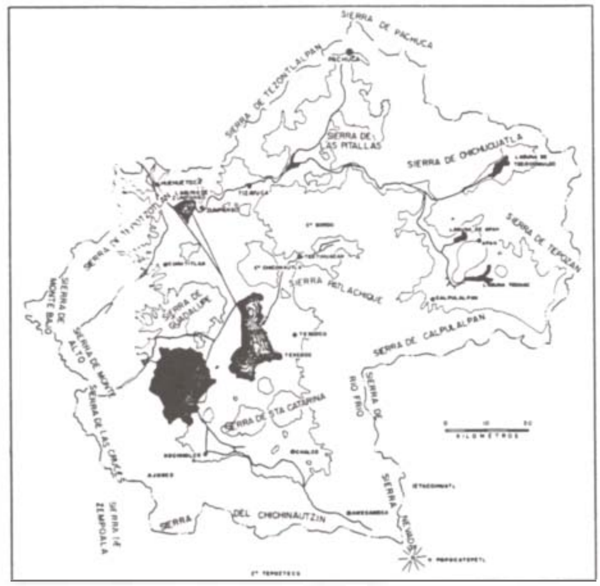

Figura 1. Las Sierras y Lagos del Valle de México.

Dentro de esta cuenca se encuentran otras formaciones menores, como la Sierra de Guadalupe, la de Santa Catalina y la de Caldera, al Oriente, así como eminencias aisladas, como el Cerro de la Estrella, el Peñón del Marqués y algunos otros.

Clima

Dadas las grandes variaciones orográficas, las características climaticas de las diversas zonas de la cuenca son igualmente variadas. En términos generales se encuentran dos regímenes climáticos establecidos: al Norte, según el sistema de Köppen para condiciones medias, existe un clima de tipo "seco estepario" con lluvias escasas. Al Sur, incluyendo la gran masa de la Ciudad de México, se tiene un tipo templado moderado lluvioso, con precipitaciones mayores a 750 mm. anuales, resultantes principalmente de los vientos alisios húmedos provenientes del Noreste. Por otra parte, hay una tendencia a tener una mayor precipitación en las faldas de las montañas que en las áreas planas. La temporada de lluvias se extiende en general, entre los meses de Mayo y Octubre.

La temperatura media anual para la cuenca es de 15°C.; la máxima a la sombra es de 31°C. y la mínima de 4°C. a 6°C, con algunas heladas en invierno, aunque existen diferencias según alturas y cercanías a las montañas. Por otra parte, la temperatura ha aumentado en áreas como la Ciudad de México a 8°C, ó 10°C, debido al gran aumento en la contaminación ambiental.

Hidrología

La condición de cuenca del Valle de México determina que todas las corrientes superficiales provenientes de la serranias circundantes, fluyan hacia la depresión central, la cual, no teniendo salidas de descarga, ha formado una serie de lagos y lagunas, entre las que se pueden señalar como más importantes las de Texcoco, Chalco, Xochimilco, Zumpango, San Cristóbal y Xaltocan. De éstos poco existe ahora debido por una parte a la tala inmoderada en los bosques existentes y a la extracción de grandes volumenes de agua fuera de la cuenca desde el Siglo XVIII. Ultimamente, gran parte ha sido bombeada del subsuelo con la consiguiente deformación diferencial del mismo.

Geología

Las principales formaciones pétreas son de rocas ígneas extrusivas (andesicas, riolitícas y basálticas) del terciario y cuaternario, que yacen discordantemente sobre las rocas mesozoicas marinas, cubriendo la mayor parte de la cuenca; en las faldas de las serranías también existen rocas sedimentarias clásticas (areniscas y gravas) y arcillas, asociadas con piroclásticas (tobas). La mayor parte de la planicie de la cuenca está formada por arcillas lacustres, prácticamente impermeables, o con depósitos permeables o gravas y arenas, concentradas especialmente en las áreas de desembocaduras de ríos.

Suelos y flora

La complejidad litológica de la conformación del área ocupada por la zona metropolitana, determina que en ella se haya desarrollado una gran cantidad de tipos de suelo. Sin embargo, la relativa juventud de las formaciones geológicas explica la existencia de andosoles ricos en cenizas volcánicas, y litosoles con formaciones petreas aparentes, predominantes hacia el Sur y el Oeste, así como las grandes extensiones de regosoles y fluvisoles de origen aluvial volcánico, presentes en la vecindad de los volcanes Popocatepetl e Ixtaccihuatl. Por otra parte, hacia el Norte predominan formaciones como vertisoles, (Cuautitlán a Texcoco), muy arcillosos con concentraciones de calcio, y suelos feozem, ricos en materia orgánica y de gran productividad agrícola, denotando una mayor antiguedad. Finalmente se tienen suelos solonchac en los fondos de los antiguos lagos, complementados por histosoles y gleysoles en el antiguo lago de Chalco (Xochimilco y Mixquic), con altas concencentraciones de sales y cambiosoles húmidos en las áreas boscosas cercanas a los volcanes.

Los suelos mencionados definen ampliamente los tipos de vegetación existente: bosques de montañas, yendo de caducifolias a coníferas según la altura, pastizoles con matorral en las partes bajas,con algunas especies mayores como pirul, fresno, etc., y en las zonas más áridas existencia de plantas de tipo desértico, como nopales (opuntia sp.) y magueyes (agave sp.). En muchos lugares el crecimiento desorbitado de la mancha urbana ha deteriorado el balance ecológico en forma irreversible.

Desarrollo de la Ciudad de México y la presencia histórica del adobe

Al igual que en otras regiones del mundo, México ha conocido una larga historia en el uso del adobe. En "La Venta", Edo. de Tabasco, existen pirámides recubiertas de piedras y lodo, que datan del año 800 A.C. y en Cuicuilco, en el Valle de México, desde el año 600AC. se construyó el primer basamento de piedra de grandes dimensiones, en que se usó barro como aglutinante; en Comalcalco, Tabasco, ya en tiempos clásicos (c. 700 D.C.) los Mayas construyeron pirámides y templos en ladrillo crudo y quemado a falta de piedra en la zona.

En el año 1325 D.C., fecha tradicional de la fundación de la Ciudad de México-Tenochtitlan, el Valle de México se encontraba ya considerablemente poblado, con una economía basada tanto en agricultura de temporal, incluyendo agricultura por terrazas, como de chinampas en las áreas lacustres. Era generalizado el uso de técnicas de bajareque y de adobe para las construcciones de los macehuales (ciudadanos comunes) y aun de clases mas altas, como los comerciantes (pochteca); la construcción de mampostería con mortero de cal se reservaba principalmente para la nobleza o los templos.

Figura 2.

Tras la conquista de la Gran Tenochtitlán, los Españoles no tuvieron gran dificultad en entrenar a los indigenas en las técnicas de edificación europea para los trabajos de reconstrucción, puesto que muchas de ellas se utilizaban en México, entre ellas las de adobe.

Un buen ejemplo de adobe prehispánico fue encontrado en las excavaciones de salvamento efectuadas durante 1989 en la calle de Francisco González Bocanegra, Colonia Morelos, por las Arqueólogas María del Jesus Sánchez Vazquez, Margarita Carballal Staedtler y María Flores Hernández, Subdirección de Salvamento Arqueológico, I.N.A.H. La excavación, localizada en lo que aparentemente fue un barrio de nobles y pochtecas, descubrió restos de construcción habitacional correspondiente al postclásico tardío (1473-1521). Esta incluye cimientos de piedra basáltica y de tezontle de sólo 22 cm. de ancho y 3.8 cm. de altura, sobre los que desplantan muros de adobe de 47 cm. de largo, 22 cm. de ancho y 8 cm. de altura, evidenciando poca preocupación por los problemas de humedad ascendente y una cubierta necesariamente ligera, probablemente armazón de madera con paja, lo que se confirma por huellas de postes. (ver figuras 2 y 3).

Figura 3.

Durante el siglo XVI existió una clara diferencia entre la construcción española hecha en mampostería de piedra con argamasa de cal, en el centro de la Ciudad de México y otros poblados importantes, y las construcciones indígenas de la periferia, realizadas en su gran mayoría con adobe. Kubler (1) menciona que, según Cervantes de Salazar, los materiales de barro eran considerados viles, comparando con la piedra. Esta noción se mantuvo en todos los niveles sociales, incluyendo a los remanentes de la nobleza indígena que logró sobrevivir a los profundos cambios sociales promovidos por un progreso de colonización, mismo que dentro de sus posibilidades adopta las formas Españolas, incluyendo la construcción de casas de mampostería y mortero de cal con puertas, ventanas y cubiertas de viguería escuadrada.

Otra condicionante para la existencia de construcciones de adobe fue la vecindad del Lago de Texcoco y el constante peligro de inundación que presentaba si la precipitación pluvial era excesiva. Este fenómeno era conocido desde mucho antes de la conquista y era de considerable importancia, dada la gran dependencia de la economía de los habitantes del Valle con los Lagos. Se ha detectado desde tiempos preclásicos un constante cambio de ubicación de poblados ribereños a la relación de los cambios de nivel de las aguas.

Antes de la llegada de los Españoles hubo inundaciones importantes; la de 1449 (2) llevó a la construcción del albarradón de Netzahualcoyotl, que extendía desde el poblado de Ixtapalapa hasta Atzacoalco, cercano al cerro del Tepeyac. Los primeros años de la Colonia transcurrieron sin grandes incidentes, hasta 1555 en que la Ciudad de México y otros pueblos ribereños quedaron inundados con gran daño a las construcciones. Siguieron las inundaciones de 1579-1580, de 1604, 1607 y la de 1628, que continuó hasta 1633, obligando a las autoridades a buscar una solución al problema la que, tras mucho argumentar, fue dada por el ingeniero Alemán, Enrico Martínez. Esta consistió en desviar las aguas del Lago Zumpango, hacia el Río Tula, que queda fuera de la cuenca, por lo que se debía hacer un socavón de unas 14,850 varas (unos 11,880m)

A partir de estos trabajos y posteriormente con la apertura del tajo de Nochistongo, comenzado en 1798, el gran canal del desagüe realizado durante el siglo pasado, y los trabajos del sistema de drenaje profundo de la Ciudad de México, de realización reciente, los niveles de los lagos han ido bajando hasta hacerlos casi desaparecer (ver figura 4).

Las inundaciones producidas por los lagos y posteriores medidas de control trajeron dos resultados importantes para la construcción de adobe:

1a. Que es casi imposible encontrar edificios anteriores al año 1700 (y aun posteriormente), debido al peligro que se corre con construcciones de adobe en áreas inundables. Por lo tanto, se puede decir que prácticamente todos los edificios de adobe pertenecientes al período 1521-1700 se podrán encontrar en regiones tradicionalmente secas, como los antiguos poblados de Mixcoac, Tacubaya, Tlalpan, Huexotla, Texcoco, Tlalmanalco, Teotihuacán, Amecameca, Tlalnepantla, etc.

2a. Que, debido al drenado de los lagos a partir del Siglo XVIII se construyó mucho en adobe en las tierras ganadas. En términos generales se podría establecer una cronología de construcciones en base a su ubicación relativa a los niveles de secación alcanzados en fechas dadas, como en el caso de Chalco, en que encontramos un edificio con rasgos barrocos típicos de mediados del Siglo XVIII, pero con muros de adobe, o de los pueblos de Ixtacalco, Santa Anita Zacatlalmanco, y la Magdalena Mixhiuca, cercanos a la Ciudad, en que la construcción de adobe sería posterior a 1800, o Ayotla en que las construcciones son más recientes.

El principio del fin

El desarrollo de la construcción en adobe en el Valle de México en tiempos en que los cambios sociales, tecnológicos y económicos eran lentos y paulatinos garantizaron la supervivencia de tecnologías netamente tradicionales como el adobe. Pero con los tiempos de paz que a partir de 1921 se experimentan en la Ciudad de México, con el fin de la Revolución Mexicana, comienza un proceso de acelerado crecimiento en todos los órdenes.

La población del Distrito Federal, que en 1895 era de 426,804 habitantes, para 1900 era ya de 540,478. A partir de 1930 la población comienza a modificar con mayor rapidez todos los patrones tradicionales, incluyendo formas de construcción.

Como indicador claro se muestra el crecimiento de la población en la tabla I.

Figura 4. Los lagos de la época diluvial.

A comienzo del Siglo XVI.

A comienzo del Siglo XIX y en el año 1889.

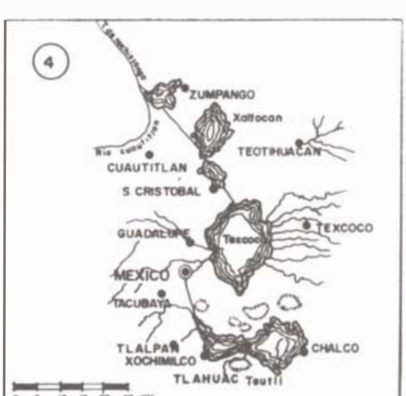

Tabla I: Crecimiento demográfico en la cuenca:

	Distrito Federal	Cuenca
1895	426 804	
1900	540 478	
1930	1 229 575	1 625 935
1940	1 757 530	2 225 000
1950	3 050 442	3 633 407
1960	4 870 876	5 807 232
1970	6 874 165	8 643 425
1980	9 639 800	12 600 000 (aprox.)

(fuente: censos de población 1895-1980)

Figura 5-6. Ixtapaluca.

Se estima que para este año la población ha llegado a los 18 ó 20 millones, que equivale al 20% del total del país. Tan rápido crecimiento sólo se puede atribuir a un fuerte proceso de inmigración, que es explicable si se considera que en la zona metropolitana existe más del 30% de la planta productiva.

Las cifras anteriores se reflejan claramente en los tipos de construcción que se han detectado en los diferentes levantamientos censales. Los de 1950, 60, 70 y 80, muestran la tendencia irreversible a la desaparición de la técnica del adobe en el Valle de México. Para efectos comparativos la tabla II presenta los datos de vivienda total y las hechas en adobe, tabique o block de cemento, y madera, en el Distrito Federal.

Figura 7. Casa colonial en Chalco.

Tabla II: Vivienda

	Total	en adobe	en tabique o block	en madera
1950	784 082	128 709	394 012	53 924
1960	902 083	191 314	618 962	44 466
1970	1 219 419	73 256	1 076 766	33 417
1980	1 747 102	46 144	1 637 070	16 438

(fuente: censos de población 1950-1980)

Estas cifras indican que, mientras el número de construcciones de adobe en sólo 30 años se ha reducido en un 60%, la construcción en tabique rojo o block de cemento con refuerzos de concreto armado ha crecido en mas de 400%, constituyendo mas del 93% del total.

Figura 8. Troje en Texcoco.

Características del adobe existente

Al respecto, hemos realizado una encuesta preparatoria de treinta construcciones en varios sitios del Valle, ya mencionados al principio de este trabajo. Se obtuvieron los siguientes resultados:

1. Período de construcción. Mas del 50% de las construcciones datan de finales del Siglo pasado y sólo el 15% son atribuibles a las primeras décadas del presente.

Otro 15% fue difícil de datar, por no incluir elementos estilísticos, pero tendería a corresponder al primer grupo. (ver figuras 5 y 6).

Se encontraron además tres construcciones coloniales de especial interes, (ver figuras 7,8 y 9). En todos los casos los constructores son anónimos.

Figura 9. Iglesia abandonada en Texcoco.

2. Usos, original y último. En el 85% de los casos el uso, original y último, es habitacional, con algunas variantes que incluyen establos o comercios, (ver figura 10). Sólo se encontró un caso en que el uso original era de caballeriza y troje y el actual es habitación. Dos de los tres ejemplos coloniales son atípicos: uno es una iglesia y otro un troje.

3. Cimientos. En todos los casos se encontraron cimientos hechos con piedra, de preferencia volcánica extrusiva, para evitar en lo posible la humedad ascendente. El aglutinante fue en el 40% de las veces mortero de cal. Sólo en dos ejemplos de lodo y el restante en mezcla de ambos. Siempre se construyeron sobre el nivel del suelo, variando entre 30 y 30 cm. con algunos ejemplos que pasan el metro.

Figura 10. Casa con establo. Gpe. Victoria, Ecatepec.

4. Adobes. Se encontraron en una gran diversidad de dimensiones. Se supone que el dimensionamiento se hacía por cuartas, u otras medidas corporales, variando entre los 35 y 50 cm. de largo, 30 y 40 cm. de ancho y 8 a 10 cm. de alto. Todos los ejemplos coloniales llegaban a mediar hasta 60 x 50 x 15 cm.

Las juntas varían igualmente entre 2.5 cm. y 4 cm. y algunas veces más, casi siempre con rajueleo de piedra o barro recocido para fijar aplanados.

5. Cubiertas. En casi todos los casos las cubiertas son planas con enladrillado y viguería, en correspondencia con las áreas planas del Valle. En las áreas altas como Tlalmanalco y Amecameca, hay una decidida preferencia por cubiertas a dos aguas, dada la mayor incidencia de heladas y probabilidad de nieve. Los elementos portantes son casi universalmente de viguería. Por otra

parte, es muy raro encontrar edificios de adobe en dos niveles, (ver figuras 11, 12, 13 y 14).

6. Acabados. El aplanado de cal es el mas usado, aunque en tiempos recien - tes se usa cemento por facilidad. También es común utilizar únicamente una lechada de cal, pintura casi universal.

En cuanto a la composición de los adobes, se encontró que en las partes planas del Valle hay una tendencia a mezclar material que ayude a dar adherencia tal como paja, estiércol de caballo y cenizas, especialmente en suelos feozem y solonchac cercanos al lago, a diferencia de los fluvisoles de Ameca - meca y áreas cercanas, donde ésto no parece ser necesario.

Conclusiones

En el Valle de México hubo una larga tradición en construcción de adobe con gran capacidad de adaptación a las condiciones naturales imperantes de composición de suelos, accidentes geológicos, variación climática y diversidad de vegetación. Este sistema constructivo hoy se encuentra en proceso de extinción ante la dificultad de adaptarse a los rápidos cambios que impone el desmesurado crecimiento de la zona metropolitana de la Ciudad de México, y, a su incapacidad para competir con ventaja ante materiales como el tabique recocido, el block de cemento y el concreto armado. Por tanto, es de gran importancia comenzar cuanto antes su estudio sistemático y la identificación de ejemplos rele - vantes para su conservación.

Notas

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I.N.E.G.I. 4°, 5°, 6°, 7°, 8°, 9° Y 10° Censo General de Población.

Figura 11. Construcción típica de cubierta plana; Ayotla, Edo. de México, C. 1900.

Figura 12. Construcción a dos aguas con lamina Galvanizada, C. 1900. Tlalmanalco, Edo. de México.

Figura 13. Construcciones a dos aguas con teja plana, C 1900; Amecameca, Edo. de México.

Figura 14. Construcciones a dos aguas con teja plana, C 1900; Amecameca, Edo. de México.

ARQUITECTURA DE TIERRA EN ITALIA: DESDE LAS COLONIAS GRIEGAS HASTA LA DOMINACION ESPAÑOLA

Eugenio Galdieri
Via dell'Accademia Platonica 12
00147 ROMA, ITALY

ABSTRACT

This contribution does not claim to be a complete catalogue of all the mud brick architecture that has been built in Italy over a span of almost thirty centuries. Instead it aims to show that this ancient technique has a continuity of its own in Italy, too, and has produced good examples of building construction. It was not, however, a technique that ever became a practice with deep-rooted traditions and, consequently, it did not attain high levels of maturity.
The paper denounces the past responsibilities of archaeologists who, with their Classical, academic training that was directed towards the study of great monuments of Greek and Roman civilization, paid little attention to, or even destroyed, the evidence of buildings in mud brick, especially of the Etruscan period.
The article also emphasizes the fact that, in spite of the recent interest in this subject that has been recorded over the past twenty years in Italy, very little has been done by the competent authorities to gain better knowledge of, or to catalogue and conserve these numerous, important testimonies of our past.

KEYWORDS

ITALY'S HISTORICAL EARTHEN ARCHITECTURE

Hasta hace algunos años Italia no estaba incluída entre los países dignos de ser citados en el campo de las construcciones de tierra: uno de los primeros estudiosos de este fenómeno técnico, social y económico - el Prof. P. Vidal de la Blache - en su obra póstuma del año 1948 (1), ignora completamente Italia como lugar de "casas de tierra", así como lo ha ignorado la Exhibición de Paris en el año 1982. Estudios efectuados en los años treinta de geográfos como Baldacci (2), además de otras investigaciones más recientes efectuadas en los años ochenta (3), han permitido modificar sustancialmente este juicio negativo, poniendo a la luz un panorama bastante interesante, sea desde un punto de vista cuantitativo como cualitativo. Aunque de manera geográficamente discontinua (y ésto también por causa de la naturaleza del terreno en Italia) en vastas zonas del territorio peninsular e insular son muchas las pequeñas ciudades compuestas en gran parte por edificios de tierra y numerosas son las construcciones en el campo, aisladas o agrupadas en grupos homogéneos. Se puede afirmar que la práctica de la construcción de casas de tierra se llevó a cabo por lo menos hasta el año 1950, cuando, por motivos higiénicos, pero a través de leyes no escritas, las autoridades impidieron que se continuase construyendo con dicho método. Al estado actual de nuestros conocimientos- y a pesar de tener en cuenta las numerosas demoliciones y sustituciones de los últimos decenios - el patrimonio de las casas de tierra en Italia (entendemos referirnos a aquellas en normal y continuo uso civil) abarca a una decena de millares de edificios. Estos están distribuidos en el territorio de al menos setenta ayuntamientos, con las mayores concentraciones en las provincias de Alessandria (Piemonte), de Cagliari (Cerdeña) y de Catanzaro (Calabria). Una catalogación completa de tales núcleos de edificios, y de las respectivas tipologías se lleva actualmente a cabo en un proyecto que une algunas Universidades italianas y centros autónomos de investigación (4) . Pero el argumento que nos interesa tratar en este encuentro es de carácter histórico. Nos interesa efectivamente ver que hay detrás del notable número de construcciones todavía existentes; nos interesa, por lo tanto intentar entender si también en Italia se puede hablar de una tradición constructiva de la tierra. Ante todo hay que decir que nuestras investigaciones nos han llevado a dos conclusiones : la primera es que, no obstante la gran difusión de las casas de tierra (fenómeno mucho más extendido y rico de cuanto se haya imaginado hasta ahora), la técnica del adobe no ha logrado nunca en Italia , convertirse en una verdadera y radicada tradición. En consecuencia tal tecnología específica no se ha desarrollado más allá de un cierto límite, ya que han faltado los apoyos fundamentales de la creatividad y de la continuidad temporal. La segunda es que el uso de la tierra no ha sido casi nunca autóctono sino importado del exterior, a través de inmigraciones - más o menos pacíficas - de otras culturas. Si se quieren buscar los períodos y la naturaleza de estos aportes externos, sobre todo en lo que concierne la antigüedad, se pueden individuar cuatro rumbos principales: El púnico-fenicio desde el Sur, dirigido sobre todo hacia Cerdeña meridional; aquel proveniente de Asia Menor, en el cual pueden incluirse sea la corriente griega en el Sur y en las Islas, sea el etrusco, presente en Italia central y en el Véneto; el rumbo de Europa Oriental (los Balcanes islamizados), dirigido principalmente hacia las zonas adriáticas de Italia centro-meridional, hasta en el interior; por fin el rumbo español, dirigido hacia Cerdeña, las costas tirrénicas y, quizás, las zonas de tierra adentro de la Liguria. Para estas últimas áreas y para aquellas cercanas a la Francia meridional, se habla de una posible influencia de poblaciones islámicas expulsadas de España. Pero éste es un argumento que, no obstante me interese particularmente, tendrá que ser estudiado más profundamente.

Por lo menos cuatro, entonces, fueron las contribuciones externas al desarrollo de la arquitectura de tierra en Italia, dichas contribuciones comienzan en el siglo VIII a.C. (influencia púnico-fenicia) para llegar al siglo XVI con la ocupación española. En este lugar nos interesa examinar solamente los periodos más antiguos, para demostrar que, favorecida por las influencias exteriores que hemos individuado hace poco, la técnica de las construcciones de tierra en Italia tiene raíces muy remotas.

Como sería demasiado largo y de poca utilidad ocuparnos de todas las obras de edad antigua realizadas en tierra en Italia (muchas de ellas han sido en efecto reducidas a importantes pero míseros testimonios arqueológicos), será quizás más interesante concentrar nuestra atención sobre algunos ejemplos de mayor importancia histórica.

En Tuscania existe la gran instalación etrusco-romana de Roselle (VIII - III a.C.). Excavaciones recientes pero también descubrimientos casuales han puesto a la luz algunos edificios civiles del período arcaico (c. VII a.C.), formados por grandes ladrillos de tierra.

El hallazgo de los restos es importante sobre todo porque confirma la hipótesis de finales del siglo pasado (5), según la cual casi todas las construcciones civiles etruscas estaban hechas de tierra. De Tuscania pasamos a Lucania y precisamente a Elea (la moderna Velia). De esta colonia griego-iónica fundada por los focenses entre finales del siglo VI y la primera mitad del siglo V a.C., se conoce sobre todo la parte monumental de la Acrópolis. Pero en la zona casi llana, en la desembocadura del río Alento, los restos de la antigua instalación (aquella en la que enseñaron el filósofo Senófane y luego el mismo Parménides), muestran numerosos edificios civiles realizados en ladrillos de tierra (6). La técnica etrusca del ladrillo de tierra pasó directamente , como es sabido, a los constructores romanos. Es apenas el caso de recordar que buena parte de las habitaciones medio-bajas de Roma estaban construidas en pisé o en adobe (según Plinio y Varrone, el nombre de láteres indicaba exclusivamente los ladrillos de tierra) y que Octaviano Augusto en los años treinta a.C. se vanagloriaba de haber sustituido con piedras y mármoles aquellos barrios de Roma que habían sido construidos con arcilla cruda.

Más imponentes y de mayor impacto visivo son los tres ejemplos elegidos entre las murallas urbanas, que aquí describimos rápidamente:
En Gela, en la parte meridional de Sicilia , el general Corintio Timoleonte es obligado en el 340 a.C., a potenciar y a reparar las murallas de la ciudad, hechas con bloques de arenisca. La solución más rápida y económica fué la de subir las murallas (hoy quedan de ellas casi 350 metros, algunos puntos con una altura de más de 9 metros) con bloques de tierra de 40x40x8 cm.

Las murallas de Arezzo en Toscana , una de las más importantes de la confederación de doce ciudades etruscas, fueron construidas en el siglo III a.C. con ladrillos de unas dimensiones de 42x28x12 cm. de sólida arcilla roja; el examen de los restos de aquellas murallas dió lugar a la hipótesis que refiere la nota (5).

En Reghión, una de las más ricas colonias griegas de Italia meridional (la actual Reggio Calabria), el cerco de murallas urbanas tenía una longitud aproximada de 4 km en forma de anillo, con una parte de contacto con el mar y con otra opuesta sobre la llamada Colina de los Angeles, entre las cotas +100 y +200 . Hacia el final de los años sesenta fueron descubiertos y puestos a la luz más de 150 metros de la parte más alta de las murallas, datadas en el siglo III a.C.; éstas a diferencia del trecho hacia el mar, realizado con sólidos bloques de caliza, están realizados en ladrillos de tierra de unos 30x30x8 cm. Sobre uno de estos ladrillos por efecto del enarenado, se ha conservado afortunadamente una breve inscripción esgrafiada con el nombre del lugar PHΓIΩN (7)

Para terminar una curiosidad; justamente en el centro de Roma, durante las recientes excavaciones arqueológicas realizadas para liberar la Crypta Balbi, ha sido hallado y afortunadamente conservado un manufacto circular de unos 5,80 metros de diámetro y unos 4,00 metros de altura, posado directa - e inexplicablemente - sobre un mosaico de época romana; acerca de la fecha y de la función de esta singular estructura, realizada con sutiles y regulares ladrillos de arcilla clara y depurada. Los estudios se encuentran todavía en curso. Sin embargo, se puede atribuir la construcción a los siglos II o III de nuestra era. De los datos hasta ahora en nuestro poder podría individuarse el período antiguo más interesante, aquél etrusco y etrusco-romano, más o menos entre el V y el III siglo a.C. Acostumbrados como estamos a considerar la arquitectura etrusca ligada al uso de los bloques de toba o de nenfro o incluso a las obras excavadas, en negativo, en la roca; y aquella romana realizada en mármol, piedra o fuertes ladrillos cocidos, el estudio de una técnica tan diferente sería para nosotros de extrema importancia. Pero, por desgracia, de aquel período tenemos más citaciones literarias que testimonios concretos, más documentos que monumentos: la responsabilidad de tal hecho (y por consiguiente de la destrucción de muchos restos etruscos de tierra) recae en gran parte sobre la preparación académica de nuestros arqueólogos del siglo pasado (pero también de nuestros días...). Para ellos, un "monumento" era tal solamente, si estaba construido con materiales nobles, pues la atención científica que ellos prestaron a estructuras aparentemente inestables e informes fué muy escasa. El mismo fenómeno , por otra parte, se había verificado en los primeros tiempos en Oriente Medio, con la destrucción de aquellos que se confundían con pequeñas colinas de fango.

Esta es pues la situación en Italia; una situación que tiene que ser estudiada todavía en su totalidad, seguramente más rica y prometedora de cuanto se pueda imaginar. Pero se está llevando a cabo una furiosa lucha con el tiempo: por una parte nuestro deseo de descubrir, registrar, salvar; por otra el avanzar del cemento, el bienestar, el desinterés de las autoridades. Este último es el aspecto más preocupante del problema, no obstante el interés suscitado también en Italia en estos últimos años, las autoridades municipales y aquellas nacionales de tutela parece que no se dan cuenta que un patrimonio singular - no sólo aquel de valor histórico sino también aquel todavía hoy de uso normal y civil - está lentamente, pero inexorablemente yendo hacia la destrucción.

Termino aquí mi intervención pidiendo que en las recomendaciones finales del Convenio se haga un apelo explícito para la salvaguarda de todas las construcciones de tierra existentes en Italia.

NOTES

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ABSTRACT

The use of adobe has had a long tradition in the arid regions of the American Southwest. The evolution of this tradition from 1848 to 1948 has produced three distinct construction systems (Indigenous, Victorian and Revival) and has left behind a wide variety of historical resources. Deterioration of adobe resources is often related to the misapplication of construction principles from one of these systems to another. The conservator of adobe buildings must understand the basic nature of these systems, the problems which arise when they are combined and how to approach preservation interventions by impacting the least significant element.

KEY WORDS

ADOBE CONSTRUCTION SYSTEMS
DETERIORATION INTERACTION
CONSERVATION PRINCIPLES
EARTHEN ARCHITECTURE

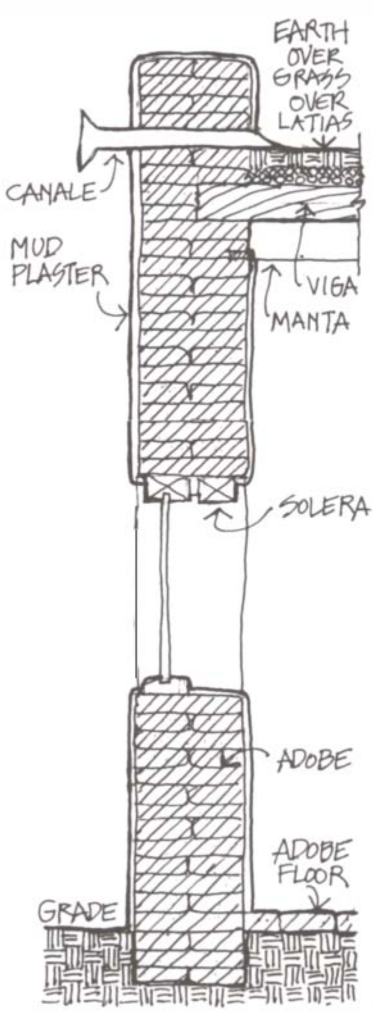

Figure 1
The Indigenous System
(1848-1881)

THE EVOLUTION OF ADOBE CONSTRUCTION SYSTEMS IN THE SOUTHWEST (USA) AND RELATED CONSERVATION ISSUES.

James W. Garrison, Historical Architect
JANUS ASSOCIATES INCORPORATED
602 North 7th Street
Phoenix, AZ 85006
U.S.A.

Introduction

With the signing of the Treaty of Guadalupe-Hidalgo in 1848 and the completion of the Gadsden Purchase in 1853, that area now known as the American Southwest came under the control of the United States. Imprinted over the natural topography of the region and the earlier Native American, Spanish Colonial and Mexican cultural traditions came American settlement patterns and architectural development. Adobe as a primary building material has had a long tradition within this pattern of regional development. Evolutionary in nature, the wide variety of adobe resources can be classified into three basic systems of construction: Indigenous (1848-1881), Victorian (1882-1914), and Revival (1915-1948). The timing of the primary use of each of these systems is tied to the development of the region's transportation, and industrial infrastructure. As the cultural acceptance of adobe rose and fell within this evolution the transition from one construction system to the next occurred. It is important to remember that each of these unique systems was balanced in its use of materials, detailing and method of reaction to the causes of deterioration.

Today many adobe resources constructed between 1848 and 1948 are considered historically or architecturally significant. At the same time most of these resources have undergone additions, repairs and rehabilitation measures; many times mixing together the three basic systems of construction. Conservation measures undertaken today on historic adobes must consider the basic nature of these construction systems and the significance of each building feature.

Historic Adobe Construction Systems in the Southwest

From 1848 to 1948 three separate adobe construction systems evolved in the American Southwest; the Indigenous System (1848-1881), the Victorian System (1882-1914) and the Revival System (1915-1948). Each of these systems is described below.

The Indigenous System (See Figure 1)

The Indigenous System of Construction, derived from Native American, Spanish Colonial, and Mexican Influences, maximizes the use of earth throughout the building. Thick adobe walls (46 to 61 cm/18 to 24 inches) rise directly from shallow trenches. Openings are small and framed with local wood lintels. Simple doors are usually batten while windows have shutters only. Floors are packed earth or adobe pavers. Roofs are flat having packed earth over a simple system of log beams (vigas) branches (latillas) and straw (or grass). Rainwater runs off the roof through wood or metal drains (canales). High ceilings (± 4.27 m/14 feet) might have muslin linings (mantas). Fireplaces are usually of a bee-hive style, located in a corner of the room and built entirely of adobe. Walls are rendered inside and out with mud plaster similar to the adobes.

This system of construction reacts to storms like a sponge. The earthen materials soak up the rain water during intense downpours and dry out over a number of hours. Leaks were not uncommon but easily repaired. Maintenance was required more often but was simple in execution. The massive walls and small openings also tempered the hot-arid climate.

Although virtually every community developed its own variations of this system based upon the local climate, types of plants and trees available and the traditions of local craftsman; the basic approach, applying site-formed adobes with locally cut wood and branches, was constant. Details often varied by location with wood canales in many parts of New Mexico and metal canales in many parts of Arizona. In Tucson latillas were often made of Saguaro cactus ribs while in Yuma they used Arrowweed.

The Victorian System (See Figure 2)

As the U.S. Military established camps, posts and forts in the southwest and as railroads were constructed, Victorian age industrial products and processes arrived in the region. Two industrial structures changed the method of constructing adobe buildings, the sawmill and the limekiln. Using dimensioned lumber in place of logs and branches and lime as an exterior coating, adobe structures needed less maintenance. They could also pass as more traditional brick or stone Victorian structures through the use of gingerbread wood detailing and scoring of the lime stucco.

The Victorian Construction System of adobe retains the basic thick adobe walls, but they are constructed on continuous stone foundations. These foundations were used for two reasons; first, to reduce the potential for rising damp and, second, to support wood framed floors above an adequate crawl space. Windows have larger Victorian proportions with simple wood casement or double-hung windows. Lintels and casings are of dimensioned lumber. Doors are usually four panels with moldings. Rafters and ceiling joists are usually 5x10 cm (2x4 in) with spacing as wide as 76 cm (32 in) on center. Wood shingles are supported on 2.5x5 cm (1x4 in) spaced sheathing. Rain water falls directly from moderate eaves or is channelled away from the building through half-round gutters and round downspouts. Ceilings may still be cloth or 2.5x5 cm (1x4 cm) beaded tongue and groove fir or pine, but have been lowered 61 to 122 cm (2 to 4 ft).

Exterior walls are rendered with smooth lime plaster applied directly to the scored or raked adobe surface. The lime stucco is usually whitewashed and is often scored as stone or brick. Lime is also used for mortar in the stone foundation. Lime is rarely used as adobe mortar. Interior walls remain plastered with mud and either wallpapered or limewashed. Simple wood jigsaw details or moldings are often used. Metal is limited to hinges, hardware, fasteners, square nails (pre 1890) and anchor bolts. Fireplaces are most often constructed of fired common red brick, with midwall placement and detailed with Victorian mantels and overmantels.

The Victorian adobe also has many design variations. In New Mexico adobes with flat roofs and Victorian detailing are referred to as "Territorial" designs while in Arizona this term is most often applied to houses with square plans and pyramidal roofs. Stylistically most designs follow Gothic Revival, Queen Anne or Colonial Revival trends. The most visual change during this period is the shift from property line row house site placement to discrete detached and often set back site placement. Fired red brick is often found combined with adobe. It can be found in fireplaces, at openings, and along parapets as copings.

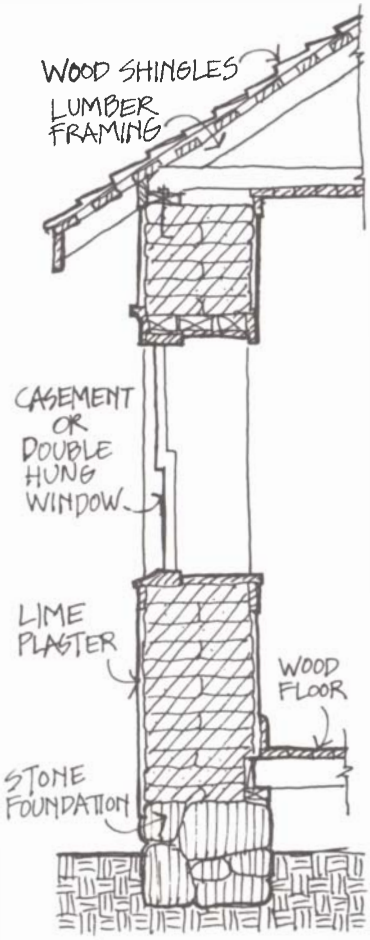

Figure 2
The Victorian System
(1882-1914)

The Revival System (See Figure 3)

When the settlers in the Southwest finally realized that sudo-Victorian designs from the East lacked regional climatic and cultural appropriateness, they spent a good deal of time looking at the Indigenous examples to develope Mission, Spanish Colonial and Pueblo Revival Architecture. Although based upon earlier examples these new designs are contemporary in function and construction method. Adobe, primarily found in Pueblo Revival buildings, is now found combined with Portland cement concrete and steel components.

The thick adobe walls are thinned to 25 or 30 cm (10 or 12 in). The natural sun-dried adobes are difficult to see, being totally encased in concrete. Reinforced concrete foundations are topped by a "damp proof course" of bitumen or metal. The adobes rise to concrete sills, steel lintels and reinforced concrete bond beams. The walls are plastered inside and out with Portland cement stucco attached to chicken wire or wire lath with nails driven into the adobe. Floors are also constructed of concrete using the "slab on grade" method. The slabs are often topped with very hard tinted and/or scored concrete. Windows feature steel sash usually using casement styles. Corner windows are used sparingly. Doors are most often batten with rustic wrought iron hardware and face mounted hinges.

The roofs are structured with telephone pole beams, heavy timber decking and composition built-up flat roofs behind parapets. Ceilings may be plastered or left natural wood. Mud mortar is still preferred when laying the adobes. Rounded corners, arched doorways and recessed nitches are often found. Fireplaces are more rustic but found in both corner and mid wall locations. Many buildings constructed during this time period are stylistically tied to earlier adobe styles, but have no actual adobes in them, being replaced by fired red brick or cast-in-place concrete.

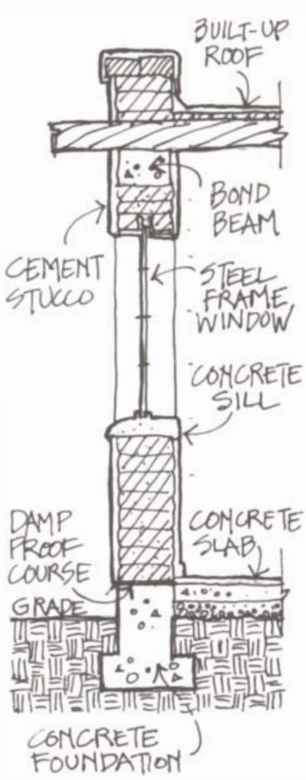

Figure 3
The Revival System
(1915-1948)

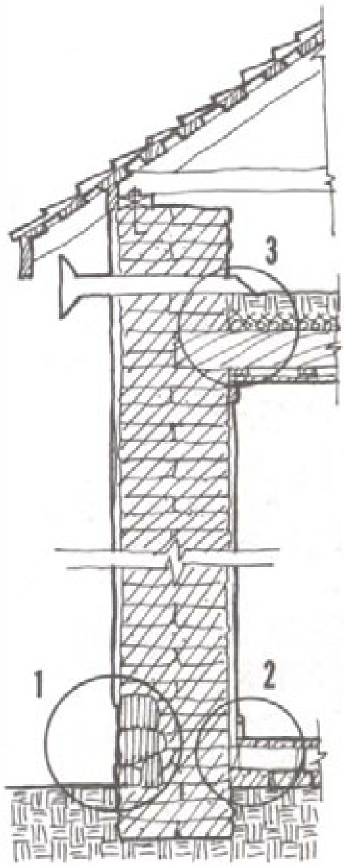

Figure 4
Indigenous/Victorian
Combination Problems

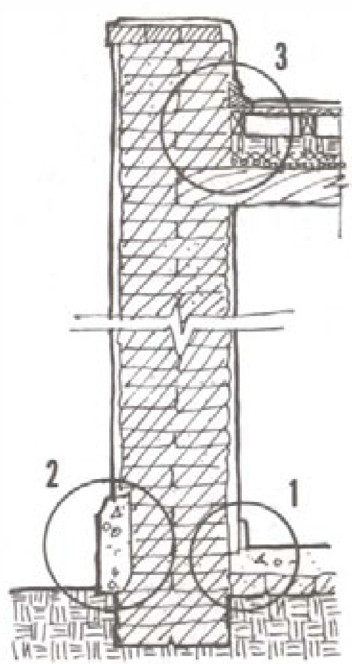

Figure 5
Indigenous/Revival
Combination Problems

Deterioration Problems

It is important to fully understand how each of these discrete adobe systems was designed to react to the causes of deterioration and therefore the weaknesses in their design. But it is also important to realize that through time, repairs can have been made to adobes designed under one system with materials and techniques from another. The haphazard combination of construction systems has, in many cases, led to accelerated deterioration problems. At the same time combined elements may have become historically significant and therefore require unique preservation treatments in order to preserve incompatible details and materials together. A prime example of this process was the Victorianization of many of The Spanish Colonial churches in New Mexico. Currently many Victorian features, many over 100 years old are being removed for "aesthetic purity", without documented historical justification. The main deterioration problems of each system of construction and combinations of systems are described below.

Indigenous System Deterioration Problems

1. Base wall erosion, caused from rising damp because the adobes extend directly into the ground.

2. Surface erosion and/or coating failure, caused by lack of maintenance.

3. Cracks or leaning walls, caused by ground movement and lack of any substantial foundation.

Victorian System Deterioration Problems

1. Base wall erosion, caused by the use of porous stone (sandstone or limestone) for the foundation, which allows rising damp.

2. Surface coating failure, caused by lack of a mechanical key between the lime plaster and the adobe.

3. Cracks or leaning caused by differential settlement of the stone foundation, or improper triangulation of the roof framing system.

Revival System Deterioration Problems

1. Moisture build-up in the adobes, caused by lack of a damp-proof course, cracks in the concrete stucco, or lack of proper roof drainage.

2. Surface coating failure, caused by the corrosion and rusting of metal elements including chicken wire, wire lath, nails and reinforcing bars.

3. Cracks, caused by the difference in expansion coeffencients between concrete and adobe.

4. Rotting of viga ends and other wooden elements, caused by the trapping of moisture behind the concrete stucco.

Indigenous/Victorian Combination Problems (See Figure 4)

1. Stones used to repair base wall erosion rarely extend completely through the wall allowing rising damp to rise higher.

2. Wooden floors are installed directly on earlier earthen floors with little or no crawl space.

3. Frame gable roofs over earlier dirt roofs allow for potential increase in damage from insect or moisture damage to vigas and latillas by hiding formerly open areas.

Indigenous/Revival Combination Problems (See Figure 5)

1. Concrete floors poured into rooms over dirt floors force ground moisture into the surrounding adobe walls.

2. Concrete aprons or boots also trap ground moisture into the surrounding adobe walls.

3. Framed roofs over dirt roofs hide moisture and insect problems.

Victorian/Revival Combination Problems

1. Concrete floor slabs, often used for porches, allow moisture to build-up in the base of the walls.

2. Changing the surface coating to cement stucco increases damaged from nails and chicken wire corrosion and traps moisture in the walls.

3. Removing Victorian roof framing to create a flat roof causes a significent loss of historic fabric.

4. Placing mission tile on Victorian roof framing can severely overload the structural members sized for wood shingles.

Conservation Principles

When working on an historic adobe building the following principles should be followed:

1. Document all existing conditions especially the evidence and the sources of deterioration. Cosmetic repairs should be avoided.

2. Fully understand the primary method of construction. Analyze both the materials used as well as all original details (ie. floor to wall connections, roof to wall connections, wall to opening connections, and wall to foundation connections.)

3. Evaluate the significance of all building elements. Based upon chronology, artistic value or historical association define which elements should be treated with the greatest sensitivity and highest conservation standards.

4. Make repairs based upon the primary method of construction. Avoid using hard materials to preserve soft materials. Remove as much concrete as possible from Indigenous or Victorian adobes. Explore the use of lime as a compromising measure on either Indigenous or Revival adobes.

5. Preserve and maintain the existing conditions, unless a less significant element is damaging a more significant element, then impact the less significant element.

6. Make repairs that are reversible wherever possible. The wrong intervention can often not be corrected by the next conservator.

Detail of a Victorian Adobe
TOMBSTONE, ARIZONA
Janus Associates Inc.

Conclusion

Many times the focus of adobe conservation is placed upon the material itself and those mechanical and chemical properties which cause the material to deteriorate. The focus of the above discussion has been to place adobe within a construction system or context, specifically three historic construction systems found in the Southwestern region of the United States. By understanding the nature of each system as well as their individual materials the conservator can make appropriate intervention decisions; and thereby, preserve adobe in its natural, original, aesthetic state.

ON THE HISTORY OF CLAY BUILDINGS IN GERMANY

Jochen Georg Güntzel
Department of Architecture and Interior Design
Fachhochschule Lippe
D-4930 Detmold, Bielefelderstraße 66
Federal Republic of Germany

ABSTRACT

From time immemorial, clay has played an important role in the building of houses in Germany. Its greatest importance lay in its utilisation as infilling material for walls and ceilings, for laying floors and as mortar. All of these techniques were common until the nineteenth century and were still occasionally employed in the twentieth century. Solid ("monolithic") clay structures, that is, buildings with load-bearing walls consisting only of clay, without timber or stone, have been in existence in Germany since the Middle Ages. Their number is considerably larger than had formerly been assumed and they are formally and technically interesting buildings. Few of these buildings have been placed under protection as historic monuments because the peculiarities of this building technique are on the whole unknown. There have been many attempts in Germany to revive clay architecture. The most important reasons for the use of clay as a building material were its incombustibility and the saving of wood and energy.

KEYWORDS

Clay architecture; Architectural history; Building techniques; Propagation of the use of clay as building material; Utopian architecture.

Fig. 1 Depicts a rammed-earth house.
(" Representat domum ex argilla contusam." Drawing by Ludovicus Reischl, Wien, 1780). [7]

Next to timber and stone, clay has been the most important building material used in Germany. It served as infilling material for walls and ceilings, as a sealant for crevices in log cabins, and was used for the construction of floors, vaults and ovens.

Most certainly, clay´s greatest importance lay in the realm of timber-framed buildings ("Fachwerkbau", see fig. 2) where it was used as a filling material. Incidentally, this type of work (daubing) was nearly always done by the owner himself, or with the help of his neighbours, and it is for this reason that it never developed into a professional craft and consequently seldom enjoyed high status.

However, this paper does not need to address the uses of clay in timber-framed architecture: The number of publications on this subject, always the favourite child of building historians and ethnologists, is legion. The problems of the restoration of framed buildings are not nearly as great as those of solid clay structures, since the framework of these buildings, the "primary structure" ("Primärstruktur"), is of timber. Instead this paper will focus on the history of solid ("monolithic") clay structures in Germany, in particular those buildings whose supporting walls consist solely of solid clay (See figs. 1, 3 and 4). Until recently, little was known about the history of these edifices, the special techniques used in their construction, their advantages and disadvantages, their number and the areas of their distribution. On the contrary, a great many misconceptions and prejudices about them are in existence. One can indeed maintain that there have been few types of architecture in the course of German history about which so many falsehoods have been propagated.

If a German art historian, architect or curator of public buildings were asked if he knew of any solid clay structures in Germany he would probably be unable even to name a few, let alone correctly to differentiate between the various building techniques. He is not likely to know the age and geographical distribution of these buildings or conditions of their construction. Yet the sheer number of them is impressive. It has been estimated that the solid clay structures in Germany originating in the eighteenth and nineteenth centuries number in tens of thousands and that those built in the twentieth century number somewhere between 30,000 and 40,000. Yet in Germany much more is known about clay structures in Africa, America or Asia. It is, after all, vastly more interesting--as the saying goes--to sweep in front of your neighbour´s door than in front of your own.

It is probable that the technique of building with solid clay has been used in Germany since the early Middle Ages: Several buildings excavated and dated by archaeologists were possibly constructed as early as the eighth or ninth century. However, it is also possible that these buildings date from a later medieval period; the archaeological evidence is unfortunately not always easy to interpret. In any case, more important than the question of exactly how long these solid clay structures have been in existence is the question of why it was decided to build in solid clay. Did this material make for more comfortable living quarters? Was it because clay was a safeguard against fire? Or did solid clay houses afford the owner higher prestige? Lack of timber was certainly not the reason, as this material was still abundantly available during the Middle Ages.

The oldest known buildings are in Saxony and Thuringia, where most existing clay buildings are to be found even today. When this type of construction aroused interest in the eighteenth century, it was reported to be very old even then, and one hundred- or two hundred-year-old buildings were not in the least a rarity.

Fortunately, there exists a very old written reference which we can use as evidence for this piece of research. Today we would call it a detective story. A peasant from a village near Leipzig testified in 1560 that the clay walls of his granary had been dug through for the purpose of stealing grain. He expressly referred to the thickness of his granary walls: they were one and a half ells thick, i.e. 87 cm [1]. Therefore we are certainly dealing with a solid clay wall, not a timber-framed one, which normally has a thickness of only about 20 cm.

The first solid clay structures were built of clay mixed in its wet state with plant material and then laid in several layers with pitchforks. Sometimes the walls were formed with the aid of a shuttering, although the clay was not rammed (the method used with the "pisé technique"). After drying, the walls were smoothed. This technique is well known in many countries of the world; in Great Britain it is usually called "cob". In England this type of building has been intensively studied [2]. There are a number of handsome cob buildings, such as the birthplace of Sir Walter Raleigh who pioneered the first (unsuccessful) English settlement on the coast of North America at Roanoke in 1585. Captain Cook (born 1728) is also reputed to have been born in a clay cottage. The latter is no longer in existence in situ: According to my information it has been transported to Melbourne, Australia. In addition to this "cob" technique, there were buildings constructed of unfired clay bricks called "clay lumps", made of clay mixed with straw, what in America is mostly called adobe (See fig. 3).

Fig. 2 Depicts a timber-framed house. ("Representat domum ex viminibus contextam." Drawing by Ludovicus Reischl, Wien, 1780). [7]

In Saxony and Thuringia the authorities began to express interest in this type of construction at a relatively early date. The motives for this interest are understandable as it offered a safeguard against fire in the city and the country (most buildings were very much endangered because of their thatched roofs, timber ceilings, etc.). One was also concerned with reducing the amount of wood used [3].

Since it is important to clarify this motive of limiting the use of wood, let me digress for a moment. I shall not lose sight of my goal, which is the exploration of the history of clay architecture.

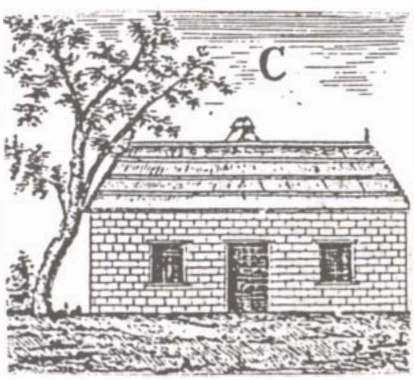

Fig. 3 Depicts a house built of unfired bricks ("Representat domum ex tegulis incoctis constructam." Drawing by Ludovicus Reischl, Wien 1780). [7]

Originally, the forest and its produce belonged to everyone in common. With increasing population and the claims of the nobility and clergy to more exclusive rights to the woods, the consumption of firewood and timber for building constantly increased. Until 1800, the consumption of wood in thickly populated areas was extraordinarily high due to the fact that it was practically the only fuel used in household heating, cooking and industry before coal became available in quantity. Correspondingly, it was used in ever-increasing amounts in areas of growing industrial development. Many wooded areas were ruthlessly plundered and degenerated into heaths. This was true not only of the forests in densely populated areas, but also of the woodlands from which timber could be transported with relative ease, e.g., by raft. An immense amount of timber was used for the construction of commercial vessels and warships. For example in the eighteenth century about 2,000 oak trees were needed for a man of war of 64 guns. It was reported that rafts of immense proportions were floated down the Rhine and the Elbe. Gradually people were faced with an ecological catastrophe (had they known and used this term at that time), the depletion of wood supply. The danger was that soon there would be no more trees and the forest would be unable to fulfill its function of regulating the climate.

In Saxony, which had several industrially developed areas, the authorities tried to limit the use of wood as early as the end of the sixteenth century. Local ordinances permitted the use of timber for new buildings only if it was demonstrably impossible to construct them of clay. Other rulers of territories issued similar regulations, but often not until 200 years later.

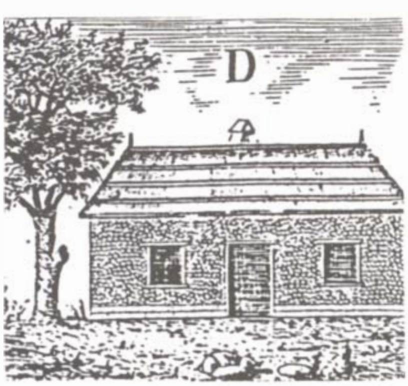

Fig. 4 Depicts a house built of wet clay lumps.("Representat domum ex glebis argillaceis confectam." Drawing by Ludovicus Reischl, Wien, 1780). [7]

A special feature of clay architecture in Germany, as opposed to those of her neighbours, is the fact that clay was assigned a particular role at the turn of the nineteenth century. Individuals as well as groups (notably the agricultural societies), were enthusiastic about this building material and praised it almost euphorically as being the one and only material suitable for the improvement of building technique. At the same time it was believed that clay could be utilized for the promotion and improvement of public housing. Thus the writings of Cointeraux describing the rammed earth technique became better known in Germany (and also in Switzerland, Denmark, and England) and received more attention in these countries than in the author's native France.

A girl moistening the clay.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

The first printed work on solid clay architecture identified by the present author was published anonymously in 1736 as a simple kind of pamphlet. It was a propaganda piece of sorts praising the virtues of solid clay architecture as an ideal method of improving the fire resistance of buildings. The author of this pamphlet was in all likelihood an architect by the name of Richter, who was prevented by illness from practicing his profession and therefore had the leisure to write little articles embellished with drawings on the improvement of daily life (see fig. 5). He had these printed at his own expense and distributed them among his friends. In his article on the "fireproof farmhouse," Richter suggested methods which must have been extremely radical for his day and age, and they have been propagated and put into practice on a large scale only in the present day. Richter not only suggested the use of solid clay wall and pillars instead of the usual timber-framing of his time, he went one step further: In order to avoid having even a flammable roof of wooden beams and thatching, he suggested that the farmhouse be vaulted. In addition, on top of the vault there was to be spread a layer of clay and soil, about one metre deep, which could be used for planting. Richter had also conceived an ingenious plan to make this roof garden accessible: A spiral stairway around a central newel, on top of which sat a cone-shaped hood which could be lowered to cover the stair-well in inclement weather.

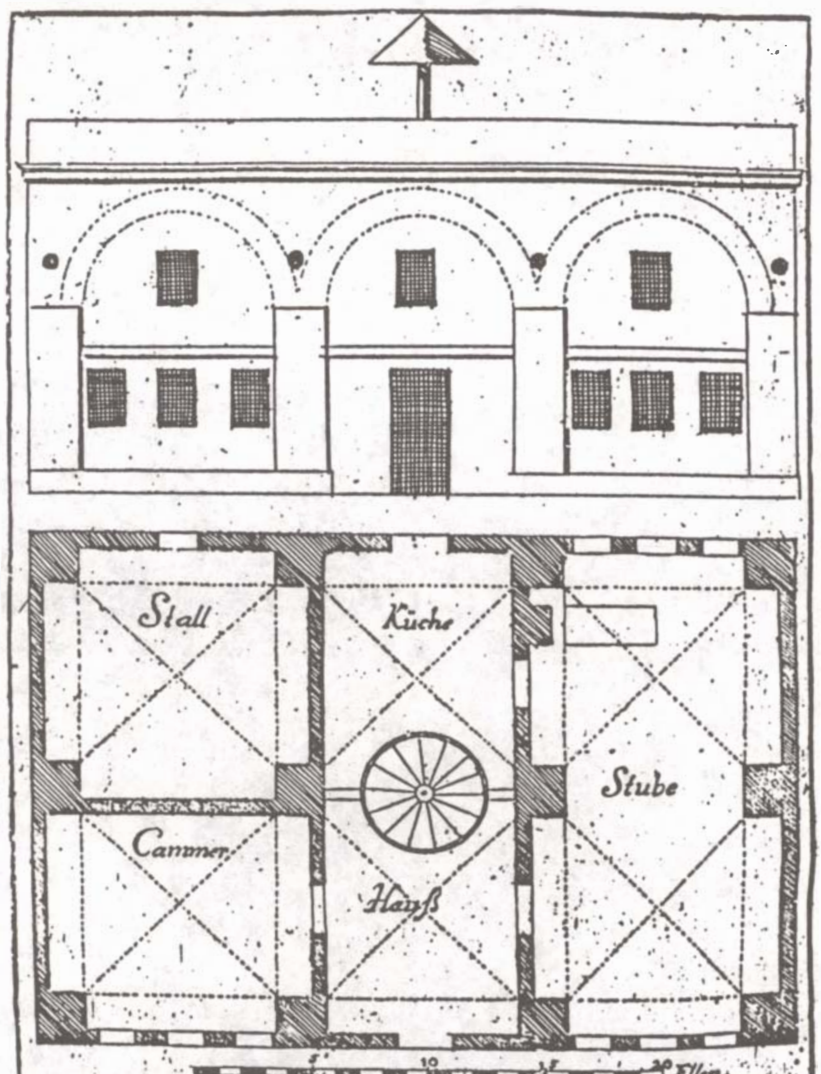

Fig. 5. Floor plan and elevation of a "fireproof farmhouse", as planned by the Saxon architect Richter in 1736. Walls and pillars were to be made of solid clay, the vaults of stone. The roof area was to be filled to a level of about one metre with clay and fertile soil and planted as a garden. The cone-shaped roof to the circular stairway was to have been mounted on the newel of a spiral staircase and could be lowered in inclement weather. [3] (Stube = lounge; Hauß = hall; Cammer = chamber; Stall = stable; Küche = kitchen).

Children helping to mix the clay by stamping it with their feet.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

This theoretical contribution of the Saxon Richter to the advancement of architecture is extraordinarily significant: The dwelling of man, who can only then justifiably be called "homo sapiens" when he is part of God´s creative order, is to be built mainly of clay. Clay structures need little energy for their construction; they are fire-resistant and enduring; and when they deteriorate they can also be creatively incorporated in the natural cycle of growth and decay. Seen from this point of view using the roof as a garden is also logical, since the land which is lost by construction of the building can be reclaimed as fertile land.

During the following decades many more suggestions were made for the improvement of architecture and housing with the aid of clay, but none went beyond those of Richter.

In her essay "Telling Lives: The Biographer´s Art" [4], the historian Barbara Tuchman states that biographies can arouse and grip the reader´s attention in major historical themes, since people are interested in other people and since the biographical form can illuminate general truths by means of the particular. What follows are a few biographical details meant to acquaint the reader with some ideas of certain little known thinkers and architects. In doing this, I have purposely chosen those thinkers and builders who are scarcely known today.

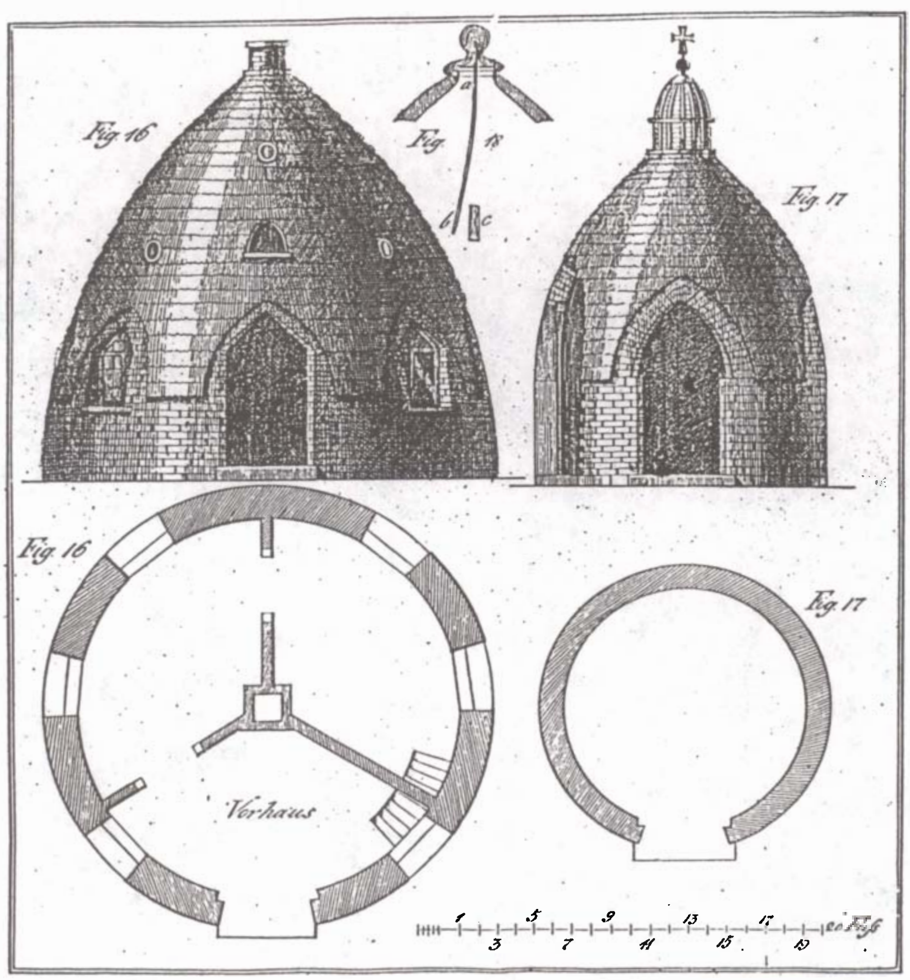

Fig. 6 Wilhelm Tappe, design of a house (Fig. 16´) and goat-shed (Fig. 17´) for a poor family. Both buildings were constructed in 1818 of adobe witout using a centering and thatched with straw. With simple buildings of this kind which were to be constructed by the owners themselves, Tappe hoped to solve the problem of housing shortage. [3]

Children helping to carry clay-loaves.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

One of those who was not well known in his own day and is practically unknown today, is Wilhelm Tappe (1769 to 1823). Tappe, a nineteenth century architectural theorist, artist, architect and poet, desired to set amazing things in motion with clay, that very economical building material. Above all, he hoped to solve the housing problems of the lower classes.

We know very little about Tappe´s training and development, mainly because a large part of his writings and designs are lost. Only a few of his printed works, which he had published at his own expense and of which he sold only a small number, are still in existence. He began his career as advertising expert and industrial designer and then became a teacher and inspector of draughtmanship in the schools. He later turned his attention to the field of architecture. It is impossible to establish with any certainty whether he had practical training or an academic and theoretical education.

From 1813 to 1819 Tappe was the chief architect of the small principality of Lippe, where he found a patroness in the person of Princess Pauline, a very progressive personality and one dedicated to the social welfare of her subjects. For example, she founded the first day-care center for poor children in 1802. It was here that he developed his unusual ideas for solving the pressing housing problems of his age. These ideas should have assured him a place among the most innovative thinkers in the realm of architecture, but he was simply forgotten. He wrote two books on historic buildings in the city of Soest, thus presenting us with the very first inventory of historic monuments in Westphalia. In addition he composed an ode to architecture ("Lied von der Baukunst").

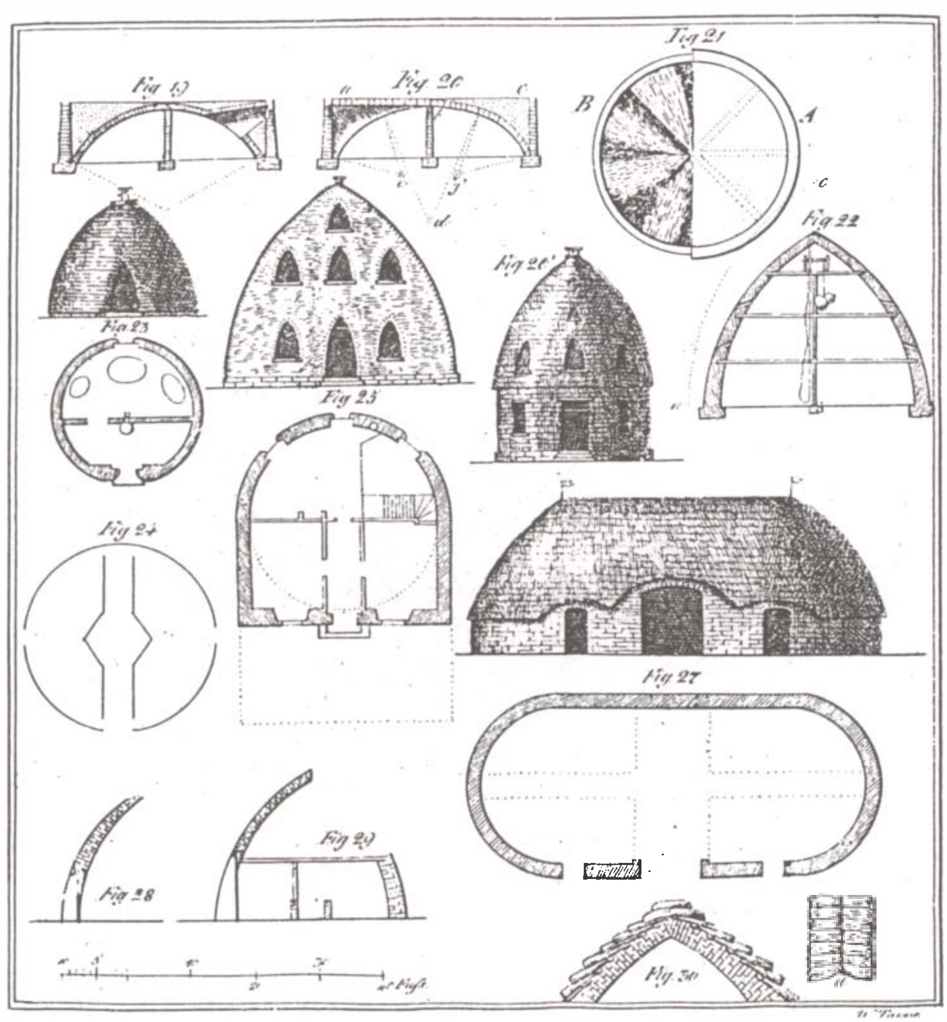

Fig. 7 Wilhelm Tappe´s designs for various buildings derived from the basic "hut shape". Cross-section of a granary with a pulley for grain sacks (Fig. 22´). Floor plan and a facade of a barn (Fig. 27´), living and working quarters for day-labourers (Fig. 25´), and a bath-house with three iron bathtubes (Fig. 23´). This structure (with heated anteroom) was very progressive for that time, as bathing was then considered to be reprehensible.

Women forming clay-loaves on a table.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

The extraordinary thing about Tappe's ideas was that, unlike those of his contemporaries, they were not limited to the development of methods by which individual parts of a house, walls, ceilings, roofing, etc., could be replaced by the cheap and incombustible building material clay. Rather, he made the radical suggestion of having a circular floor plan and of making the houses dome-shaped, like half an egg, and of building them entirely of sod, turf or clay (see fig. 6). He decided on the round floor plan for aesthetic and economic reasons, and the dome shape because of its stability and endurance. The prototypes which he developed and--rather unhappily--named "huts", were adapted from almost forgotten architectural archetypes and were intended to solve the housing problems of the poorer classes. The houses could be built by the owner with the help of neighbours and with a minimum of expense, that is, without employing a professional craftsman. He had designed the shape and size in such a way that the vault could be constructed without a centering; he also developed an ingenious model for checking the vault's shape.

Tappe had the opportunity of having one of his models actually built. The construction of the first adobe hut, which resembled a beehive with its straw thatching, was a veritable sensation. Curiosity seekers came from miles around. Unfortunately the building could be admired for only four years, as it had to be demolished because of permanent damage caused by dampness. The use of straw for thatching the roof proved to be completely inadequate because it could not dry and consequently rotted. Because of the curved shape, water had run into the wall openings and damaged the base. For this very reason it is said in England that clay houses should have a "broad-brimmed hat and dry feet". Another of his dome-shaped buildings made of adobe, a mill near a brook, survived for several decades. Here, tiles had wisely been used on the roof.

In his next seven booklets Tappe waxed ever more enthusiastic about the elliptical shape of buildings. He presented suggestions for the construction of churches, barracks, entire neighbourhoods, bridges, monuments and light-houses in this form (see fig. 7). These were, however, unlike the "hut" of the poor, to be built of stone and not of clay.

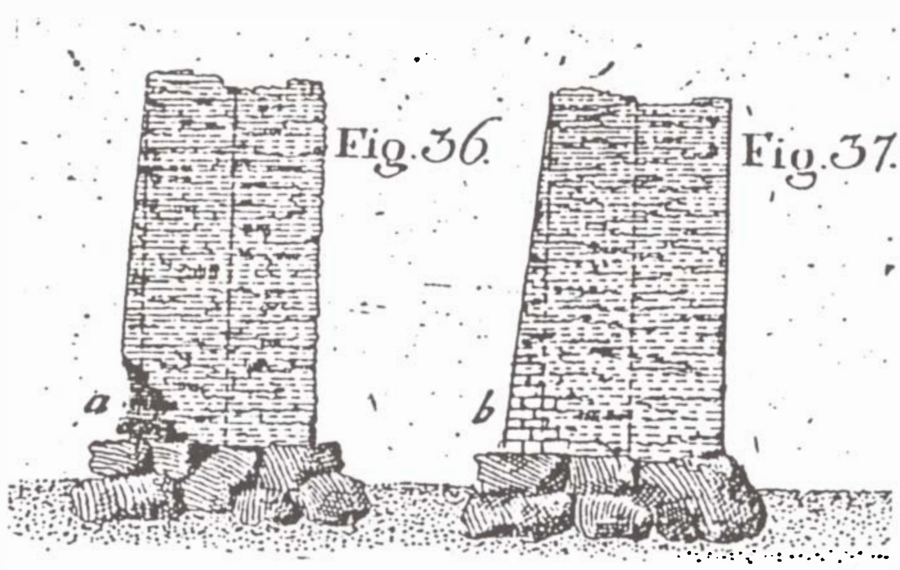

Fig. 8 Cross-section of the exterior wall of a cob building. As all of the participants of "Adobe 90" know, an important rule has been violated: The base should have been high enough to prevent water from splashing onto the vulnerable clay.
(Drawing by Joh. Gottfr. Lange, Breslau, 1779). [3]

Plastering a wall made of clay-loaves.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

Another innovative brain among those who euphorically praised clay as a means of improving the usual type of architecture, was that of the physician Christoph Bernhard Faust (1755-1842) one of the leading hygienists of the nineteenth century. Faust made a number of meaningful suggestions which--had they been consistently put into use--would have made some of the oral and written contributions to "Adobe 90" superfluous. For example, in an age in which this was by no means usual, he advised using two layers of impermeable tiles, glued together with pitch, as a horizontal barrier against rising moisture in the walls of buildings. In addition he suggested dissipating damp vapours rising from the earth by means of horizontal and vertical shafts in the walls. His idea of orientating the house to take the best possible advantage of the sunlight, of using double windows and doors, and of calculating the thickness of the walls so as to waste as little energy as possible make him one of the co-founders of the concept of the "Zero Energy House". The solar energy stored in the solid clay walls was to be used to raise flowers and fruit.

I am coming to the end of my article without having quoted anything from Vitruvius or Francois Cointeraux. And indeed, this is something that one could expect to read in a paper dealing with architecture in general and clay architecture in particular. It should be mentioned that in Renaissance Germany Vitruvius' comments on clay bricks were thoroughly misunderstood, because--and this is true even in the present day--several translators wrongly confused fired bricks with (unfired) adobe. In this way the use of clay was brought into discredit, in some cases perhaps even intentionally. The writings of the French architect Cointeraux, which recommended the ramming method and in general strongly contributed to the advancement of clay architecture, were probably read with greater interest in Germany and neighbouring countries than they were in France. Within the space of a few years, several translations and adaptations appeared. For several decades, pisé de terre was the fashionable technique. However, many of the buildings erected were for purposes of testing and demonstration.

In Germany, the man who, under the influence of Cointeraux, built the most enterprising rammed-earth structures was Jacob Wimpf (born 1767). Like many others who were enthusiastic about this method, he was not a professional builder but a lawyer and factory owner. Indeed, he had all of his factory buildings, some of which were of very respectable size, built of rammed earth because he recognized that clay walls were superior to stone in regard to such factors as thermal insulation and room climate. In 1837 he constructed the tallest clay building in Germany. It is a multiple-family dwelling in Weilburg, built on a steep mountainside (see fig. 9). There are three storeys on the side facing the mountain and five on the side facing the valley. This house still looks as if it had been built only a short time ago.

It has remained the tallest clay structure in Germany; later on the building authorities ruled to restrict clay buildings to one and two storeys. About 1970 the regulations governing clay architecture were withdrawn, so that today solid clay architecture is no longer permitted. And this after some 100,000 to 200,000 clay buildings, erected without any official regulations, had proven their worth! Jacob Wimpf had, in addition, a very special faith in the rammed earth method. To him is attributed the statement "... I would dare to build a tower as high as the Straßburg Minster (142 m). The cohesion which the earth receives through this method of ramming is far greater than that of a stone wall." [3]

Wimpf also believed that living conditions in the New World could be improved if immigrants brought their knowledge of building with clay to their new homeland. What he did not know was that in 1806 an American or British citizen named S.W. Johnson in New Brunswick, New York, had concerned himself with the advancement of clay architecture and dedicated his publication to the American President who was himself a talented architect, Thomas Jefferson. [5]

In the nineteenth century, when Germany was evolving from an agricultural to an industrial society, solid clay architecture as well as timber-framed architecture was gradually replaced by (fired) brick buildings. After the First World War, when the scarcity of energy and transport caused a renewal of interest in this building material which could be obtained and processed practically without fuel, there were hardly any people left who

The forming of clay-loaves.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

were conversant with the techniques of its use. Nonetheless, many thousands of buildings were erected during this time. After the devastation of the Second World War, clay was used in the construction of about 30,000 to 40,000 buildings. Unfortunately, this type of architecture was considered old-fashioned and inferior because hardly anyone was willing to consider its special qualities. It is necessary to revise this judgement. Now that we have recognised that clay is part of the natural life cycle and can be obtained and processed without wasting energy, there has been a revival of interest in clay building in Germany during the past few years.

Conclusions

Clay architecture had a much greater significance in Germany than has previously been assumed. Its greatest importance, however, is to be found not in the structures themselves, but rather in the innovative impulses issuing from the buildings and the literature concerning them.

As a glance at their history will reveal, the opportunities offered by the use of clay in building have by no means been exhausted. If we succeed in abolishing all the well-tended prejudices which exist regarding its use in architecture, then we will have the best chance of creating those conditions necessary for the preservation of numerous historic buildings in Germany, ranging from the dwellings of the humble cottagers up to the level of palaces of the ruling class.

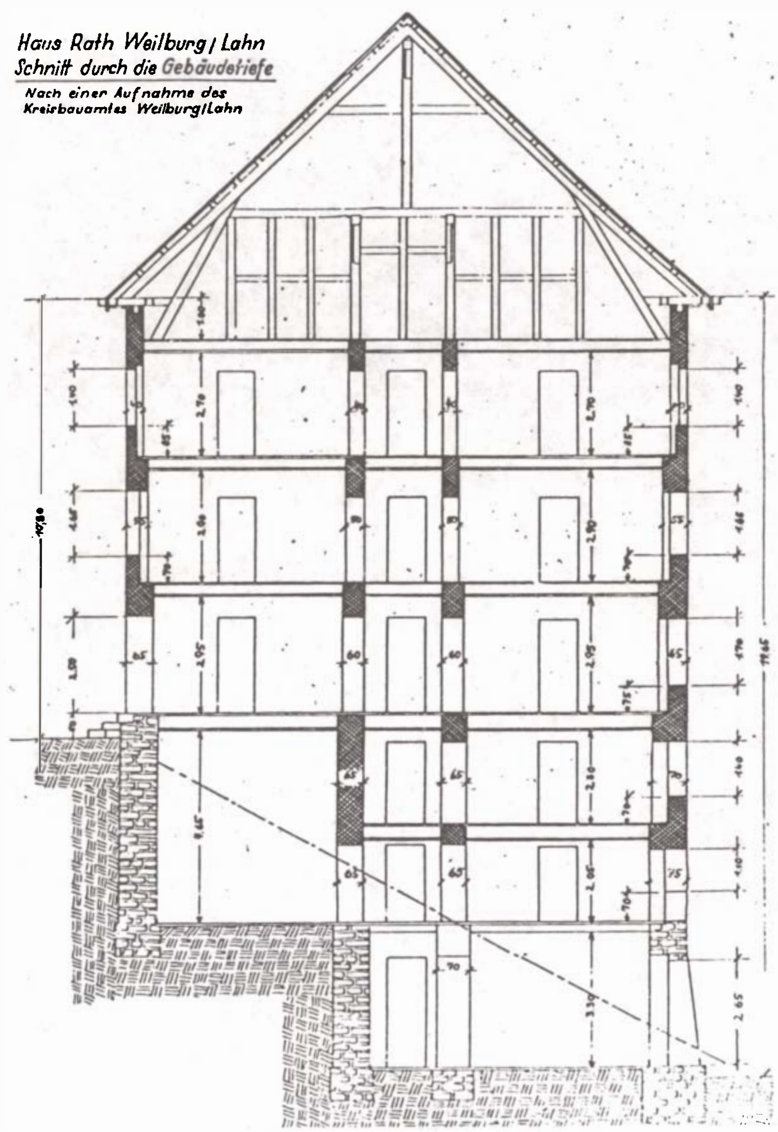

Fig. 9 Cross-section of "Haus Rath", built by Jacob Wimpf in 1837 in Weilburg/Lahn. Built of rammed earth and with five storeys on the valley side, it is the highest clay building in Germany. [3]

A house built of clay-loaves.

(So called "Dünner-method", a method developed in the nineteen twenties). [6]

NOTES

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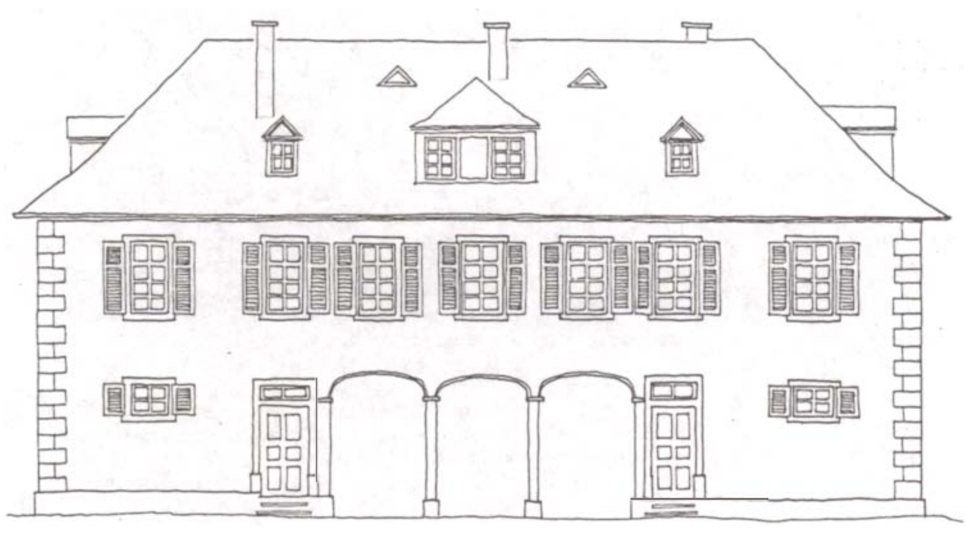

Fig. 10 Princely hotel built of rammed earth 1811 in Fürstenlager near Auerbach-Bensheim. [3]

THE "SLOW" METHOD OF CONSTRUCTION OF TRADITIONAL WET MIXED AND PLACED MASS SUB-SOIL WALLING IN BRITAIN

J R Harrison
English Heritage
Keysign House
429 Oxford Street
London W1R 2HD
Great Britain

ABSTRACT

This study is intended to offer some background support, analysis and, by implication, lines of action, for those seeking to revive the craft of "mud-walling" in Britain. It is based on documentary research and fieldwork and confirms the tradition as of relative complexity and sophistication with many correspondences in international practice. It is dedicated to Alfred Howard, Devon master-builder and conservationist.

KEYWORDS

Britain, mud walls, construction, historical practice.

Introduction

The use of sub-soils in building is a large subject and it is important to confirm the limits of this paper, which concentrates on the now largely defunct British tradition of wet mixed and placed mass sub-soil walling. The parallel and related practices of continuous wet mud building, shuttered mud and mud brick - techniques once also known in Britain - are excluded. An understanding of the basic principles involved is assumed in the reader (1) but some specifically British terminology requires explanation. The terms "cob", "clay" and "mud" were all once used in Britain to describe material prepared for wet-placed mass sub-soil walling. Here 'mud' is used to refer to wet clay-based, and "chalk-mud" to wet chalk-based, mixes. The traditional East Anglian terms "lump" and "clay-lump" refer to unbaked mud brick. The paper is divided into sections describing individual operations within the wall building process or elements relevant to the process at particular stages. Some sections also offer a gloss on the purpose and benefits of the activities and elements described. A few amplify previously made points. All are prefaced by a traditional or modern phrase descriptive of what follows. The study opens with a note on aggregate which, through mix-balancing, offered the builders one way of modifying strongly shrinking "as found" sub-soil, and continues through the other types of mix-modifying additives. The various stages in preparation of the material are then considered and this is followed by an introduction to alternative course building methods and the tools used. Further sections examine the detail of course, and over all wall, construction. "Paring-down", the last phase in the main building process, closes the investigation, leaving matters of building and drying-out time, finishes and overall structural context, to another occasion.

Aggregate

Some sub-soils contained ingredients whose natural balance suited them to wall building "as found". With less reliable sub-soils extra aggregate might have to be added while, over a certain size, it might have to be removed. Large stones were a hazard during mixing and might 'blow' at the wall face and they were therefore invariably removed. Stones above the size of a walnut were picked out by some 'lump' makers, to ensure homogeneity. Where a wall has been left unrendered, aggregate shape and size can be seen to affect weathering performance to a greater or lesser degree.

Mix balancing

As noted above, some sub-soils required no amendment before use. With others, sand, gravel or small stones were added to bulk out the material in order to reduce the 'strength' of the clay element present. 'Dirt, Gravel and Compas' were in use in walling in Leicestershire 200 years ago (2). This practice, in the form of 'stream gravel' added to the mix was still utilised in the County in the 1960's. Pit gravel had been employed sixty years earlier by the squatter builders of the New Forest (3). In Devon, as in Britanny, where a sub-soil was too 'strong', small stones or gravel were added (4). A Cornish ratio was two parts of 'clay' to one of 'shilf' (small, flat slaty material) (5), the same ingredients being mixed together also in Pembrokeshire (6). In Suffolk in 1849 'clay' dug from a pit for lump manufacture was mixed with 'as much sand as it will carry to remain tenacious, say one yard of clay to half a ton of sand' (7). Buckinghamshire "wichert" shows that naturally occurring mixes of clay and chalk can produce very good walling. A well known recipe of 1843 advises that clay-marl is 'best' for building (8). If this is unobtainable, chalk and grit should be added to the clay. In the early 19th century three parts of chalk to one of clay was a common mix in parts of Hampshire and the Isle of Wight (9), while lime is known to have sometimes been added to Devon cob, south country chalk-mud and Irish mud.

Animal organics

The use of dung is so extensively quoted that there can be no question about its value with clay-based preparations. There is no record of its employment with chalk-based mixes. It may have helped to plasticise refractory, and therefore potentially useful, clays and soils low in clay content as well as flocculating soils with an over-expansive clay fraction. All the other common animal organics were well enough known to broad vernacular building tradition but were not extensively used with mud walling.

Vegetable fibre

Fibre of all kinds, was usually but not invariably, added. Sometimes it was pre-soaked but more often it seems to have been added dry to the mix. Where a preference is expressed it is always for barley straw, probably because it was both 'tough' and 'soft'. Before it was added, fibre might be chopped into short lengths or it might merely be 'pulled abroad and bruised with the hands' (10). For binding purposes within the wall - one of a number of functions performed by the fibre - the longer the material the better. Uncut barley straw presumably had the advantages of 'softness' for mixing, handling and placing, and length when laid in the wall course. Some mud was laid with little or no fibre content; some chalk-mud mixes are a case in point while certain Midland iron-bearing sub-soils harden without additions of any sort. Such hardening must represent a one-way chemical set, preventing the re-use of the material, in contrast with what may be a mechanical and therefore possibly reversible set found with some Devon cob claimed as fibreless. The quantity of fibre required in a mud mix is proportional to the 'strength' of the clay element and the quantity of aggregate and water used. One modern West Country builder states that 'the straw makes the cob less sticky. You should add water and straw to the material gradually. Too much straw and the cob gets weak, like dung' (11). In Britain, as elsewhere, 'local custom as to the composition and preparation of the mixture will generally be found to have adjusted itself to the peculiarities of the soil' (12), and localised standard measures such as that at Bridstow, Devon, in 1813 where 'eight bundles or one horse load of straw is mixed and tempered' with nine cart loads of clay to make $4^1/2$ perches ($16^1/2$' (4.950 m) x 2' (600 mm) x 1' (300 mm) high) of cob, ruled (13). Even with mix balancing and the use of fibre, large scale course-confined 'unit' or 'block' drying cracking sometimes occurred, as for instance with walling in the New Forest and Buckinghamshire "wichert". The effects of block contraction were taken in their stride by the builders; some of the most highly performing mud walling in Britain is found in Buckinghamshire.

Weathering the raw material

Weathering the excavated sub-soil over the winter in the open so that rain and frost could act on it was, and still is in places, common practice in brickyards, yet the record suggests that the builder in clay-based mud made little use of the process. Occasionally however, the raw material was 'raised' in the autumn for use the following spring. The practice is known for both Devon and Norfolk 'clay'. It seems by contrast to have been considered a wise precaution with chalk-mud, and was employed if there was time. There is good reason for this - getting newly excavated chalk rubble down to an acceptable aggregate size could be a back-breaking and lengthy task.

'Soaking' the raw material

This process has affinities with weathering but is less time consuming. Henry Best, the 17th century Yorkshire Wolds farmer and diarist recommends it for the preparation of mud mortar for thatching but his principle stands for wider use, 'Mortar neaver doeth well unlesse it bee .... well watered and tewed; it is accounted soe much the better if it bee watered over night, and have nights time to steepe in ..... water it and tewe it well, till it bee soe soft that it will allmost runne; then lett it stande a while till the water sattle somethinge from it, and it will bee very good mortar' (14). Soaking allows water to split down the clay particles and increases plasticity. It compresses them under their own weight and brings them into maximum association with the fine aggregates in the mix, bringing strength - or this at least should be the result once 'soaked' material is mixed and turned over prior to placing. In the New Forest after 'puddling' (mixing), the material was worked to a 'slurry' and then left to drain before use (15). Draining would presumably have removed the finest and most unstable part of the clay fraction. In the western Scots Borders in 1810 it was noted that mud builders first worked the "common clay" with water into good mortar and then let it lie to get more consistency (16). One authority has it that 'wichert', the natural chalk and clay mix, was soaked before use (17). It was certainly thought an advantage to pre-soak chalk-mud. During the recent experimental rebuilding of a chalk-mud boundary wall it was found that a lesser amount of water standing in the chalk-mud mix over a longer period is of greater benefit than a larger amount of water added just before use. The material is more easily worked and laid, and shrinkage cracking arising from drying-out is reduced with the lesser quantity of water (18).

Souring

An Irish survey mentions that after wet-mixing with fibre, mud might be left to 'temper' or 'sour' for several days, being turned over or re-kneaded occasionally (19). In contrast to the mechanical action of soaking, souring changes alkalinity to acidity through bacterial action and promotes flocculation in the clay. It seems that the British mud waller rarely sought to bring about deliberate souring though the writer has personal experience of its being achieved accidentally with a re-used daub mix. However, the adding of organic matter such as dung would, in the right circumstances have some potential for encouraging flocculation, as noted earlier.

Tempering or Puddling

These were the terms for mixing, descriptive of the process. Hand mixing persisted to the end, work that would 'pull the ribs out of a man'. The term 'treading' was often used for the actual process of mixing. Hardy says of Dorset that women were sometimes put to treading, an echo of ancient tradition. The work might be done barefoot, but heavy boots, sometimes shod with irons, were needed for stoney mixes. The correctness of Ellis's description of central Devon mixing methods is borne out by more recent practice. Moving inward from the perimeter and treading down the mud as they go, the circular heap is turned over and trampled down once by a couple of men while barley straw and water are sprinkled on. The process is repeated and then the cob is ready for use (20). Such speedy preparation helps to bear out the claim that Dunsford cob is among the best in the West of England. At the other extreme chalk-mud builders in Wiltshire are said to have needed an hour or two to produce a reasonable amount of useable material (21). In the light of this, their now-lost mudwallers' song chanted while they toiled, was a very necessary adjunct to the operation as was, and still is, the liberal consumption of cider. In Cumberland and Dumfriesshire whole communities still came together at the end of the 18th century to make short work of mixing - and the remainder of the job. Tempering by driving domestic hoofed animals through the mud is known from Ireland, north east Scotland, north west Wales, the West Country and East Anglia. Oxen were originally preferred to horses for the work because of the cloven hoof. A 'sandwich' of three successive layers each of 'soil, hay and water' round which horses or oxen were driven is described for Devon in 1810, and 'as the cattle in treading it cause it to spread, a labourer with a three pronged fork throws it up again ...' (22). For a watered and straw-spread bed trampled by horses in Essex in 1843 it was noted that the mud '... can hardly be too much trodden. The clay-dauber's joke is, "You spoil it if you tread it too much"' (23).

Compression while mixing

The 'clay-dauber's joke' confirms a deeply held traditional view of the value of treading, beating and chopping of mortars, both lime and clay based. After soaking, further compaction of the mud took place while it was trodden and turned. A hint at more serious efforts at compression at this stage can be found in the former use in Devon of a mud beater - described as a semi-circular iron hoop whose base was attached to a wooden handle by a flail type joint.

Wet built, unshuttered, mud, slow method

The raw material was prepared fairly stiff and was picked up either in bare hands or on a fork in amounts called 'clats' in Devon, placed on the wall, beaten down and built up to form a course, often a couple of feet high. This had to reach a certain level of dryness before the next course could be superimposed. Courses were known alternatively as rases, scars, rearings and berries. Ellis refers to them as lifts. Where the fork was used there were two ways of raising individual courses; these are described below.

Hand placed mud walling

Only one example of this technique is recorded - by Deas in Norfolk in 1938 - but this stands as a pattern for innumerable similar structures long ago razed and swept away, '... the clay was moist when laid; the builder simply gathered up a quantity of clay and pressed it into shape to facilitate handling and make it conform to the wall thickness ...' (24). Here we are in the presence of widespread and ancient practice. The method allowed construction to the finished wall thickness from the outset, an advantage for the self-builder with limited resources of time and effort available.

The fork

The use of tools allowed the worker to keep relatively clean, to extend the reach of his arm and to improve compaction through beating as he worked. From north-east Scotland through the Borders to Lands End, the fork was the prime instrument of construction with both dung and hay forks featuring largely in the oral tradition. So identified was the tool with the technique that mud walling in Norfolk was known as 'forked clay'. As late as the 1920's, an observer of New Forest methods complained that there were those who '.. could not build a wall with a "mud prong" but trusted to board "clamps", and thus this serviceable walling material has been discredited, most unfairly' (25). The term 'mud prong', as also 'mud' or 'cob, pick', suggests a specialised tool and there was indeed such an implement. Known recently from Cornwall to Buckinghamshire this took the form of a small trident. Ellis accurately illustrates the type. The prongs were set at an angle to the haft to allow for a scoop action and the small size of the head underlines the need to keep to the minimum the weight of each 'clat' moved. Strain on the worker was reduced since material was taken in small packets, while many small packets consolidated better in the wall than fewer, larger, ones.

Using the fork

Compression continued during the mud moving and placing stages. After mixing, a 19th century Devon labourer is described as taking his 'three pronged and somewhat flatted' fork and 'striking the soil therewith until it lies like a cake' - a modern Devon builder does exactly the same - 'he takes it up with the fork and lays it on the wall, striking it there repeatedly at top and sides until he has packed it close' (26). Once the wall reached any height two men were needed, one standing on, or next to, the wall head. For this stage as recorded in Buckinghamshire, 'One man then stands on the stone grumpling (wall base) and holds the fork in front of him with its tines resting on the grumpling. Another man ... digs a forkful of wichert and smacks it down on the fork of the builder, who immediately turns it over and, with a smart pat, puts it in position' (27). Each 'pat' brings further, if minor, compression. Beating the material on the wall was common practice, with the back of a spade or more usually the fork; it was sometimes combined with treading. Ellis confirms the use of treading, noting that the heels should be well used. Latterly scaffolding was little used and only then in certain specific circumstances. Rose says that when wall height became 'greater than a man can pitch to, a third man is needed, who stands on a raised stage, also with a fork, taking the wichert from the first man and passing it up to the builder'. Recent practice in Devon follows the same approach; elsewhere carts might be used as pitching levels. Comment above relates to average 2'0" (600 mm) to 2'6" (750 mm) thick walling for buildings - for the thinner boundary walling, down to 1'0" (300 mm) thick or less it is hard to see how staging could be avoided.

Course building by diagonal layering

Ellis notes that under the system he examined cob was laid and trodden in diagonal layers to a course height of about two feet (600 mm) (28), an approach also seen outside Devon. The method has parallels with the herringbone effect seen in some masonry as well as in peat block and sod work. It allowed each succeeding layer of angled wet mud to bond with the previous one, producing a continually advancing ramped face against which it was easy to work. The builder took his stand on the hardened top of the course below. He moved backwards, away from the advancing mud work, convenience perhaps dictating that course height would be the level to which the 'boot heel' could easily reach.

Course building by horizontal layering

This approach used thin layers, a number of which made up a full course height. A Devon report says that successive layers were about 6" (150 mm) deep, were coated with long straw and were then trodden down. A few layers were done at one mixing and then left to harden (29). Much thinner layers have been observed in walls in other parts of the country. It was normal for workers to stand on the wet material. A Devon eyewitness notes that straw was spread on the top of a 12" (300 mm) to 18" (450 mm) high course and well trodden in. In Ireland, with courses of similar height, a light person or child might be given this task (30). In Devon in 1980 one of Alfred Howard's workers had to operate on top of the wet material of a small cob structure in a constructionally awkward situation, a gable peak, and this was managed without undue difficulty.

Course height

For those aiming for maximum course height, performance depended primarily on physical matters and especially the amount of water present, while by contrast the course height possible for a self-builder might be limited by the time available to him in the evenings. The number of thin horizontal layers going to make up a course was controlled by wall thickness, wetness, overhang of the wet material at each side and the inherent properties of the sub-soil involved when mixed with fibre and perhaps dung, all this following compaction. Courses ranging between 18" (450 mm) and 30" (750 mm) high are very common with clay and chalk based mud. Sometimes a lesser range of between 12" (300 mm) and 18" (450 mm) was preferred.

Course joints

Though generally formed without mechanical connections, occasionally attempts to 'pin' courses together with pegs between lifts have been observed - a reminder of the close relationship between mass-mud and daubing. Sometimes straw laid across the wall forms a physical course-break. A Devon tradesman believes that such layers prevented the upper, wet, course from destabilising the lower, hardened, course, and if so this would also prevent the new work losing moisture content at too quick a rate into the old. However, a recent practitioner wets the top of the hardened layer before placing the next to help courses "knit" together (31). The straw bed here may relate to the "treading down" stage in the lower course, not to overall structural or constructional requirements.

Paring down

The mud-work was always initially built overhanging the (stone) plinth. In one area late walling has a permanent overhang but usually the face of the mud was brought into line with the base by paring. Paring was known as "dressing" or "facing". Various tools were used, commonly the fork or spade but also mattocks, hay knives and even axes. It was done either from the side or from the wall head, depending on the tool employed. Initial overhang varied somewhat with the raw material. In Ireland paring could either be by course or on full height completion (32). In the New Forest by contrast it was done by course (33). Nationally both approaches were used, choice being partly influenced by the nature of the material involved. Good chalk-mud for instance proves extremely hard when allowed to go fully off, as was found during the rebuilding experiment mentioned earlier. Paring down by the course could thus be seen as the logical approach with this particular material.

Conclusion

It is hoped that this brief and incomplete survey has demonstrated the variety - and incidentally the extent - of one part of the former tradition of the use of "mud" in building in Britain. This was a tradition - now generally, but not entirely, disregarded - bearing a deep understanding of the potential of the material, an understanding nicely displayed in the words of Henry Best on the subject of flooring-clay, "when a floore is decayed, that there are holes worne, they usually leade as many coupe loades of redde clay, or else of clottes from the faugh (fallow) field, as will serve, but they must leade their clottes from such places where the clay is not mixed with sand" (34).

NOTES

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25. H. Sumner, A Guide to the New Forest (1923): 62.

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28. Williams-Ellis, "Cottage Building in Cob, Pise, Chalk and Clay," 38-39.

29. Rex Gardiner, "Extract from a short talk on the repair of cob buildings," given to the Society for the Protection of Ancient Buildings: undated.

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31. Personal communication, Mr A. Howard, Morchard Road, Devon.

32. C. O. Danachair, "Materials and methods in Irish traditional building," 66-67.

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ABSTRACT

The technique of earth construction has a long history of 6000 years, and reached maturity in China by the time of Qin Dynasty (221 B.C). The earthen cave-dwellings in the reaches of Huanghe river valley are an embodiment of Huanghe valley culture. The Great Wall (6350km in length) was rebuilt repeatedly from 476 B.C. to A.D. 1344. The ancient cities of Gaochang and Jiaohe of Tang dynasty (618—907) on the Silk Road have a history of 1500 years, and their historical & cultural value must be protected. The present engineering conservation of the Xian city wall is a prime example of the need to protect rammed earth architecture.

KEYWORDS

Banpo Village, Cave-dwelling, Adobe, Terraces, Huanghe River Valley Culture, Jiaohe and Gao Chang, Rammed Earth

NOTE:

* Yangshao culture is a culture of the Neolithic period in the reaches of Huanghe river valley in China. Because potteries with colour patterns were discovered in the remains, so it is also called Painted Pottery Cuture. The painted pottery is the index of civilization during the Neolithic period in China to a certain extent.

* * These are scripts on tortoise shells or animal bones, the original of Chinese pictogrphic character.

EARTH · CULTURE · ARCHITECTURE

—— The Protection and Development of Rammed Earth and Adobe Architecture in China

Professor Hou Jiyao and Master Jia Weitung
Department of Architecture
Xian Institute of Metallurgy and Construction Engineering
Xian, Shaanxi Province
People's Republic Of China

Vice Chairman of The Cave Dwellings and Earth Architecture Institute of China

A Background

A—1 A Long History of Earth Construction in China

For over 6000 years,the Chinese people in the Banpo Village have used the technique of earth construction to build villages, caves and semi-cave dwellings. Dwellings were circular or square in plan (see Fig 1). In order to meet the needs of life, the technique of making pottery was developed. As exemplified by archaeological findings, the painted potteries * have good shapes and painted patterns (see Fig.2).

China has recorded history since the Xia Dynasty (2100 B.C—1600 B.C) , the first slave system regime. This culture was formed in the middle reaches of Huanghe River valley during the Chinese Bronze Age. The houses and palaces were built on the rammed terraces, according to some Chinese characters from the Shang Dynasty (16th Cent.B.C), for example, 宅、京、高* *. The earth-ramming and wooden Shuttering rammins techniques were used to build walls, according to other shang dynasty characters, 围* *(see Fig.3).

Many earth dwellings, cave-dwellings, palaces and rammed earth and adobe terrace architecture were constructed in big cities during the Warring States (475 B.C) period. Seven States built defensive walls competitively. Then the Qin Dynasty conquered the other states and established the first centralized feudal society in Chinese history and built the unified Great Wall. The technique of earth construction in China had reached maturity.

A—2 Cave Dwellings In The Area Of Huanghe River Valley And The Huanghe Valley Culture.

The area of Huanghe River valley is the cradle of Huanghe valley culture, Located in the northwest China loess plateau region. Our ancestors made full use of the physical qualities of loess —— its plasticity, thermal insulation and easy workability. Simple tools were used to excavate cave-dwellings. By combining expertise in site selection, space organization and the technique of earth construction, cave dwellings with rich Chinese cultural charteristics were created. For example, Mangshan, in the suburb of Luoyang, Henan Province, is a wonder among cave-dwelling villages, a treasure of human culture and also the crystallization of Chinese Huanghe valley civilization, which urgently awaits preservation and development (see Fig.4).

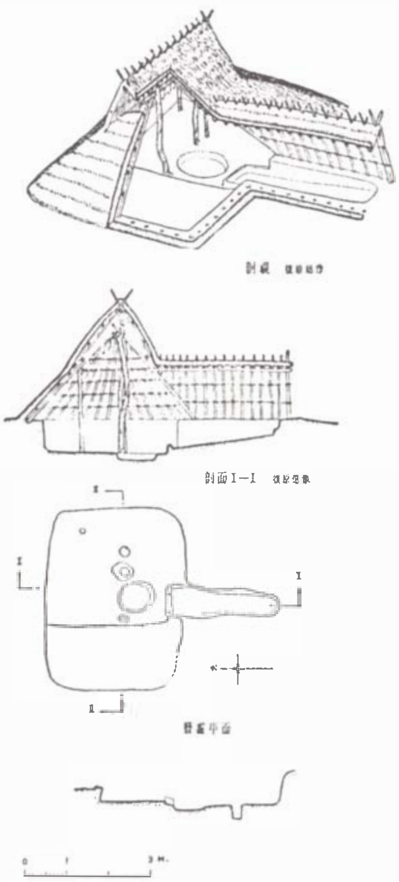


Fig.1 Square Earthen House In Banpo Village, Xian ShaanXi

Section I-I
Section II－II
Plan

A－3 The Great Wall And Chinese Culture

The Great Wall in China is one of the greatest engineering constructions on our earth

The construction of the Great Wall started 2200 years ago. From the period of the Warring States (476 B.C) to Ming and Qing dynasties (1368－1911), efforts were made time and again to extend and strengthen it. As a result, its full length exceeds 6350 kilometres. The Qin, Han and Ming dynasties mostly built with rammed earth and adobe. At the time of the Qin dynasty (221 B.C.), the Great Wall, starting from Lin Zhao of Gansu Province to the east of Liaoning Province, required 300,000 people and 10 years to complete by A.D.213.

The portion of Great Wall in the suburb of Beijing was rebuilt in Ming dynasty over a period of 100 years. The Great Wall, a great military construction, is the crystallization of the ancient Chinese people's labor and intelligence and is the pride of ancient Huanghe River valley culture (see Fig.5).

B. The Protection And Development Of Earth Defense Ramparts In China

B－1 The Ancient Cities Of Gaochang And Jiaohe In Tang Dynasty (618－907)

The ancient city of Gao Chang built during the Tang dynasty is located in Turfan district of the Xinjiang Province. It had been the capital of the Gaochang Empire for 1500 years, and was the only one of 5 states on the Silk Road in Han dynasty. Remains of city wall built with rammed earth still exist. The area is 200 square km with a 5 km perimeter, and is divided into 3 sections － the palace, the inner and the outer city, with ramains of adobe architecture scattered over a wide area. An intact temple still exists in the southwest corner of city, with an area of $10000m^2$, Its gates, squares, chambers and pagoda are still visible. There is an earthen pagoda, 15m in height, in the inner city. All constructions within the city were built with rammed earth and adobe. There is a great adobe dome-shaped roof in the temple with an amazingly high level of building technique (see Fig.6).

The ancient city of Jiaohe is located 10km away from Turfan county. The city is built alongside an earth precipice without a city wall. It is 1000m long from north to south, and 300m wide from east to west. There were gates and a road leading to the centre of the city. The road is 350m long and 3m wide. There are high and thick rammed earth walls on the side of the road, and the buildings behind the walls are divided by lanes into 3 sections. The northwest section are mostly sites of temples with pagodas which house Buddha images in niches. The northeast section is a residential zone where court-type houses are densely clustered, most of which are well preserved. The southeast

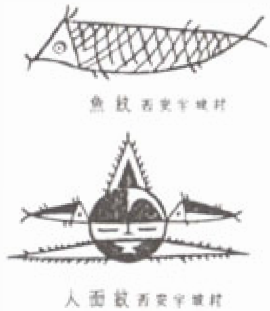


Fig.2 A Painted Patterns On A Colour Pottery In The Epoch Of Yangshao Culture

Fig.4(a) The Bird's-eye View Of Pit Cove Dwellings Village In Mang shan

Modern Chinese	Script on Animal Bones	English
宅		House
京		Capital
高		High
圃		Hunting Field

Fig.3

section buidings are mostly ruined, except for a large edifice with chambers, courtyard, steps and widing corrider; This area of the city is possibly political centre. On the north termination of the road is an edifice built with brick and tiles. The eave tiles have the Tang dynasty lotus pattern. Jiahe flourished more than 1865 years from Han Dynasty to Yuan Dynasty (1272—1368) (see Fig.7).

These two ancient cities were important cities along the ancient Silk Road. Because of the dry climate, it is a architectural wonder that their adobe and rammed earth structures are so intact.

B-2 City Wall in Ming Dynasty (1368-1644) — The Protection And Development Of Xian City Wall

The city wall of Xian was constructed during the Ming Dynasty. It is 13. 7km in perimeter, and lies 4.2km long from south to north and 2.65km wide from east to west. The wall is 12m high, 15-18m wide at the bottom, 12-14m at the top. Its rammed earth core is encased with bricks. There are 98 combat quarters in a 10×12m area along the wall. Bricks are paved along the top of the wall. On the outside of the wall there are concave crenels spaced at 2.36m interval; the parapet walls inside are 0.75m high.

There are gates on each side of the city, with a main tower, embrasured watchtower and locktower at each gate. The city canal is around the city wall, and is 14.6km long and 14-24m wide. There is also a suspended bridge under the locktower.

Zhu Shuang, the son of Zhu Yuanzhang (first emperor in Ming Dynasty) established his palace in Xian and began to build the Xian city wall, which was built on the base of the Feng Yan city of the Yuan Dynasty (1271-1368) and extended the area by 1/4. From then on the wall had been rebuilt many times. It was first built by the rammed earth method and was then enclosed with brick in 1558. During the Qing Dynasty (1781), the city wall was heavily repaired, and a sewer system was constructed. In 1983, the city wall was protected and developed a third time by the committee of city wall conservation in Xian.

From the time of the construction of Daxing city in the Sui Dynasty (581 -618) to that of Changan city in the Tang Dynasty, the Xian city has a history of 1400 years, it is the crystallization of the Chinese labourer's intelligence and labor. The section of Xian city where there is evidence of the king's palace, has rammed earth walls dating from the Sui and Tang Dynasties which are 4600m in length. A very precious historical and cultural relic, the Xian city wall was the first cultural relic to be protected by the government in 1961 (see Figs.8,9.).

Because of war, lack of maintenance and erosion by wind and rain, the

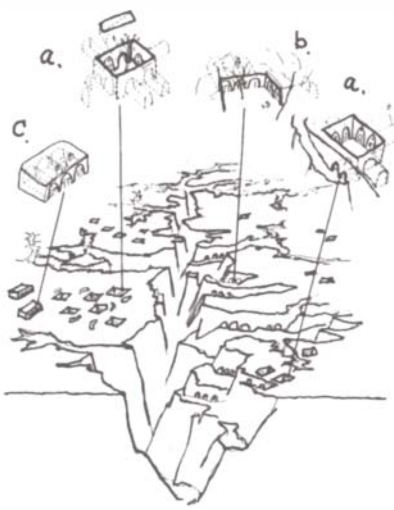
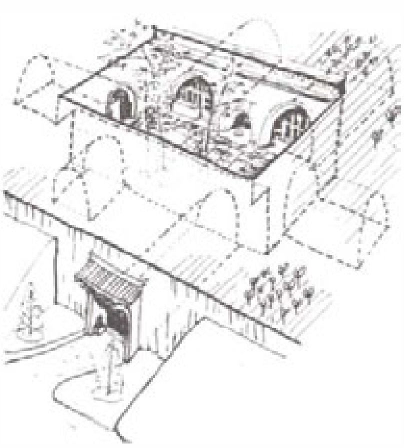


Fig.4(b) Types Of Cave Dwellings In The Northwest China Loess Plateau Region

a. Pit Cave Dwelling
b. Cliff Cave Dwelling
c. Earth Sheltered Dwelling



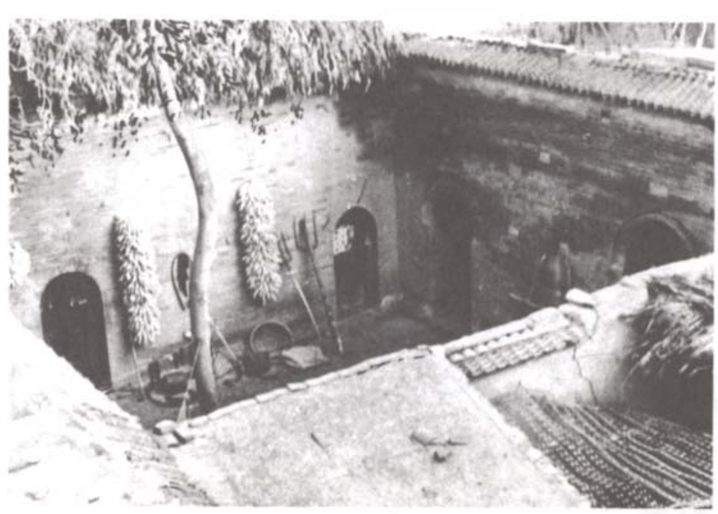


Fig.4(c) Pit Cave Dwellings

Xian city was ruined severely after the Qing Dynasty. In 1983, the state council allocated a special fund of 53 million yuan (RMB¥) to assist in the conservation of Xian city. A committee of city wall conservation in Xian was founded; the project goals were to restore and renovate the city wall, transform the woods around the city wall, bring the old city canal under control and open the road enclosing the city wall. The construction budget for forty—four main projects was 135 million yuan (RMB¥) and utilized labor of 8 million volunteers. Before the rain season in 1985, the conservation of the city wall and canal were mostly finished and has benefitted society and the environment. It is an important milestone in Chinese architectural history.

C Conclusion:

China is one of the five ancient countries in the world with a long continuous history. Rammed earth and adobe were the first materals used for architectural construction. From the prehistoric age through slave and feudal societies, nearly all of the construction in the world depended on the earth technique. In the reaches of Huanghe river valley, there are still 40 million people who live in the cave-dwellings and other earth architecture. Consequently, the history of adobe and rammed earth architecture and the site of Great Wall built with rammed earth embody the course of Huanghe culture. It should be recorded in the treasure home of human culture, and compared with such constructions as the pyramids in Eygpt.

The ancient wars stimulated the building of defense ramparts, and the activities of building city walls advanced the technique of adobe and rammed earth. The Great Wall, the ancient cities of Gaochang and Jiaohe and other remains are like all the rare cultural relics in the world, worthy of protection and restoration.

The good example of developing and protecting the ancient city in China is the conservation engineering of Xian city wall. Now, through the renovation by Xian people, It has been the main relic in Xian and has benefitted society and economy for 3 years.

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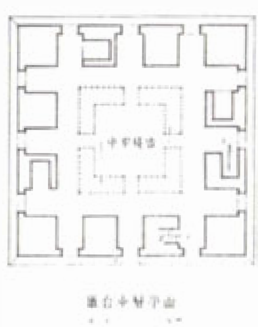

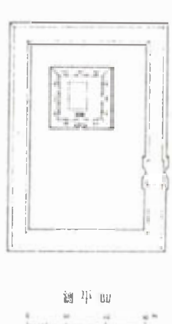

Fig.5(b) A Combatting Quarter Of The Great Wall

Plan

General Plan

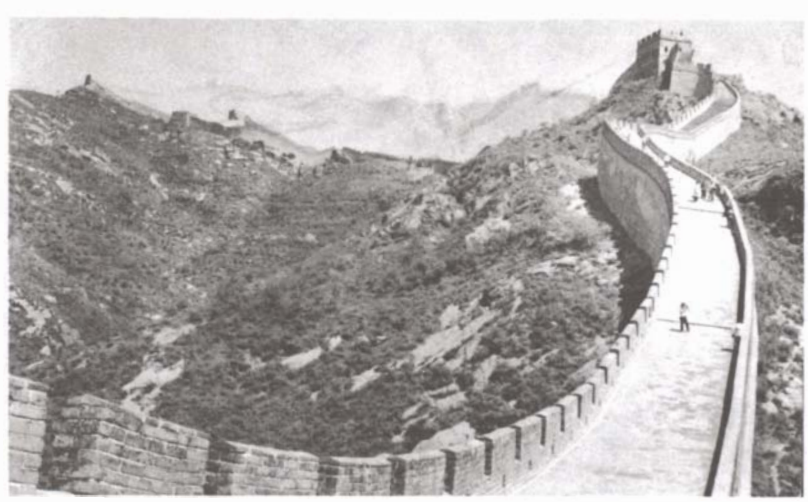

Fig.5(a)
The View Of The Great Wall In Badaling, Beijing.

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Fig. 6
The View Of Ancient City Of Gaochang

Fig. 7
The Full View Of The Ancient City Of Jiaohe

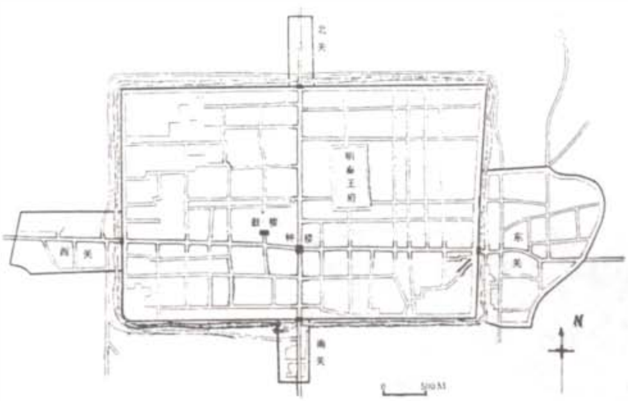

Fig. 8(b)
The Plan Of Xian City Wall In Ming Dynasty

Fig. 8(a)
The View Of Maintenance Of Xian City Wall

Fig. (9)
The View Of Xian City Wall Which Renovated by Xian People

CYCLICAL MAINTENANCE OF EARTHEN ARCHITECTURE AS A FUTURE POLICY IN TANZANIA

Donatius Msobwe Kamana Kamamba
Ministry of Labour, Culture and Social Welfare
Department of Antiquities
P.O. Box 2280
DAR ES SALAAM

ABSTRACT

In spite of the fact that the conservation of cultural heritage is a concern of the world today, the heterogeneity of this heritage has caused conflicting conservation philosophies among policymakers and professionals who do not agree on common solutions to common problems. Conservation philosophies and practices become difficult when talking of architectural conservation, as one is dealing with structures exposed to all the environmental hazards and much worse when dealing with earthen structures, built of a material described as poor, fragile, archaic, and primitive.

It is obvious that in developing countries like Tanzania both policymakers and professionals have been promoting and advocating the use of modern building materials and consigning the vernacular architecture, earth structures included, to village museums.

The actual fact is that modern building techniques are beyond the reach of the general rural population in Tanzania, as it is in some other developing countries. Regardless of the above fact, policymakers and professionals are encouraging and promoting the use of modern building techniques. Despite this conflict between the ideals of policymakers and actual reality, it must be understood that the heritage has to be passed over to the next generation. I am of the opinion that cyclical maintenance and conservation of the earthen architecture could be a compromise in our country. Techniques of traditional earthen architecture should be perpetuated and yet adapted to changing conditions.

KEYWORDS

Cyclical maintenance, traditional crafts, legislation, training, improved designs, dissemination of information, conservation within a rural built environment.

Introduction

Despite prejudices that have continued to flourish under many guises, condemning earth as poor, fragile, archaic, and primitive, evidence from all over the world points in precisely the opposite direction: earth is a versatile and durable building material with many qualities to justify its use today.

Supporting the use of earth as a building material, Dr. Julius Nyerere, President of the Republic of Tanzania, declared in 1977:

> People refuse to build a house of burned bricks and tiles, they insist on waiting for a tin roof and "European soil" - cement. If we want to progress more rapidly in the future we must overcome at least some of these mental blocks. [1]

And Mrs Indira Gandhi, Prime Minister of India, stated in 1980:

> All the new houses are built for energy consumption. They are hot in summer and cold in winter, whereas our old houses are not. So we have not only to have new technology, but look a bit to the old technology. There is much sense in what people have evolved over the years to suit their climate, their environment, their way of living. You can't keep all of it, because our way of life has changed, but I think a lot of it can be adapted and made efficient. [2]

Archaeological research has revealed that earthen architecture was in use during the ninth century A.D. along the East African coast, especially in Kilwa Kisiwani and probably much earlier in some inland areas. It is a heritage to be proud of, a symbol and identity of our architectural development. Today, this type of building dominates the vernacular architecture in the country.

The International Charter for the conservation and restoration of monuments and sites - The Venice Charter - which was adopted by the Second International Congress of Architects and Technicians of Historic Monuments (at its meeting in Venice from May 25th to 31st 1964), explicitly states:

> Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognised. It is our duty to hand them on in the full richness of their authenticity. [3]

While President Nyerere and Mrs Indira Gandhi have encouraged the use of earth as the best way of developing our building industry, the International Charter too, advocates the handing over of a country's architectural heritage to succeeding generations in the full richness of its authenticity. This is a clear indication of the need to conserve this architecture in every possible way. But it is obvious that culture is never static and so conservation of earthen architecture has to take into consideration not only the conservative and scientific way of architectural conservation but also the social and economic factors which necessitate the idea of cyclical maintenance.

Historical Background

Earthen architecture is still a living art in Tanzania, as well as elsewhere in the world. It has been used for thousands of years, not only in rural housing, but also for monuments that reflect the material and spiritual development of communities: warehouses, aqueducts, pyramids, religious buildings, and defensive walls. Earth is one of the most practical and viable building materials as it is an ecological resource the use of which is based on regionally derived techniques. "Earth structures, built of local materials by local people, do not demand a high level of technology. They are not built to scientific principles nor are precise quantities and mixes used. Each new generation had to reassert the way and pass on the method to the next generation." [4]

In Tanzania, traditional building construction in rural areas was always a highly cooperative venture. It was a major social occasion in which both men and women cooperated. There was very little division of labour and everybody was supposed to know everything. Given these considerations - very little division of labour, the need to use essentially voluntary manpower, and the uniformity of the structures - one would think that construction techniques would have to be extremely simple. In fact getting any sort of earthen dwelling to stand up requires a good deal of skill and the use of techniques developed conscientiously over a long period of time. These techniques involve choosing the soil, preparing the soil for building, and selecting admixtures and finishes. The durability of these structures depends very much on their maintenance. They can survive nicely as long as they are in use.

Types of Earthen Architecture

There are three main types of earthen architecture in Tanzania. Buildings are mainly curvilinear or rectilinear in plan. Roofs are either flat, conical, pyramidal, or beehive type, usually supported by a central pole and made of closely spaced, heavy rafters tied together to form a strong support for thatch. Thatch may be tucked into the framework or applied in layers fastened to the framework and tied together by means of thin reeds and sticks. Floors are made by beating mud with a wooden beater while it sets. The mud is mixed with charcoal, small aggregate, or cow dung and then smeared with ashes, clay or cow dung. Mud floors can become almost as hard as cement and quite smooth.

The most popular type of earthen architecture is wattle and daub which is found in both rural and urban areas. Walls of buildings are made of upright wood posts to which horizontals are tied in parallel pairs. This framework is filled with mud and plastered on the inside and outside with cow dung, ashes, or clay. The plaster, which acts as a protective layer, is usually applied in several coats, and in some cases vegetable oils are added to create a kind of water repellant. The rigidity of the structure depends very much on how deep the posts are planted in the ground. The mud which is used for both framework filling and plastering is prepared by digging a pit and discarding the top soil. Then the red soil is broken into clods while wet, puddled by stamping and then applied by hands.

Another principal type of earthen architecture is made of sun-dried clay bricks. This type is used widely and is probably of a recent development. Clay bricks are shaped in moulds, dried in the sun (preferably under shade), and then used to build walls. These walls are usually built on stone foundations, but in some cases a foundation trench is excavated and the wall built up from it. The soil is prepared in the same way as the wattle-and-daub construction, usually without admixtures. Much care is needed in the selection of soils for these bricks, so as to avoid cracks and shrinking.

A third type is rammed earth, which is limited to very few areas in the country. A building is erected in courses of about 30 cm^2, which are left to harden before the next course is applied. Soils are prepared in the same way as the other examples and usually a 30-cm wide trench is dug in which the wall construction starts. The walls are plastered only on the interior, using cow dung, ashes, or various types of clay.

Existing Conservation Strategies

Archaeological Sites

Earthen architecture has survived in archaeological sites and in very old settlements in Tanzania and elsewhere in Africa. It is this heritage that must be handed over to the next generations in its authentic form. Experience has shown that earthen structures will not survive if they are subjected to environmental hazards: in other words, unexcavated archaeological sites stand a better chance of survival.

The conservation of these archaeological remains - for science, culture, and tourism is in its infancy in Tanzania, not only because of the lack of expertise and funding, but also, to a great extent, due to lack of will. Both the government and the general public are complacent about the conservation of these sites and the preservation of the skills and techniques that could save them. The existing legislation only covers the conservation of structures built before 1863, but does not include (or recognize) the skills and techniques used to build these structures. Thus, with time, they will vanish, and it may become difficult or impossible to conserve structures using traditional materials and skills. This will then open the way for the use of expensive synthetic materials.

These earth structures, which have been standing for thousands of years, may inspire little interest in and of themselves. What is interesting is how these structures could have survived for so long in such conditions; and what is even more interesting are the techniques and skills that have allowed these structures to go on through centuries in such a satisfactory manner.

The Building Research Unit, a Department in the Ministry of Local Government, Community Development, Cooperatives and Marketing in Tanzania, has been undertaking scientific research to find out the secret to the earth structures' durability. These superficial research findings have resulted in treatments that are not only expensive but also cumbersome to use and control. They need special expertise, exotic admixtures, and maintenance. I have called this research superficial because, with the architecture still extant, it seems such studies should have concentrated on the traditional skills and techniques and, if need be, then improvements could be taken as a supplement.

In Tanzania, conservation legislation is geared towards the selection, listing, or scheduling of buildings that are of historic or architectural significance as historic or national monuments. This legal provision is deemed adequate for securing the protection and preservation of monumental remains of past cultures or civilizations - archaeological sites - which in most cases are either ruined or situated in abandoned settlements. However, when we talk of conserving the character, technique, skill, or craft, which are the backbone of this heritage, such legislation is inadequate since it does not address these issues.

Museum Conservation Approach

Tanzania has established a village museum in Dar es Salaam, at Kijitonyama, where examples of the country's vernacular architecture, earthen architecture included, have been recreated for display and conservation purposes. The establishment of such museums has in most cases been influenced by the European open-air museum concept without a critical analysis of the rationale for such types of museums. "Whereas earth architecture in Europe is generally speaking a phenomenon of the past, in Africa it is still a living reality providing housing for the majority of the rural inhabitants, about 85% of the population." [5] It still dominates the rural built environment and the basic problem is not the preservation of the dying tradition or even an extinct one, but how best to achieve rational and planned development of such architecture.

It is fallacious and ridiculous to start reconstructing buildings in village museums for display and conservation when such buildings are widespread in the country. It is absurd not to understand that in a country like Tanzania - where this architecture is varied in terms of materials, construction skills and techniques, and design and spatial arrangements - the reconstruction or assembling of a representative sample is a gargantuan undertaking. It is also contrary to conservation philosophy because such museums are out of context, and it is not possible to recreate the environment in which the buildings were conceived, developed, and lived in.

Of course, bringing together all these different buildings simplifies their management and conservation, but what is forgotten is the environmental influence so important in architectural development. It is practical and logical to build an earthen flat-roof building in Dodoma where it doesn't rain very much, but not to build the same in Dar es Salaam where it rains heavily for most of the year.

Future Policy

It is evident that existing conservation policy in Tanzania, as well as in other African countries south of the Sahara, needs to develop new perceptions and targets. In the formulation of policies and the planning of programmes there is a need to foster a concept of conservation which - without abandoning the traditional listing, scheduling, and preserving of monuments according to their archaeological, historical, and artistic significance - will have a wide scope to embrace the conservation of skills, crafts, and traditional techniques. This concurs well with what Dr. Julius Nyerere declared in 1977 and Mrs Indira Gandhi in 1980, as quoted earlier in this paper, who were emphasizing the use of local and traditional resources in our building industry. Thus local and traditional resources, especially earth, with proper planning and management can contribute both to the building industry and to the socioeconomic development of the communities which created them and so to the nation at large.

Earthen architecture is still a living entity in Tanzania, as well as in other countries. This does not mean that its future is unassailable or unthreatened. On the contrary, its future is very insecure, and modern development policies represent a major threat. Urban development has not yet reached a point where it is fast destroying the rural areas, but the attitude of the policymakers, planners, professionals, and building material industrial managers make the future of earthen architecture uncertain. This tendency has been pertinently described by Jean Dethier:

> Although unbaked earth no longer needs any real justification on technical or material grounds, resistance to it persists from quarters whose economic, psychological, cultural, institutional and political well-being is threatened by it. Such opposition is sometimes calculatingly self-interested, for the economic systems characteristic of earth construction might injure influential interest-groups. Industrial corporations and multi-nationals which

> produce building materials, as well as the technical consultants responsible for employing them, occasionally seek to discredit unbaked earth in order to protect their own market. [6]

Thus it is upon the policymakers, planners, and professionals in the field of architectural conservation to come forward with conservation legislation, conservation programmes, and training opportunities that offer the possibility of preserving the architectural character, skills, techniques, and crafts through training, dissemination of information, and designation of conservation areas within the rural environment. Training could take a form of formal education in both secondary schools and institutions of higher learning, apprenticeship, on-the-job training, workshops, refresher courses, and seminars. These people have to be assured of job opportunities and market demand for their products, otherwise such programmes will never attract them. Such problems could be reduced by starting big government housing schemes using earth as a building material in different parts of the country, especially in rural areas.

Conclusion

The success of cyclical maintenance of earthen building can be possible if most of the population has the necessary skills, techniques, and will to live in those buildings. Therefore it should be the duty of the professionals, not only to record and document the heritage, but also to study in detail the soil as a building material, its construction techniques, and the socioeconomic and cultural patterns associated with this heritage. These studies should be made easily available and the country's training institutions should teach these techniques, skills, and crafts so that people living in these earthen buildings can understand their structures in a better and scientific way. This understanding should help them to do the construction, repair, and maintenance of their houses, a tradition which is now disappearing rapidly.

People have to understand not only the value of earth as a building material but also the comfort and pleasure of living in such buildings, an aspect which calls for improved design and finishes. The buildings have to meet today's needs and functions in order to provide a comfortable environment. As said above, this has to be done through training. Young people must be trained to design and use earth as a building material, a subject which now is never taught in architectural training institutions. However, it is agreed that earthen structures, just as any other structures, are important in terms of function, science, and culture, and this is why the world is concerned with their conservation.

Whereas a lot of research and studies have been done in the industrialized world and a lot of training is also available, often this information is not disseminated to places where it might be useful. The use of modern building materials in the developing world is promoted without considering that the economy and expertise do not allow the use of such materials in most rural areas.

In addition to the research training and dissemination of the findings, such a heritage could be protected and preserved within the rural built environment in clearly demarcated conservation areas which should be integrated with the village planning and development process. This, as opposed to the museum approach, is rooted in reality since the buildings keep their original set up and function and receive care, repair and maintenance from the owner. Cyclical maintenance by the owner reduces the financial commitment from government and addresses itself to functional requirements of the people who use the buildings.

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ABSTRACT

Earth is one of the most common traditional building materials of Britain. It occurs as mortar, plaster (on a mesh frame), in mass and block form. Its technology though has not developed and has now fallen into disuse. The material does not command the respect and consequent protection that other materials of historic buildings do. Its conservation is becoming critical.

KEYWORDS

TYPE, DISTRIBUTION, HISTORY, REPAIR.

SOME NOTES ON EARTH BUILDING IN BRITAIN

Shawn R H Kholucy BSc(hons) Arch Dip Arch

Earthen buildings abound in Britain. They are found as a) the principal element in timber-framed buildings (the weather protection infill panels; b) monolithic structures without special foundations; c) monolithic earth laid between shuttering supported on special foundations; and d) earth block construction on special foundations.

Particular types of construction are usually associated with specific areas of the country. Type a) is the most common and is found throughout the country wherever timber building was used (generally widespread). Type b) is concentrated particularly in the southwest part of the country (Cornwall, Devon, Somerset) but is not uncommon further east (Wiltshire, Oxfordshire, Hampshire). Type c) is found in the eastern part of the country (and is commonly encountered in specific parts of Norfolk, Suffolk, Essex and Cambridgeshire). Because in the eighteenth century, instructions as to its manufacture and construction were published for and distributed among embrionic non-conformist church congregations, planning to build their churches, chapels are found of the material throughout the south part of Britain. I do not know of any in the north. Type d) is largely confined to the same areas as type c), and in those areas is far more commonplace. (See the distributions maps in Brunskill's Vernacular Architecture (London Boston, Faber 1971) 190-192).

The earliest attributable surviving examples of earth used as a building material in Britain (other than as mortar) date from the Roman occupation (before 400 AD). Examples of Roman earth walls are Norwich Castle and Hadrian's Wall. These were in block or shuttered construction[1]. But it is likely that it was used long before that, and examples may well exist unknown.

The type of timber-framed work which employs earth infill (called wattle-and-daub), type a) above, is accepted from wide spread examples throughout Britain to date from the twelfth century. But as earlier timber-framing exists the daub panels may well be earlier too.

The monolithic, unfounded type described as b) above, certainly survives in the south-west peninsula from the fifteenth century and probably much earlier too. Intermittent construction has continued until today when its use has diminished greatly, limited to the southwest part of the country.

In both the above cases the uncertainty as to the date of origin is due to the lack of a typology or records for the types of relevant buildings. Timber-framed buildings have traditionally interested historians and archaeologists and typologies of their frame form exist but are now found to be defective in their attributed date (the typology ocassionally suggests the building is younger than other considerations would direct). The daub has not been the subject of historical analysis.

Monolithic buildings formed with the use of shuttering (type c) are thought to date from the mid-eighteenth century to the mid-nineteenth. This is substantiated by estate maps and records as well as roof typology. They are founded on flint or brick plinths.

Earth block buildings (type d), apart from the few Roman fragments, are now thought (also from estate maps, records and comparitive typology) to largely date from the mid-eighteenth to the mid-nineteenth centuries. There was a brief resurgence of earthen construction at the beginning of this century, especially in the areas which had an existing earth building tradition, but also in unexpected ones too. They tend to be issolated examples rather than high consentrations. They are founded on flint or brick plinths. Twentieth century earthen structures often have slate or bitumen damp proof courses, earlier ones do not. In one Norfolk village the bottom three courses are bedded in lime mortar. This has not been noticed elsewhere. A clay slurry is otherwise used for bedding.

The method of construction of timber framed panels varies slightly in the construction of the wattle in different parts of the country. Broadly, frames in the west are divided into half or third storey squares, filled by wattles of thin wooden slats arranged in a 'basket weave' pattern. Those in the east, where the divisions are closely spaced uprights of one or two storey height with a panel width of about 300 mm - 600 mm, the wattle may be nothing more than vertical hazel branches wedged between the cross beams. Sometimes intermediate shaped cross bars hold these in place. Irrespective of the wattle, the daub (sand, clay, straw, dung mix) was then thrown on from both sides in one coat (per side) to the face of the adjacent timbers (about 100 mm - 150 mm in total thickness). The whole would then be limewahed (including the timbers). Sometimes a thin lime render may have been skimmed across the surface for a smoother finish. Decay of the wattle is usual but is not greatly significant to the life of the panel as once the daub has set then its job is largely finished. Domestic buildings from the Royal Palaces downwards were built of this material. The use of daub died out during the seventeenth century.

1. Pitchford Hall, a fifteenth century timber and earth renaissance mansion in Shropshire.

Monolithic construction used the same materials as for daub. The mix, having been thoroughly trampled (usually by cows or bullocks) is simply piled on itself. The resulting mass is then pared to form straight sides. The walls of the buildings are usually about 500 mm - 1000 mm thick and taper slightly to the top. The corners are usually rounded. Such devices as bread ovens are formed within the thickness of the walls and therefore are expressed architecturally. The walls are usually lime rendered and limewashed. Any domestic and allied (i.e. out-house) building can be found in this material, grand houses as well as hovels.

2. A nineteenth century basic monolithic cottage near Christchurch, Hampshire (now demolished).
(Photograph reproduced courtesy of the Hampshire Museums Service)

3. Pulham Manor Farm is a mediaeval timber and earth building with a nineteenth century earth block addition.

Monolithic work using shuttering is known for its straight vertical sides and sharp corners. Wall thicknesses can be 225 mm - 500 mm. The shutter lifts are usually about 600 mm - 900 mm. They were held by two rows of staggered through bolts, and the scars left from the later filling of these is the tell-tale sign this type of construction. They too were usually covered with a two-coat lime and/or clay render and limewashed. Often they were also tared. Recipes for limewashing and taring together, in one operation, exist. Naturally this method lends itself to repetition of type. Chapels and barns are the most commonly found structures .

Block buildings of the eighteenth and nineteenth centuries are generally composed of 450 mm x 225 mm x 225 mm blocks, making 225 mm thick walls. Small variations do occur. They are always two-coat rendered and tared and/or limewashed. It is thought that they supplanted the shuttered work. Chimneys are built of brick. Sometimes bonding timbers are found at the corners. This method was used primarily for cottages, farm and garden buildings. Orchard walls against which peach trees were grown made use of the material's thermal capacity even in areas where itnot otherwise common. Excluding the twentieth-century work, the writer knows of only one piece of 'architecture' (an eighteenth century 'Gothic' folly) built of block.

A resurgence of interest in building in types c) and d) was engineered by the government after the first world war to cope with the need for the great number of houses which were then needed by the soldiers returning, to be built quickly and without expensive fuel. A similar but lesser resurgence occured after the second[2]. These had only limited success due to the speed of recovery of the established brick and later concrete block production, and the newly imposed bureaucracy which limited available building sites.

The base material for all the above is the same, the variation is in the percentage of clay to sand or chalk and whether straw is added or not. Generally daub has a clay content below 5 per cent while monolithic and block has a clay content above 5 per cent.

Visual analysis and sedimentation[3] testing of the block and monolithic work (types c) and d) above) of samples collected from one representative village in Cambridgeshire, Suffolk, and Norfolk respectively has revealed the following:

SAMPLE (site)	% CLAY	SILT	SAND	GRAVEL
Ltle. Shelford	5-10	30-35	30	30
Hoxne	15	25	25	35
Gt. Hockham	15	35	15	35

The clay content is interestingly low in comparision to the following samples from elsewhere in the world[4]:

SAMPLE (site)	% CLAY	SILT	SAND	GRAVEL
Tumacacori	46	26	24	2
Escalante	27	55	18	
Samarra	26	12	62	
Ur	15	68	17	
Choche	34	59	7	
Aqar Quf	28	58	14	
Tell Omar	19	49	32	

The straw content in our samples varied from 'none' to 'a good deal'. Alva and Teutonico report that it is assumed that where the straw is not found it has already decayed. We have made and laid new blocks with and without straw and have not yet noticed any difference in their performance. In daub work the straw helps spread the shrinkage - not a problem in lump work - but reducing the clay content reduces the overall shrinkage far more satisfactorily.

The material is named as follows according to region

Type a) Called 'daub' throughout Britain

b) 'cob' from Cornwall to Hampshire.
'chalk mud' from Wiltshire to Berkshire.
'wichert' in Buckinghamshire.
'clay daubins' in Cumbria.

c) no traditional name. Pisé, and cob are used in the area where c) is found but they are modern names.

d) 'clay lump' in Norfolk, to Essex.
'clay bat' in Cambridgeshire.

Daub is only infrequently repaired, replacement with alterative materials has become commonplace. Repair is uncomplicated and simple to achieve once the host surface has been made receptive. The other materials were repaired by piecing in brick or concrete block or filling voids with mass concrete. This is usually destructive of the ancient fabric[5] and so now attempts to repair with reconstituted 'cob', 'clay lump' etc. or remaking it to marry with the host material is now being pursued.

CONCLUSION

Britain has been slow to respect its earthen buildings. Although its history here is regularly punctuated with periods of interest in its capabilities, these have not been sustained.

The water proofing qualities of daub and limewash are now seen to be more protective to ancient frames than the modern substitutes that have been used. Concrete blocks have not yet equalled the popular approval for thermal ability that earthen ones have.

The repair of the material has highlighted the need for greater care and respect. At the moment this is an aspect that has not been addressed adequately. Knowledge and practical application of successful repair techniques in Britain lags far behind that for the other traditional building materials.

NOTES

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3. John and Nicola Ashurst, Practical Building Conservation, Volume 2, (Aldershot, Gower 1988) 94-97.
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PREHISTORIC MOGOLLON AND ANASAZI EARTHEN ARCHITECTURE OF THE SOUTHWESTERN UNITED STATES

David Teal Kirkpatrick
Human Systems Research
3201 Linden Avenue
Las Cruces, NM 88005
U.S.A.

ABSTRACT

Between A.D. 1150 and 1400, Mogollon peoples of the Chihuahuan Desert in the American Southwest built pueblos (settlements) using puddled adobe construction techniques. The ruins of these pueblos are found across southern New Mexico and west Texas. Smaller pueblos had one or more linear room blocks, while 50-room or larger pueblos were generally U-shaped or enclosed a plaza. Large, melted adobe mounds may indicate the remains of multistory room blocks.

Archaeologists have excavated and studied prehistoric Mogollon adobe structures over the past 50 years. The architectural details of these structures are described and compared with prehistoric Anasazi adobe sites in northern New Mexico of Pindi and Pot Creek pueblos and with the large prehistoric site of Pacquime, Casas Grandes, Chihuahua, northern Mexico.

KEYWORDS

Prehistoric; United States; Jornada Mogollon; Puddled; New Mexico; Earthen Architecture.

Figure 1. Site Locations
1. **Chaco Canyon**
2. **Mesa Verde**
3. **Keystone Dam**
4. **Los Tules**
5. **Bradfield Site and Condron Field Pueblo**
6. **Alamogordo Sites 1 and 2**
7. **McGregor Site**
8. **Pindi Pueblo**
9. **Pot Creek Pueblo**
10. **Paquime**

Introduction

Shelter can be simple or complex--a brush hut, a shallow cave, an adobe pueblo, or a steel apartment building. As prehistoric peoples across the world moved into new, unsettled areas, a primary concern was to provide shelter for their families. They built short term occupation structures using hides, tree limbs and branches, dirt and mud, and other locally obtained materials. With increased sedentism, these peoples used other materials to build more permanent structures, including large trees, rocks, and native soil.

The people of the southwestern United States between 5500 B.C. and 300 B.C. were highly mobile, moving across the landscape, hunting small mammals, and gathering native plant foods. About 3,000 years ago these peoples began planting corn, and later, beans and squash, eventually becoming full-time, sedentary agriculturalists by A.D. 500. They developed their own distinctive cultures, recognized today by the distinctive remains of their architecture and pottery. The Anasazi of the northern Southwest uplands are characterized by gray ware pottery and well-built masonry pueblos, such as those at Chaco Canyon, New Mexico, and at Mesa Verde, Colorado (see fig. 1). The Mogollon of the southern Southwest occupied regions of well-watered uplands and desert lowlands. Their culture is characterized by brown ware pottery and masonry architecture in the uplands and puddled adobe structures in the desert lowlands.

The Hohokam of southcentral Arizona lived along major rivers and in adjacent arid regions. Their culture is characterized by brown ware pottery, extensive irrigation canal networks, monumental architecture, and surface earthen structures. All of these surface architecture traditions evolved from pit structures or pithouses.

The topic of this paper is the mud or earthen architecture of the desert Mogollon peoples, with comparisons to earthen architecture of the Anasazi of northern New Mexico, of the Hohokam of southern Arizona, and at Casas Grandes, Mexico.

Archaic Architecture (6000 B.C.-A.D. 400)

The Archaic hunters and gatherers--who lived in southern New Mexico, southwestern Texas, southeastern Arizona, and northern Mexico--are the ancestors of the later peoples that archaeologists called the Jornada Mogollon. The earliest evidence of Archaic architecture in the southern lowland desert was found during archaeological excavations at Keystone Dam in northwest El Paso, Texas (1). Remains of 23 to 41 houses were identified during excavation and soil core sampling. Radiocarbon dates are between 4450 and 3750 BP (years before present). The structural remains are shallow depressions averaging approximately 3 m in diameter and 10 cm deep at the center. The unplastered floors are loose to slightly compacted native sand. The data on the roof structure is very minimal. Possible post holes are present around the exterior edges of three house depressions. The tapered holes range from 5 to 14 cm in diameter and from 7 to 14 cm deep. No post holes were found in the interiors of the house depressions. The superstructure may have been limbs leaning together, which were then covered with smaller branches, rushes, and grass. Fire-hardened clay fragments have been recovered from the remains. A clay mud was probably placed over the grass to form a weatherproof roof, as impressions of grass and reeds were found in the roof remains. Hearths are the only interior feature found in these structures, informal shallow depressions filled with charcoal. Entryway locations are inferred by erosional patterns on the east and southeast sides of the structures.

The inferred construction sequence (2) starts with excavation of a shallow, saucer-shaped depression. Leaners (poles placed at an angle from the perimeter of the depression to the center of the depression above the floor at an unknown height) were placed around the exterior edge of the depression, possibly in holes or sockets, to help support the roof. Small branches on the leaners were covered with reeds and grass. The superstructure was then covered with a thin clay layer. The houses were probably not occupied on a permanent basis but may have used for relatively long periods of time, such as over a winter.

Early Jornada Mogollon Architecture, Mesilla Phase (A.D. 400-1200)

The Archaic peoples added corn to their diet around 2000 B.P. (50 B.C.), starting their shift from nomadic collectors of wild foods to sedentary producers of domesticated agricultural foods. With increased sedentism came the need for more permanent shelter. This culture is known today as the Mesilla phase of the Jornada Mogollon (3). The type site is Los Tules, on the west bank of the Rio Grande, just west of La Mesilla, New Mexico. These people lived in pithouses that were slightly deeper than the Archaic-age, saucer-shaped depressions, with vertical walls. Two types of pithouses were originally described by Lehmer (4). The first is rectangular with ramp entrances to the east and southeast. The second is circular with a roof entrance. Mesilla phase sites in the El Paso area are similar in shape and size but have plastered walls and floors (5). The roof construction is poorly known. Post holes are found around the edge of the pit and in the center of the floor. Unlike the Archaic pit structures, no dried mud roofing material has been found in the excavation of the Mesilla phase pithouses. In the Hueco Bolson east of El Paso, the structures are similar, with shallow hearth features located just inside the structure, past the rampway (6).

Late Mogollon Achitecture, El Paso Phase (A.D. 1200-1400)

The El Paso phase represents an established, sedentary lifeway based on full-scale agricultural practices. The basic architectural shift, as in other parts of the Southwest, is from a pitstructure to a surface room unit (7, 8). The El Paso phase Mogollon (A.D. 1200 to 1400) sites are recognized by their earthen architecture and brown ware pottery. These peoples used puddled earth construction techniques to build their homes. Puddled earth is wet soil that contains sufficient calcium carbonate so that the soil dries to a hard mass capable of supporting the weight of the additional upper walls. The walls were built in courses. Wet earth was usually placed in a foundation trench and shaped by hand into a linear course that extended slightly above ground. When this earth dried, another layer of wet earth was placed on top, shaped into place by hand, and allowed to dry. The process was repeated to achieve the desired wall height. In cross-section, each layer of the wall can be identified by a drying crack at the bottom and top of the course.

No evidence of roof structures remains in the Jornada Mogollon area. The two large post holes often found inside the north and south walls indicate large supports for north-south beams; these may have held smaller east-west posts, which rested on the walls. These were probably covered with branches and grass and dirt for insulation. The roofs may have been covered with mud.

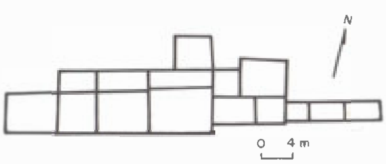

Figure 2. Bradfield Site (after Lehmer 1948:fig. 14)

The ruins of smaller pueblos have one or more linear room blocks with 3 to 20 rooms for a family or an extended family unit. Larger pueblo ruins are U-shaped, with enclosed plazas and 50 or more rooms. The very large ruins of extensive, melted adobe mounds may represent the remains of multistory room blocks. These larger communities probably housed several extended family units. In the following section, I present descriptions of El Paso phase architecture found at selected excavated archaeological sites. All of these sites are located in the Tularosa Basin east of Las Cruces and north of El Paso, Texas.

Bradfield Site

The Bradfield Site was excavated by Lehmer (9) in 1940 after portions of the 16-room pueblo were dug into by pothunters. The east-west linear room block measures 25 m (north-south) by 95 m (east-west) (see fig. 2). A study of wall abutments determined the growth of the pueblo. The walls were started in foundation trenches 20 to 25 cm below floor level. No stones were used in the foundation trenches or in the walls. Walls were built first and then the roof, followed by the plastering of the floors. The walls average 25 cm in width, with a range between 10 to 60 cm. The wet-laid courses were 20 to 35 cm high. The excavated wall remains were no higher than 75 cm, indicating a severe amount of erosion occurred after the abandonment of the pueblo over 600 years ago. Vertical and horizontal drying cracks marked individual courses. Mud floors ranged from 5 to 15 cm thick, based on the number of replastering events. The first floor was laid over native soil. Room features include hearths and post holes; however, it is thought that roof beams were laid from wall to wall, with the posts in the rooms used as secondary supports. Roof beams were probably covered with smaller beams and brush, then with a layer of dirt. Entry was probably through the roof, although some evidence for doorways in walls was present.

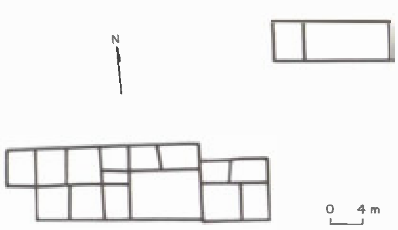

Figure 3. Alamogordo Site 1, House 1 (after Lehmer 1948:fig. 16)

Alamogordo Site 1, Houses 1 and 2

The excavations were conducted at Alamogordo Site 1 by Wesley Bradfield in 1929 and by Stanley Stubbs in 1930 (10). House 1 is an east-west room block measuring 10 m (north-south) by 45 m (east-west) (see fig. 3). The 15 rooms are laid out two rooms deep. The walls were set in foundation trenches 20-25 cm below the surface. Bradfield did not record wall measurements in his notes, although he noted the presence of coursed lumps of dried mud that were part of the wall. Fire pits were located near the center of the rooms. Severe erosion of the walls removed evidence of possible doorways. Roof construction is thought to be similar to that at the Bradfield Site.

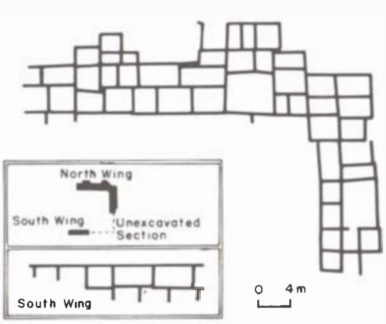

Figure 4. Alamogordo Site 1, House 2 (after Lehmer 1948:fig. 23)

House 2, located approximately 230 m from House 1, is a room block built around the three sides of a plaza that opens to the west (see fig. 4). The room block measures 85 m (north-south) by 80 m (east-west). Fifty-sixe room were excavated, with an estimated total of 75 to 100 rooms. Rooms averaged 3.5 by 4 m, ranging from 2.5 by 3 m to 8 by 9 m. Wall foundation trenches were 25-30 cm below floor surfaces with stone slabs lining some trenches. The walls were made of irregular courses of mud, 25-30 cm thick and of unknown height. Floor features are primarily shallow hearth pits and roof support post holes. Roofs were constructed of horizontal poles measuring 2.5 to 10 cm in diameter and spaced 30 cm apart, often laid from the walls to a central beam. The poles were covered with reeds, grass, cornstalks, and brush and were topped with dirt.

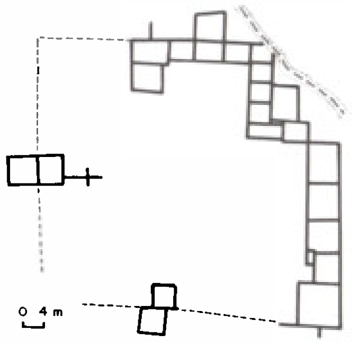

Figure 5. Alamogordo Site 2, House 1 (after Lehmer 1948:fig. 24)

Alamogordo Site 2, House 1

This site, located southeast of Alamogordo (11), consists of a rectangular room block enclosing a plaza (see fig. 5). The exterior walls measure 60 by 60 m. Twenty-two of the estimated 60 rooms have been excavated. The rooms average 3.5 by 4.5 m, ranging from 3 by 3.5 m to 7 by 8 m. The dried earthen walls, which average 45 cm thick, often had large stones (up to 25-30 cm in diameter) incorporated into the. Wall foundation trenches had stone slab floors. Roof construction was similar to that at Alamogordo Site 1. During excavations, Bradfield and Stubbs noted the presence of earlier, eroded wall foundations and wall remains.

Condron Field Pueblo

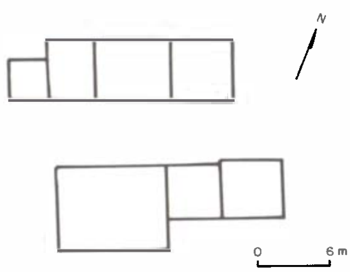

Figure 6. Condron Field Pueblo (after Hammack 1962:fig. 1)

The remains of Condron Field Pueblo are located under the airport for White Sands Missile Range, just south of the Post Headquarters. The site, excavated in 1960 (12) and 1970 (13), consisted of two linear room blocks with a total of seven rooms (see fig. 6). The wall thickness averaged 20 cm. No evidence of a foundation trench was found. The rooms ranged in size from 3.3 by 3.5 m to 7.5 by 10 m. Hearths were present in all rooms near the center of the south wall. Post holes were random. The floors were finished with hard-packed clay over sterile soil and were often replastered. No evidence of doorways was found. Some of the smaller post holes in the floors may be sockets for ladders associated with roof entrys.

The McGregor Site

The McGregor Site is located on Ft. Bliss northeast of El Paso. Excavations conducted in 1964 (14) revealed a small, three-room site (see fig. 7). A foundation trench was present 30 cm below floor level. The wall stubs showed vertical and horizontal cracking. Wall thickness averaged 20 cm. Caliche (poreous calcium carbonate) was used to plaster the walls, which were then painted; they were replastered and painted as necessary. Puddled earth/mud steps were present along the interior of the south wall in two rooms. The floors were built by covering native soil with puddled earth/mud, followed by a caliche-based plaster. Repair patches were evident. Two major post holes for roof support posts were placed just off center on the west and east walls. These probably supported a central beam, which supported smaller limbs. No evidence of roof materials was found. Hearths were located about 1 m off the south wall and equidistant from the west and east walls. The room block, which probably housed a small family, was constructed as a single unit with the southern wall (oriented east-west) laid first and the remaining walls abutting against it.

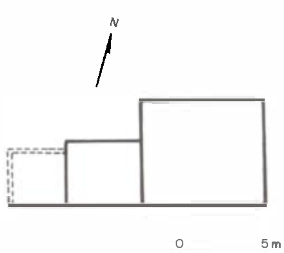

Figure 7. McGregor Site (after Brook 1966:map 2)

Anasazi Earthen Architecture

The prehistoric Anasazi occupied the Four Corners area of the southwestern United States (the shared state corners of New Mexico, Colorado, Arizona, and Utah), extending eastward to the Rio Grande region of central New Mexico. Anasazi architecture is typically masonry with mud mortar, the best known examples are the pueblo ruins at Mesa Verde and Chaco Canyon. In some areas of northern New Mexico, earth was used if suitable rock was not available. Puddled-mud pueblos have been recorded in the Chama Valley (15), the Taos area (16), and the Santa Fe area (17).

Pindi Pueblo

Pindi Pueblo, located south of Santa Fe on the banks of the Santa Fe River, is one of these prehistoric puddled mud ruins. Pindi Pueblo was excavated in 1932-1933. The pueblo was occupied in the A.D. 1200s. The construction started by digging foundation trenches a few centimeters to 60 cm deep and slightly wider than the average wall thickness of 22 cm. Only 10 of the 200 rooms had stones in the trenches. Adobe mud was gathered from mixing pits located outside the pueblo, as well as some that were inside rooms. Later, these interior pits were filled in, and floors were built. The mud courses showed impressions of hands and fingers along the walls and on the tops of courses. Impressions of grass and brush are also preserved. No evidence of forms, such as parallel lines in the dried mud of the walls, were found during the excavations or during the analysis of construction techniques. Horizontal and vertical cracks were common, suggesting short segments of adobe were laid, but it appears that each course was as long as the wall. The individual courses averaged 49-59 cm high, although some were only a few centimeters and others were nearly a meter thick.

Room-block construction was irregular; rooms were apparently added as necessary. A long wall was often built and numerous walls abutted it to create several smaller rooms, which were then enclosed with one long or several short walls. The highest excavated walls were 2.2 m tall; these lacked roof beam sockets, indicating the walls were probably taller than 2.4 m. The pueblo may have been two or three stories high, based on the numbers of collapsed floors found in the stratified deposits in several of the rooms. One section of the pueblo may have been four stories high. The rectangular rooms averaged 2 by 2.7 m, with prepared floors 3 cm thick over native soil and, rarely, over flat river rocks. Hearths were shallow, plastered basins in the center of the room or against a wall. Evidence of roof construction methods is lacking. Stubbs and Stallings (19) suggest the roof construction was similar to that at Picuris Pueblo, near Taos, New Mexico. A center post supported a primary center beam across which secondary beams or vigas were laid and were covered with smaller materials and soil (see fig. 8).

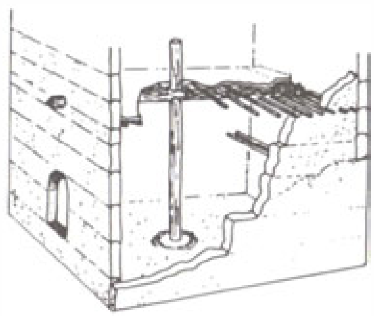

Figure 8. Room details (after Wetherington 1968:fig. 16)

Pot Creek Pueblo

The ruins of this large pueblo lie on the banks (see fig. 9) of Pot Creek about 22.5 miles south of Taos (20). Excavations began in 1957 and continue to the present. The site was first occupied ca. A.D. 1000 by the Anasazi, who built shallow square pithouse with walls made of coursed mud and floors of puddled mud. Later surface earthen rooms date into the A.D. 1300s. About A.D. 1200, construction of multiroom and multistory coursed mud room blocks began. The described architectural details are from rooms built between A.D. 1250 and A.D. 1350, which are very similar to those at Pindi Pueblo.

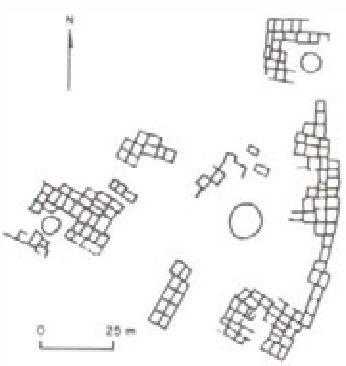

Figure 9. Pot Creek Pueblo (after Crown 1990:fig. 3 [23])

Foundation trenches were dug at varying depths but not deeper than about 30 cm. These were the same width as or slightly wider than the coursed mud walls. No reinforcing stones were found in the trenches. The courses were 27 to 40 cm thick, 45 to 55 cm high, and of unspecified length, presumably the length of the room. Finger- and handprints were common, and no evidence of molds was found. Some walls consisted of two individual courses that supposedly supported the weight of upper-story rooms.

Remains of center support posts were found in the majority of the ground-floor rooms. The posts were placed in holes dug into native soil. In trash-filled rooms, the post hole was dug to the old floor, and a stone was often placed at the bottom prior to setting the post. The beam supported a main rafter, which supported secondary vigas (see fig. 10). Remains of second- and third-story floors provided evidence of upper-level, central post support systems (see fig. 8). At Pot Creek and Picuris Pueblo (21) circular floor basins were placed around the center support post, a trait unique to the Taos region. Hearths were placed between the post and the wall.

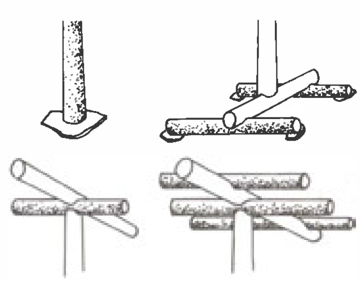

Figure 10. Central post support system (after Wetherington 1968:fig. 16)

Room floors were built over native soil or in leveled trash deposits of previous occupations. Puddled mud was poured over the soil or a foundation layer of sandstone slabs and cobbles. Entryways (open and sealed) were found in ground-floor rooms, the door bases being the tops of the first course of puddled mud. Doors were 30 to 60 cm wide, but their height is unknown, as no lintels or complete entryways were found. Entry to most rooms was probably through roof hatchways.

Adobe Architecture of Paquime, Casas Grandes, Mexico

The prehistoric pueblo of Paquime, Casas Grandes, Mexico, is about 320 km southwest of El Paso, Texas. Di Peso (22) has provided an excellent, definitive study of Paquime and its peoples. The earthen architecture of Paquime differs from that of the Mogollon and the Rio Grande Anasazi, because forms were used to contain the puddled mud for each course added to the wall. The use of forms indicates a greater labor commitment--procuring materials to create forms, using and maintaining the forms, and replacing the wornout forms--in addition to the auxillary materials, such as ropes, hammers, cutting and shaping tools, and associated labor costs for these.

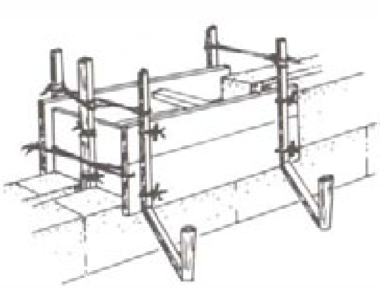

Figure 11. Form details (after Di Peso 1974:fig. 149-4)

Wall construction started with the excavation of foundation trenches, ranging 15-47 cm deep (average 18 cm). Trenches were as wide as the wall. The trench floor had clean gravel and a red clay laid for the wall base. The puddled mud walls of Paquime were formed by pouring mud into plank forms supported by stakes and braces (see fig. 11). After each course of mud dried, the form was removed and adjusted for the next pour. The use of the dropped key technique plus roughened contact joints strengthened the walls. Evidence of forms include adobe walls with cast impressions, evidence of slipped forms, and preplanned, squared space (rather than curvilinear space) for vigas (roof beams). Also, postholes for bracing stakes remain parallel to the walls. The use of forms allowed walls to be thicker, averaging 52 to 74 cm for single story rooms and 77 to 92 cm for additional, load-bearing walls. Roof construction techniques were similar to Mogollon and Anasazi techniques. Primary beams supported secondary beams, which were covered with brush and grass and were sealed with a poured puddled mud floor. In general, the architectural features of Paquime was more complex than those of the Mogollon and Anasazi pueblos.

Discussion

Prehistoric earthen architecture has a long tradition in arid areas of the Mogollon and a short tradition in the temperate areas of the Anasazi. In the Mogollon region, puddled mud structures were typically small, single story, and spatially dispersed across the landscape. This reflects low population density. The larger, multistory pueblos are situated in better-watered areas with access to upland timber resources. Studies of wall and roof construction techniques are hindered by the poor preservation caused by severe wind and water erosion. Studies of earthen construction material is needed to help understand differential preservation between Mogollon and Anasazi ruins. In the upland Anasazi areas, some of the ruins are better preserved, with taller walls remaining. All that remains of Mogollon structures after 600 years is short wall stubs and floors, which have been protected by accimulated soil. In areas of severe erosion, only foundation rocks or cimientos remain. An occasional mound may indicate an unexcavated, multistory structure. In both areas, adobe walls were built by hand without the use of forms. The walls average 20-30 cm thick, with ground-floor wall thickness limiting the construction of upper-story rooms. The use of forms at Paquime allowed puddled mud walls to be built up to 1 m thick for load-bearing walls. This resulted in construction of an extensive, yet compact pueblo. In all three regions, adobe architecture was successfully used by prehistoric peoples to construct shelters in areas lacking suitable timber and masonry construction materials.

The main goal of the majority of excavation projects is to study prehistoric lifeways, not to excavate and develop a ruin into a public park that would require conservation management. The conservation of these earthen ruins is very limited, with the exception of Paquime, where a major effort is ongoing to preserve and protect the ruin for visitors. During excavation, rapid deterioration of the Mogollon earthen structures probably accounts for very poorly preserved walls and floors. The excavation of these ruins or portions of the ruin is usually done in a few weeks so that the wall stubs and floors are exposed a short time. Large tarps are used to protect the features during rain storms. After excavation, the ruins are covered with dirt. The excavtion of Anasazi sites are conducted in a similar manner, with the wall and floor remains protected by tarps during storms. Overhead shelters are not used during the excavations of Mogollon and Anasazi sites, primarily because the short-term exposure of the ruins.

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Abstract

The vernacular mud mortar, brick and timber multi-story houses in Kashmir, India are interesting not only because of their architecture, but also because of their seismically resistive construction. The masonry piers and walls are held together at each floor level and above the windows with layers of heavy timber laid directly in the walls.

There are two variations, one known locally as *Taq* with horizontal timbers only, and the second with vertical as well as horizontal timbers, known as *Dhajji-Dwari*. Although of weak construction, these buildings have resisted earthquakes because of their flexibility.

Kashmir has been relatively insulated from the West and from the defusion of modern construction technology and ways of life, and thus has preserved this building tradition until very recently. Now, with the money brought by tourism, new reinforced concrete houses are rapidly replacing these traditional mud houses.

KEYWORDS

Earthquake resistant construction, Mud-brick construction, Mud mortar, Historic Preservation, *Dhajji-Dwari*, *Taq*.

Kashmir, India, Yugoslavia, Greece.

Above: *A narrow lane in Srinagar which is also one of the city's principal thoroughfares. Now many of these lanes are being widened by demolishing the buildings along one side.*

Upper right: *The Rainawari Canal, Srinagar. Canal boats used to be the main means of transportation through the city. Now one short stretch of this canal is reminiscent of the magical scene which used to exist where an ancient canal once penetrated the densest section of Srinagar until filled in during the 1970's (see p5.)*

OF TAQ AND DHAJJI DWARI: THE EARTHQUAKE RESISTANT MUD AND BRICK ARCHITECTURE OF KASHMIR

Randolph Langenbach
Assistant Professor
Department of Architecture
University of California, Berkeley
Berkeley, California, 94720

During recent months the news has been increasingly filled with reports of the conflicts in Kashmir. The images of men in traditional dress standing in front of the timber and brick houses, surrounded by tanks and jeeps, recall the pictures of Afghanistan. Here it is, yet another religious and ethnic conflict which might turn into a civil war. The problem is that such conflicts cannot be easily resolved once they are started, and regardless of the outcome, in their wake often lies the ruination of the traditional culture, way of life, and the fabric of the historic built environment.

Both the traditional architecture and the ways of life are very fragile in Kashmir. It is a land of breathtaking beauty but few resources, a land where the economy depends for basic survival on subsistence farming, traditional handicrafts, and tourism. A protracted conflict will wipe out tourism and thus the market for most handicrafts. This will bring renewed hardship to the population, and has the potential of destroying many buildings in what is one of the most interesting, if not magical, settlements left on the planet.

In this paper I take a closer look at the buildings which make up this city - not the mosques, temples, palaces or other monuments - but the ordinary houses constructed of mud, straw, timber, brick, sod, and (more recently) galvanized steel. These buildings provide an opportunity to study the linkage between traditional construction technology, vernacular design, and a traditional way of life. These particular buildings also are significant because they have an inherent resistance to earthquakes.

Srinagar, a "Medieval" City

Entering Srinagar, in Kashmir, is like going back in time. The houses appear to be ancient and timeless, with much evidence of wear and tear. V. S. Naipaul made the observation in 1964:

> It was a medieval town, and it might have been medieval Europe. It was a town of smells: of bodies and picturesque costumes...; a town...of disregarded beauty...a town of narrow lanes and dark shops and choked courtyards [1]

Srinagar is a densely packed city full of houses. In the oldest portions the residences are mixed together with shops and even small manufacturing industries, such as carpet weaving and metalworking. The view of this dense development and teeming activity is like a scene out of the pages of Dickens or from the canvas of Brüegal. The houses themselves are what form the essential backdrop for this remarkable scene. They appear rickety and insubstantial, almost as if they were deliberately built only as a stage set for the human pageant which takes place around them.

A single house is usually occupied by a joint family, with the grandparents living together with the families of each of their sons. The houses were clustered into small districts, known as *mohallas*. Until the present strife, the families of each *mohalla* formed a tightly knit neighborhood of both Muslim and Hindu families who, regardless of their religious differences, were very close. [2] Often a temple, mosques, a *madrassa* (a muslim religious school), a school, and a few shops, form part of the *mohalla*.

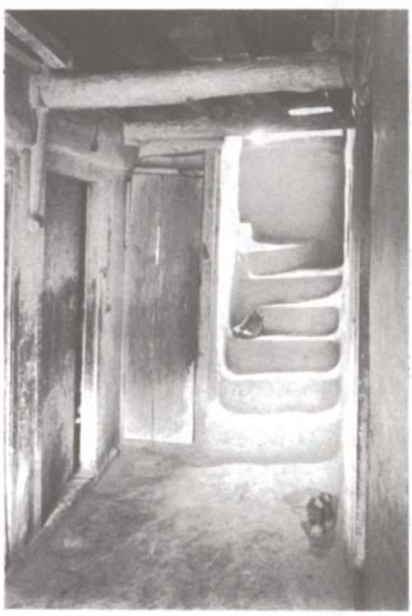
The Jalli shutters showing, on the left, the remains of the paper attached for winter protection.

The entrance to the typical house would be through a door in a wall separating a small paved private court from the street. The W.C. is usually detached from the house, and set in the corner of the front court, while the bathroom usually consists of a small room next to the hot water tap behind the kitchen stove.

The houses are mostly square in plan, with windows on all sides. In the densest areas, the houses are attached to their neighbors with common walls, but rarely did they line up in even rows. The windows are traditionally closed only with two sets of shutters, the inside set being of solid wood, and the outside with a *jalli* - an open filigree of carved wood. Glass has only recently come into general use in Kashmir. Traditionally oiled newspaper was glued onto the *jalli* shutters to admit light into the houses during the winter.

The living room and the kitchen were always located on the ground floor, with the bedrooms located on the second and third floors. The top level of the house was usually enclosed only with timber. It was usually one single large room with many windows. The family traditionally moved to this room during the summer in order to take advantage of the cool breeze and also, in moist areas, to move away from the mosquitos. This room was also used at times for gatherings and social events. In winter it was used mostly for storage.

Before the recent introduction of corrugated galvanized steel sheeting, the roofs of the houses were most frequently covered with mud laid on an underlayment of bark. In the spring the soil roof became covered with grasses and wildflowers. In the spring, the blossoming of the tulips and lilies on the roofs of the dense mass of houses in Srinagar was famous until most of the mud roofs had disappeared in favor of the corrugated steel.



The entrance lobby of a typical traditional house showing the timber and mud interior finishes. This front lobby, located at the center of the house, is considered to be the safest place to go to during an earthquake. (Running out of the house is more dangerous.)

The Aseismic Attributes of Traditional Construction in Kashmir

Earthquakes in Kashmir have occurred with regularity over the centuries, and the Kashmiri houses reflect an adaptation to this threat through the interlacing of heavy timber within the plane of the exterior walls of the masonry buildings.[3] In Kashmir, as in most countries, wood and nails are simply too precious to be used for more than what is absolutely necessary, so masonry is the primary building material Most of the traditional buildings in Srinagar can be divided into two basic systems of construction. The first system, sometimes referred to as "*Taq*,[4]" consists of load-bearing masonry piers and infill walls, with wood "runners" at each floor level used to tie the walls together with the floors. The second system, known as *Dhajji-Dewari*[5] construction, consists of a braced timber frame with masonry infill.

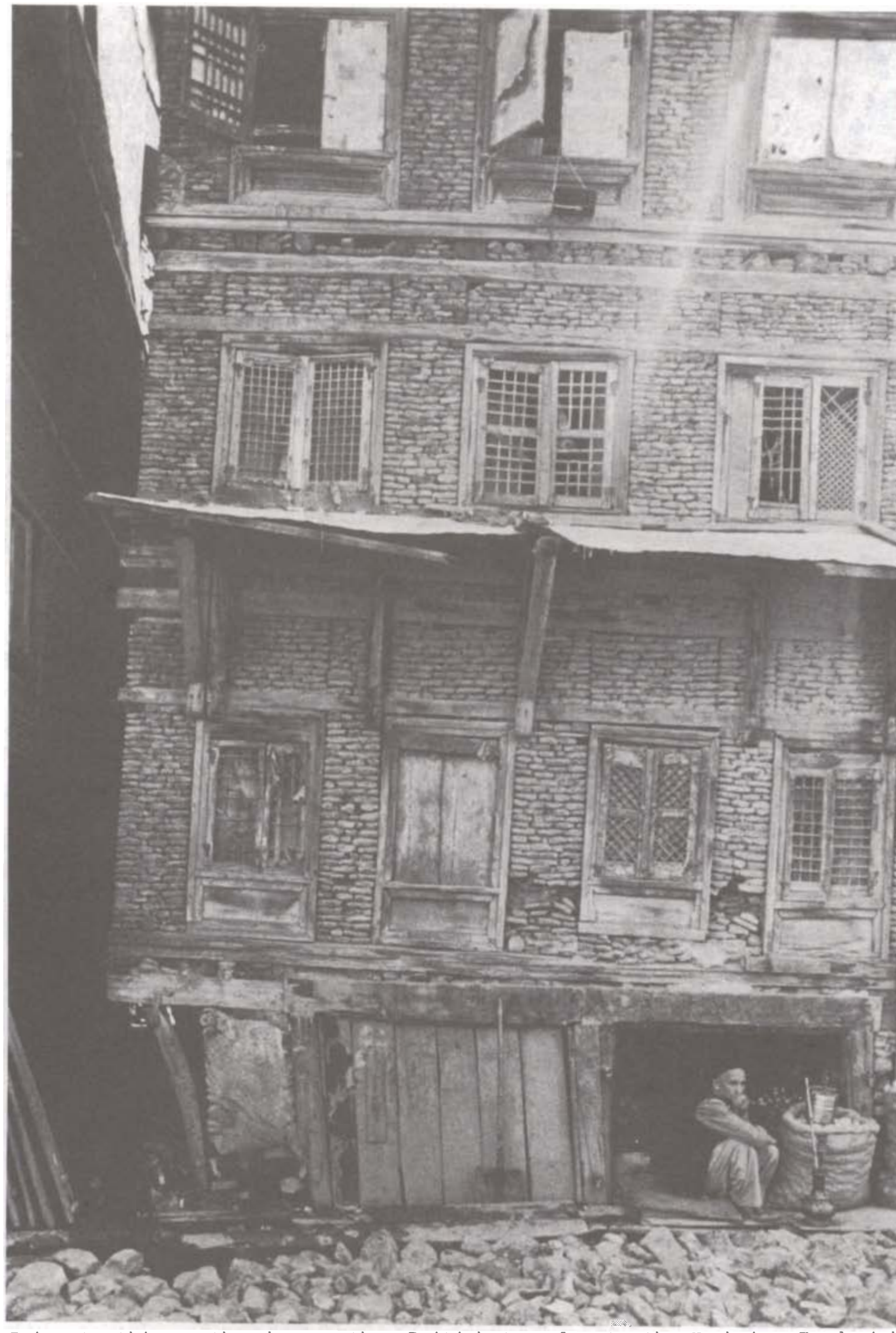
The houses were almost always raised on a plinth made up of stone masonry laced with heavy timbers measuring at least one meter in height. Above this stone the exterior walls were constructed of a mixture of brick and rubble stone set into a thick bed of mud mortar (*Taq*), or with a single layer of modern size brick surrounded by heavy timber (*Dhajji-Dewari*). The *Taq* houses were usually faced with a layer of small, very hard, hand made clinker bricks, known as *Maharaji bricks*, which give the houses their distinctive appearance.[6]

The mud, brick and timber construction was usually left uncovered by any plaster on the exterior. The interior was plastered with a mixture of clay, straw, and other ingredients. This layer of mud plaster provided insulation in summer and winter. The internal plaster was renewed by the application of a coat of a thin mixture of clay and water over the existing surface about every two weeks, a process referred to in Kashmiri as *livun*. When this dryed, the undulating mud walls were left with an unblemished beige clay surface.

The *Taq* System. The timber beams in the *Taq* buildings do not constitute complete frames. Instead, large timbers "runners" rest along the load bearing masonry walls, with the floor beams and the "runners" for the cross walls lapping over them. The wood serves to tie the walls of the structure together with the floors. The weight of the masonry serves to "prestress" the wall, contributing to its resistance to lateral forces.[7]

The construction practices used for these buildings in Kashmir which stand in contrast to the codes and commonly accepted practices today, include (1) the use of mortar of negligible strength, (2) the lack of any bonding between the infill walls and the piers, (3) the weakness of the bond between the wythes of the masonry in the walls, and (4) the frequent (historical) use of heavy sod roofs. It is just such buildings that were observed almost a century earlier by Arthur Neve, a British visitor to Kashmir who witnessed the 1885 Kashmir earthquake:

> To a European traveler, the city of Srinagar looks tumbledown and dilapidated to a degree; very many of the houses are out of the perpendicular, and others, semi-ruinous. But the general construction in the city of Srinagar is suitable for an earthquake country; wood is freely used, and well jointed; clay is employed instead of mortar, and gives a somewhat elastic bonding to the bricks, which are often arranged in thick square pillars, with thinner filling in. If well built in this style the whole house, even if three or four stories high, sways together, whereas more heavy rigid buildings would split and fall...Part of the Palace and some other massive old buildings collapsed...[but] it was remarkable how few houses fell....[8]



__Above:__ A masonry pier resting on a timber cantilever bracket on a ca. 18th century house. The beams extend across the width of the house, tying it together, while the weight of the masonry holds the wood in place in an earthquake.

__Upper right:__ A ca. 18th century Taq system house showing the horizontal runner beams and the masonry piers between the windows. Notice that in this unusual case the piers do not even line up.

Prior to this earthquake, another British traveler to the Kashmir, Frederick Drew noted that these houses were locally recognized for their aseismic attributes, "these mixed modes of construction are said to be better as against earthquakes (which in this country occur with severity) than more solid masonry, which would crack."[9] More recently, two Indian engineers, N. Gosain and A. S. Arya ascribed the damage from a 1967 earthquake to the different types of traditional and modern construction in Kashmir:

> The timber runners...tie the short wall to the long wall and also bind the pier and the infill to some extent. Perhaps the greatest advantage gained from such runners is that they impart *ductility* to an otherwise very brittle structure. An increase in ductility augments the energy absorbing capacity of the structure, thereby increasing its chances of survival during the course of an earthquake shock. This was substantiated by the observation that "*dhajji-dwaris*" [sic] in which a larger volume of timber was used were comparatively safer.[10]

Gosain and Ayra note that during the 1967 Kashmir earthquake buildings of three to five stories survived relatively undamaged. According to Arya, one of the most important reasons for this was the damping of the motion of the building caused by the friction induced in the masonry of the *Taq* walls when it begins to crack and move along the mortar joints. Internal damping "may be in the order of 20%, compared to 4% in uncracked modern masonry (brick with Portland cement mortar) and 6%-7% after the masonry has cracked." His explanation for this is that "there are many more planes of cracking in the *Dhajji-Dewari* compared to the modern masonry." It is this distribution of the forces throughout a large area of the wall, preventing destructive cracking in one

Many of the houses in Srinagar remain radically askew from weak soil and past earthquakes.

area, that leads to a much greater level of energy dissipation than would otherwise be possible. As a result, even though the mortar is extremely weak, causing the wall to yield under a much smaller load, the masonry continues to have a good chance of holding together. The timber runner beams and floor diaphragms keep the individual piers from separating, which would cause the house to break apart. In Kashmir, rigidity carries the potential for destruction. The more rigid a building is, the stronger it must be in order to avoid fracture. Because the primitive materials and means of construction used in Kashmir did not provide strength, flexibility was essential.

A similar form of construction can be found in Afghanistan but not in Nepal. The cultural context in which it developed extends to include Yugoslavia, Turkey, Iran and Iraq, all once part of the Ottoman Empire. [11] Houses found in parts of Greece affected by earthquakes also have horizontal wood members, but in the buildings seen by this author, the walls are far more massive. The use of horizontal wood ties is also common in seismic areas of Turkey, with less use in nonseismic areas, thus supporting the claim that they were used deliberately for earthquake resistance. [12] The bond beams in Turkey are credited with "incorporating ductility to the adobe walls, substantially increasing their earthquake resistant qualities." [13]

The *Dhajji-Dewari*. The half-timber, brick-nogged type, known as the *Dhajji-Dewari*, exists side-by-side with the *Taq* in Kashmir. Half timbered construction continues to provide an efficient and economical use of materials. The use of wood, while kept to a minimum, nonetheless enables the thin masonry walls to resist out-of-plane collapse, while also restraining the in-plane movement of the masonry.

Dhajji-Dewari comes from Persian and literally means "patch quilt wall." This method of construction appears to have emerged into common usage alongside of the *Taq* system during the late nineteenth century when bricks of a more standard large size became available. This larger size brick (65mm X 115mm X 230mm) [14] set into the timber frame enabled the construction of one-wythe-thick brick wall. *Dhajji-Dewari* buildings constructed with unfired mud bricks also were common, especially in the villages.

An example of Dhajji Dewari construction.

Variations of the brick-nogged type were common historically in many areas not affected by earthquakes, such as medieval England and Europe, where bricks provided an alternative infill to wattle and daub. It even extended into North America, where the German *Fachwork* tradition gave root to a number of vernacular buildings with masonry infill in the United States. Since much of this construction was far from earthquake country, it is not possible to ascribe its continued use in Kashmir solely to the incidence of earthquakes. It is clear, however, that the almost universal use of either timber restraint system is a logical response to both the incidence of earthquakes and the instability of the soils. Variations on this system have proved especially suitable in seismically active regions such as Yugoslavia, Greece, and Turkey, and it is probably from this region that the Kashmiri system developed.

In a survey of the damage caused by the 1963 Skopje, Yugoslavia, Earthquake, a London engineer, N.N. Ambraseys, reports that the "old adobe construction, particularly those with timber bracing, resisted the shock with some damage, but behaved far better than the [modern] brick or the hybrid [reinforced concrete with brick infill] construction." Many of the modern reinforced concrete buildings, which ranged from 3 to 6 stories in height, were seriously damaged or destroyed, while the less substantial adobe buildings survived. [15]

In Kashmir there are many examples of houses where both the *Taq* and the *Dhajji-Dewari* are used side by side in the same structure. The *Dhajji-Dewari* is frequently found used for the party walls between buildings, whereas the *Taq* is used for the front walls. In principle, the *Dhajji Dwari* is lighter in weight, allowing for its use on walls which are cantilevered over the street. The brick-nogged type of construction also is found in Greece, where it is sometimes used for the upper part of the houses - where masonry would be less stable because of the lack of the precompressive force provided by the weight of the building above. In Kashmir, the top floors of the houses were frequently made only of timber, probably for the same reason.

This construction type has shown enough resistance to earthquakes when compared to plain masonry structures, whether of fired brick or adobe block, that in some of these areas where earthen or brick buildings continue to be built it is encouraged by the local building codes. [16] A. S. Arya reports that it has formed the basis for the current Indian Standard Building Code #4326. [17]

Present-day Construction

Over the course of the last twenty years, construction practices have changed dramatically in the Kashmir Valley. Now, most of the new buildings are of reinforced concrete. Brick is still used, but only for infill walls between reinforced concrete floor slabs. Considering the world-wide trend towards concrete or steel construction, this is not surprising. In Kashmir, however, it does represent a major shift in the nature and the cost of construction. In addition, much of the building which is done in reinforced concrete is neither well engineered nor carefully constructed. Concrete in Kashmir, as in most of the Third World, is not treated as a sophisticated material requiring careful quality control. It is mixed by hand, dumped by the basket-full, and retempered if necessary. In addition, much of the construction is not engineered for earthquake forces. Instead, it must rely on the infill masonry for most of its lateral strength. The timber runner beams and *Dhajji-Dewari* frames have been abandoned as unwanted vestiges of the pre-modern way of life.

A Dhajji Dewari house being reconstructed using the traditional materials, including mud mortar. All of the exterior walls were reconstructed while the family continued to live in the house.

This author did come across one project involving the reconstruction of a house in Srinagar where the *Dhajji-Dewari* system was still being used. In this particular construction project it was observed that the mortar in which the brick infill was laid was made from mud mixed with straw. A man was mixing this mortar with his bare feet. Next to this pile was another made up of cement and sand. In response to the inquiry as to why both materials were being used for mortar on the same project, the mason pointed out that the mud was used for the brick infill, while the cement mortar was being used for a brick wall behind the structure which did not have the timber surrounds.

While the mason could not fully explain in English why it was done this way, it was clear that he understood that the use of cement for the infill bricks would be a mistake. It is possible that the higher cost of the cement contributed to the decision, but wood is even more expensive. Mud was being used because cement would not have withstood the movement of the timber frame without cracking. Like many traditional systems, the *Dhajji-Dwari* system is an almost organic balance in the economical use of locally available natural materials. Once one part of it is changed, the whole system necessarily must change.

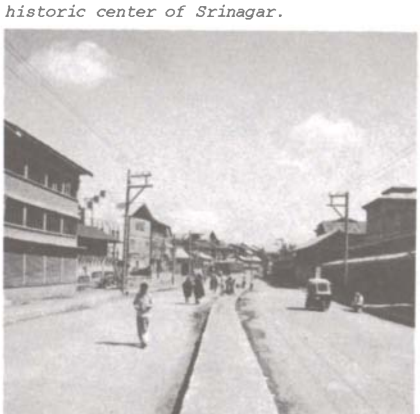
In this particular case not only was the internal core of an existing house conserved while all of the exterior walls were being reconstructed, but the family continued to live in the house as the work was being done. Such was probably the rule rather than the exception in Kashmir, until the recent introduction of Western-style building technology. When asked the age of the Kashmiri houses, earthquake engineer Anand Arya responded by telling the story of a barber who passed his razor on to his son, saying that it was precious because "it had been in the family for three generations." This barber went on to say, "My father replaced the blade, and I replaced the handle." His point was that these changes made in the course of its use did not erase the time honored significance of the artifact, and "the Kashmiri houses are the same as that razor." They are ancient, regardless of whether the physical fabric had been replaced in time, simply because they represent the embodiment of a tradition. The timeless quality of the buildings in Srinagar is undoubtedly a product of the fact that they have been rebuilt in fragments whenever needs changed or deterioration required it over many generations. This probably explains why the travel diaries from the nineteenth century describe a typical Srinagar scene to be one of rickety falling down houses, which look every bit the same as their late twentieth Century counterparts.

The "Modernization" of Srinagar: The Destruction of the Old City

On every level, from the scale of the individual dwelling to the scale of urban and regional planning, Kashmir's reach for modernity threatens to be a disaster. The tragedy is all the greater, because this fragile place is also one of the most unique and beautiful places in the world. For one hundred years, it has been the beauty and character of Srinagar's natural and human environment that has been the region's primary "export." It is this same beauty that is threatened with destruction in the current efforts to "modernize" it.

The clash between old and new in the historic part of Srinagar. Buildings, like the one on the right, threaten the coherence, scale and character of the historic center of Srinagar.

The least recognized but most important issue is the tremendous aesthetic and cultural loss that inevitably would accompany the rebuilding of Srinagar and other cities that have similar pre-modern vernacular buildings. Total replacement of these structures with buildings of a new reinforced concrete technology destroys that continuity. The work is taken out of the hands of the people who had traditionally done it and put into the hands of specialists trained in a new way. An alien form thus makes its appearance on the landscape. What is needed is a combination of traditional vernacular construction techniques with a modest and compatible introduction of some modern materials and technology.



The new road constructed during the 1970's which replaced the picturesque 14th century Mar Canal which used to penetrate the heart of Srinagar. The sewerage line which was supposed to replace the canal was deleted in a budget cut, so now the sewerage which used to flow out of the city through the canal now backs up into Dal Lake.

The problems in Kashmir are not entirely the fault of the shift towards reinforced concrete construction. The desire to have a concrete house is emblematic of the desire to be modern, especially when modernization is actually confused with Westernization. If it were only people wishing to renew their houses in a new material, the change would be gradual, and the culture and way of life would remain intact. However, Srinagar itself is being rapidly eroded by a town planning scheme designed to modernize the city by widening the narrow streets in order to carry auto and truck traffic. In the eight years between this author's first visit in 1981 and his most recent visit in 1989, many of the narrow lanes had been widened into major traffic ways. The buildings along one side had been demolished and replaced with a continuous stream of buses, trucks, and motor rickshaws, with horns blasting. Rarely were sidewalks constructed, as people have always walked in the street. Now they must compete with the motor traffic, and residents frequently get run over.

The Chief Town Planner, M.L. Chaku explained that before they had built the roads "the center was dead." It was clear that his conception of city "life" was incompatible with the traditional life of the walking pace, the mule carts, the small shops facing directly onto the lanes, and the residences mixed together with the shops. The main new street has the shops lined up like bunkers, and few of these new shops appear to support the kind of activities and industries as the older ones.

The local desire for modernization presents a real social dilemma. To recommend a maintenance of the old houses and narrow streets because they are picturesque is unsupportable. Reasons for preservation must be founded in a broadened understanding of how the buildings can continue to support the health and quality of life of the people in the future. Ironically the technology of these houses, although traditional in execution, is still "modern" in concept.

Above: *A house in ruins shows the timbers imbedded at each floor level in the Taq System masonry wall.*

Above right: *A Taq system house undermined by the river shows the remarkable flexibility and strength of this timber/masonry system (and the fearlessness of the workers.)*

Embroidery craftsmen in the living room of a Taq System house. The traditional Kashmiri house has no chairs and few tables. The Kashmiris are accustomed to sitting on the floor.

Modernity should not only constructed on a Western model, and in this case the blind pursuit of the Western model portends disaster. It is a disaster not only because of the major cultural loss that the destruction of the historic environment would cause, but also because, except for the most wealthy, the comfort and quality of life of the people will most likely be diminished by the changes.

For example, by abandoning the soft restraints of the timber beams, while failing to provide the strong restraints of good engineering and quality control in the construction, the new concrete houses are potentially far more dangerous in earthquakes than the traditional timber and masonry ones. With reinforced concrete, a greater degree of life safety can be promised, but, as seen in Armenia, not necessarily delivered. Perhaps by forgetting the unwritten knowledge of past generations, in preference for the seeming certainty of an imported industrialized alternative, a greater risk may result.

Another shortcoming exists in the overall thermal comfort provided by the concrete houses. These houses usually have many large windows, but central heating is practically nonexistant in Kashmir, and most Kashmiris would not be able to afford the fuel it would require anyway. An additional disadvantage is that the concrete has a much greater thermal conductivity than does the mud, timber, and brick making the new houses impossible to heat with primitive stoves. Some of the better traditional homes even had a room, called a "*hamam*", constructed with its floor slabs above a wood fire box which allowed the hot gasses to heat the floor. When interviewed in 1989, many people commented that in winter the newer houses were much colder even than those mud houses which lacked the *hamam*.

Even the sanitary arrangements of the new houses in the old city fail to fit the local conditions. The new houses usually have bathrooms with flush toilets, but the government has yet to install a modern sewerage system in Srinagar, spending its money on new roads instead. As a result, the flush toilets only serve to transport its contents to a ditch in the middle of the public footpath! In the past, the "night soil" had been gathered by workers on a daily basis and taken to the fields, but as of 1989, there were no provisions for the removal of either liquid or solid waste, other than allowing it to migrate slowly to the river in the open gutters.

In other words, modernization has come to Kashmir from the wrong end first. The home appliances and visible trappings of a consumer society are beginning to be accumulated, before the infrastructure is in place. The results are devastating, and these changes have substantially eroded the ecological balance which traditionally existed in the valley. In addition, the removal of the people from some of the older neighborhoods has upset the human ecology as well, because Muslims and the Hindus have moved to separate areas in the new colonies which tends to aggravate the sense of difference and distance between the two communities. As one member of the Legislative Council, Sadiq Ali, observed, in the older neighborhoods the two groups had traditionally lived close together in harmony.

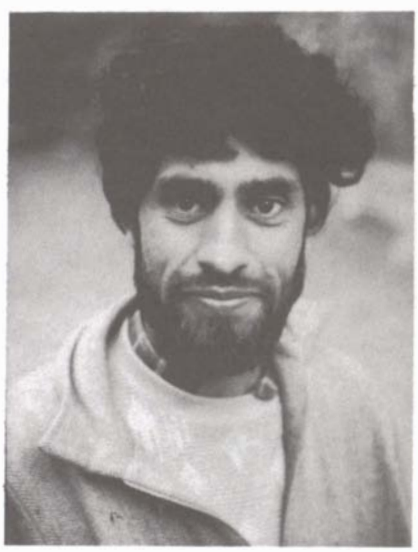
What is ironic is that all of this planning effort begins with the desire to improve the quality of life of the people and to repair the environmental damage that has already occurred. The problem is that in an area like Kashmir, First World industrialized solutions just will not work. With foreign aid, facilities such as water treatment plants can be constructed, but they will not work unless the local community has the money and technological know-how to

A Kashmiri family in front of their Dhajji Dewari *home.*

operate them.[18] Solutions must be in sympathy with the existing society and economy of the region. Kashmir could have a lot to teach the world about life in balance with nature, but first it must rediscover the value of its own traditions. The place to begin is to rediscover the advantages of the timber and mud houses - not in order to return to the past but to bring this technology into the future as an essential step in the effort to return intrinsic wealth to the people in the form of affordability, comfort, family closeness, and social compatibility.

The possibility that this approach might be viable was made poignantly clear when the head of one family living in a traditional mud and brick house, Fayaz Bhat, reported in an interview that for years he believed that he would have "to build a new [modern concrete] house" like that of his neighbors, to replace his house originally constructed by his grandfather. He said that when he was traveling in central India, he met an English couple and was struck by how they were always interested in the old things. He said that it was only then that he realized that, when he returned to Kashmir, he "did not have to tear down his grandfather's house." As T. S. Eliot said in Little Gidding: "We shall not cease from exploration, and the end of all our exploration will be to arrive where we started and know the place for the first time."

These old structures possess something which no architect can put into a new design - the visible manifestation of *time*. Most of all, these structures already belong to the people. They are their houses, their businesses, their parents and ancestor's houses. They carry the unspoken history of generations. They are not just good design; they are an inextricable part of a way of life which defines the character of Kashmir. Their destruction will do no less than destroy this relationship, and thus diminish the cultural heritage which can be a source of Kashmir's pride. It is a loss which no amount of money or material goods can recoup, and it is not the tourists who will suffer most when the loss takes place. It will be the Kashmiris themselves.



Fayaz Bhat, when interviewed in 1989.

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1 V. S. Naipaul, An Area of Darkness, London, 1964, p123.

2 With the recent fundamentalist-inspired conflicts, most of the Kashmiri Hindus have been forced to leave Kashmir.

3 Seismicity of 8-9 on the Modified Mercalli scale (Arya, interview)

4 This system, sometimes incorrectly identified as "Dhajji-Dewari," actually has no specific name in Kashmiri to identify the construction method. The closest name identified by local experts to describe it is "Taq." "Taq" refers to the modular layout of the piers and window bays, ie: a 5 taq house is 5 bays wide. The piers are almost always 11/2 -2 feet square, and the bays are approximately 31/2 feet in width. This traditional system with the piers and horizontal wooden runner beams was in common usage before the Dhajji-Dewari came into use. The bricks commonly used were small size, rough surfaced, and hard fired. They are known as "Maharaji Bricks." The reason for the name is unknown. Bricks of this type can be found in the Mogul Period buildings as early as the 16th Century, but the houses which survive date from the 18th and 19th centuries.

5 *Dhajji-Dewari* comes from Persion and literally means "patchquilt wall." This method of construction appears to have emerged into common usage alongside of the *Taq* system during the late nineteenth century when bricks of a more standard large size became available. This larger size brick (21/2"x41/2"x9") set into the timber frame enabled the construction of one-wyth-thick brick wall. *Dhajji-Dewari* buildings constructed with sun-dried mud bricks were also common, especially in the villages. The brick-nogged type of construction is common throughout many parts of Europe from the middle ages, including some of the half timber construction in England and the *Fachwerk* in Germany. Examples originating from these traditions can be found also in the United States. Since most of these areas were far from earthquake country, it is not possible to ascribe its continued use in Kashmir fully to the incidence of earthquakes. It is, however, clear that the almost universal use of either timber restraint system is a logical response to both the incidence of earthquakes, and the existence of soils subject to differential settlement.

6 As folk lore has it,the hard-fired brick technology was imported to the valley by the Maharaja. The date for this is uncertain.

7 Gosain, N. and A.S. Arya, 1967. "A Report on Anantnag Earthquake of February 20, 1967.", Bulletin of the Indian Society of Earthquake Technology, Vol 4, # 3, September, 1967.

8 Arthur Neve, Thirty Years in Kashmir, London, 1913, p38

9 Frederick Drew, The Jummoo and Kashmir Territories, Edward Stanford, London, 1875, p184.

10 Gosain & Arya, "Anantnag," p. 29 (italics added). In this case the authors are referring to the *Taq* system. (The English spelling of *Dhajji-Dewari*" varies.)

11 A.S. Arya, interview, August, 1988.

12. Gurpinar, et al, "Siting and Structural Aspects of Adobe Buildings in Seismic Areas," International Workshop on Earthen Buildings, Univ. of New Mexico, 1981, p 145.

13 Alkut Aytun, "Earthen Buildings in Seismic Areas of Turkey," International Workshop on Earthen Buildings, Univ. of New Mexico, 1981, p 352.

14 21/2"x 41/2"x 9"

15 Ambraseys, N.N., 1965. An Earthquake Engineering Viewpoint of the Skopje Earthquake, July 26, 1963.

16 For example see: Panayotis Carydis, "The Extent of the Problem of Earthen Buildings in Greece," International Workshop on Earthen Buildings, Univ. of New Mexico, 1981, p 120. (The buildings constructed "have withstood the various earthquakes quite well.") Also Arya reports that India encourages the use of this system.

17 Arya, interview, August, 1988. (Arya participated in the preparation of this code.) Note that the comparison here is with other forms of masonry construction which are still commonly used in India. Neither this nor the Dhajji-Dwari are as resistive to seismic forces as properly constructed steel and reinforced concrete buildings.

18 For example, when the new tourist and convention hotel, the Centaur Hotel, designed by an American and an Indian architect, was approved, it was promised to have a sophisticated sewerage treatment plant. It is reported that this plant has broken, and has not operated for years. The hotel is right on the edge of Dal Lake, into which its sewerage now flows.

MUD CASTLES (KASBAS) OF SOUTH MOROCCO - WILL THEY SURVIVE ?

Jean-Louis Michon, architect, Dr. in Islamic Studies (Paris, Sorbonne),
UNDP/Unesco Consultant for project CERKAS, Morocco
30, chemin des Cornillons - 1292 Chambésy - Switzerland

ABSTRACT

In the southern parts of Morocco earth, used in the form of "pisé" and sun-dried bricks, has been for many centuries the main building material and has produced under the guidance of traditional master-masons innumerable settlements and impressive fortresses (kasbas).

Due to historic circumstances and socio-economic changes, this architectural heritage has undergone a marked deterioration during the last decades.

In an effort to save at least a part of this patrimony, the Moroccan government has set up, with help from UNDP and Unesco, a "Center for the Restoration and reuse of the Southern Kasbas" (CERKAS) which is based in a restored section of the historic Kasba of Taourirt (Ouarzazate).

The first project to be implemented by CERKAS will be the rehabilitation of Ksar Ait Ben Haddou, a Berber fortified village of great architectural value and interest to tourists which has already been inscribed on the "List of World Heritage".

KEYWORDS

Conservation - Morocco - Kasba - Ksar - Rammed earth - Pisé - Re-use - Rehabilitation

The main justification for presenting a paper on the above subject stems from the affinity existing between South Moroccan earth buildings and the adobe constructions found in this Southwest region of the U.S. - the so-called "pueblo area" where the present Conference is taking place. My strong feeling is that active links and fruitful exchanges of information and experience may be established between all those who, on both sides of the Atlantic Ocean, are interested in the conservation and perpetuation of earthen architecture, for its historical and cultural value as well as for its technical, economical, social and ecological potentialities.

The "kasbas" of South Morocco : types and characteristics - their origin

In Arabic, the word "qasaba", usually transliterated as "kasba", means "fortress" and generally (like in many parts of North Africa and throughout North Morocco) applies to purely military works, either guarding strategic routes and rebellious areas or protecting cities against potential invaders. In South Morocco, however, the term "kasba" has taken a broader meaning, being used to designate the half-defensive and half-residential mansions built by the feudal chieftains, the "lords of the Atlas" and their lieutenants whose power was exercised over vast territories in the Atlasic and sub-Atlasic regions. The term even came to be applied to a variety of single family, patriarchal dwellings belonging to local landlords and embodying some elements of military architecture, in particular to the very typical castellated house, with its four towers at the corners and central patio, locally called the tighremt, a Berber name meaning "small citadel". To the same family belong the agadirs, i.e., the collective granaries where the village dwellers used to keep their provisions (of grain, barley, onions, etc.) and where they could seek a refuge behind high walls in case of an attack by enemies. Finally, a whole village built upon a rocky eminence, with its houses tightly packed to form a rampart dominating a plain or valley, may also be called "kasba" by way of simplification, while the real word to be used to designate a fortified village should be "ksar" (plur. ksour).

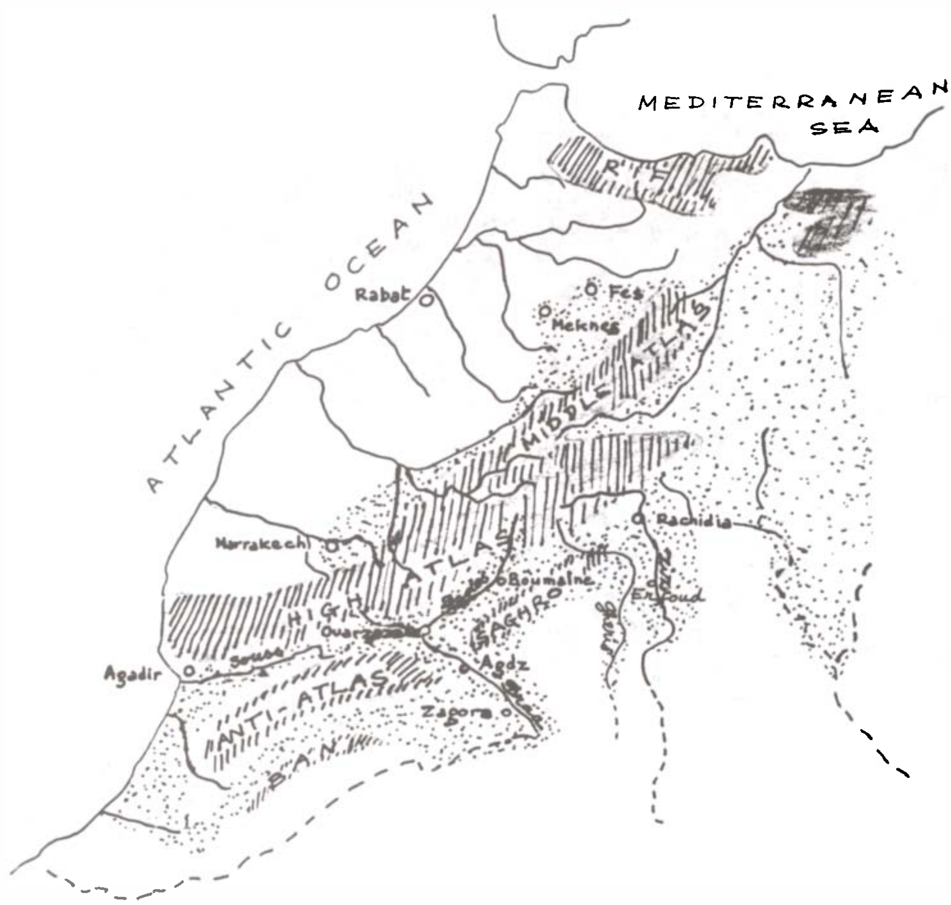


Figure 1. Morocco - Range of mud architecture

: rammed earth buildings

: mountains

Source : Nijst A. et al., Living on the edge of the Sahara, The Hague, 1973; p.5.

The kasbas built with rammed earth or pisé (Arabic: tûb, tâbya) are mainly to be found in what the French historian Henri Terrasse (the first to devote a well-documented and beautifully illustrated monograph to this architecture) has called the "exterior Morocco". This area looks beyond the Atlas range eastward and southward towards the Sahara, and westward to the Atlantic (in contrast with the "interior Morocco", north of the Atlas, which is closed in by the Atlantic and Mediterranean coasts)(see fig.1). Stretching along the valleys of the rivers which spring from the Atlas: the Ziz, Gheris, Drâa, Todgha, Dades, the kasbas climb up to very high altitudes and even reach plateaus where rain and snow are abundant and stone -still used in many parts- would appear to be a more appropriate material. From historical evidence, it thus appears that the art of building with earth had been first practiced by oases dwellers and had spread northward little by little, notably under the influence of the several dynasties originating from the Sahara.

The very origin of the southern kasbas nevertheless remains a fascinating and largely unelucidated problem. Henri Terrasse himself, in the above-mentioned monograph (1), does not exclude the possibility of an Egyptian filiation (slanting walls, pyramidal towers) and insists on the Roman influence (impluvium house as prototype of the tighremt, ksar with its regular plane derived from the castrum and submitted to the law of the cardo). Mrs. Dj. Jacques-Meunié, who is an authority on South Moroccan history, puts forward an hypothesis according to which kasbas and ksour of Moroccan oases might be late descendants of a very old art from Persia and Mesopotamia (2). Jean Mazel favours the theory of an importation from Yemen and Hadramawt via the Jews and Hymiarites several centuries before the advent of Islam in the region (3).

(1) Terrasse H., Kasbas berbères de l'Atlas et des oasis Paris 1938; p.70 et seq.

(2) Jacques-Meunié D., Architectures et habitats du Dadès, Paris, 1962; p. 102.

(3) Mazel, J., Enigmes du Maroc, Paris 1971; p. 132-133.

Only systematic research based on comparative data drawn from archaeology, ethnography, linguistics (terms and songs used by craftsmen, oral traditions) and history will be able to shed light on the respective contributions brought from the various sources. It might be one of the tasks of the newly-created "Center for the Restoration and Reuse of Southern Kasbas"(CERKAS; see below) to promote and organize exchange of information between specialists of architectures in various parts of the Islamic world in order to solve this problem.

Functional role of the kasbas

Apart from their defensive role against potential aggressors -a role which has lost its signification since the French "pacified" the region some sixty years ago and the more so since Morocco regained its independance in 1956- the kasbas and ksour of South Morocco are designed to protect their occupants against several climatic constraints, namely:
- The extreme variations in temperature, both daily and seasonal, against which the thick mud walls offer a very efficient insulation. The presence of a patio, the positioning of small openings in the external walls and the very height of the houses create an effect of draught with natural conditioning action.
- The sand storms which are buffered against the walls and angled alleys of the ksar or against the blind façades of the houses.
- The blazing light of the sun which is subdued by the shade of the patios and narrow alleys and by the use of wood lattices (machrabiya; fig.2).

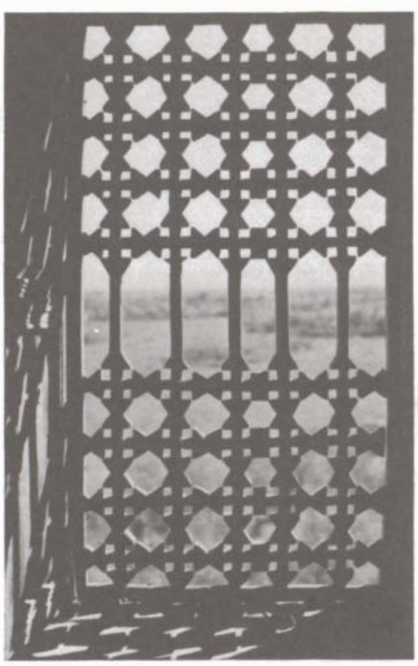


Figure 2. A Berber machrabiya (Kasba of Toundoute, at the foot of High Atlas range; photogr. Ministry of Culture/ Baamri, 1975)

Being situated in areas of essentially agrarian economy, inhabited by populations of various ethnic and tribal origins, who however are all of Muslim religion, southern architectures have to respond to a number of collective and individual needs. They are meant, inter alia:
- To group people according to their ethnic, tribal or professional affinities (peasants, craftsmen, tradesmen, religious teachers and students), which is always translated, in space, into very compact structures.
- To mark a clear delineation between "public" spaces, in the ksar as well as in the family house, and private quarters.
- To guarantee for each family, the privacy of its hurm, the protected domain of the women.
- To allow for a reasonable quantity of food and fodder to be kept within the house at all times, dates and cereals being the staple foods while sheep, goats and occasionally a cow may be sheltered in a pen outside the house or on the ground floor surrounding the patio.
- Finally, to facilitate religious practice. Thus, each village, and even the greater kasbas, has its own mosque where the community gathers for Friday prayer.

Briefly outlined, such are some of the main factors which have contributed to shape the various types of buildings and settlements commonly grouped under the denomination "Southern kasbas", and of which a few representative specimens are shown on the following pictures.

Figure 3. Building a kasba.
The master mason and his assistant are pounding earth, lightly moistened, in wooden shuttering (lawh) about 2,0 m long and 0,9 m high. Average thickness of the wall is 50 cm. Six such lawhs are mounted in a daytime.
(Ksar Tirsal, Djebel Rat, High Central Atlas; photogr. by author, sept. 1976)

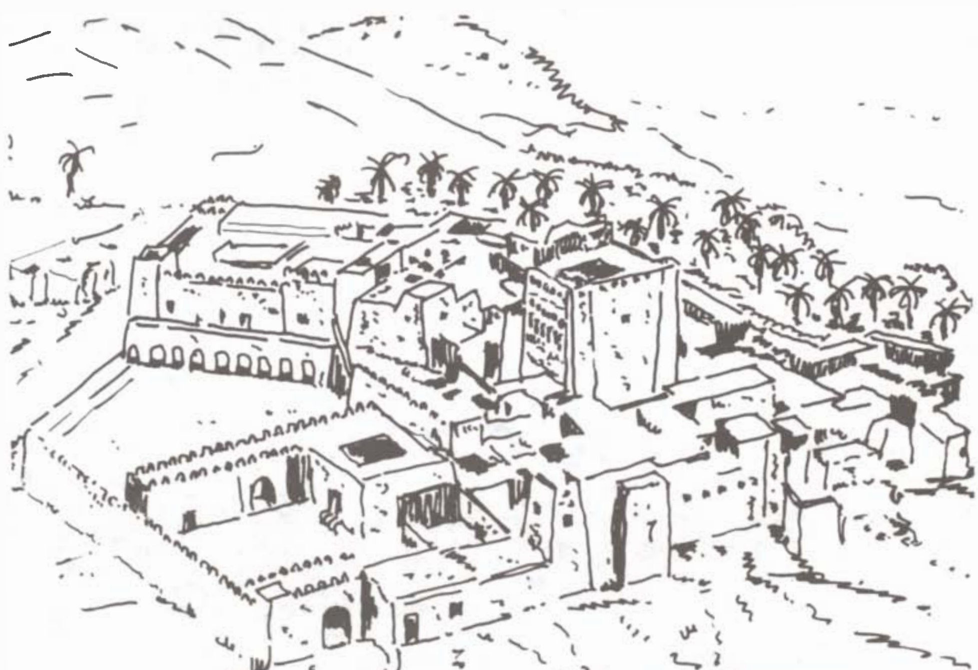


Figure 4. A chieftain's kasba : Tifoultoute (near Ouarzazate).

It comprises an old tighremt (on right) and a more recent one (left), with a large entrance courtyard (front) and numerous dependancies.

(sketch by author, after an air photograph Ministry of Housing/ Papini, mid-1960ies)

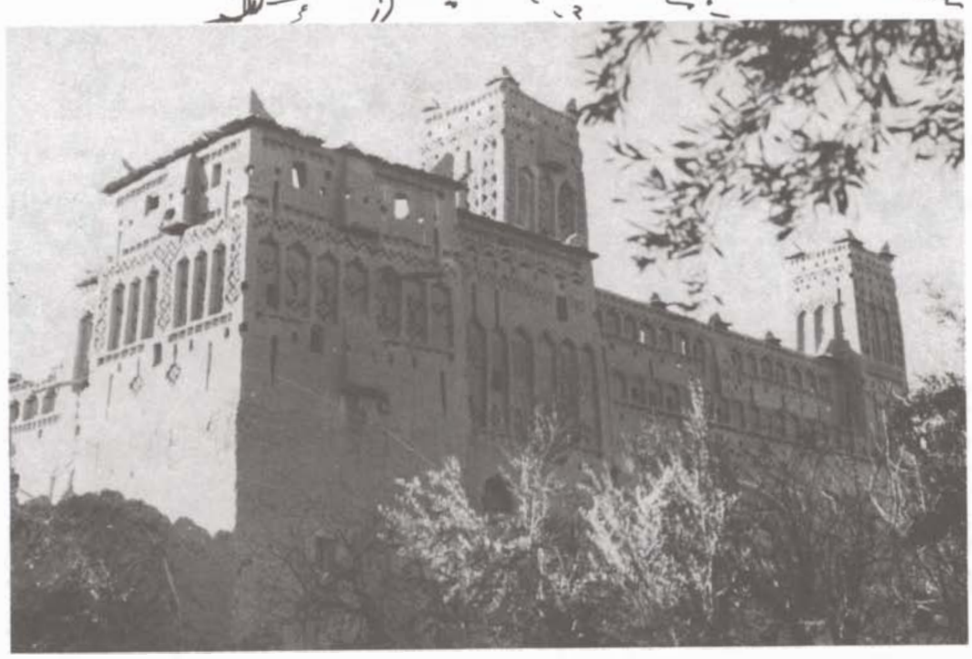
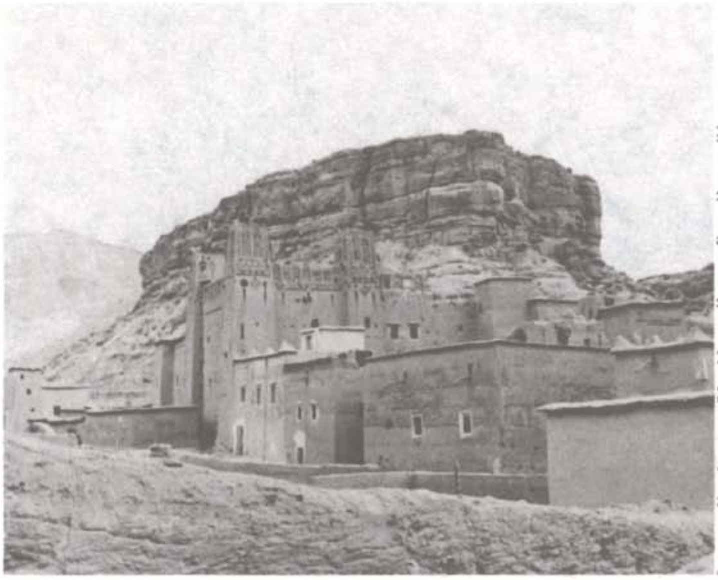


Figure 5. Kasba Ait Souss, Skoura

The oasis of Skoura, east of Ouarzazate, contains a number of beautifully decorated kasbas the walls and towers of which are made alive with crude briok reliefs and arcades.

(Photogr. Ministry of Culture/ Baamri, 1975)



Figures 6 & 7. Two tighremts (one-family dwellings) on the Atlas foothills.
Right : Imin Ouarguifrane (after photograph J. Vérité, 1976)
Left : Ait Aissa, Bou Taghrar, M'goun (photogr. by author, may 1977)

Figure 8. Interior of a kasba, showing the construction of the patio and galleies, supported by mud-brick pillars; palm-trunks and reed-stems support the layers of pounded earth and waterproof coating of lime and silt of the terrace.

(Igherm Amallal, N.E. of Ouarzazate; photogr. Ministry of Culture/Baamri, 1975)

Figure 9. The village of Ait Hammou ou Sa'id, near Agdz, comprises all the main elements of the "Southern kasbas" architecture, i.e.: the village -ksar- itself (left) surrounded by walls; the towered dwelling -tighremt- of a notable (center); and the stately fortress -kasba- dominating oued Drâa and the palm groves (right). (Photogr. by author, may 1977).

Problems of conservation

From the above descriptions and pictures, it may be realized that a number of dangers threaten the very existence of many of these buildings and settlements.

The main cause of decay of earth buildings, apart from the occurrence of natural disasters like earthquakes and floods, is always to be ascribed to human factors, i.e., to neglect in maintainance on the part of the occupants or, worse, to the partial or complete abandonment of a ksar or kasba. In the case of larger kasbas, for instanoe, those whioh had onoe belonged to the "Lords of the Atlas", historical and politioal ciroumstances accompanying the return of Morooco to Independance (in 1956) have brought with them the "fall" of these local ohieftains who, having lost their wealth and power, moved out of their field residenoes. Thus many an imposing kasba has beoome a prey for looal "oannibalism" and, bereft of all its doors, windows and rafters, has quickly been dilapidated to a point of no return. Elsewhere, particularly in rural communities, economio and social ohanges have attraoted at least a part of the population to the oities, or have prompted the young generation to separate from the patriarohal family unit, creating new housing types mostly oopied from urban models and using industrialized materials. The consequenoe has been either the juxtaposition of two heterogenous styles of building or, even worse, the disruption of the previous architectural unity of a ksar and shocking intrusion of cement blocks andaggressive forms, ooatings and materials (corrugated or plated iron doors replacing the oarved and often delioately painted wooden doors, eto.). Moreover, in a context of impoverished rural economy, even a landlord oannot afford to maintain his kasba or tighremt properly, as he used to do it in the past : he must be content to periodically renew the coating of its terraoes but will omit the repair of the eaves protecting the top of the walls, so that water will penetrate into the pisé, weaken its strength and eventually oause entire seotions of the higher floors and towers to collapse.

The oauses of disuse and deoay of loam oonstruotions being manifold, a variety of remedies have to be applied. A first attempt to encourage the inhabitants of the ksour to renovate and modernize their villages and dwellings themselves using traditional methods was made during the years 1968-1974 by the Ministries of Interior and Housing, with participation from the World Food Programme of FAO (the Food and Agrioulture Organisation of the United Nations). The latter institution has distributed supplementary food rations to those villagers who volunteered to work for the recoating of the ksar walls, the installation of drainage and water supply systems, the oonstruction of pit latrines and animal stalls outside the village. About fifteen villages, mostly situated in the Drâ'a valley, benefitted from this programme, whioh proved quite successful and met with great enthusiasm on the part of the population. Though logistioal difficulties led to its discontinuation, it nevertheless brought many lessons whioh will no doubt be useful for the broad programme presently envisaged for the rehabilitation of Southern architectural heritage.

Between 1972 and 1977, the Moroooan Ministry of Culture has undertaken, with technical help from UNDP and Unesco, to establish a full system of inventory of the national heritage, including monuments and sites, museum property and folk arts and traditions. Since the rioh patrimony of southern architeotures had hitherto been utterly ignored and negleoted by the higher levels of authority, a special effort was made to bring it to light and draw official attention to the dangers whioh oonfronted its survival. A "pre-survey" was then made of some 300 kasbas and ksour of partioular value. The resulting dooumentation, in the form of identity oards and photographs has formed the basis of a programme of oonservation and rehabilitation to be carried out in oooperation with all governmental departments.

Figure 10. Kasba Taourirt, Ouarzazate, viewed from South. This part is now occupied by the Center for the Restoration and Reuse of Southern Kasbas (CERKAS) and its restoration has just started (photogr. Ministry of Culture/Baamri, 1975).

The Center for the oonservation and re-use of Southern Kasbas (CERKAS) : present status and perspectives

After a decade during which no protective action was taken on any of the surveyed monuments, the Ministry of Culture decided to create, with support from UNDP and Unesco, an organ with the specific task of safeguarding and revitalizing the arohitectural patrimony of the South Region, using it as a vital component of the general development of this relatively unprivileged part of the national territory.

The Center for the Conservation and Re-use of Southern Kasbas (CERKAS) set up in 1987 now exists and funotions, although still with a rather limited staff (one director, two architects, some draughtsmen, clerical staff and teams of masons and unskilled workers). Its headquarters are located in Kasba Taourirt, Ouarzazate, a former seat of power of the Glawa qâ'ids, a section of whioh has been restored to house the Center. This operation in itself has been a very successful experience and has aroused confidence even in those who did not believe that a badly damaged earth building could be rehabilitated at a very reasonable cost (less than half the prioe of a new oonstruction) and provide comfortable and aesthetic premises for all kinds of uses: as offices, meeting rooms, workshops as well as housing quarters. Of the spacious area which the Municipality of Ouarzazate put at the disposal of the Center (about 3,200 m2 on the ground), more than half has to the present been rehabilitated and work is being pursued to restore and re-use the remaining parts (see fig. 10).

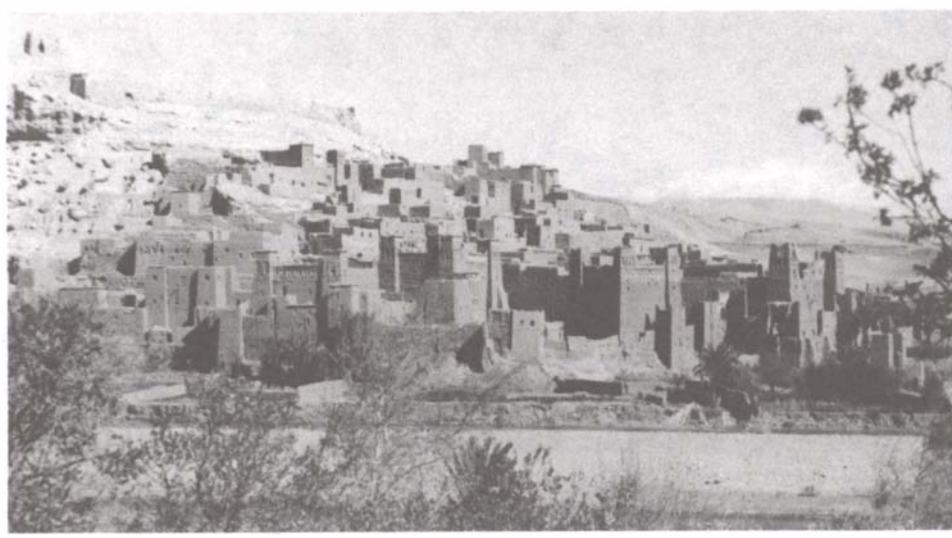


Figure 11. The ksar Ait Ben Haddou (25 km N-E from Ouarzazate) is threatened with destruotion. Its rehabilitation is now being planned under the leadership of CERKAS (Photogr. Ministry of Culture/Baamri,1975)

The first project to be tackled by CERKAS -apart from the restoration of its own precincts- concerns the rehabilitation of Ksar Ait Ben Haddou, an ancient village formed by a number of tighremt ascending a hill at the foot of which flows a mountain river while its summit is orowned by an antique citadel (see fig. 11). Considered as a unique specimen of the southern tradition of earth architecture, and as a model of harmony between natural and man-made environment, this ksar has been classified as a monument having "outstanding universal value" and included in the World Heritage List. Deserted by the majority of its population who have resettled the opposite bank of the river (where they have found more amenities and facility of communication with nearby Ouarzazate), the ksar is now on the verge of utter ruin and a request is being presented for its inclusion in the "List of World Heritage in Danger" according to article 11,4 of the World Heritage Convention of 1972.

The master-plan ourrently being established to safeguard the ksar is based on the asumption -confirmed by oral evidence obtained from the inhabitants themselves- that most ksourians will come back to live in their original homes provided they are given basic facilities and opportunities to maintain, and even raise, their present standard of life. The main components of the project are: provision of safe tap-water, electricity (possibly from solar energy), drainage and sewage systems, security against floods and landslides as well as various equipments: post and telecommunications, Quranic and primary schools, health center, sport and recreational installations, local museum and handicraft workshops, the whole process of rehabilitation being conducted in the spirit of authenticity, according to the principles of the Charter of Venice and other international standards and recommendations, due account being taken of local specificities. It is hoped that this project, which receives full ooperation from all Provincial authorities and services, will be actively supported by the international community and will serve to demonstrate how tradition and modernism may be associated and oontribute together to creating a better and more dignified way of living for rural populations in arid or semi-arid areas of the Third World.

Apart from the referenoes appearing in the present artiole, a guidance to bibliography has been given in my artiele published in ICOMOS Information N°4, 1986, pp. 2-14.

See also my paper on "Earth Arohitecture of South-Morooco : Problems of Conservation", in : Proceedings of the 8th General Assembly of ICOMOS, National US ICOMOS Committe, Washington D.C. 1987, Vol.II, pp. 961-968.

TRADITIONS AND TECHNIQUES OF EARTHEN ARCHITECTURE OF SRI LANKA

B.D. Nandadeva
Department of Fine Arts
University of Kelaniya
Kelaniya
Sri Lanka

ABSTRACT

The aim of this paper is to present an account of the earthen architectural traditions of Sri Lanka, and the techniques followed through several periods of time, as seen in archaeological evidence and in the practices of present day building construction. The author will explain five different building techniques and other uses of mud for building work. These building techniques vary from the simple methods of construction of walls, with or without timber skeletons, to advanced methods of construction using adobe or rubble, and the use of mud for flooring. Aspects of maintenance of mud houses under tropical-monsoonal conditions will also be dealt with.

KEYWORDS

Earthen architecture, wattle and daub, timber skeleton, mud tempering, rammed mud, sun-dried bricks, tropical-monsoonal effects

Introduction

Earth must have been the only building material known in ancient Sri Lanka until knowledge of fired brick and stone masonry was introduced from India around the third century B.C.; this date coincides with the beginning of the historic period of the country. However, the use of these more durable materials seems to have been confined to religious and other public buildings as well as buildings exclusive to the royalty; the houses of commoners were constructed of earth. Excavations by archaeologists in ancient settlements belonging to the Proto or Early Historic periods have yielded only foundations of such buildings.

Earth is the most popular building material, even today among the low-income populations of Sri Lanka. Earth is used for the construction of foundations, walls with or without timber frames, floors of buildings and as a bonding medium in constructions where non-earthen materials are used. Even among the more affluent classes and even the moderate-level income groups, who tend to have their dwelling houses built of permanent material, earthen constructions still play an important role. While the main house is constructed of brick and cement, one or two other peripheral buildings, detached from the main house, such as the open-hearth kitchen, shed for bric-a-brac and a pit toilet are constructed of earth.

Technical Aspects

Knowledge of such aspects of building construction is acquired through experience. In the construction of simple dwelling houses, the owner does everything himself, with the help of friends or family members. Sometimes, advice is sought from an elder in the village. Experience and common sense help to solve simple technical problems as they emerge. The body of knowledge involved in the construction of mud buildings is a rather simple one, illustrated in the following four main points.

1. Site selection: A mound or high ground, free of the possibility of water-logging, is considered as the best site for earthen buildings.

2. Preparation of earth: Much care is taken in the quality of earth used for construction purposes. Humus-free soil of a sticky quality is considered as the best material. By adding water and trampling under foot, the soil is transformed into a mud of a soft consistency. Often, earth from anthills is mixed in order to increase the cohesiveness. The mud is then piled-up into a dome shape and covered with banana leaves or similar kind of leaf or jute bags to conserve heat loss, and left for a period of three to four days. Hydration, hydrolysis and microbial action within the mud now generate heat which tempers the mud. This tempered mud has a high degree of adehesion and is suitable for all types of building construction work. Any failure in any of these steps may result in poor bonding quality or subsequent cracking or loss of mud from the wall.

3. Obtaining correct right-angles at corners: There is an oral tradition of specifications of lengths and breadths of buildings. These are adhered to very closely. Traditional builders find it sufficient to have corners at approximate right angles. The right angle is marked by the simple expedient of comparing the diagonals.

4. Obtaining the plumb of the wall: This is considered as a crucial factor. A simple weighted rope is used to obtain the perpendicularity of the wall.

Types of Earthen Constructions

The author has identified six different methods of application of mud to buildings.

Figure 1. Wattle and daub house under construction, showing the roof tatched with woven coconut branches and the timber skeleton, partly filled-in with mud.

Figure 2. A part of the timber skeleton of a wattle and daub house showing a column supporting the roof, vertical 'core columns' and horizontal bamboo splinters.

Figure 3. Balls of mud placed inside the 'pockets' of the timber frame of a wattle and daub wall; new work with wet mud is seen at the top of the picture.

1. Wattle and daub houses (where walls are constructed using a timber skeleton): This is the most popular and widespread method of earthen construction in Sri Lanka. The archaeological evidence from ancient settlements indicates that the builders of the past had taken an enormous effort to use a raised, damp-resistant podium, made of rubble pressed into soft mud, in order to protect the timber framework from rising damp and termite attacks. As an added precaution, dressed stone slabs, cut to take the timber columns, were placed on this podium.

The present day wattle and daub builders show no serious concern about having a raised platform or sometimes even a foundation. Not having a solid foundation, indicates a major deviation from tradition.

Construction work takes place in this order; the floor is laid, the timber columns of the walls are fixed, the timber-work of the roof comes next, followed by thatching with cadjan (woven coconut branches) or straw. The earth-work of the walls is then taken up under the protective roof. This order of work allows protection for the workers from the heat of the tropical sun, prevents washing away of partly constructed walls, gives a storage place for the tempering mud mixture and prevents the walls from too rapid drying.

Narrow trenches are cut demarcating the position of the walls. The trenches are sometimes filled in with rubble pressed into soft mud to act as a foundation. Sometimes no foundation is used. In either case, the timber frame of the wall is erected along these trenches.

The timber frame or the skeleton of the wall is constructed by first putting in a row of core columns, between the columns that support the roof, at an interval of 40-50cm. The material is invariably of cheap and low quality. Trees or branches of about 15cm in diameter are split into two, to form the upright columns. Then splintered bamboo shafts about 5cm are fixed horizontally at an interval of about 20cm onto these core columns on the inside and outside of the building so that they run parallel to each other, thus forming a 'pocket' in which balls of clay is placed (see figs 1,2). The wood work is bound by coir rope or green vines. Spaces are left for doors and windows when the timber frame is built.

After completion of the frame, the actual mud-building work now begins. Tempered mud, formed into balls of about 12 to 15 cm in diameter, are placed inside the pockets of the timber frame. As the soft wet mud cannot bear much load, the construction work has to be done in stages to allow sufficient time for drying and hardening of the previously placed mud (see fig. 3). At this stage, the wall is levelled by sçraping out the mud with the

Figure 4. A completed wattle and daub house, after a final coating of soft kaolin. The raised plinth provides a place for relaxing or storing things.

fingers and splashing it back to cover any exposed part of the frame. Finger marks are left on the walls so as to produce a rough texture. The wall at this stage is called the 'katu mati bittiya', literally the rough-textured mud wall. 'Demati gahanava', literally applying the mud for the second time is done after the first coating is adequately dried. This time too, splashing the mud and scraping are done by hand. If the owner so desires, a coating of lime, kaoline or cow-dung is put on to obtain a better finish (see fig. 4). Sometimes, motifs of Folk Art are drawn on the wall, not only for decorative purposes but also to serve magical functions of warding off evil and inviting prosperity.

The wattle and damb technique is also used for a special type of building known as the 'tampita vihara', that stands on stone pillars, exclusively used as image houses in places of Buddhist worship. Here, a wooden platform is erected on top of short vertical stone pillars that serve to prevent dampness seeping through the walls. The timber framework for the wall is then set on the wooden platform. The main columns which support the roof are fixed outside the timber frame. Only the walls are of earthen work; the floor is made of timber. These walls act only as an enclosure and a canvas for religious paintings and other decorative art. The walls do not take the load of the weight of the roof.

2. 'Tappa bitti' or rammed earth-walls: This is a method of erecting a solid mud wall with no timber skeleton within. Planks of timber, about 20 to 25cm wide, are set on the 'rubble in mud' foundation about 25cm apart along the entire length of the exterior and interior lines of the wall to be built. They form a mould into which mud can be rammed. The planks are removed only after the mud is adequately hardened and able to stand without sagging. This method does not allow building more than 20 to 25cm of wall-height at one time. This process is repeated over and over again until the required height of the wall is achieved. The most important point here is to build all the walls of the entire house simultaneuosly. All the door and window frames have to be fixed while the wall is being constructed. A temporary canopy of a thatched roof is made in order to protect the walls from rain and excessive solar radiation. Once the construction of the walls is completed, a traditional thatched roof or, as is done today a roof of corrugated galvanized iron sheets is placed using a timber structure set on the walls so that the load of the roof is transfered through the walls.

The walls constructed in this manner are sometimes plastered using a mixture of clay and sand and then lime-washed. Rammed earth walls are considered much more durable than the wattle and daub ones.

Figure 5. A house with rammed earth-walls, under construction; note the temporary roof standing on timber supports.

Figure 6. A section of fig. 5; the new work with wet mud looking darker than the rest of the wall, is noticiable.

There is another technique of constructing walls that is called '<u>tappa bitti</u>' but differs from the method explained above. This probably evolved from a method used to construct boundary walls (known as <u>tappa</u>) around private properties mainly in the coastal region during the Late Historic Period (c. 16 to 17th centuries). This method has now gained popularity as a house-building technique especially in areas where timber is scarce.

Here, the method of construction is very simple. Once the 'rubble-in-mud' foundation is done, mud balls are placed on top of each other, in two or three rows, to build the wall. The width of the wall varies depending on the load it has to receive from top. It is possible to build a height of about 50 cm at one time giving an interval of about three to five days for that section to dry before the work on the next section starts (see figs. 5,6). This wall may be coated with mud or plastered with a mud and sand mixture and then lime-washed if desired (see fig.7). It must be noted that no supporting timber frame is used.

Figure 7. A completed house with rammed earth-walls and a tile roof with the front wall plastered and white-washed; the side-wall shows how the work progressed.

Figure 8. A house constructed with sun-dried bricks (adobe).

3. 'Moda gadol bitti' or walls with sun-dried bricks(adobe): The use of sun-dried bricks, made by using a wooden mould, is still a popular building construction method (see fig.8). It is the only true adobe construction method in Sri Lanka. Dimensions of these bricks are generally much larger than that of fire-baked bricks. Walls are built on a 'rubble-in-mud' foundation. The method of construction is the same as in fired-clay brick construction, but here wet mud mixed with sand is used as the bonding medium (see fig.9). These buildings are sometimes plastered with a mixture of mud and sand and then lime-washed.

Figure 9. Bonding of sun-dried brick work.

4. Walls built with 'kabok' or blocks of laterite: In the southern and western coastal belt of the island, laterite is quarried in blocks. These blocks are used in the construction of walls using a mixture of tempered mud and sand as the bonding medium. If desired, these walls can be plastered and white-washed.

5. 'Sakka bammi' or stone-and-mud-wall: Mud is used as a bonding medium when walls are constructed of rubble made up of stones of varying sizes (see fig 10). In this case, some soft sand is mixed into the tempered mud. Walls constructed in this manner can have a width of about 30-40 cm. If desired, the wall can be plastered with the same mixture of mud and sand, and white-washed over. This technique is used also in the construction of 'Tampita vihara', a type of religious building that stands on stone pillars (mentioned above).

6. Flooring: Traditionally the mud buildings have earthen floors. Moistened earth is spread-out over the floor area and rammed manually with the use of a simple wooden rammer. The firmly rammed floor is coated with moistened mud. A second coating is done with a mixture of anthill clay and fresh cow-dung. The third or the final coating is a layer of fresh cow-dung and water. A floor made in this manner is very clean and insect-resistant. Another advantage of this floor is that it absorbs instantly any spillage.

Figure 10. A wall made of rubble bonded with mud.

Maintenance

The maintenance of a mud-built house in Sri Lanka generally means the replacement of the tatch roof and the repaire of the cow-dung coated floor. When the floor has to be repaired, it is merely dampended and a coat of anthill clay and cow-ding is applied, followed by a coat of moist cow-dung. This adds another few milimeters of new material to the floor. This is done customarily as preparations for the annual Sinhala and Hindu New Year celebrations around early April. After many years of such repair, the floor level rises substantially. It is, therefore, a practice to remove a few centimeters of old layers, probably once in ten years before applying a new coat.

During heavy monsoonal rains, rising dampness is a problem. The only known remedy is to drain the water from the compound to help to keep the site dry. Once a building gets dampened in this way, it takes a fairly long time to dry as these houses have very few openings and air circulation inside the house is restricted.

Figure 11. The cracked kaoling coating falling off a mud wall.

No complicated technology is applied to maintain the walls. The main causes of wall decay are termites who distroy the timber frame and build nests within the wall, and rats who burrow into the foundation. Cracking of the wall can be seen as a result of tilting or settling. Also, the process of expansion and contraction caused by rapid changes in humidity and temperature in the atmosphere result in the cracking of the mud coating of the wall and eventually falling off. Use of insufficiently tempered mud too contributes to the same result (see figs. 11-13). When cracks become very apparent, they are simply filled in with mud rather than treating the cause of decay.

Summary

In rural Sri Lanka where the socio-economic base is predominantly agricultural, the earthen building traditions described above are the most popular methods of housing construction. As the materials are freely available in abundance, and the technology involved is simple, and common knowledge, and the maintenance does not present serious problems, the rural house owners prefer to go for earthen houses, despite their impermanancy. However, due to the economic development experienced by the rural agricultural sector in recent times, together with the government support for better housing, a new trend is emerging in favour of permanant non-earthen material such as fired-brick and cement.

Figure 12. The exposed timber skeleton, of a wattle and daub wall, after the loss of the second coating of mud.

(The author acknowleges the grant support given by the Getty Conservation Institute to participate in this conference to present this paper.)

Figure 13. Decay of timber work after the loss of the mud-coat of a wattle and daub house.

REVALORIZACION DEL MATERIAL TIERRA EN LA ARQUITECTURA CHILENA

Hugo Pereira G. Arquitecto
Centro de Estudios de la Tierra
Carlos Antúnez # 2467 Santiago-Chile.

ABSTRACT

The use of earth for building in Chile is as ancient as the country, being a synthesis of Indian and European techniques brought over Spain. For over four centuries earth was the most important material for building especially in rural areas, where agriculture developed as the most important economic activity. Today, Knowledge of earth building is in decline, eventually to be lost entirely.
The present study attempts to recall the cultural factors involved with earth building. There is a great heritage of different types of construction with historical and cultural values influencing, that need help to be restored.
The factors that cause damage and destruction to these construction are earthquakes and inundations. A second aim of this study is to investigate the use of earth building techniques for low-cost housing in present day in Chile.

KEYWORDS
Palabras claves:

-ADOBE
-TAPIAL, Tamped earth (pisé)
-QUINCHA, Earth on timber frames.
-Hacienda, Farm houses
-Earthen Construction techniques.

Definición del área de estudio:

Se define la siguiente área geográfica que presenta construcciones en base a tierra. Es la comprendida aproximadamente entre los paralelos 20º y 40º Lat. Sur y 75º y 85º meridiano. Dentro de ésta área, en la que se observan construcciones en tierra existe una sub-área que concentra el mayor desarrollo de estas técnicas y que coincide con el ámbito en que se consolidó la cultura chilena y que contiene la mayor densidad poblacional del país. A esta última se la conoce como valle central teniendo como límite norte el valle del río Aconcagua y como límite sur el valle del río Maule.

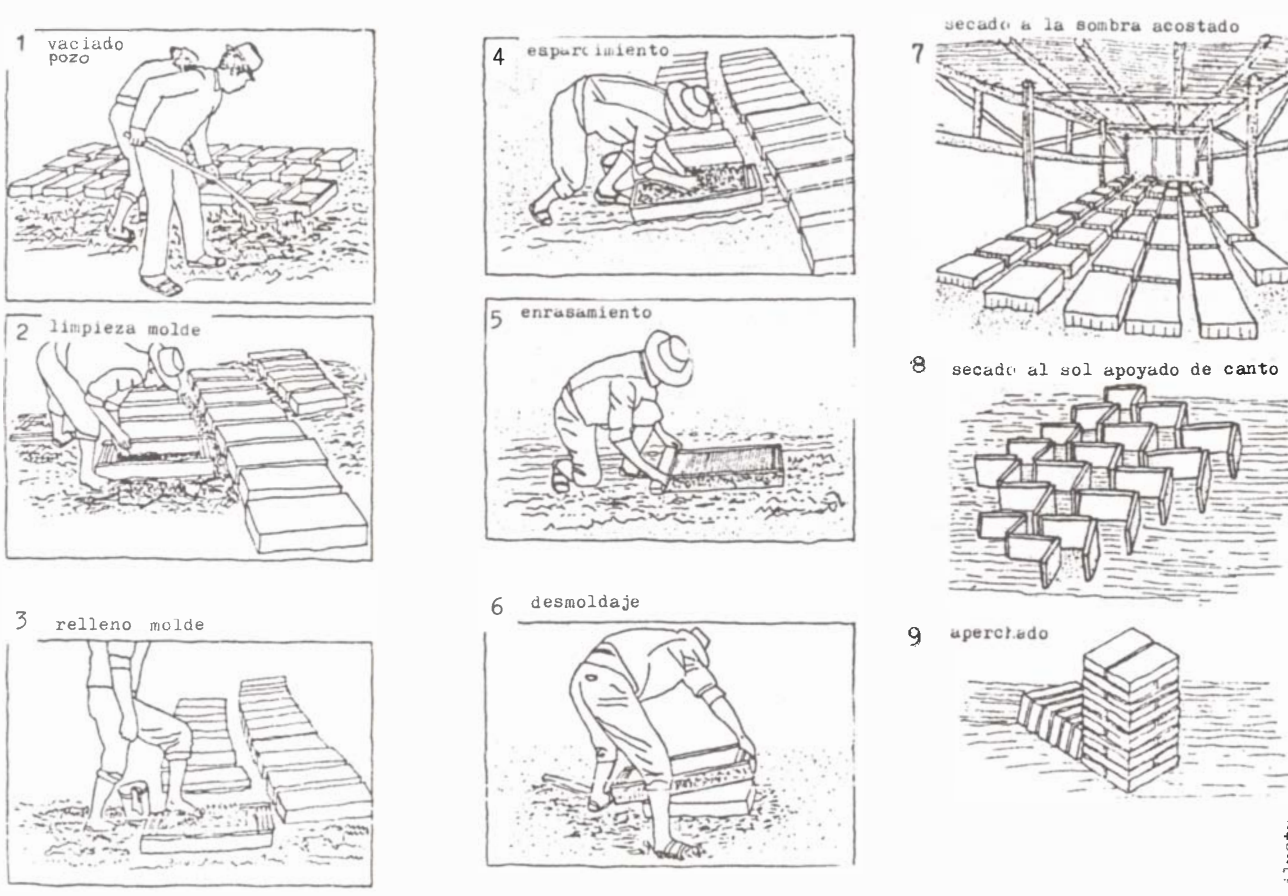
El régimen de lluvias de esta sub-zona es de entre 500-1000 milimetros anuales.

Clima : la zona del valle central tiene un clima templado mediterráneo con tres estaciones secas y una lluviosa. El norte grande se caracteriza por la ausencia de lluvias y su condición desértica, la que es suavizada por los efectos de enfriamiento de la corriente marítima de Humboldt que asciende desde la Antártida a lo largo del litoral.

Tipología edificatoria de Construcción con tierra :

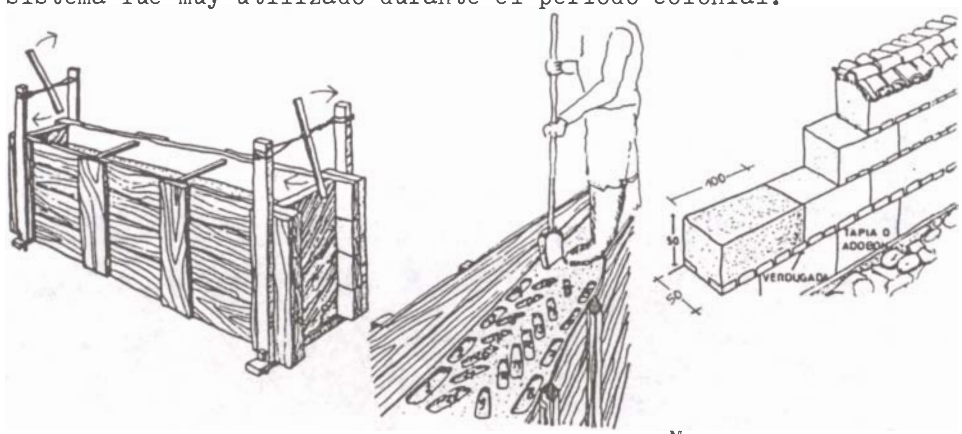
Los principales sistemas constructivos en base a tierra usados en Chile a lo largo de su historia son:

ADOBE : Albañilería de prismas de tierra-paja, ejecutados in situ, secados al sol. Usualmente miden 10 x30x 60 cms, se usa generalmente paja de trigo, esporádicamente paja de cebada, ambos cereales abundantes en la agricultura chilena. La revoltura se hace en pozos donde se deja impregnar de agua la paja, durante 1 día a lo menos. revuelto a pie o con animales, dependiendo del volumen de mezcla a preparar (graf.1)



ilustr. L. Dominichetti, R. Marchetti i y otros, ALBAÑILERIA 1 de bloques de adobe Apuntes Catedra de diseño estructural, Acultad de Arquitectura y Urb. Universidad de Chile, Santiago, Chile.

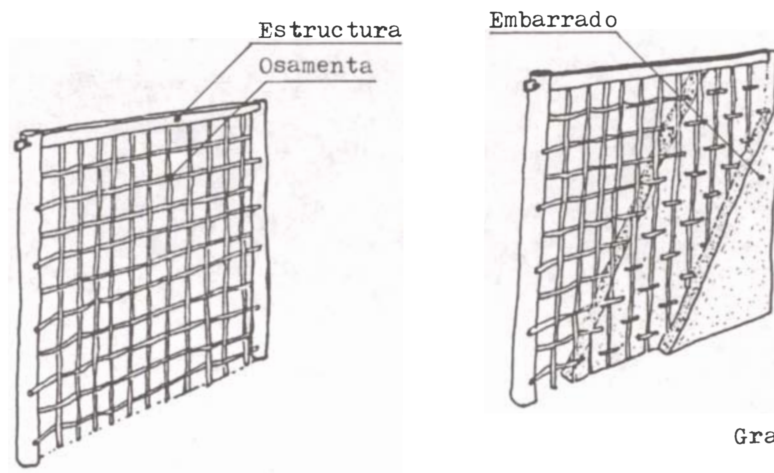
TAPIAL : Consiste en la confección de bloques de mezcla de tierra-paja in-situ mediante la compactación en moldes de madera de grandes proporciones, siendo la más usual 50X50X 100 cms (Graf.2) Este sistema fue muy utilizado durante el período colonial.



Molde Faena Apisonado Muro

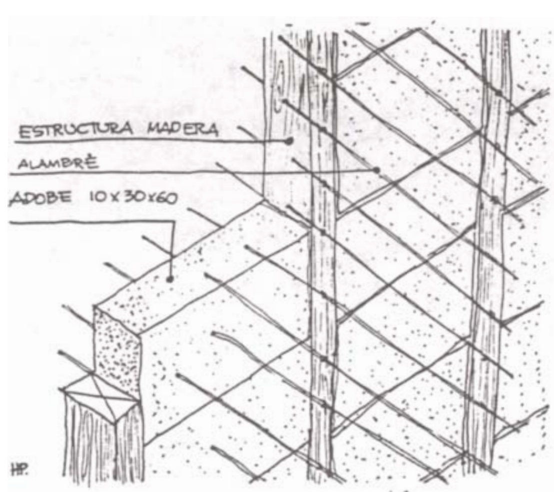
Graf.2

QUINCHA : (enquinchado o encañizado) Consiste en la confección de un entramado de ramas independiente al cúal se le adheriere por impacto una mezcla de tierra-paja en estado plástico.Esta técnica tiene una amplia gama de alternativas dependiendo del lugar específico en que se emplea y de las disponibilidades del lugar.(Graf.3) Durante la colonia al entramado de caña revestido en barro se le conocía como "bahareque".



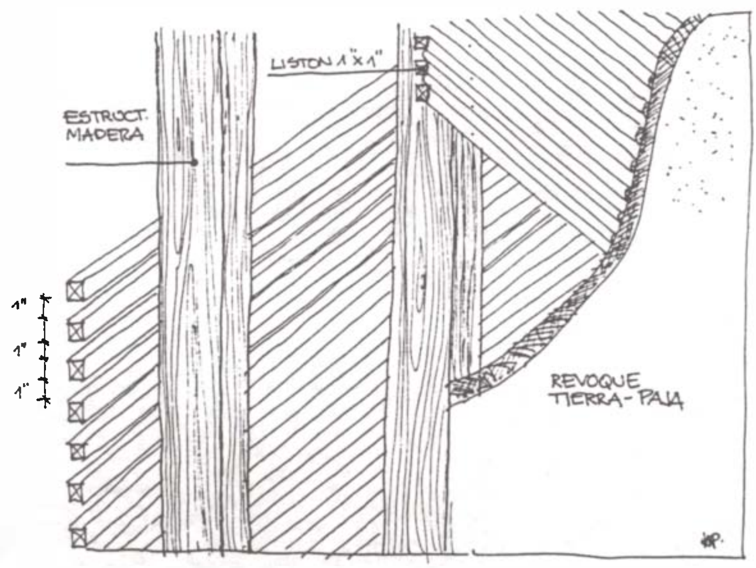
Graf.3

ADOBILLO : Consiste en la colocación en posición de canto de adobes de 10 X 30 X 60 cms. sujetos por medio de una estructura de madera y varias corridas de alambre fijo a la estructura cada 20 cms. aprox.(graf.4)



Graf. 4

PALILIAJE: Consiste en la proyección de una mezcla tierra -paja en estado plástico, sobre un entramado de madera de 1 "X 1", separado 1", afianzando a una estructura de madera.(Graf.5)

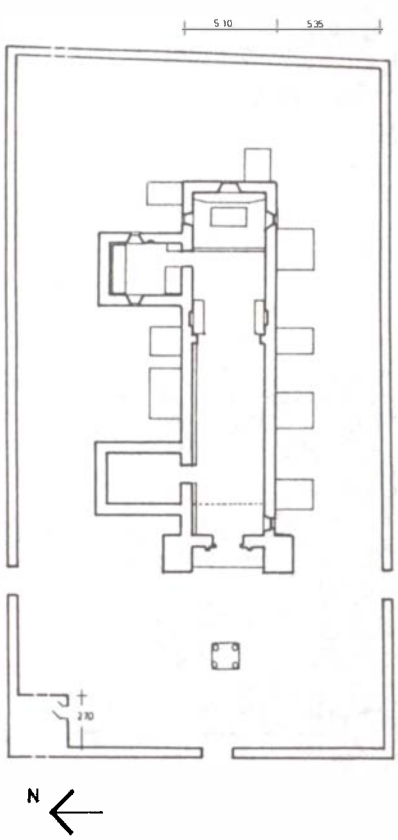


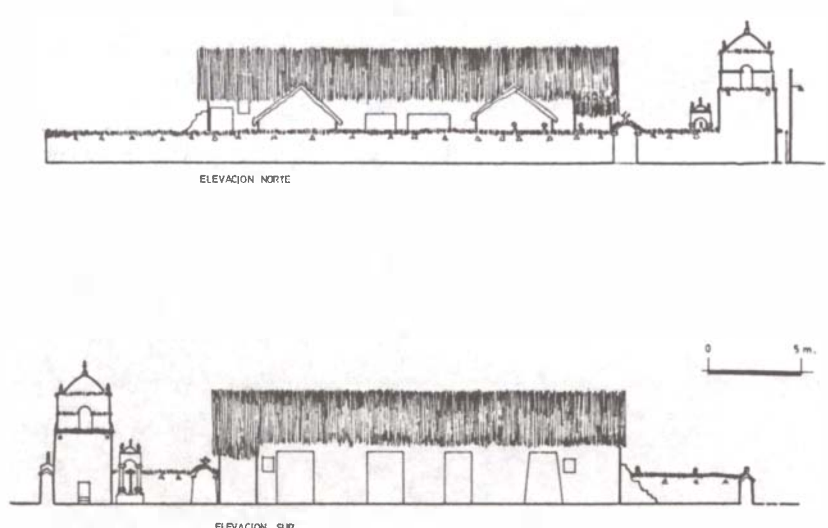
Graf.5

Antecedentes históricos:

Las construcciones en base a tierra, hechas por los conquistadores españoles son las primeras de las que tenemos registros. La casa de Don Pedro de Valdivia en Quillota (1542) probablemente fue construída en tierra dadas las descripciones de macisez que de ella se tienen. El mismo Pedro de Valdivia utilizó la técnica del adobe en la construcción de la muralla defensiva de la ciudad de La Serena luego de su destruoción por parte de los aborígenes, testimonio que encontramos en una carta que el conquistador envió al rey Carlos V en 1541; en ésta explica que cortó 200.000 adobes para su construcción y que estos medían 1 vara de largo por 1 palmo de alto.(1)

En el norte grande el uso de la tierra se asocia con la técnica de albañilería de piedra, usándose como argamasa de pega; en cierros exteriores se utilizaba la técnica del tapial. La cubierta de estas construcciones es más liviana que la cubierta de teja del valle central, utilizándose paja gruesa abundante en las praderas pre-altiplánicas (caña brava). Estas construcciones son más antiguas que las del valle central ya que se encuentran emplazadas en la ruta de la conquista de Chile desde el Perú, a través del llamado camino del Inca, el que recorría toda la zona norte a través de la precordillera. (Graf.6)





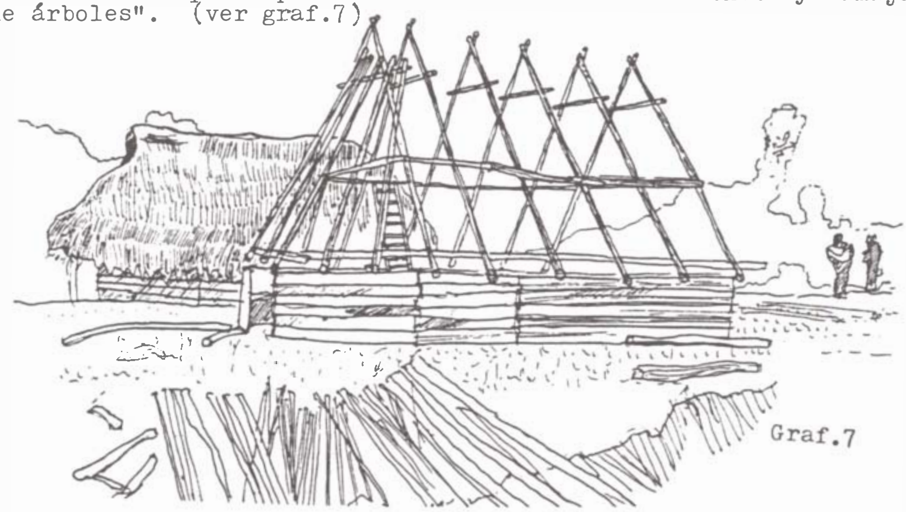
Graf.6

ilustr. J. Benavides, R. Márquez de la Plata, L. Rodríguez, Arquitectura del Altiplano Caseríos y villorrios ariqueños Stgo.Chile, Fac. de Arquitectura y Urbanismo U.de Chile. Edit.Universitaria 1977, 88 89

1) E. Greve, Historia de la Ingeniería en Chile Tom. 1 Santiago, Chile Imp. Universitaria 1938.

Existen testimonios acerca de la utilización de la tierra en las construcciones agrícolas,como los del naturalista francés avecindado en Chile Claudio Gay,quién describe detalladamente la vida del país durante el siglo XVIII. Al respecto escribe Gay,que se "cortaban" adobes y que con ellos se hacían tapias en los campos las que servían de cierros (cercos) para las cuadras (unidades de medida de los campos).Estos se hacían con paja revuelta con tierra con la ayuda de animales.Se refiere también el autor a la selección de los suelos,debiendo rechazarse los arenosos y utilizarse los arcillosos;se refiere también al tiempo de duración de las tapias, estableciendolo entre 30 y 40 años,y esto a causa de la constante utilización que hacen los animales de los muros,para frotarse.(2)

La primitiva "ruca",vivienda de la tribu de los mapuches, pueblo aborígen de la zona sur de Chile (mapu=tierra,che=hombre),estaba construída principalmente de un entramado de troncos y ramajes de árboles". (ver graf.7)



Graf.7

la construcción aborígen sólo les pudo ofrecer la "ruca",de la cúal tomaron los sistemas de trabazones de los materiales de coligue;la"ramada",derivación criolla de la anterior y la "pirca" separatoria de los campos de cultivo que parece también de origen precolombino".

En Chile, a raíz de una crónica escasez de recursos técnicos y de mano de obra calificada, se desarrolló una Arquitectura caracterizada por la austeridad y sencillez,obra de las manos de artesanos-campesinos. Esta característica austera es consecuencia también de los continuos terremotos que se encargan de eliminar de los edificios todo lo superfluo. El 13 de Mayo de 1647, un violento terremoto destruye gran parte de lo dificultuosamente edificado a la fecha.

No existen datos científicos precisos al respecto, pero lo cierto es que este hecho marcará un hito en la historia de la Arquitectura chilena ya que obligó a nuestros antepasados a replantearse los principios constructivos que habían aplicado hasta entonces.Comienza a desarrollarse entonces una Arquitectura distinta,los muros empiezan a engrosarse, llegando a sobrepasar 1,00 mt. de espesor,disminuyen los vanos y las grandes luces; las alturas de las construcciones se restringen, eliminándose torres y todo elemento agregado a la estructura que pudiera significar un riesgo de desprendimiento.(3)

Las repercusiones del sismo afectaron también la configuración de la casa chilena del siglo XVII adoptándo sistemas constructivos tales como la "quincha" original de la ciudad de Lima,Perú,técnica mixta de tierra y madera distanciada cada 90 cms - 120 cms y listones horizontales en los que se teje la caña, soporte del barro (4)

En otros escritos del período colonial encontramos testimonios sobre la importancia del adobe en la construcción otorgándosele excelentes características de comportamiento antisísmico,incluso comparándolo con edificaciones de piedra y ladrillo.

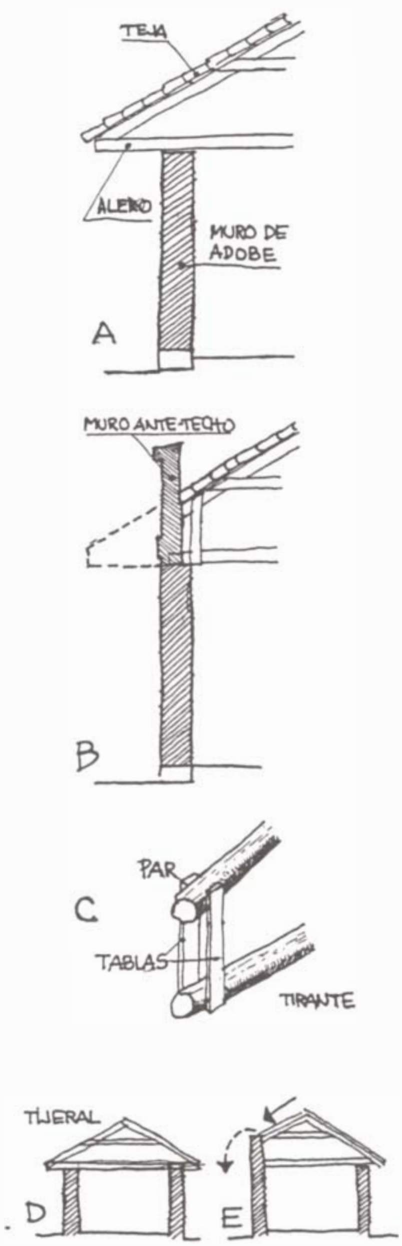
Las haciendas, constituían las grandes unidades de producción del campo chileno del período colonial, constituyendo centros de gran actividad y concentración poblacional y expresando arquitectónicamente algo propio, hecho que se fundamentaba en la utilización.

2.- C.Gay Manuscritos sobre las costumbres generales de Chile.V-19 Santiago, Chile, Arch. Nac. Cat.Gay-Morlán 1771,12,23,56,58

3.- B.Vicuña-Mackenna, Historia Crítica y Social de la Ciudad de Santiago desde su fundación hasta nuestros días: 1541 - 1868 Stgo, Chile Editorial 1869.

4.- E.Pereira, Historia del Arte en el reino de Chile.Buenos Aires Argentina. Impresoras Argentinas 1965,50 .

Históricamente, en un período de tres siglos y medio, la Arquitectura chilena utilizó masivamente el adobe,como material constructivo.Esto es posible constatar en construcciones de diverso tipo, religiosa, Habitacional etc,tanto en el ámbito rural como urbano. A raíz del proceso de Independencia Nacional,se produjo un corte histórico con la cultura del período colonial,y es así que a partir del siglo XIX, se manifiesta fuertemente una tendencia a la adopción de modelos y arquetipos extraños al período anterior;fenómeno que se agudizaría a fines del s. XIX. Las nuevas estéticas serían abandonadas con la misma irresponsabilidad con que eran adoptadas. Un eclecticismo desenfrenado se apoderaría de la arquitectura nacional. Comenzó un proceso de destrucción de los testimonios edilicios del pasado colonial, entre los cuales abundaban edificios construídos en base a tierra, con el consiguiente empobrecimiento del patrimonio arquitectónico.



Graf.8

A partir de la década de los 40, a raíz de la industrialización del país y el aparecimiento de nuevos materiales de construcción, en el mercado,y a causa de las destrucciones ocasionadas por el terremoto de 1939, disminuye notoriamente el empleo de las técnicas de construcción con tierra, especialmente la del adobe.

Lo que ocurrió fue que se destruyó una gran cantidad de casas construídas con adobe, pero no se investigó el porqué. El dramático caso de las destrucciones de la ciudad de Chillán, que cobró miles de vidas humanas es ejemplar. Al respecto el profesor E.Guzmán que las fallas en las estructuras se debió a una grave modificación del modelo estructural primitivo.

"Se trata de viviendas antiguas de adobe, con alero a la calle, que fueron en algún momento"modernizadas",suprimiendo el alero o parte saliente de la techumbre y prolongando hacia el muro de la calle hasta ocultar el techo. Al cortar el extremo del tijeral,se sostiene el par con un soporte vertical,probablemente dos tablas laterales en cepo (graf.8C)mientras se construye el muro , para apoyarlo allí en definitiva.Con éste cambio se consigue transformar el triángulo perfectamente indeformable (graf. 8d),en un elemento de cuatro lados,que no sólo es deformable , sino que da origen a una fuerza inclinada que empuja al pequeño muro antetecho; con gran parte del peso de la cubierta de teja , tratando de volcarlo.(graf. 8E). Después de una transformación como ésta , resulta extraño que el muro antetecho no caiga de inmediato.En todo caso , la techumbre dela la vivienda queda transformada en una trampa,que caerá sobre sus moradores justamente en el momento en que salgan a la calle por efecto del sismo." (5)

Deficit habitacional y proyecciones del uso del material tierra

Chile tiene un déficit habitacional de aproximadamente 1 millón de viviendas. De acuerdo a los porcentajes de incidencia de las partidas en el costo total de una vivienda, podemos descubrir que la incidencia de los muros sobre el costo total aumenta mientras más económica es la vivienda, y vice versa, pudiendo llegar a incidir hasta el 50% del costo total (6), considerando que el material tierra prácticamente se encuentra a muy bajo costo en gran parte del área del valle central de Chile, es que es posible asegurar que sin duda es un material alternativo que brinda excelentes posibilidades de aplicación en viviendas de bajo costo. Las recientes experiencias de construcción con tierra así lo están demostrando;el período 1983-1987, se dieron cerca de 18.000 soluciones habitacionales que utilizaban la tierra como material de muros y aislación térmica sobre el encielado. Muchas de éstas experiencias han empleado el sistema de autoconstrucción dirigida, lo que ha contribuído a abaratar los costos. Los principales motivos que han llevado a elegir estos sistemas mixtos de construcción en base a tierra son los siguientes:

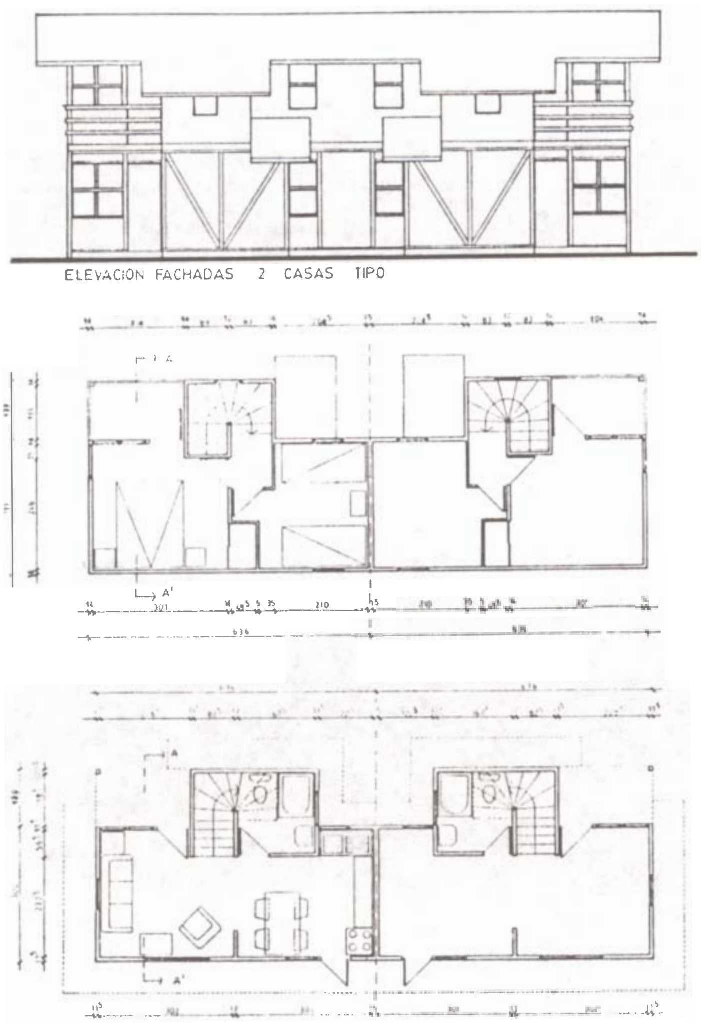
1) Seguridad antisísmica
2) Buena respuesta a condicionantes físico-ambientales
3) Rapidéz de ejecución
4) Posibilidades de reciclar materiales en desuso
5) Facilidad para implementar autoconstrucción

La mayor parte de éstas viviendas han surgido a causa del déficit producto del terremoto de 1985, que destruyó una gran cantidad de viviendas, especialmente localizadas en áreas rurales.

El desarrollo embrionario de esta tecnología obliga a estudiar con mayor profundidad las condiciones físico-químicas de la tierra,ya que hasta el momento se ha trabajado utilizando como base de datos la simple experiencia de obra, sin la asistencia de un estudio técnico riguroso.

En alguna medida, las construcciones realizadas presentan deficiencias producto del desconocimiento del material tierra , lo que lleva muchas veces a presentar un panorama confuso en relación a la real posibilidad de aplicación de éste material.

Un caso interesante de vivienda económica construída en base a un sistema mixto de tabiquería de madera y tierra (palillaje) y malla metálica,es el ejemplo del Graf. 9, ejecutado en 1986 en una Comuna de extrema pobreza de Santiago,Chile, ejecutado por autoconstrucción con asistencia técnica de profesionales. (taller Norte,Arqtos. J.M.Cortínez, R. Jiménez).



ilustr. A.Hays,S.Matuk, F. Vitoux,CRATERRE. TECNICAS MIXTAS DE CONSTRUCCION CON TIERRA Plan Construcción, 1986, Rexcoop,

Graf.9

Conclusiones : La tecnología de construcción en base a tierra , tiene una gran proyección a futuro,ya que habiendo sido abandonada recientemente (década 1940-50), se hace necesaria en vista a la manutención,reparación y modificación de un legado patrimonial de gran valor arquitectónico que abarca cerca de tres siglos de historia.Es importante retomar científicamente el estudio del material de tal forma de poder incorporarlo al repertorio de materiales "seguros". Es particularmente útil , poder promover el uso de técnicas mixtas de construcción con tierra , dado que por una parte se elimina la variable de "riesgo sísmico" , y por otra se aprovecharía un abundante recurso material en nuestro país,como es la madera. Según proyecciones realizadas durante 1985,en Chile se habrían construído gran cantidad de viviendas de bajo costo en base a éste último tipo de técnicas, con diversos inconvenientes de orden normativo y socio-culturales,hecho que avala como cierta la opción de desarrollar la investigación científica en esta área y que tendría subsidiaramente otro efecto muy positivo,cuál es,el de recuperar un aspecto perdido de nuestra identidad cultural.

5 - E.GUZMAN. Curso de edificación Cap IV Santiago Chile Edit. Universitaria 1977, 205

6 - J.SALAS SERRANO " Aspectos Económicos de las Construcciones con tierra" MONOGRAFIA No 385 - 386 INSTITUTO EDUARDO TORROJA, MADRID ESPAÑA (1987): 77 - 82

ABSTRACT

The use of unfired earthen mixtures for the wall construction of load-bearing masonry structures has generally been regarded as unsuited to the harsh climate of the northeastern United States. In fact, at least twenty-four mid-nineteenth century earthen-walled buildings exist in New York State today, attesting to the potential for exceptional longevity of earthen construction in this unlikely climate.

Unburnt brick construction in New York State was influenced by reports documenting earthen walled construction in Canada and England in the 1830's. Mud brick construction was championed at the same time in the United States by U.S. Commissioner of Patents Henry Leavitt Ellsworth. Ellsworth's patent reports reprinted excerpts of British and Canadian journals, and documented Ellsworth's own experiments with mud brick construction. By the mid-nineteenth century over forty mud brick structures dotted a nine county area spanning half the state. Buildings reflect then current Greek Revival, Gothic Revival, and Italianate styles, and were erected by members of various socioeconomic groups.

KEYWORDS

Adobe, Cob, Pisé, New York State, History

EARTHEN ARCHITECTURE OF NEW YORK STATE: ADOBE CONSTRUCTION IN A NONARID CLIMATE

Richard Pieper, Director of Preservation
Jan Hird Pokorny, Architects & Planners
306 East 51st Street, New York, NY 10022

In the United States, the use of earth for building construction is most frequently associated with the adobe structures of the southwestern states or the sod houses of the untimbered stretches of America's northern plains. In the northeast, infrequently applied techniques such as "wattle and daub" and "mud nogging" exploited the insulative properties of earth used as infill in wood frame buildings. The use of unfired earthen mixtures for the wall construction of load-bearing masonry structures has generally been regarded as unsuited to the harsh climate of the northeastern United States, however. In fact, at least twenty-four mid-nineteenth century earthen-walled buildings exist in New York State today, attesting to the potential for exceptional longevity of earthen construction in this unlikely climate.

The early popularization of earthen construction in nineteenth-century United States may be traced to the seminal writings of Francois Cointeraux, French agriculturalist and architect, whose publication of a series of cahiers on pisé, or rammed earth, construction in 1791 started a chain of translations and adaptations that reached the United States in the nineteenth century. Cointeraux was not the first Frenchman to report on rammed earth construction, which had been chronicled by others reporting on pisé construction then common in the areas around Lyons. Cointeraux's reports were backed by considerable personal experimentation, however, and he pursued the dissemination of his techniques with a proselytic zeal that soon attracted the attention of like-minded architects in Great Britain.

By 1797 Cointeraux's first and second cahiers on pisé construction were translated into English by noted English architect Henry Holland, and published with new illustrative plates in the Communications of the Board of Agriculture of Great Britain. Holland's translation was reworked and plagiarized in America by Stephen W. Johnson, who published Rural Economy: Containing a Treatise on Pisé Construction in 1806 in New Brunswick, NJ. Johnson's book was illustrated with plates resembling Cointeraux's original engravings, and included sections on such disparate topics as road building and viticulture. Most significantly, Johnson included a chapter on "cob" or mud walling, a traditional English technique of monolithic earthen wall construction, which, unlike pisé, used a mixture of moistened earth and straw. Johnson's book, and Holland's translation, which was republished in the agricultural journal The American Farmer in 1821, sparked a series of experiments in pisé construction in the Mid-Atlantic and southeastern United States that were chronicled in agricultural journals in the first four decades of the nineteenth century. Curiously, no similar experimentation in true pisé construction appears to have taken place in New York State.

New York's earliest documented extant earthen structures are two cob walled residences. The Lawrence Johnston House (1832 or 1833) and the William Gorse House (1836) are located a few miles apart in Penfield, Monroe County, near Rochester. While the Johnston House's wall construction is now obscured by clapboard siding, several exposed areas in the interior show that the mixture of mud and straw was placed within wooden wall forms in layers about 15 cm (6") deep. An account of the construction of the Gorse House republished in Penfield's Past: 1810-1960 by Katherine Wilcox Thompson states:

> "A pen was built on the ground and clay drawn from a nearby creek bed spread over the ground to a depth of about a foot. On this, cut straw was spread to a depth of three to four inches. Oxen were driven around and around inside the pen to thoroughly mix the ingredients. Plank forms about a foot high were set up on the wall foundations and filled with the clay mixture. As soon as the clay and straw had dried sufficiently to be self-supporting, the forms were raised and another course poured. Floor joists were laid across the walls and another layer poured on top, thus embedding the joists in the wall. When completed a year later, the house was given a thin plaster coat of clay and the interior walls were plastered and kept white-washed."

About the same time that Gorse and Johnston were experimenting with cob wall construction outside of Rochester, English architect and horticulturist John Claudius Loudon was publishing his influential Encyclopedia of Cottage, Farm, and Villa Architecture (1833), a compendium of designs and prescriptions for construction that contained no fewer than twenty-nine illustrations for cottages that Loudon proposed were appropriate for earthen construction. Loudon noted Cointeraux's pisé experiments but also quoted the report of fellow Englishman John Denson whose Peasant's Voice reported on the use of "clay lumps" or unburnt brick, for the construction of cottages in Cambridgeshire.

Whether prompted by Loudon's encyclopedia or simply immigrant English technique, buildings were being constructed of unfired mud brick near Toronto, Canada as early as 1836. By September 1842 the Canadian publication The Church was reporting of the new Hurontario Church, "the new church is to be built of mud (or unburnt) brick, which in the opinion of the best informed architects, is the material of all others the fittest for the building with in this province." In February 1843 The British-American Cultivator, a Toronto agricultural journal, reported that "houses, properly constructed (of unburnt brick) are warmer, more durable, and also cheaper than frame, and are destined to take the place of the log shanty, as well as the more expensive wooden walls."

Unburnt brick construction was being championed at the same time in the United States by U.S. Commissioner of Patents Henry Leavitt Ellsworth. Son of U.S. Supreme Court Chief Justice Oliver Ellsworth, and brother of Connecticut Governor William Ellsworth, H.L. Ellsworth chronicled advances in agricultural science in his patent office reports of the 1830s and 1840s. Ellsworth's reports of 1842, 1843, and 1844 reprinted excerpts about unfired brick from Loudon's encyclopedia and The British-American Cultivator, and reported on Ellsworth's own successful experiments with mud brick construction in Washington, D.C. and Grand Prairie, Indiana that had begun in 1842. Ellsworth's influential reports were widely excerpted and reprinted in agricultural journals such as The Cultivator (Albany, N.Y.) and The Genesee Farmer (Rochester, N.Y.). The New York Tribune, which published an excerpt about unburnt brick construction soon after the first report's publication in February 1843, separately reprinted a sizable portion of the report in pamphlet form under the title Useful Works for the People No. II.

Ellsworth's motivation to experiment with this novel form of construction was apparent. Already a landowner in the Wabash Valley of Indiana, Ellsworth was to become an agent for Federal lands in the area following his departure from the Patent Bureau in 1845. An illustration of Ellsworth's proposed "prairie cottage" in the 1844 report leaves no doubt that, in spite of his rather large (5.5 m x 16.5 m, or 18' x 54') experimental brick structure in Washington, D.C., Ellsworth was proposing that unburnt brick would well serve those of modest means settling on the prairies of the then far west.

Ellsworth's intentions notwithstanding, at mid-century over forty mud brick structures, most not nearly so simple as Ellsworth's prairie cottage, dotted a nine county area in New York that spanned half the state. Ontario County was quite certainly the center of this mud brick vogue; census records indicate that at least twenty-two mud brick structures had been built in the county by 1855, far more than in any other. At least fourteen mud brick buildings were constructed in the village of Geneva alone.

One contemporary account reveals that the initial use of unburnt brick in Geneva antedated Ellsworth's first published report, however, and the discrepancy between the brick sizes recommended by Ellsworth (30.5 cm x 17.8 cm x 12.7 cm, or 12" x 7" x 5", and 30.5 cm x 15.2 cm x 15.2 cm, or 12" x 6" x 6") and that of the majority of mud brick buildings in Geneva (38.1 cm x 30.5 cm x 15.2 cm, or 15" x 12" x 6") suggests that English or Canadian practice may have served as a model for the earliest Geneva construction.

In September 1844, The Home Missionary, journal of the Presbyterian and Congregationalist American Home Missionary Society, published a lengthy article entitled "Churches of Unburnt Brick" featuring an analysis of "several houses of unburnt brick" in Geneva and proposing that "houses of worship of unburnt brick are desirable for congregations of the ordinary size..." The president of the A.H.M.S., Henry Dwight, was a Geneva resident, and Geneva was the site of the society's western New York office. Although the article obviously intended that the use of mud brick construction be adopted by impecunious congregations, much of the domestic earthen architecture that sprang up in Geneva following The Home Missionary report was anything but modest. By 1850 one mud brick Gothic Revival style residence had been constructed for Miles P. Squier, former regional secretary for the A.H.M.S. and the niece of Henry Dwight's wife, Sarah Bradford, lived in another prominent earthen structure on Geneva's fashionable South Main Street. Still another adobe was constructed on a nearby lot belonging to Charles Cooper, the namesake of Bradford's eldest son.

Of the fifteen mud brick residences eventually constructed in the Geneva area, eleven are extant today. Five of the Geneva adobes exhibit striking decorative similarities, and no doubt the apparent popularity of mud brick here was due in part to the presence of a body of builders willing to work with this unusual material. It is apparent also that Geneva mud brick construction influenced others wishing to experiment with the method that Ellsworth and others were espousing; the 38.1 cm x 30.5 cm x 15.2 cm (15" x 12" x 6") brick size can be found in buildings in Bath, Steuben County, and Interlaken, Seneca County. By 1855 earthen buildings had been constructed in Erie, Monroe, Steuben, Ontario, Yates, Seneca, Tompkins, Oswego, and Otsego counties.

Although the architectural treatises of the period were not silent on the subject of unburnt brick, few dealt with the mode at length or in adequate detail to assist a would-be builder. One notable exception was The Architect (1849), a journal published by the New York City architect William Ranlett. Ranlett's book may have been the first eastern publication to use the Spanish term "adobe" for the construction technique that previously had been identified as "unburnt brick," "sundried brick," "mud brick" or even "Egyptian brick." While Ranlett devoted only two pages and three designs to adobe construction, he gave detailed prescriptions for construction and undoubtedly his copiously illustrated pattern book lent a certain cachet to the novel building mode that had prompted so much publicity in the previous five years. It appears that Ranlett's work inspired the construction of what is by far New York's largest documented earthen building, the Judge Samuel Ludlow Residence in Oswego. Under construction in 1851, the Ludlow residence when complete had a major facade seventy feet long, two 2-1/2 story hip-roofed ells forty-five feet long, and an adobe tower with a wood frame top that rose forty feet. Today clad with fired brick, Ludlow's residence serves as a convent for a neighboring Catholic high school.

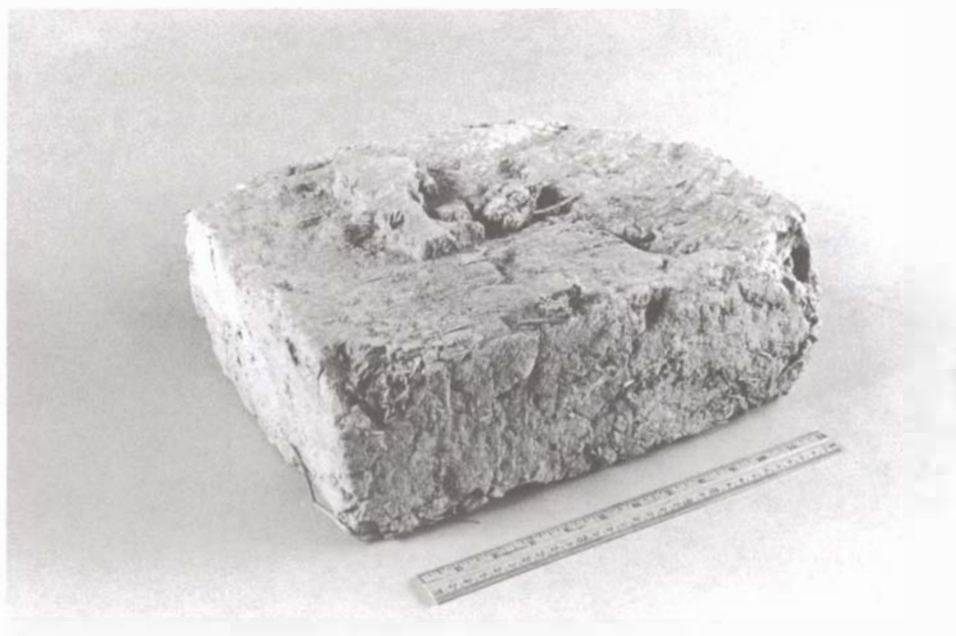
By the early 1850's, however, the mud brick vogue was slowing considerably, no doubt prompted in part by the difficulty of preventing exterior stucco finishes from failing. The stucco problem had been mentioned frequently in early accounts, and prompted at least two New York State builders to include horizontal wooden members within the walls between alternate layers of brick so that the completed masonry building could be sided with wood.

Despite the generally glowing tone of the early press, not all later publications treated the topic so favorably. In his 1852 book Rural Architecture, Lewis F. Allen indicated "we are aware that unburnt bricks have been strongly recommended for house building in America; but from observation we are fully persuaded that they are worthless for any permanent structure, and if used, will in the end prove a dead loss in their application." The Cultivator, which in March 1847 had published an article about mud brick construction entitled "The Cheapest and Best Mode of Building", was by February 1855 stating "...this mode of building is falling into disuse, doubtless for some substantial reasons, among which is probably the difficulty of having every part done well, and especially the great difficulty of securing good cement, so essential to success." Some innovative builders, inspired by Orson Fowler's The Octagon House, A Home for All turned instead to what was to become the next heralded replacement for fired brick masonry--the gravel wall. As early as February 1846 one correspondent to The Cultivator offered a comparison of the two technologies:

> "I read in Ellsworth's report of last winter, the manner of building cheap houses of unburnt brick; but I think they have an improvement in Wisconsin over all others. The material consists of gravel and lime--one-eighth part lime, and the balance of coarse sand

and any kind of gravel or small stones, mixed so as to make a mortar that will "set" so hard as to stand well."

All but three or four of New York's adobe structures can be confirmed through census research to antedate 1855, although one Geneva building is known to have been constructed after 1870. Few stylistic generalizations can be made, even in Ontario County, where the disparate buildings reflect then current Greek Revival, Gothic Revival, and Italianate styles. Similarly, the buildings cannot be said to have been favored by one socioeconomic group; the 1855 census records values for the buildings ranging from $100 to $15,000, stretching the limit of what might be considered vernacular architecture. Today most remaining examples are in sound condition and all are occupied. Many retain their original exterior stucco finishes, although some have long been resided with wood clapboard, aluminum, or brick, and hide their identity from the casual observer. Quite certainly others remain to be found, unlikely relics of an innovative era in American masonry construction, confirming the claims of adobe's nineteenth century proponents about the durability of earthen construction in New York's harsh climate.



Mud brick from 247 Washington Street, Geneva, New York. Brick size is approximately 38 cm x 30 cm x 15 cm (15" x 12" x 6") and is typical of adobe buildings in New York State.

Samuel Sill residence, circa 1845, 247 Washington Street, Geneva, New York.

John and Sarah Bradford residence, circa 1845, 629 South Main Street, Geneva, New York. Gothic Revival design was utilized for a number of adobe residences in Geneva.

14 West Morris Street, Bath, New York. This Greek Revival style residence is covered with a natural cement stucco which was scored to resemble ashlar.

Theodore Irving residence, circa 1845, 731 South Main Street, Geneva, New York. Several of Geneva's adobes retain their original exterior natural cement stucco.

RETENTION OF THE TRADITIONAL VALUES OF AFRICAN EARTH ARCHITECTURE

David Smail, Architect
P O Box 240305
Ndola, Zambia

ABSTRACT

The critical shortage of housing is probably the single greatest problem facing developing countries in Africa today.

Severe economic restraints, coupled with unimaginative and ill-directed policies by developers have created hectares of sterile concrete block units unaffordable to the average worker.

Across Africa examples of fine vernacular architecture created by self-reliant developers are evident. These non-pedigreed architects used the earth, their own unskilled labour, and their concerned minds to create architecture with qualities of communal awareness, security, serenity, and aesthetics. Unfortunately, these have been neglected by historians.

Retention of these values will educate consultants and authorities on the merits of traditional design and use of materials and possibly unleash the energy to make use of the abundant supplies of land, labour, love, economy, and earth to solve the housing problem.

KEYWORDS

TRADITIONAL VALUES, ADOBE, DECORATION, MODERN URBAN - BLIGHT

One of the greatest problems facing practically all counties in Africa today is providing satisfactory shelter for their burgeoning urban populations. The mushrooming of the towns and cities has been a feature of both the colonial and post-independence period since the end of the Second World War with the consequent increase of satellite townships and shanty dwellings surrounding the old town centres housing those in search of a pot of gold.

The response of most governments has been directed through their quasi-governmental housing authorities. Many agencies with deep social commitments tried to help by building new housing estates in modern renewal projects. The existing shanties were regarded as slums - chaotic and "bad"; the planners and sociologists failed to understand or appreciate the social organisations, the delicate expressions of neighbourliness and territory found in them. New "good" housing was provided on the grid, lacking heart, individuality, privacy, and security. Soon, discomfort became tension and developed into vandalism and thuggery, similar to what happened in the vertical developments erected in the First World by similar well-meaning developers. Comparing a typical scheme in Zambia (Figure 1) with an older development in Mali (Figure 2) one can only be saddened by the results of progress. The town plan of Mopti in Mali is full of delight, surprise, interest, drama, and variety, as organic as a cross section through the gut of a chicken, compared to the inhuman precise grid now universally common as the accepted answer to modern housing developments.

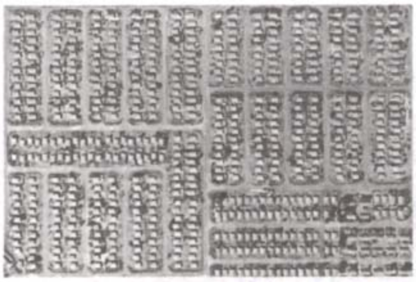


Figure 1 Modern Housing plan

Figure 2 Mopti in Mali

Those responsible on the town councils, aid agencies, architects, planners, and contractors congratulated themselves on their success with typical pronouncements, as one made by the Lusaka City Council on one such scheme: "the local authority low cost house has within 20 years, developed from the traditional hut built of sun dried brick to a modern structure of plastered blockwork and asbestos cement sheeting that will stand comparison with public housing all over the world". (Reference 1).

That these units were sterile and costly mattered little to the developers; cement or burnt brick are mandatory, big windows looking across small plots on to the heat of the road are the norm, corrugated iron or asbestos roofing sheets are a must. Aesthetics are regarded as a frivolity and therefore totally expendable. The very real cost in foreign exchange expenditure, deforestation through burning bricks, and lack of comfort in small hot houses with curtains inevitably drawn in a vain search for coolness, privacy and security are all accepted as part of the modernisation process. Traditional housing values have been dismissed as unsuitable for the contemporary scene. One of the early voices raised to protest the trend was that of founder President of Tanzania, Julius Nyerere, who said, "the widespread addiction to cement and tin roofs is a kind of mental paralysis". (Reference 2).

It is important to appreciate the very elementary level at which a solution to this problem must be found. Even one of the standard local-authority-type houses costs the equivalent of about 30 years of earnings for an average worker and is consequently unattainable. Modern housing can only really be afforded by companies for their employees. Many countries in Africa have to import many of their building materials for the most basic house and due to the crippling foreign exchange problems these costs are enormous. Materials such as cement, glass, tin roofing, plastic floor tiles or piping cannot be used in low cost housing. Environmental restraints exclude others like timber, as the deforestation of great areas of the continent rules out wood for either burning bricks or for structural purposes.

This leaves earth and, to a lesser degree, grass, reed, lime, and some small timber sections as the available construction materials.

Attempts to build a truly appropriate structure using only local materials have been scorned by authorities, consultants, and contractors alike. The problem of overcoming the "minimal" connotation of using earth structures is very real indeed. The authorities invariably regard these proposals as condescending: Doesn't independent Africa deserve at least the same modern building materials as the developed world? Conservative contractors prefer using tried and tested materials without risk. Also, the true savings in using earth as a medium are negated by inflated costs or insurance added by the builder. Traditional crafts, rarely used, have tended to die out. Consultants prefer to concentrate on larger more prestigious jobs and so very little constructive thinking has gone into low-cost housing design.

Land is readily available, as is earth as a building material, and there is plenty of labour due to high unemployment and the population explosion. These are the seeds of a solution, provided that the prejudice against mud can be overcome. The way through this dilemma can be seen in several examples from across the continent, where for centuries laymen have built sensitively planned houses out of basic materials and created true examples of quality vernacular architecture; a tradition that must be conserved.

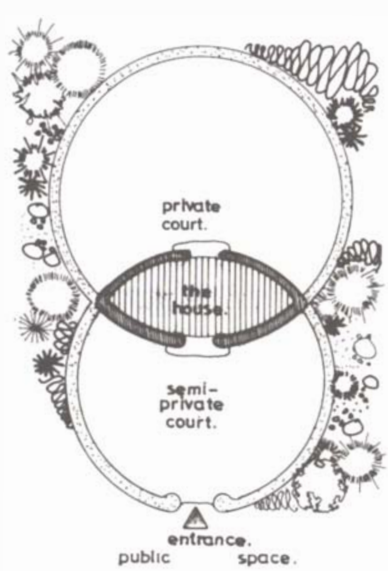


Figure 3 Bilobial Plan

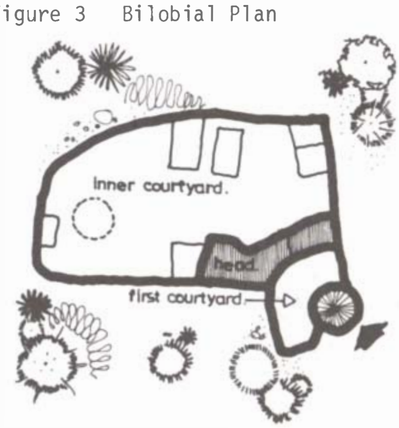


Figure 4 Hausa House Plan

Three schemes typical of many throughout Africa are the Hausa compounds in Nigeria, the Tswana housing in Botswana, and the Ndbela dwellings in South Africa, have the following similarities of :-

a) They are self-designed and self-built, non-pedigreed architecture;

b) They have a bilobial plan with its heirarchy of spaces, from public to private, giving a sense of privacy, territory, and neighbourliness; (Figure 3)

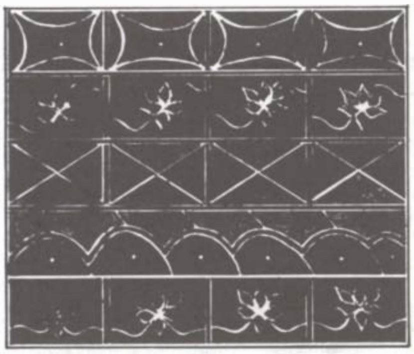
c) They are economical since they use readily available earth as the major building material;

d) The decoration of the earth structures declares the author's pride in his or her creation

The most interesting of the Hausa people's mud-built architecture is situated at Zaria in the Northern Savannah region of Nigeria. As in the Malian town of Mopti, the Hausa houses or compounds cluster along busy foot-paths around the town's two main focal points; the mosque or palace and the social economic centre, the market place.

The compound plans generally follow the design of two courtyards with their characteristic heirarchy of spaces leading from public to semi-public, to semi-private, and private areas. (Figure 4). The entrance is normally crowned with an impressive thatched roof under which the head of the household practices his trade or craft and meets the passing world. The first court is a transitional semi-public space with several rooms for servants, guests, adolescent boys, and sometimes a horse or cow. The quarters for the head of the household open off the first court and have a meeting area for important guests, while the inner courtyard houses the wives, girls, boys below the age of puberty, chickens, kitchens, and granneries. The privacy and tranquility of the courtyards form a haven from the bustling roads, a serene open-aired space, private and secure. The earth-built walling provides a unifying element to the compound that is delightfully decorated with sculptured rabbit ears, bas-relief, murals, and various roof forms. All in all a public demonstration of the owner's private pleasure in his architecture (Figures 5 and 6).

Figure 5 Hausa architectural elements



The earth walls are built from egg-shaped bricks the size of a melon that are made at borrow pits from earth that is trampled with water to form a workable mix before being roughly moulded and left to dry for at least two weeks. Mortar of a similar mix is used for laying the bricks directly on a 450 mm deep foundation trench. No more than three courses are laid each day, but the walls are plastered again with the same mortar both internally and externally.

Both straw/thatch and mud are used for roofing, the latter being applied in two layers 50 mm and 75 mm thick supported on split poles which are tied into the mud walls.

Figure 6 (left) Typical hausa mural

Further south in Botswana the Tswana people have for centuries been building bilobial dwellings similar to those of the Hausa using similar earth materials, yet with more subdued but equally heartfelt decoration. (Figure 7)

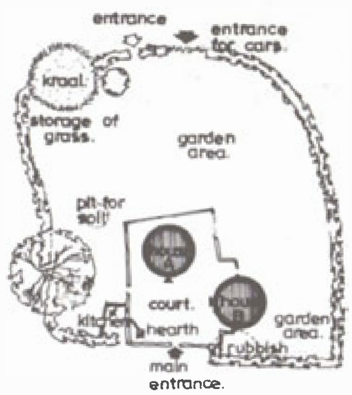


Figure 7 Typical Tswana House Plan

Women do all the building and crafting in mud. They collect the material, mould the blocks, erect the walls, and they do the plastering and colouring. The wall is built from a mixture of sand or clay and water, although cow dung is often added to the mix. The soil is carried in baskets on their heads to the building site. Foundation trenches 100 mm deep are dug, levelled, and lightly compacted.

Two types of bricks or blocks are used for the wall; wet (traditional) or dried. Wet bricks are moulded by hand about 300 mm x 50 mm in size and laid on top of each other while still damp, plastered and allowed to dry - three courses at a time.

Bricks may also be shaped in a simple mould of wood. Water is not pressed out as this would reduce the strength of the bricks. The bricks are dried in the sun then laid in a mortar of the same mixture as the brick. There is very little difference in strength between the wet or sun-dried brick, although some inveterate improvers say it is easier to cut out and re-use the sun-dried type.

The wall is always covered with two or three layers of plaster, both inside and out. The plaster is put on by hand and a finishing coat of sand, water, and cow dung is used, which covers any cracks or crazing and gives the house a smooth look. Women will go to great lenghts to decorate their walls, and complete redesigns will be done for special occasions such as births, initiation ceremonies, graduations, weddings, funerals, or even at the start of the planting season.

This concern with beauty is illustrated by the description by an old woman who told how she collected the mud when colouring her house and the other houses in the yard. "The brown mud I collected in Sekwane (about 35 km away) and the pale brown from Muchudi (about 30 km away). The black mud I collected from South Africa where I went to stay with my mother's sister. The other type, the yellow-ochre, was collected from a borehole north of this village. We went there to collect mud, but we are not allowed to by the owner of the borehole. The ivory white was collected from a stream which passes through my fields at the lands " (Reference 3).

Roofs are thatched and have big overhangs to throw the rainwater from heavy storms well clear of the base of the wall. The floors of the houses are rammed soil, finished with a mixture of cow dung and water spread with the hand in beautiful patterns giving a hard, odourless, dust-free surface that does not attract flies (Figure 8).

Figure 8 Floor Pattern

The tree of life grows from man's heart

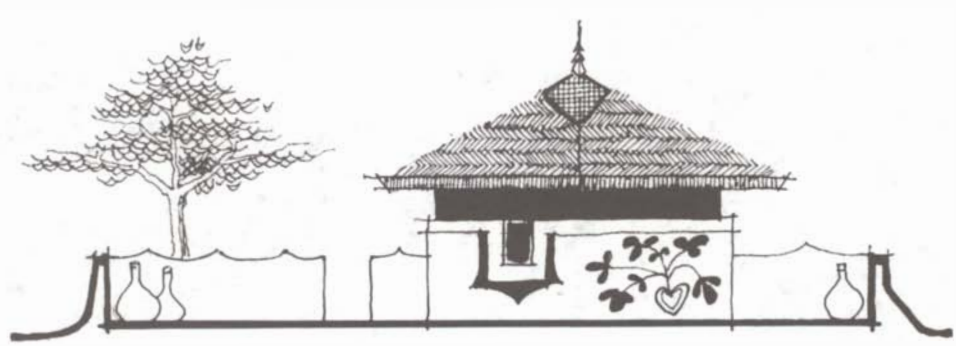


Figure 9 Typical Tswana House

The Ndebele people of the Northern Transvaal of South Africa have developed the bilobial theme into a very sophisticated and refined art form. A series of territorial statements is made defining the heirarcy of spaces that form their dwellings (Figure 10).

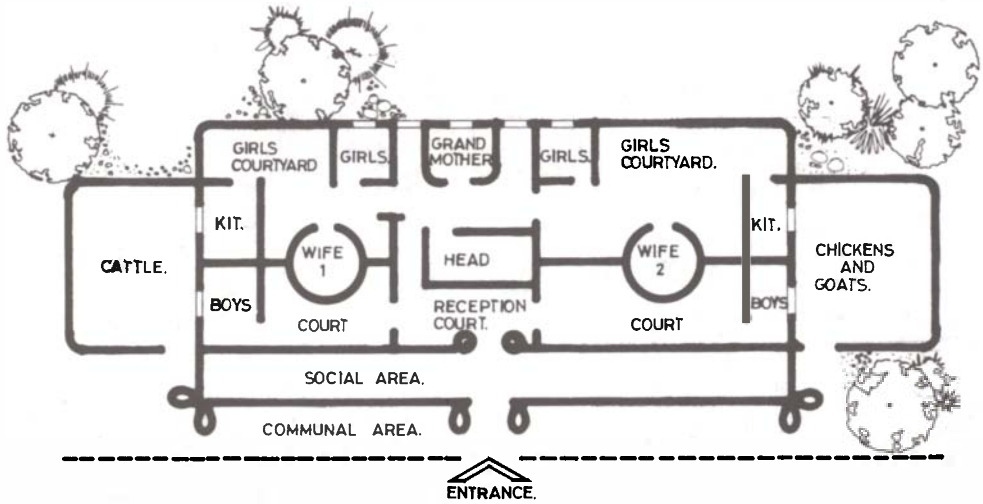


Figure 10 Plan of Ndebele Dwelling

The public area is a hand-crafted low platform that indicates the house is being approached; a second area is entered through gate posts and has a low wall. This is where the women of the household do their chores, supervise the children, and socialise with the settlement. Further zones with higher and higher walls lead to the front court with the dwellings buildings forming one side of the court. A series of rear or side courts radiate from the main dwelling, each housing a kitchen, a dwelling for the eldest daughter or grand-parent, or livestock compound. This building type responds to environmental conditions to a remarkable degree and the exhuberant decoration illustrates the delight of the Ndebele people for their creation.

Dr Hassan, the great Egyptian architect, has shown his brilliant ideas for building in earth and taught the construction of an earth vault without using any timber formwork. Several attempts at building earth domes and vaults in areas with heavy rainfall have failed and the discovery of a covering that uses neither cement or timber (for burning tiles) will open up the whole field of building low-cost houses. Experiments with sisal fibre, lime, or pozzalano cement, where available, have made some progress; tiles burnt with heat generated from a methane biogas digester have been manufactured but are not as yet satisfactory.

History has been indifferent to indigenous housing developments with very little recorded material, preferring to concentrate on the "noble" architecture. This is perhaps the reason for the current neglect of earth as a valuable construction material in the Third World. It is ironic that mud is completely accepted by the hotel industry for their luxury hotels serving First World tourists and also by city dwellers for their country retreats where, despite the lack of high-tech luxuries in their splendid apartments, the environment of the structure enables them to relax in serene surroundings.

Retention of the qualities of earth as an acceptable construction material is a necessity. Conservation of the tradition of building in earth which is freely available, plastic, easily worked, economic and beautiful is a nec-essity not for the sake of quaintness but the retention of a spontaneous architecture. As Dr Fathy has said, the cost of building the present ugly town developments will drive us to build more beautiful homes in mud as this will be all we can afford.

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ACKNOWLEDGEMENTS

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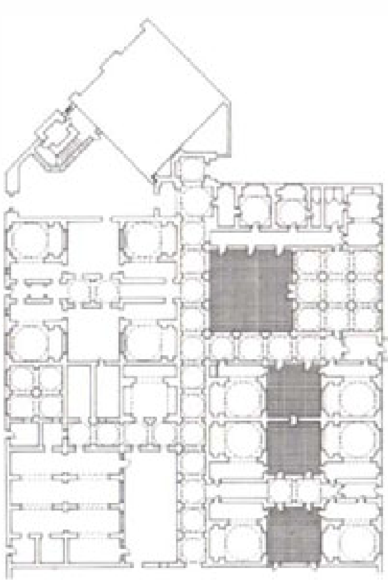
Figure 11 (left) Ndebele Mural

ABSTRACT

The Dar al Islam community, located near Abiquiu, New Mexico, was first conceived by Abdullah Nuridin Durkee and Sahl Kabbani in 1979 and implemented through grants from many individuals and Islamic foundations. The founders commissioned the well-known Egyptian architect Hassan Fathy to design the project, and he visited the site in 1980 with two Nubian masons to present his plans and demonstrate his techniques of building in mud brick. After a promising start and the construction of the mosque, which was to be the focal point of the community, problems in building procedure began to emerge, greatly increasing construction time and cost of what was intended to be a low-cost, self-help village. The source of these problems is indicative of the obstacles facing those who contemplate similar projects in the southwestern United States.

KEYWORDS

Dar al Islam, Hassan Fathy, Adobe.



1. Village plan as revised, provided by the Dar al Islam Foundation.

THE LESSONS OF DAR AL ISLAM

James McLeod Steele Jr.
Texas Tech University
College of Architecture
Lubbock, Texas 79409 U.S.A.

The idea behind Dar al Islam was first conceived by Abdullah Nuridin Durkee, after a chance meeting with Saudi businessman Sahl Kabanni in Makkah in 1979. Both men then discussed the possibility of a seed community for American Muslims who had previously been fragmented and seemingly cut off from the mainstream traditions of their religion. Initially visualized as both a religious and educational as well as a residential center, the community began to emerge as one that would provide a cultural focus for more than one hundred Muslim families and would be a model for others of kind throughout the United States. After a great deal of effort, the search for a suitable site for such a project led its founders to select 1,200 acres of land in the Chama River Valley near Abiquiu, New Mexico, fifty miles north of Santa Fe, which was purchased with funds made available by Kabbani, as well as the Princesses Mothie and Johara, who are the daughters of the late King Khalid ibn Abdul Aziz of Saudi Arabia. Because of its relative seclusion and the similarity of its terrain to other Islamic countries such as Tunisa, Algeria, Morocco, Syria, Iraq, Iran, Afghanistan, and parts of Pakistan, this site seemed ideal to all concerned. As Durkee himself has said:

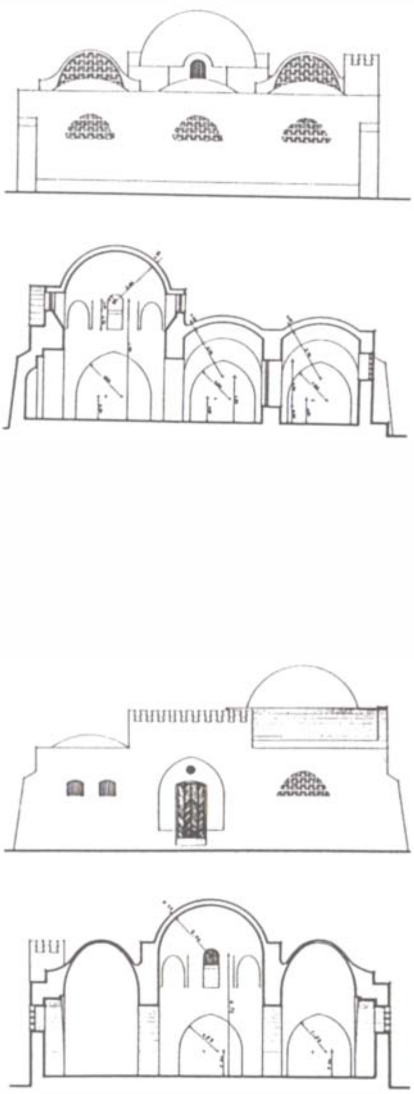
> In addition to its physical assets, that is, the necessary land, water, and soil for cultivation, construction and habitation, the Abiquiu site has geographic, climatic, and cultural characteristics that make it ideal for an Islamic Center. Located at the same latitude as many of the major Islamic regions of the world, it also shares a similar topography, climate, and long history of mud brick architecture.(1)

Even before an architect for the complex was chosen, the heart of the new community was intended to be a mosque, as well as a _madressa_, or religious school, and a _riwaq_, or living quarters for the students and teachers using this school. In addition to these religious and educational institutions, an administrative center to include an Institute of Advanced Islamic Studies, as well as houses, shops, a women's center, library, and clinic were also considered essential to the establishment of the new village. Because of his venerable reputation as the leading architect in the Islamic world at that time, as well as his long experience in using mud brick construction, Hassan Fathy was unanimously considered to be the most logical choice as the designer of Dar al Islam, and after having been introduced to Abdullah Nuridin Durkee by journalist Abdullah Schleifer in Cairo in 1980, Fathy enthusiastically agreed to do so without a fee, because of his deep belief in the ideals involved in the project. Soon afterward, in June 1980, Fathy visited Abiquiu and presented his proposals to the prospective residents there, while also showing the construction methods to be used. These were demonstrated by two Nubian masons (_Muallims_) who accompanied him and were based on a system that has been used in Egypt since 3000 B.C. In this system, which is eloquently described in Fathy's book _Architecture for the Poor_, as used in his village of New Gourna on the west bank of Luxor, a vault serves as the base unit, and the construction of this vault begins with the erection of a "kick-wall" built up to the desired height of the space to be constructed. Once this kick-wall is complete, the masons, usually working in pairs, do a free-form outline of the parabolic vault in mud on the wall as a guide. Although this may sound simple, the proper shape of the curve is crucial for structural success and learning how to lay it out without surveying tools of any kind requires long hours of practice, usually received in a father-to-son apprenticeship arrangement.

After this mud guideline has partially dried the _muallims_ dress the rough edges with sharp adze before applying the first course of mud bricks to it. The bricks of this first course, and of each successive course of the vault, differ from those used in the construction of the walls in that they have a higher proportion of straw to mud, which makes them much lighter, and each brick is scored with two finger grooves by the _muallims_, while still wet, to give more friction and adherence to the mud mortar.

A starter brick is then laid straight up at the base of the vault line on both sides, and mud mortar is packed on it to form a wedge that is thinner at the top of the bricks and wider at the bottom. This sets the angle for each of the vault courses to follow, ensuring that they incline toward the kick-wall in compression, rather than remaining perpendicular to the ground, which would make them collapse.

As each course of bricks is added, the muallims gradually make the mortar thicker at the base of the arch than at the peak to make sure the entire assembly is leaning on the end wall, as well as staggering the joint lines between each row of bricks to assist bending. This calculated incline of the vault as it is put into place accounts for the characteristic massive vertical end wall and sloped front edge of the vaults that are usually found in the mud-brick buildings around Aboul-Riche and Gharb Aswan in Upper Egypt.(2)



2. Mosque Elevation and Section. Courtesy Hassan Fathy and the Aga Khan Award for Architecture.

The presentation of this technique was made to more than 300 people who included architects and adobe builders from all over the United States and Mexico as well as government officials interested in the economic potentital of the system and, of course, the intended residents and board of directors of the community. The presentation also began to evolve from a construction workshop into a teaching session, in which Fathy gave a series of lectures that compressed a half century of hard-won experience into a stream-of-consciousness summation of the architect's most personal beliefs. Perhaps seeming somewhat disjointed and irrelevant to many of those in attendance, who had little or no knowledge of the remarkable background of the speaker, these lectures nonetheless went to the heart of many of the questions that were later to emerge as problematic issues for the community. One man in the audience, for example, made the observation that the mosque being proposed by Fathy was the result of thousands of years of evolution in a certain environment and culture, and had its own justification as a spiritual and ceremonial building, but that "most of us here are not concerned with ceremonial buildings but with the places people live in, as well as the whole question of solving the problem of re-developing the village economy as well as its architecture."(3) While not directly responding to this statement, Fathy answered that

> . . .the solution to any problem requires time and effort and cannot be achieved overnight, especially when we have had two-hundred years of cultural alienation. I personally cannot solve it, because it has gained a great deal of momentum, like a steamroller pressing an entire culture in front of it. People make excuses today by saying that everybody is now the same, but I say, no sir, this is escapism and we must not avoid our responsibilities. We should never be chauvinistic or exclusive, but have to be open minded about tradition. If something doesn't work we must wipe it out with the confidence that it is not worthwhile keeping.(4)

Both themes, of a concern for comfortable habitat on the one hand and the appropriateness of cultural traditions on the other, continue to reappear throughout the brief history of Dar al Islam and offer an important key to understanding the lessons that it provides.

In addition to the inspiration provided by these lectures and the feeling of high expectation and cooperation that the workshop provided, the immediate tangible legacy of this official inauguration of the community was the elegant 220 m^2 Masjid, or Mosque, that still remains the spiritual heart of the complex, standing as a graphic reminder of the structural and spatial possibilities that once existed. Ingeniously designed to achieve the separation of the sexes required in all religious and secular public buildings in the Islamic world, the Mosque is dominated by a large dome which is built over its main prayer area. As in the construction of a majority of his domes, Fathy uses the Sassanid method here, so that the corners where the arches meet to form the springing of the dome are first leveled off and then bridged with half domes to form squinches. These squinches then in turn create an octagonal base on which the structure sits.(5) Regardless of the deceptively simple success of the vault and dome construction of the Mosque, however, the American masons were unable to continue the example of their Nubian instructors, and structural revisionism slowly began to creep into the construction process. Expensive plywood templates, which still litter the site, were soon substituted for the parabolic curves that the

Nubians produced, and had to be used to form all future arches and springing lines of vaults. Small details that went unobserved during the Nubian demonstration also soon began to have unexpected and drastic consequences on construction progress. Score marks have always proved essential for the adhesion of one brick course to the next in vaults and domes in the past; they have been etched on the face of mud bricks by Egyptian, Nubian, and Hebrew masons in Egypt for 5,000 years and can still be seen in the remains of the storehouses of the mortuary complex of Pharaoh Ramses II in Luxor, built between 1290 and 1225 B.C. but at Dar al Islam they were eliminated with disastrous results.(6) Mortar, on the other hand, while essential on the brick faces of these same vaults and domes, proved dangerous when applied to the ends, because its inevitable shrinkage caused loss of contact and ultimate failure. Significant changes in the composition of the mud brick itself, such as the expensive addition of limestone aggregate suspended in a lactic acid emulsion with long cellulose fibers added to cope with thermal expansion, were made to offset the poor adhesion of the local soil. The final result of the initial failures that occurred seems to have been a basic distrust of the traditional system proposed by Hassan Fathy and successfully used by him in numerous major projects in Fgypt. This distrust is especially evident today in the full lining of laminated plywood used as shuttering to permanently support the long barrel vaults covering the kitchen and dining area at the end of the village center, as well as in the steel reinforcing bars that project out of unfinished adobe walls, and in the concrete slabs, corner columns, and lintel beams that reduce the final high tech mud brick infill to a symbolic remnant of its former self.

3. Plywood forms for arches.
Photo: James Steele.

The persistent concerns voiced about comfort levels in the cold nights and winters of New Mexico, which were raised during the opening ceremonies for the center, have also been put to rest by the installation of costly, electrically heated radiant mesh embedded in all concrete slabs. Commercially produced, fired clay bricks that are now in evidence in the uncoated domes of the arts and crafts center next to the main dining room also give clear testimony to the ultimate extent of the builders' distrust of mud brick, and the conceptual distance that has been traveled between the architect's original intentions and the realities perceived by decision makers at Dar al Islam later on. To be fair, many of the alterations made, such as concrete floor slabs, corner posts, and ring beams, were required by New Mexico's building code, which, while permitting adobe construction, converts it into something quite different from its traditional counterpart.

Perhaps nothing proclaims this conversion more unmistakably than the regulations related to coatings, and it is these that have had the most disastrous consequences on the overall physical appearance of all the buildings of Dar al Islam, making what should be a soft and natural earth plaster surface look like pressed plastic. While making a token gesure at acceptance of adope as a building material, this code, especially in its attitude toward coatings, betrays a prejudice that is unfortunately pervasive among all highly industrialized societies in the developed world. In the southwestern United States, that prejudice is usually rationalized by building authorities by reference to studies that track in great detail the deterioration of a single mud brick submerged in water. As Jean-Louis Bourgeois has noted in his excellent assessment of the inherent fallacy behind the use of such evidence as proof of the supposed weakness of adobe and the unsuitability of natural mud plaster as moisture protection in temperate climates, dissolving a single brick by constant immersion in water is an unfair way to evaluate the stability of an entire wall system intermittently dampened by rain. As Bourgeois has said:

4. Barrel vaults.
Photo: James Steele.

> The tests are accurate. They are just irrelevant. . . such behavior has little to do with the performance of an adobe wall. No brick that supports any weight in a slanting wall ever gets that wet. How a single adobe brick resists water attacking from six sides has little to do with how a massive adobe wall resists rain from one side. . . .Adobe bricks function as a structure. . .traditional adobe is not just a material. It is a system.(7).

The consequence of the acceptance of such tests by those enforcing building codes has been the requirement that cement plaster be used as a coating for adobe rather than the more natural and historically proven finish of mud plaster that allows the adobe wall to breathe and dry out normally through evaporation after being wet by rain. Because it is also thermally incompatible with the mud brick that it is supposed to protect, cement plaster frequently cracks, allowing water into the wall that cannot then escape. Such cracks are already in evidence in many of the walls now coated with cement plaster at Dar al Islam. In severe cases, this trapped water causes the adobe to disintegrate and collapse.

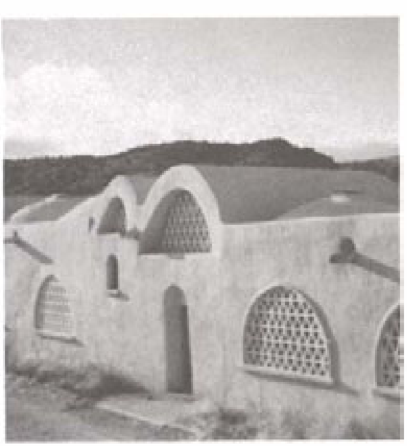
5. Buttress wall and concrete lintel beam. Photo: James Steele.

As a result of the combined effects of disillusionment with the lack of progress on the construction, as well as the alarming cost overruns caused by building code restrictions, the backers of the project began to have second thoughts. These doubts were not helped by life-style differences of the would-be residents in comparison with the people in the country for which such self-help mud brick architecture was originally intended, and the distrust of adobe that seems inherent in contemporary society in the western hemisphere, which did not impress financial supporters who are accustomed to seeing concrete, glass, and steel construction finished with great speed in their own country. In the six years following the completion of the Mosque in 1981, only half of the village center had been completed at great cost, with an estimated $630,000 in 1987 dollars then being required to finish the remaining part of the core area.(8) As these second thoughts began to turn into intractable doubts about the future of the project and tempers flared, founder Nuridin Durkee saw no alternative but to resign from the Board of Directors of Dar al Islam in 1989, preferring the peace and quiet of research and study in Cairo to further frustration and disappointment in Abiquiu. In recently reviewing the basic differences between using mud brick in the way proposed by Hassan Fathy and that required in New Mexico, Durkee echoed most of the reasons already listed here and proposed that locally produced pumice, or tufa, brick which is considered by building authorities to be more impervious to water damage than adobe, be seriously considered as an alternative material in the future.(9) Durkee's resignation, as well as this final position on the use of mud brick in Dar al Islam is a sad commentary on a vision that once held so much promise and a material that has come to symbolize the southwestern United States in the mind of the general public.

Conclusion

The lessons provided by Dar al Islam, then, to those contemplating the use of adobe construction in this region of America, and particularly those enamored with the self-help techniques associated with the work of Hassan Fathy, are certainly harsh. While it would seem to be easy to fault the builders of the community itself for their failure to carry on with the original intentions of the architect and his gift of an inexpensive structural system that had taken him an entire lifetime to perfect, this would be too simplistic. Also faulting the restrictive building codes of the area, which are admittedly disrespectful of a material that they proudly claim to "improve," is also unrealistic. The fundamental flaw behind the failure of Dar al Islam certainly includes both of these factors but finally goes beyond them to the basic questions of the appropriateness of using Hassan Fathy, along with his methods and style, in the project at the outset. By choosing this undeniably remarkable architect, the founders of the project were choosing to believe that the prospective residents of Dar al Islam would also embrace his ideas of self-help housing built with natural, available materials, as well as the Spartan lifestyle of the Egyptian peasant. As Abdullah Schleifer, who introduced Nuridin Durkee to Hassan Fathy in the first place, has so perceptively noted, construction at Dar al Islam is not proceeding in accord with

> the mutual aid cooperative system outlined by Fathy in his writings. This sytem requires pre-existing communal ties and traditional social structure, a neighboring parent village for satellite settlement, tribal or clan relationships and a subsistence economy that provides. . .the time and the available willing labor for cooperative work. The Abiquiu project unfolds in a social void.(10)



6. Cement plaster coating. Photo: James Steele.

As Fathy himself said in his lectures that inaugurated the project, such a void cannot be filled overnight.

In a deeper sense, Fathy was obviously chosen as the architect of Dar al Islam not only because of the economic appeal of the structural system that he had resurrected, but also because he had then come to be recognized as "the Father of Contemporary Islamic Architecture" for his Herculean efforts in encouraging all of the countries in the Muslim world to search for an expression of their unique architectural identity.(11) These efforts have not only made him a role model for countless numbers of young architects throughout the developing world, but have also made him an enduring symbol of high achievement to Muslims everywhere.

In his lectures at Dar al Islam, Fathy also stressed that the plans for the village he had designed stood for far more than just a construction project, but also represented "a mission" for all concerned.(12) While the failure of that mission still may not be considered a foregone conclusion, its completion really does now appear to be all but impossible. The current state of affairs at Rio Chama must be disappointing for the intended residents of Dar al Islam, but if this village is left unfinished it will most certainly represent the final frustration in the career of Hassan Fathy and stand as one more haunted community left needlessly abandoned in the wilderness.

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TRADITIONAL SUN-BAKED (ADOBE) BRICK STRUCTURES IN MACEDONIA, YUGOSLAVIA

Lazar Sumanov
Grad. eng. Architect - Senior Conservator
Republic Institute for Protection of Cultural Monuments (RZZSK)
P.O. Box 225
91 000 - Skopje
YUGOSLAVIA

ABSTRACT

The objective of this work is the professional and scientific community with the characteristics of existing traditional construction which is part of the cultural heritage in the territory of the Socialist Republic of Macedonia. This tradition is distinguished by certain architectural, structural, cultural, and historical values. Sun-baked (adobe) clay is the main construction material.

An initial inventory of this cultural heritage showed us that earth as a main building material is used in various forms as adobe brick for the construction of bearing walls, partition walls, for infill in timber-framed structures, and as a main material for mortar and plaster. The inventory also shows that such structures have significant architectural, structural, physicochemical characteristics.

Located in Macedonia (a region prone to earthquakes ranging from 6 to 10 degrees of MMS intensity), these buildings have some traditional aseismic elements and systems which have allowed them to survive many earthquakes such as the recent Skopje earthquake in 1963. For this reason, our future task is to obtain information through scientific research about the characteristics of these structures to better understand, protect, and conserve them as valuable traditional antiseismic elements and systems.

KEYWORDS

INTRODUCTION

GENERAL CHARACTERISTICS

TYPE OF STRUCTURE

EARTH USE

GOODNESS AND WEAKNESS

ASEISMIC TRADITIONAL ELEMENTS

CONCLUSIONS

Introduction

The territory of Socialist Republic of Macedonia, Yugoslavia bears material witness to architectural achievements from the ancient times to the present. It's most famous for its rich archaeological sites, the extraordinary medieval churches and monasteries, frescoes and icons, urban and rural architecture of the nineteenth and early twentieth centuries. However, there is no explanation why adequate attention has not been paid to sun-baked (adobe) structures in our Republic.

Earth mixed with water and various additives has been used as a building material for more than 10,000 years and is still in use. More than one-third of the world's population is still living in adobe and similar structures. The systematic inventory which has been carried out since 1987 has proved that on this very ground, throughout almost the whole territory, there are individual examples and even whole villages (the village of Konjari near Debar), which consist of adobe structures of not only historic and cultural but also architectural structural values worthy to be further investigated and protected by law.

Functional, architectural and structural characteristics

Sun-baked bricks are most frequently used as a basic material for the construction of simple or very complex ground floor or multistorey structures, which are mostly rectangular and are situated either individually or in rows. The ground floor and basement are almost always used for household production activities or as a ware house or pantry, while the porch serves for tool storage. The kitchen is most frequently located on ground floor, too. The upper floors are usually utilized as a living room, dormitory, or summer residence.

There are examples of structures with bay windows, typical for the residential buildings of the urban and the rural architecture of timber-frame structures of smaller proportions. These windows are made skillfully and incorporate well into the total outline of the structure. We often encounter buildings consisting of a ground floor and two stories, for instance. A building in the village Cucer near Skopje (see fig. 1) which is more than eighty-five years old and has a basement, a ground floor and two stories, displays impressive architectonic characteristics of mass and perforation distribution, as well as other extraordinary values. This is the tallest building of this type that has ever been observed in the Macedonia region.

Although the whole territory of Macedonia, especially the area surrounding Skopje, is seismically active with high magnitude earthquakes (9 Mercalli degrees), the Cucer structure suffered no damage during the 1963 earthquake. Scientific investigation was initiated to analyse the building's structure characteristics.

Sun-baked bricks have also been used for the construction of the secondary structures, most frequently in combination with timber structural systems (see figs. 2-4).

The openings of the residential buildings are of smaller proportions (narrower and lower) (see figs. 1-3) than the common ones, while the height of the premises is the same (being 1.9-2.2 m. for the ground floor premises and 2.1-2.4 m. for the upper floor premises). As a rule, the residential buildings are characterized by a hipped or complex roof; only rarely was saddle roof with low cable walls constructed. Tiles or stone plates are exclusively used for roof covering. Most frequently, the facade, timber structural elements of the doors, windows, and fence carpentry were not coloured or plastered (see figs. 1-4).

It has to be noted that all structures, either residential or secondary, are proportioned in compliance with human proportions, which is one of the main characteristics of the architectural traditional heritage in Macedonia.

Types of structural and nonstructural elements

Since the First International Symposium on Earth Structures in Yazd (Iran, 1971-1976), and third in Ankara (Turkey, 1980) and the fourth in Lima and Cusco (Peru, 1983), the following classification of the different types of structural elements was adopted:

1.0 - Hand-formed in layers
- 1.1 - simple forming
- 1.2 - earth balls, thrown and molded

2.0 - Sun-baked bricks (adobe or blocks)
- 2.1 - cut from hardened soil
- 2.2 - formed in mold
- 2.3 - molded and compacted

3.0 - Tapial-rammed earth
- 3.1 - compacted by hand blows
- 3.2 - mechanized or vibrating compaction

4.0 - Wood or cane structure, wood or cane mesh closures plastered with mud or infilled by sun-baked bricks

The results from the inventory of Macedonia adobe structures shows that the following individual or combined structural and nonstructural elements are present in Macedonia: under categories 2.1, 2.2, 2.3, 3.1, 4.0.

The proportions of the bricks range from 8/20/8 to 14/30/12 cm, depending upon the molds used which may have one or even ten cells. The quality of molding is always higher when a mold with a smaller number of cells is used.

The thickness of the weight-bearing walls ranges between 60-120 cm. (see figs. 1-2) in the lower basement premises and 40-60 cm. in the upper premises, while the wall thickness of structures under 4.0 of the above classification measures 15-30 cm. (see figs. 1-4).

The adobe structures are characterized by sun-baked brick weight-bearing walls lying on foundation walls of crushed stones in lime mortar. These walls are 1 m. high which is approximately the maximum level of the capillary moisture in winter and springtime. The base of the block masonry is protected against capillary moisture, which is one of the most dangerous effects on thise type of structures (see figs. 1-5, 7).

Timber bond structural elements have been placed on almost all the bearing and non-bearing walls at a vertical distance of 1-1,2 m.; this proved to be quite successful in strengthening and providing stability to these structures.

Other use of earth

Earth mixed up with water, sand, hay, animal hair, blood and urine has been used as a binding material for the sun-baked brick walls (see figs. 1-7). It has also been used as a plaster (see figs 1-2) and as the infilling of the wood meshes (wattles) (see fig. 5).

In urban areas, the facades are often plastered with lime mortar or lime plaster so that sun-baked brick walls would be better protected against the mechanical effect of rain (see figs. 1-2).

Other characteristics and weakness of adobe structures

The earthen structures have some advantages and disadvantages. First of all, they are good heat and sound insulators and are easily and cheaply maintained, there are many sources of damages which are merciless in affecting these structures:
- water (in the form of rain, running water, capillary moisture, or condensed water)
- sun (indirect damage caused by abrupt drying of the dampened walls, cracks form after several cycles of moistening and drying and contribute to the severe damage of the elements to the total structure)
- wind (drifting hard sand and dust particles which damage the surface of the walls mechanically)
- soluble salts (by means of chemical disintegration)
- biodeterioration (plants-insects-animals)
- inappropriate maintenance
- floods and earthquakes

TRADITIONAL ELEMENTS OF ASEISMIC RESISTANCE OF ADOBE STRUCTURES

Elements which increase earthquake resistance of Macedonian earthen adobe structures:

- quality building materials, good knowledge, experience and adequante use of additives (organic and inorganic)
- use of high quality wood, such as oak and pine
- maximum effort to eliminate capillary moisture in the very first stage construction
- quality of manufactured construction of weight-bearing walls and structures, timber-frame and all other horizontal and vertical connections
- regular protection of the adobe surface against rain damage
- regular (almost daily) maintenance
- use of horizontal wooden belts, without exception, as the highest aseismic resistance elements

In the following text we will be more familiar with the elements mentioned above.

a) As a principle, without exceptions, molds for surface sun-baked brick have one or two cells. For other use bricks for inside of walls are from molds with three and more cells. The largest mold is with ten cells (see figs. 1, 3, 4 - 7).

b) Materials for brick or mortar always incorporate cut straw or animal hair as reinforcing elements.

c) The foundation of all structures are manufactured of stone in lime mortar whose end is always 1-1.2 m. above the ground level. This is higher than the maximum level of ground capillary moisture in winter and spring time, and the contact zones of adobe wall with foundation are always dry and safe (see figs. 1-5, 7).

d) Brick wall adobe structure is of high quality. Regularly spaced bricks are inserted through all cross section of the wall in horizontal and vertical section. The thickness of the mud mortars are of the same size and are of good quality.

e) Almost without exception, all wall-bearing structures, and partition walls of adobe brick structures have horizontal wooden belts 1-1.2 m. in vertical distance. A wooden grid (named kushak) consists of two parallel longitudinal beams 8/8,8/10,10/10 cm. connected to each other with smaller wooden elements 4/4 - 6/6 cm. spaced 60-70 cm. in the rectangular direction. This wooden belt is in contact with the floor and roof construction. One wooden belt is located on the same level through all structure; this is an extremely important antiseismic traditional element (see figs. 1-5, 7).

f) In many cases the surface structure is plastered with mud plaster (with cut straw or animal hair as an additive)and a layer of lime plaster (0.3-0.7 cm.) manufactured during the wet stage of mud plaster. As a tradition, each user and owner of adobe structure in the spring time applies lime wash to all plastered surface; this ensures 1 year protection against damaging climate factors.

g) The final floors of the structure are built with timber-framed constructions, with adobe brick or mud as infill elements and they have significantly smaller thickness (15-30 cm). They have a very light construction, which is a very logical and important principle in earthquake-prone regions: to have lighter structure on the top than on ground floors.

i) regular ongoing maintenance.

CONCLUSIONS

Initial inventory and research done 1987-89 proved that in the territory of Macedonia (region prone to moderate and strong earthquakes) significant cultural heritage exists. Earth is the main building material used in various forms as sun-baked bricks, mortar and plaster, all of which have certain valuable qualities which are needed scientifically to be confirmed, as a future task. This data will allow for better understanding, protection and conservation of this cultural heritage. The application of these data on buildings and structures with the same or similar characteristics as a cultural heritage or standard modern adobe structures would be a contribution of the past to the future.

Fig. 1 - Most significant adobe structure in Macedonia

v. Cucer (Skopje region) - Durakovci House, massive adobe weight-bearing structure in combination with timber-framed structure (final floor). Village Cucer is located at 8 km distance from Skopje 1963 earthquake epicenter. No visible damage.

Fig. 2 - Typical traditional aseismic elements

v. Cucer (Skopje region)

Fig. 3 - Mixed structures

v. Gornjani (Skopje region) - Combination of massive adobe weight-bearing structures and timber-framed structure. Ground zone - stone masonry in lime mortar.

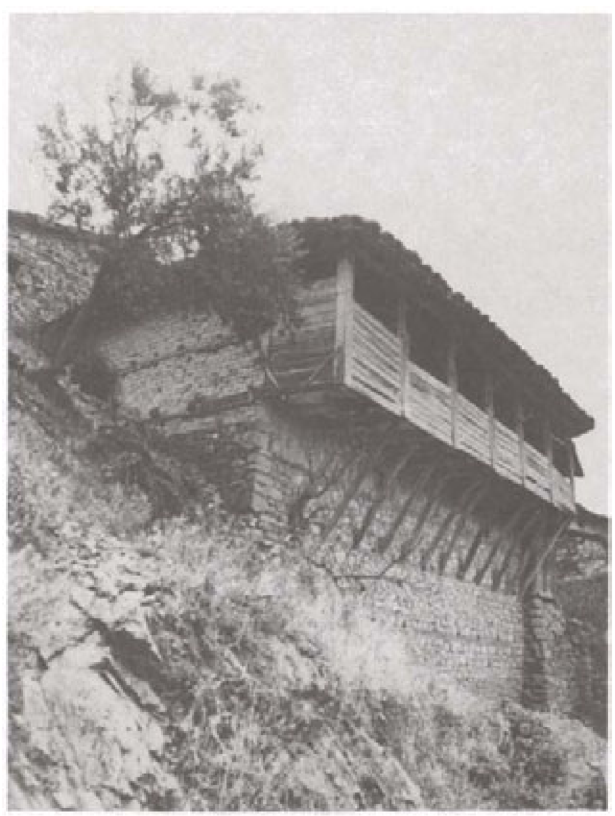


Fig. 4 - View to the valley

v. Kuceviste (Skopje region) - Stone masonry adobe wall weight-bearing structure and cantilever (erker) of wooden structure with characteristic diagonal wood elements.

Fig. 5 - High quality of manufactured elements
v. Kuceviste
(Skopje region)

Fig. 6 - Typical rain protection
v. Germjan (Bitola region)

Fig. 7 - Modern reinforced concrete belt
Struga (South Macedonia) - Application of reinforced concrete belts in adobe wall weight-bearing structures as a reflection of reinforcement new structures after Skopje 1963 Earthquake.

ABSTRACT

Ancient building in the northeastern area of Argentina employed adobe and wattle and daub techniques, of which both rural and urban examples of the eighteenth, nineteenth, and early twentieth centuries still remain standing.
At present, the use of earthen masonry has been practically lost, while wattle and daub is more widely used and in a larger range of varieties.
Internal migrations in the eastern humid zone produce constant adaptations. Where a dry climate prevails, such as in the west, there are settlements which remain more stable both in time and type of design. There earth is used also for roofing.
Recent economic changes have produced peripheral neighborhoods in various cities, reflecting the origin of their dwellers.
A well-ordered register of the situation and a set of solid bases for their preservation and maintenance must also take into account the social, economic, and cultural milieu to which each one of the examples belongs.

KEYWORDS

history, adaptation, preservation, techniques, transferences, masonry, wattle and daub, rammed earth

CONSTRUCCION TRADICIONAL EN EL NORDESTE ARGENTINO

Graciela María Viñuales
Bolivia 82
3500 Resistencia
ARGENTINA
T (54) (722) 29294

Presentación

Desde las épocas de la conquista española se sabe que en la zona era corriente el uso de la tierra como material de construcción. Asimismo, éste se unía a otras tradiciones propias del aborigen como el entretejido de ramas y troncos que hacía con gran destreza. Los aportes hechos por los hispánicos de diversas regiones y lo que el medio mismo permitía, llegó a conformar una forma de hacer arquitectura en la que la tierra era elemento fundamental.

Sin embargo, fuera de algunas publicaciones de escasa difusión y de artículos diseminados en revistas, no ha sido esta arquitectura objeto de un estudio sistemático. Menos aun lo ha sido una propuesta técnica de mejoramiento y conservación. Intentos parciales desde centros de estudio o de gobierno han sido efímeros y muchas veces directamente combatidos.

La zona que nos ocupa -la del nordeste argentino- es de clima tropical, con temperaturas que pueden pasar los 40°, aunque con posibilidades de tener algún día del año unas horas con 0°. Pero dentro de la zona hay dos partes bastante diferentes: la del este con clima húmedo, influído por la cuenca del Río de la Plata, y la del oeste, conocida como El Impenetrable, en donde el clima es seco. Si bien en ambas hay bosque, sus diferencias son notables.

En la parte húmeda, cuando en invierno se superan los 35° es casi seguro que sobrevenga una tormenta de 150 km/h con intensas lluvias y con el consiguiente cambio drástico de temperatura. En la parte seca, esto puede llegar a ocurrir alguna vez, pero lo normal es que el agua aparezca en el verano cuando los deshielos de los Andes llenen nuevamente los cauces secos de los ríos. Debe tenerse en cuenta además, que los regímenes de lluvias y de cauces no son regulares, por lo que no son raras las inundaciones y el cambio de cuencas menores.

Este panorama geográfico ayudará a comprender los problemas arquitectónicos de la región. Pasaremos ahora revista a ellos.

1. Sistemas

Las crónicas y dibujos coloniales nos muestran la hechura de tapias explicándonos todos los pormenores de su ejecución. Asimismo, aparecen menciones en distintos puntos de la zona de fabricación de adobes, palo a pique y distintas "enramadas". Debemos decir que la zona seca estuvo escasamente poblada por españoles a finales del XVI, siendo abandonada a principios del siglo siguiente. El extremo este (húmedo) correspondió a la zona de las Misiones Jesuíticas que se desarrolló en forma autónoma. La parte central (también húmeda) es la que tuvo una intensa vida hispánica y es en la cual nos quedan los principales ejemplos de edificaciones antiguas.

No todas las técnicas han podido afincarse definitivamente en la región. Factores de urbanización, falta de mano de obra, estímulo por la rapidez y la moda, han dado lugar a un nuevo panorama.

La zona húmeda, con su cambiante geografía, muchas veces obliga al poblador a emigrar y a rehacer su casa periódicamente adecuándose al nuevo sitio. La influencia de las generaciones jóvenes hace que tales ciclos de traslado y acomodo se vean alterados, con lo que también se tergiversen las formas de construcción y mantenimiento.

En la zona seca, en cambio, el clima y el tipo de idiosincrasia lleva a viviendas más estables, aunque a veces sean de uso estacional, principalmente para los hombres. La falta de lluvias o de grandes huracanes permite que las construcciones, aun sin uso continuado, perduren varios años.

1.1. Tapias, adobes y terrones

Aparentemente, *tapias* y *adobes* fueron de uso corriente desde finales del XVI. El ladrillo cocido sólo se usaba en ocasiones, y su verdadera difusión se dio hace aproximadamente un siglo. Los hornos trataban de reservarse para cocer tejas y ladrillones de piso. Hoy quedan en pie ejemplos de casas con galería al frente en varios sitios de la ciudad de Corrientes y en diversos centros poblados de esa provincia.

Lo mismo podríamos decir de Santa Fe, aunque los ejemplos son menores en número, pero mayores en su envergadura. Justamente en esta ciudad se encuentra la iglesia de San Francisco, levantada a mediados del XVII con el sistema de tapias y que hoy es Monumento Nacional. Se continuaba aquí con el tipo constructivo que había tenido toda la ciudad en su anterior emplazamiento de 1573.

Aparentemente, la tapia fue una tipología corriente hasta finales del XVIII, pero más tarde se fue optando por el adobe que resultaba más fácil de trabajar. Así éstos siguieron en uso hasta nuestro siglo, y cuando se comenzó a repoblar hacia la zona del oeste, los adobes fueron también usados. Sin embargo, con el tiempo -y quizá por una imitación del ladrillo- en algunos lugares las dimensiones de los mampuestos se fueron achicando de tal modo, que hoy encontramos adobes de medidas similares a las de aquéllos.

Otro sistema de mampostería utilizado ha sido el del *terrón*, conocido aquí como "champa". Fue de uso común en las zonas rurales y hoy todavía se lo vé de vez en cuando. Su difusión principal se encuentra en la porción sur de nuestra área de estudio.

El barro también aparece hasta la actualidad como mezcla de asiento y de revoque de construcciones de ladrillo. Pero a este aspecto lo hemos dejado expresamente de lado en la presente ocasión.

El techo de *torta* pertenece igualmente a los sistemas de entramado. Se realiza con un enmaderado similar al de un techo de tejas, pero su cubierta está formada sólo por tierra, trabajada en diferentes capas. La torta es de uso corriente en el noroeste argentino y poco a poco se fue diseminando por el extremo oeste de nuestra región, a partir de las repoblaciones del finales del XIX y principios del XX. Hoy es común su uso en toda la zona seca, pero con una inclinación mínima y con un gran grosor que atempera los calores.

1.3. Las adecuaciones urbanas actuales

Los problemas económicos que se han agudizado en estos últimos quince años, han hecho llegar a las ciudades pobladores rurales que han tratado de conseguir puestos de trabajo en la construcción de grandes conjuntos habitacionales impulsados por el gobierno. Paradójicamente, esa mano de obra no calificada fue usada pero sin contemplarse sus propias necesidades de habitación. Ellos mismos entonces, levantaron sus barrios en la periferia de las ciudades, utilizando terrenos fiscales o abandonados, a veces inundables y con falta de todo servicio. Y a pesar de ser sitios bajos, fueron aun desnivelados muchas veces por sacar de allí mismo la tierra para hacer sus casas de chorizo o estanteo.

Las técnicas que conocían se aplicaban, pero ahora con materiales diferentes. Si bien la ciudad proveía fácilmente de alambres, que se conseguían por compra o por desecho en el lugar de trabajo, las ramas, cañas y pajas ya no estaban en las cercanías y debían ser pagadas o procuradas muy lejos. El centro urbano arrojaba, en cambio, otros desechos que podían utilizarse y ser aun mejores y más fáciles de trabajar que los rurales, pero se necesitaba de una adecuación de técnicas y de una preparación diferente. Para ello los pobladores tuvieron bastante inventiva, aunque no todo fue coronado por el éxito.

Hasta hoy se utiliza el reciclaje de embalajes de madera, de donde también se sacan y enderezan alambres y clavos. Los envases de latón como los de aceites, combustibles y dulces son desarmados y utilizados para protección de los sitios más expuestos a aguas y soles, así como para cerramientos, donde igualmente aparece la tela metálica. En las cercanías de las fábricas de tanino se apela a las astillas de madera de quebracho para impermeabilizar los zócalos. Asimismo se usan diferentes desechos de otras industrias de la región.

Sin embargo, estas adecuaciones y transferencias dan pie a muchas equivocaciones, a veces provocadas por el material elegido, al que no se conoce suficientemente y al que generalmente se lo sobreestima por ser "moderno", otras veces por utilizar en una región lo que es propio de otra. En este sentido el caso más duro ha sido el de los que proviniendo de la zona seca han construído techos de torta (aunque algo inclinados) en la zona húmeda, con el consiguiente desastre posterior.

1.2. Tierra con entramado

La facilidad de algunos aborígenes nómades de la región para procurarse un refugio rápido frente a las tormentas hicieron de ellos diestros trenzadores de ramas y hojas. Con la llegada del español y la búsqueda de establecimientos más duraderos, se conjugó tal sabiduría con el uso del barro blando para darle cerramiento y mayor fortaleza a las construcciones. En el caso de los guaraníes ,que ocupaban la porción oriental y que sí tenían viviendas estables, se dio un caso similar, pero de mejores calidades. Por ello el sistema de tierra entramado se popularizó en toda la región hace ya 400 años.

Con el tiempo, éste ha sido el tipo utilizado con más asiduidad y con más variaciones. A la célula unitaria de cuatro horcones que sostienen un techo, se la ha cerrado de innumerables maneras. Describir cada una de ellas sería agobiante, baste decir que los tipos más usados se dividen en tres grandes familias: *estanteo*, *palo a pique* y *chorizo*.

El *estanteo* supone la organización de un entramado que se hace con ramas gruesas a las que luego se le intercalan otras más finas. La forma de tejido y el tipo de elemento vegetal tiene abundantes variedades, llegándose a usar cañas, pajas, cortezas, etc. Los trabajos más cuidadosos presentan un doble entramado que luego es rellenado con barro y agregados, haciéndose un terminación de barro más fino. Tiene mucho parecido con la quincha, aunque en general es algo más rudimentario. Esta familia de entramados no sólo varía en su composición y diseño, sino que en la misma región adquiere diferentes denominaciones que aluden a alguno de los elementos o de las técnicas usadas.

El nombre de *palo a pique* proviene de un tipo de construcción muy difundida en la colonia y que suponía una construcción de madera para cercar un terreno. Con el tiempo y el detrimento de la calidad de los palos y de su colocación se vio necesaria la complementación con barro. Pasó entonces a ser usado en viviendas y fue evolucionando hasta convertirse en un tipo de pared muy difundido, sobre todo con troncos de palma tipo "caranday", de gran longitud y sección constante. Hoy se lo encuentra con embarrado en una o dos de sus caras.

El *chorizo* es la forma de construir más popular de todas. Es rápida, no requiere mano de obra muy especial y puede hacerse casi con cualquier tierra. Por eso, es que se la usa mucho para construcciones estacionales o de paso. La mala calidad de la tierra se suple con las pajas que se le agregan. Antiguamente, sobre la base de los cuatro horcones se tendían ramas transversales o tiras de cuero mojado de las que irían colgándose los chorizos de paja y barro. Hoy día, esas tiras son de alambre bien tensado. Los chorizos se forman amasando paja y barro y se van colgando de abajo hacia arriba, bien juntos uno al otro hasta hacer el cerramiento. Después se revoca con barro.

Dentro de esta familia hay variaciones, pero no tanto por los elementos usados, sino más bien por la mayor o menor prolijidad de ejecución, fundamentalmente en el retorcido y contigüidad de los chorizos. Esta técnica que creíamos única de nuestra región la hemos encontrado en China, en donde también se usan chorizos horizontales para los hastiales.

2. Soluciones

Han llegado entonces a nosotros edificios de antigua data, así como construcciones actuales de tierra de muy distintos sistemas y calidades. En muchos casos ellas son desconocidas por el habitante de las ciudades o son enérgicamente combatidas. En esto tienen ingerencia la industria de la construcción, los profesionales, los gobiernos y los propios centros de estudio. Y aunque desde todas estas áreas hay quienes estén trabajando para optimizar el uso de la tierra, se hace muy dificultoso remar contra la corriente general.

Los principales intentos favorables que hubo en la región serían: los encarados por la provincia del Chaco hacia 1969 con su Plan de Mejoramiento de Ranchos, los de la Universidad del Nordeste con el diseño de viviendas de *chorizo mejorado* los que actualmente encara el Instituto de Tecnología Agraria en la provincia de Corrientes y algunas construcciones de *suelo-cemento* realizadas en la provincia de Santa Fe hace unos 20 años.

Pero nosotros, desde nuestro Departamento de Conservación del Patrimonio Arquitectónico (Universidad Nacional del Nordeste) hace años que venimos trabajando sobre el tema, sea en el amplio espectro de la misma conservación de edificios antiguos de tierra, sea en el rescate de las técnicas como medio adecuado para construir en la región. Diversas publicaciones, conferencias, exposiciones y reuniones se han llevado adelante con este fin. Sin embargo es mucho lo que aun queda por hacer.

A la cuestión técnica es necesario que se una el estudio económico global y particular de los grupos que construyen con tierra, la visión de las tradiciones y costumbres y un correcto encuadre social y cultural donde se dan estas técnicas. No debe dejarse de lado la contemplación del tratamiento de los edificios históricos, sean o no monumentales, y el conocimiento profundo de aquellas técnicas que han sido abandonadas y porqué ello ha ocurrido.

Gráfico Nº 1. Cuadro básico de inventario

SIGLA	DENOMINACION	FAMILIA	PAIS
3.1.54.	ADOBE	MAMPOSTERIA	ARGENTINA

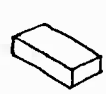
MATERIALES BASICOS	MATERIALES AGREGADOS	MORTERO DE UNION	CONSOLIDANTES APROPIADOS NATURALES	CONSOLIDANTES APROPIADOS ARTIFICIALES	ENLUCIDOS	PINTURAS
Arcilla Agua Arena Limo	Paja Virutas Pelos	Barro Paja (similar material básico)	Grasa Cal Cemento Jugos vegetales.	Bitumen Silicato de etilo	Barro Paja Cal Grasa	Cal Agua

SISTEMA ESTRUCTURAL				PERMITE		RESPUESTA AGENTES	
MONOLITICO	NO	PORTANTE	SI	ALMACENAM PREVIO	SI	HUMEDAD	TE
TRILITICO	SI	SOLO AUTOPORTANTE	NO	APERTURAS POSTERIORES	SI	VIENTOS	B
ARCO	SI	OTROS		AGREGADOS POSTERIORES	SI	INSECTOS	B
DINTEL-PLATABANDA	NO	Cadenas antisísmicas		INSTALAC. EMBUTIDAS	SI	SISMOS	B
OTROS		OBSERVAC.		OTROS		OTROS	

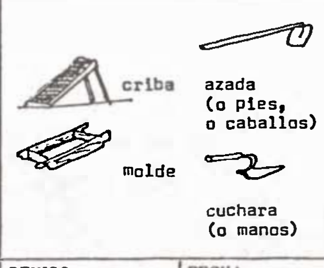
UBIC. EN EDIFICIO	DISPOSICIONES COMPLEMENTARIAS		
Muros Techos	CIMIENTO	CUBIERTA	INSTAL.
	Piedra	Paja Tierra Tejas Cinc	
	ABERTUR	PISOS	OTROS
	Madera Cuero	Terreno natural Ladrillo Mosaico Madera	

Nº MIN. DE OBREROS		1
ZONA ACTUAL	RURAL	SI
	URBANA	SI
% CONSTRUC ACTUAL	TOTAL	20
	TERREA	50

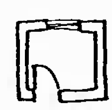
MODULO



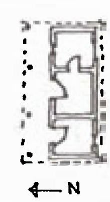
HERRAMIENTAS



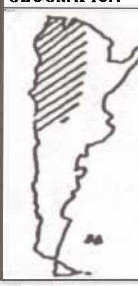
LOCAL



EDIFICIO



UBICACION GEOGRAFICA



REALIZO	FECHA	REVISO	FECHA

TE Tratamiento Especial
B Bueno
R Regular
M Malo

3. Conclusión

Es en este tema que estamos trabajando actualmente. El primer paso es la elaboración de un inventario de las técnicas de la región a partir de un cuadro básico. Sugerimos que tal cuadro sea tomado como referencia para los estudios de arquitectura de tierra en otros lugares. Por eso aprovechamos la ocasión para presentarlo a consideración a fin de hacerle los ajustes necesarios para su uso internacional. (Ver Gráf. 1).

Conservation and Restoration

CHURCHES, SYMBOLS OF COMMUNITY: THE PRESERVATION OF NEW MEXICO'S ADOBE CHURCHES

Nancy Arnon and Sam Baca
New Mexico Community Foundation
110 North Guadalupe Street, Suite 6
Santa Fe, New Mexico 87504
U.S.A.

ABSTRACT

The preservation of historic adobe churches in New Mexico results from a dynamic community process using appropriate technology. The preservation process relies on the traditional community-oriented, hands-on, low-technology approach. Sense of community is paramount to the preservation of the church through established traditions of cyclic maintenance. Yet, economic depression and declining populations are contributing to the breakdown of this necessary element in the preservation process.

In 1985, the New Mexico Community Foundation (NMCF) initiated the "Churches: Symbols of Community" project to assist communities in the continued preservation of their historic churches. NMCF assists in the revitalization of the social patterns and technological traditions that originally produced and cared for these buildings.

Through the partnership of national, state, and local organizations, communities are restoring their churches to a maintainable level using a tradition of cyclic maintenance.

KEYWORDS

Preservation, Adobe Churches, Cyclic Maintenance, Cultural Tradition, Available Technology, Community Involvement

Figure 1
Map of the Interior Province of New Mexico 1779.

Introduction

New Mexico occupies a unique niche in the architectural history of the United States. The long-standing traditional use of earth as a building material began well before the Spanish occupation in the sixteenth century and continues as a major architectural element today. Of particular note are the historic adobe churches. These archetypal churches are the symbols of community life. Often, in isolated villages, they are the first and only public structure built and cared for by the community. They illustrate past and present community organization, resources, self-sufficiency, and pride.

The "Churches: Symbols of Community" project was conceived as a means to assist communities in preserving these significant religious edifices. Physical preservation of adobe structures requires long-term commitment involving community dedication and participation, decision making and implementation. Working through existing local community structure, the New Mexico Community Foundation assists communities with technical advice, fund raising, research, and training, while also facilitating the necessary communication between those involved. If requested, the NMCF also helps cosponsor workdays where outside community volunteers work together with the local community in the preservation of the church. All decisions are made by the community. This preservation approach has resulted in a comprehensive survey and evaluation of historic churches in New Mexico, identification and interaction with community members, response to requests for technical assistance and the development of preservation plans now in various stages of implementation by the communities.

Background of Cultural Traditions

The earliest churches in New Mexico were constructed under the direction of Franciscan friars in the seventeenth and eighteenth centuries when New Mexico was a remote province of New Spain. The churches and surrounding communities were clustered near Indian Pueblos along the Rio Grande (see fig. 1). The adobe church was located in a prominent location along the plaza (see fig. 2).

The churches focused community effort utilizing all available local materials and human resources. The adobe walls were constructed by the women and children while the men felled the trees and shaped them into roof beams. The women plastered the walls with mud mixed by the men.

Recognizing the necessity for cyclic maintenance, "in 1731, Father Juan Miguel Menchero admonished the friars to emulate the zeal of the 'old Fathers' in maintaining the fabric of their churches and coventos, especially in repairing drains and other things that can cause their destruction" (1). Cyclic maintenance activities, similar to those required today, included remudding the walls and floors, cleaning out the wooden canales, or roof drains, and removing bird's nests. The flat mud roofs retained water, and periodic maintenance consisted of replacing rotted roof timbers and the upper courses of adobe bricks.

During the latter part of the eighteenth century, settlements spread outwards into the adjacent mountains and valleys as the Rio Grande Valley became crowded, and irrigable land grew scarce (see fig. 3). Despite the decreasing number of Franciscans, church building continued led by determined community members. "By the early nineteenth century, the Church in New Mexico had become for a majority of New Mexicans a Church without clergy" (2). To fill this vacuum, men united in a religious society known as the Brothers of Our Father Jesus of Nazareth, or commonly called Penitentes. The Hermanos, or brothers, "periodically sacralized an entire settlement". The morada, or chapel, became the center from which processions to calvarious, composantos, oratorios and churches wove a kind of sacred network around the community" (3).

The nineteenth century introduced an era of rapid regional socioeconomic changes brought about by the naming of New Mexico as a United States Territory. In the latter part of the century, the railroad linked New Mexico to a larger network of available resources. New factory-produced materials such as concrete and glass became available. Viewed as technologically superior and labor-saving, new materials began to replace traditional materials. Labor-intensive mud plaster was often replaced by cement stucco. Only in the more remote villages did the use of traditional materials continue (see fig. 4).


Figure 2
Aerial View of Typical New Mexico Village

The railroad brought not only new material but an influx of "outsiders". The solidarity of the Hermanos was cemented to counteract the influences of foreign cultures. Consequently, they became a major political as well as social force. "By preserving long-standing Hispanic Catholic traditions, the Brothers of Our Father Jesus contributed substantially to spiritual security and physical survival in isolated village" (4).

Maintenance of the churches was supervised in the past, as it is today, by mayordomos, or lay church caretakers. Each year, new mayordomos were selected during the funcion or celebration of the feast of the patron of the church and community. Following the Second World War, the populations of rural villages began to dwindle triggered by faltering local economies. The tradition of cyclic maintenance of the church rested on decreasing populations consisting largely of older parishioners. Despite adverse conditions, church maintenance continued under the guidance of the mayordomos and Hermanos. When a church was not being maintained, the Hermanos often moved sacred artifacts into the moradas for protection from vandilism and moisture.


Figure 3
Schematic Diagram New Mexico Hispanic Settlements
Drawing by M. Weigle

During the early twentieth century many new structures were constructed emulating the mission style of architecture, which rekindled an appreciation for the original mission churches. The increased awareness of the churches and their deteriorated condition led to isolated restoration projects. In 1985, the first survey of historic churches was initiated by the State of New Mexico Historic Preservation Office and the New Mexico Community Foundation with funds from the National Historic Preservation fund and the National Endowment for the Arts.

Archbishop Robert Sanchez formed the Commission for the Preservation of Historic New Mexico Churches in 1987. The Commission was conceived to set policies for and oversee the preservation of historic Roman Catholic churches in the Archdiocese of Santa Fe. The southern Diocese of Las Cruces and western Diocese of Gallup also work for the preservation of their churches as do Protestant church owners.

Today, through the creation of a partnership among communities, church leaders, the New Mexico Community Foundation, many volunteers and funding sources, the historic adobe churches are being preserved for future generations to enjoy.

Preservation Approach

New Mexico Community Foundation works with communities using a preservation process which reinforces the historic fabric by encouraging the values, traditions and techniques which created and still support the churches. The process simultaneously diminishes major threats of deterioration while strengthening a community's ability to continue preserving its church (see fig. 5).

Preservation of established churches is characterized by communal cylic maintenance where the mayordomos and/or Hermanos lead annual work on the church. This tradition has resulted in the presence of over 800 adobe churches in the State today.


Figure 4
San Jose de Gracia Church
Las Trampas, New Mexico
Photo by Kirk Gittings

Respecting the patterns of community preservation, the "Churches: Symbols of Community" project follows the basic principles:

1. community decision making
2. community input and information exchange at each step
3. honor and respect for communities and churches
4. respecting the pride of ownership

NMCF encourages communities to use sound conservation principles. Communities are recognizing that the best available means of preserving adobe structures is through the use of traditional methods and materials. The potentially deleterious effects of incorporating modern materials is evident in the many examples of deteriorated adobe churches clad in cement stucco. For instance, the community of Ranchos de Taos decided to remove the cement stucco from their church in the 1970's. The rear adobe buttress had almost completely disappeared leaving only the cement stucco skin (see fig. 6). Each year community members donate a week each of their time to replaster the church using mud.

Figure 5
Work in Progress
La Capilla de San Antonio
Chacon, New Mexico

The development of preservation plans and implementation must be accomplished through sensitive explanation of successes and failures (see fig. 7). Modern technological advances employed in past maintenance projects were considered state of the art and were utilized as the best available means to maintain the church. The Taos community's observation of increased and rapid deterioration of the adobe structure as a result of the use of inappropriate advanced technology has led to reconsideration of the use of traditional materials and techniques.

An awareness of community concerns is crucial, regardless of amount of time consumed, to maintain a relationship of mutual respect. Often, traditional materials are thought to be inferior. In rural communities, adobe is often associated with economic depression. In Chacon, the building committee of La Capilla de San Antonio was divided over tearing off the cement stucco and concrete plynth or contrapared, which lined the base of the wall. Historical architect Anthony Crosby carefully pointed out the affect of cement plaster in the preservation plan:

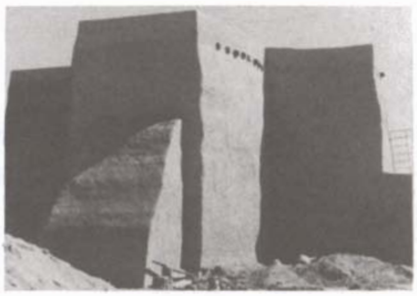


Figure 6
Rear Facade
San Francisco de Assisi
Ranchos de Taos, New Mexico

> Damage even when it does occur is not easily detectable and a great deal of damage can occur before there is even the slightest hint that a problem exists. Hard cement stuccos do not echo internal condition until it may be too late for normal repair. In the case of Chacon, we may well have identified the problem before it becomes unmanageble. But even here some structural repair and rebuilding is necessary. As in many similar cases, water has gained access to lower portions of the walls and because of the relatively impervious stucco, has not evaporated. As the walls become wet they quickly loose their strength and initially begin to slump or compress because of the weight of the upper part of the walls (see fig. 8). As they continue to slump, structural cracks will begin to form and the entire adobe structural system may fail as portions of the walls begin to act independently (5).

Figure 7
Community Discussion of Work
Chacon, New Mexico

Following this explanation, the community decided to remove the cement stucco and concrete plynth (see fig. 9). The harmful effect of cement on adobe structures became clearly evident upon removal of the concrete and stucco on the work day held during the summer of 1989. The walls were extremely wet. Coursing patterns of adobe bricks were indistinguishable at the base of the walls. In other places, the adobes were severely eroded. A pattern of white spots, or efflorescence, indicated that moisture had moved through the wall.

Thus, education is a major component of a community's ability to continue preserving its church. Understanding of traditional building systems, of presently available technology and appropriate use of the tecnology is a necessary ingredient in past, present, and future decision making about maintenance of the church. Preservation workdays are the best opportunity for the exchange of ideas and the education of all participants regarding the deterioration of adobe, as well as use of traditional materials and techniques. A work day sponsored by the community of Chacon involved replastering the church with lime plaster. Area professional plasters, interested in the use of lime plaster, helped replaster the church (see fig. 10) while community youth were instructed in mixing and application procedures. The result has been a renewed interest in the use of lime plaster. Similarly, during workdays sponsored by the community of Las Trampas in 1987, participants learned traditional plastering techniques from enjarradoras, or women plasterers, using mud supplied by the men (see fig. 11).

Figure 8
Distressed Cement Stucco
Holy Trinity Church
Arroyo Seco, New Mexico

Another component of "Churches: Symbols of Community" projects is the reliance on volunteers and donated materials. A long list of technical advisors has been developed to assist communities. The networking of interested parties enlarges the resources available to a community and facilitates project implementation. Recently, an adobe yard in the southern part of the state donated adobes for the repair of the wall of a church in the northern part of the state. Volunteers rented trucks to transport the adobes to the community.

Figure 9
Cement Stucco Removal
La Capilla de San Antonio
Chacon, New Mexico

Figure 10
Lime Plaster Workday
La Capilla de San Antonio
Chacon, New Mexico

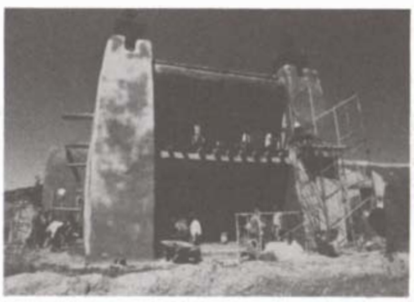
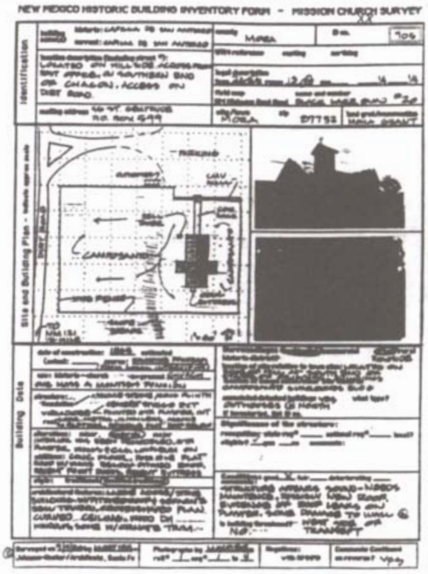


Figure 11
Mud Plaster Workday
San Jose de Gracia
Las Trampas, New Mexico
Photo by Anita Rodgriguez



NEW MEXICO HISTORIC BUILDING INVENTORY FORM - MISSION CHURCH SURVEY

Figure 12
Sample of New Mexico
Historic Building
Inventory Form
Survey of Churches

Preservation Process

The preservation process continues to evolve as each project and community make valuable constributions. Thus far, the process is the following:

1. Research
A comprehensive statewide professional survey and inventory of churches is seventy-five percent complete. The survey forms identify basic information on construction date, architectural style, architectural description, condition, photographs, sketch site plan and floor plan, and community contacts (see fig. 12).

2. Targeting
Using information from the survey, NMCF targets communities in which historic churches are immediately threatened and where community interest is high. Now that the program is better known, numerous requests for assistance are received.

3. Community Organization
Church leaders, mayordomos, and parish officials are contacted and a community meeting is held to provide information on availability of NMCF assistance, offer informational videos and handbooks if requested, assess existing resources, and help forge a plan of action (see fig. 13).

4. Community Selection
Communities are selected for NMCF assistance depending on their initiative and desire for such assistance, the extent which the church is threatened, and the availability of matching community resources.

5. Professional Site Inspection
An initial site inspection is scheduled to provide additional documentation, condition assessment, and to make recommendations for additional professional services. In some cases, all that is required is initial on-site advice. Where more serious problems are identified, a subsequent detailed site inspection may be recommended.

6. Detailed Site Inspection
A professional from a list of interested technical experts is suggested to the community to author a detailed preservation plan. The community selects a professional. The professional documents the church with photographs and drawings, collects samples, and develops a scope of work. The community reviews the plan and decides on appropriate work.

7. Implementation
A follow-up community meeting is held to set a timetable for gathering materials and labor. Local resources are used as much as possible. Once the schedule of work, crew, individuals, and costs is determined, workdays are scheduled. Outside volunteers are recruited as desired by the community. Volunteers from nearby communities or former residents are preferred. Workdays further strengthen social fabric. The mayordomo or other community-selected leader directs the workday. Additional documentation of historic materials is performed. Additional samples are collected.

8. Summary Report
NMCF writes a summary report of work accomplished, objectives attained and lessons learned during the project.

9. Training
Training programs include handbooks, videotapes, workshops and workdays. Training may be coordinated with church leaders. All phases of the process involve an exchange of techniques and skills.

Figure 13
Community Meeting to
Discuss Work

10. Networking
Key to the program is providing communities with services and materials necessary for the continued preservation of the churches. Success is measured by the gradual development of a self-sufficient network eliminating the eventual need for the "Churches: Symbols of Community" preservation project or other forms of support.

Conclusion

In a time of economic decline, rural communities often need additional support in carrying out the preservation of their adobe churches. New Mexico Community Foundation initated the "Churches: Symbols of Community" project to provide necessary assistance. Yet, the traditional bonds between community and church must not be weakened by outside intervention since it is the local resources which will continue to preserve the church. Through community-selected services and resources, the churches are restored, using traditional techniques and materials, to a condition maintainable by the communities (see fig. 14). Following this, a support network assists the communities to continue the work.

Archbishop Sanchez explains:

"The very fact that we have churches that are over 250 years old, tells us that our people have always been concerned and have always loved their churches and want to preserve them. The churches have been part of their life. And because we have them today, we need to make that effort so that our children and our children's children will have an opportunity to worship in these same beautiful temples of God that have been part of our family life" (6).

Figure 14
Removing Cement Stucco
Before Mud Plaster
San Francisco de Assisi
Ranchos de Taos, New Mexico

The ancestors of New Mexico, a land of great beauty and rich history, knew the importance of cooperation, community and cyclic maintenance. The adobe churches are symbols of that knowledge. The generations that follow retain the vivid spirit of community. Working together to maintain the church is a task that each generation carries out faithfully for the sake of the next. Today, these humble adobe churches stand as symbols of that great tradition for all the world to admire (see fig. 15).

Figure 15
Nino Jesus Church
La Puebla, New Mexico
Photograph by Kirk Gittings

NOTES

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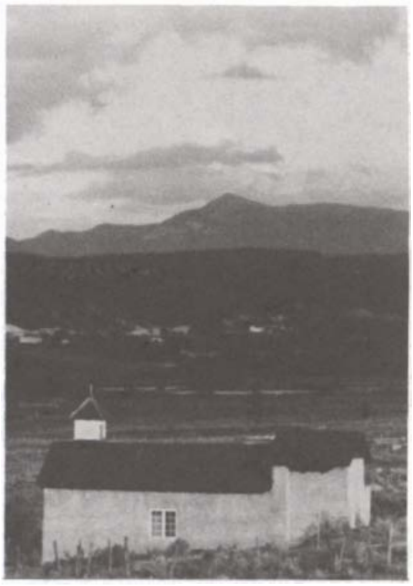

Figure 16
Adobe Church
Ojo Sarco, New Mexico
Photo by Betsy Swanson

FOOTNOTES

The New Mexico Community Foundation's "Churches: Symbols of Community" project could not exist without the generosity and support of the following:

The Graham Foundation
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Ed Crocker
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Linda Gegick
Paul McHenry
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James See
Dale Zinn
Barbara Zook

A NEW RESTORATION MATERIAL FOR ADOBE STRUCTURES

Dr. Bülent Baradan
Dokuz Eylül University
Civil Engineering Department
Mühendislik-Mimarlık Fakültesi
Bornova 35100 İZMİR-TURKEY

ABSTRACT

Turkey, an important civilization center throughout the ages, has a significant number of historical monuments and sites. Preservation of this historical heritage is an issue of prime importance. The basic building fabric in most of these historical and cultural structures and sites is earth. These buildings are more severely affected by nature throughout the ages due to well-known disadvantages of adobe such as low mechanical properties and low resistance to moisture.

A research study was performed to evaluate pozzolanic mixtures that incorporate brick powder, lime, and fly ash combinations for use in conservation problems of historical structures.

The results showed that most of the mixtures produced adequate strength and durability. It seems like an ideal material for adobe plaster amendments and historical wall treatments. Best of all, the color and texture of the mixtures can easily be modified to give the original historical appearance of the structure.

KEYWORDS

Conservation, restoration, fly ash, lime, powdered brick, pozzolanic reaction, earthen architecture.

Introduction

Earth is one of the oldest building materials known to man. It has been in use for centuries and is currently being used by a large percentage of the world's population. In addition to the continued need for earth as a construction material in underdeveloped areas, the preservation of existing monumental or historic earthen buildings has recently become an issue of major importance [1].

Basic techniques used in the manufacture of sun dried earth bricks were developed many millennia ago. Specific methods vary somewhat with geographic areas and cultural traditions, but in principle, they are basically the same. These techniques involve mixing earth or soil with water and molding the mixture into various sizes and shapes, which are then sun dried for use as building blocks. Many techniques used today have changed little from early methods. Most of these methods make use of local resources, are labor intensive, and are logical and effective [2]. However, it is common knowledge that adobe buildings are not sufficiently resistant to the destructive action of nature, especially water.

Turkey has been home to numerous civilizations dating back to the Paleolithic and Neolithic ages. Excavations have brought to light the remains of many cultures such as the early Bronze Age Hatti, Hittite, Lydian, Roman, Byzantine, Seljuk Turks and Ottoman civilizations. Adobe was commonly used by all these civilizations for structures ranging from dwellings to colossal monuments. Today, The most severely damaged buildings generally are found to be made of adobe.

Conservation and restoration of these historical sites is of the utmost importance. The use of natural unstabilized adobe plaster to preserve adobe walls has produced unsatisfactory results. Mortars made with traditional binders are not harmonius with the original structure. There is always a need for suitable restoration and conservation material that will preserve the structure without altering its original appearance.

Recent research has been inspired by a historical binder used throughout the centuries in Anatolia by Seljuk Turks and Ottomans. This binder was called "Horasan" and composed of fired brick powder, lime, and water [3]. In some references ash and egg-white are also included in this composition, but there is no evidence concerning the exact ratios of these materials. In this study, powdered brick, hydrated lime, and fly ash were used to develop a binder to fulfill these needs.

Materials

One of the most widely used building materials in Turkey is fired brick. About 10% of the 800 million bricks produced in 1988 were deformed, irregular or damaged. These by-products are not utilized in any way. For the purpose of the present study these wastes were crushed and reduced to fine powder (see fig. 1). Hydrated lime, available in commercial paper sacks, was also used.

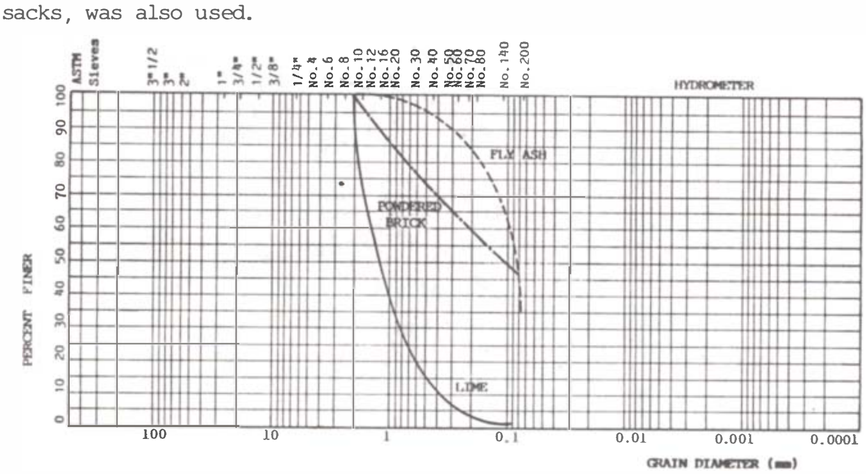

Fig. 1: Grain size distrubition of Powdered Brick, Lime and Fly ash

The other ingredient, fly ash, is a by-product of the coal combustion process at power plants. To prevent air pollution caused by thermal plants, electrostatically precipitated fly ash accumulates daily throughout the world in enormous quantities. This quantity of by product causes serious environmental, technical, and economic problems that need to be solved [4]. Fortunately, this fly ash by product can be effectively utilized because it is a pozzolana siliceous material which, in the presence of water, will combine with lime to produce a cementitous material.

In the present study fly ash samples from Soma B thermal plant were used in experiments. This plant consumes 1.75 million tons of low calorie lignite (2400 kcal/g) every year, with a 41 % C-type ash output. The chemical and physical properties of the ash are shown in Tables 1 and 2.

Table 1 : Chemical Properties of Soma B Fly Ash

Compound	Chemical Composition by weight (%)
SiO_2	47.4
Al_2O_3	25.1
Fe_2O_3	6.8
CaO	12.1
MgO	1.44
SO_3	1.60
TiO_2	0.60
Na_2O	0.10
K_2O	0.50
P_2O_5	0.30
Loss on ignition	1.1
Undet.	2.96

Table 2 : Physical Properties of Soma B Fly Ash

Property	Value
Specific gravity	2.39
Min.unit weight	1.00 g/cc
Comp.unit weight	1.18 g/cc
% Passing # 40 sieve	98
" " 100 "	96
" " 200 "	92
" " 325 "	84
Specific surface	2830 cm^2/g
Pozzolanic activity Index	82 kg/cm^2

Experimental Studies

Various amounts of fly ash and lime were added to brick powder to start pozzolanic reactions and to increase the mechanical, physical and workability properties of the compositions.

Dry and wet mixing procedures of the mortars were accomplished by means of a homogenizer and a Hobart mixer to ensure uniformity. Fabrication of the specimens was accomplished by table vibration in steel forms. The specimens were then stored under laboratory conditions until testing. Standard 4 x 4 x 16 cm prism specimens were tested for flexural and compressive strengths.

Compressive strengths were determined on portions of prisms broken in flexure test. A series of the tests were repeated on duplicate specimens soaked in water for four hours.

Compositions and their respective flexural and compressive strength variations are shown in figures 2-5.

Some of the mixtures have also been tested for their suitability as a binder material in adobe bricklaying and in plastering adobe walls.

Conclusions

From the preceeding tests and information, the following general observations and conclusions can be stated:

1. The generally required compressive strength for adobe bricks is about 1.0 N/mm^2. Even the lowest compressive strength of the test series is higher (1.2 N/mm^2) than this value. In some compositions (85% powdered brick, 12% fly ash, 3% lime) this value reaches up to 8.3 N/mm^2 in 28 days.

2. The main deficiency of adobe structures is tneir susceptibility to water damage. The mechanical properties of the duplicate specimens did not decrease meaningfully even after four hours of soaking in water. This can be attributed mainly to the pozzolanic properties of fly ash and lime.

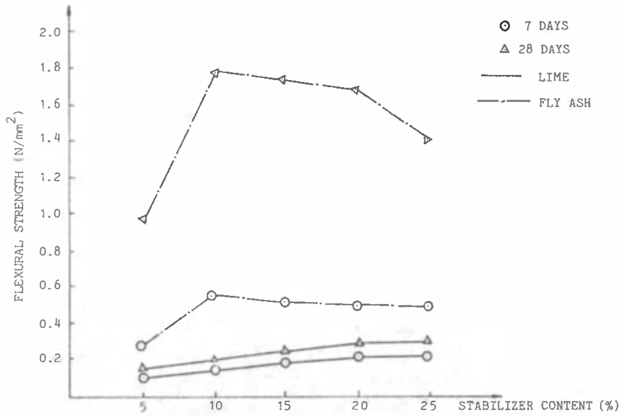

Fig. 2: Flexural strength vs. stabilizer content for lime or fly ash stabilized powdered brick.

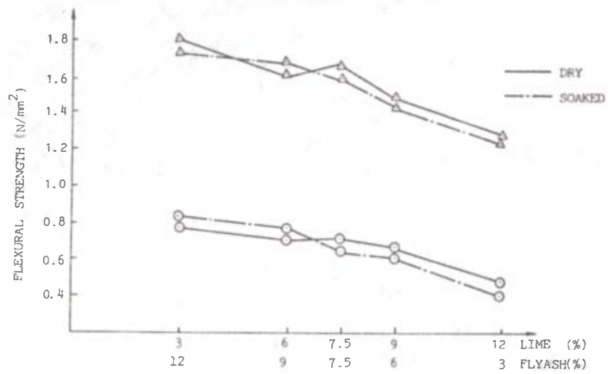

Fig. 3: Flexural strength vs. Lime/Fly ash ratio for lime-fly ash stabilized powdered brick.

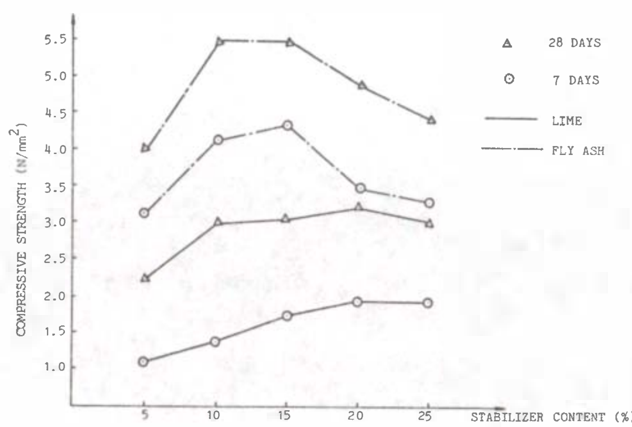

Fig. 4: Compressive strength vs. stabilizer content for lime or fly ash stabilized powdered brick.

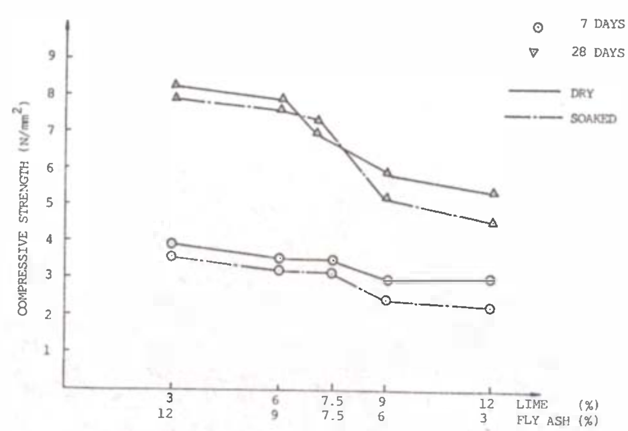

Fig. 5: Compressive strength vs. Lime/Fly ash ratio for lime-fly ash stabilized powdered brick.

3. The color of mixtures can be altered from red to grey within a wide range by changing the proportions of the ingredients. This procedure does affect the mechanical properties, but this does not create a problem due to adequate mechanical properties of all compositions.

4. These pozzolanic mixtures can be used for a variety of purposes and seem to be an ideal preservation and restoration material since they may be used in brick forming, repairing, and plastering, or as a binder.

5. The plaster application of some compositions to test walls was quite efficient and very few shrinkage cracks were observed.

6. Unit weight of specimens varied from 1.285 g/cm^3 to 1.260 g/cm^3. Coefficient of thermal conductivity λ was determined as 0.202 $kcal/mh^oC$ for the mixture stated in item 1. These results indicate that these mixtures may be used in manufacturing structural elements in the form of panels or blocks. And if further tests reveal positive results, these structural elements may be economical too, since the two main ingredients, fly ash and brick powder, are discarded by-products.

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ABSTRACT

Efforts are underway to preserve traditional buildings in the Kingdom of Saudi Arabia. Much of this work is being concentrated at Dir'iyah, the original capital of the ruling Sa'ud Dynasty. A ruin since 1818, historic Dir'iyah is under the administration of the Department of Antiquities and Museums. Work at the site involves researching the history of the site, investigating and analyzing the surviving structural remains, understanding and developing traditional building crafts and techniques, developing stabilization and interpretive plans for significant buildings and the site in general, the construction of an on-site museum, and the selective reconstruction of significant buildings in the al-Turaif Quarter of the old city of Dir'iyah.

KEYWORDS

Saudi Arabia
Najd
architecture
adobe
stabilization
reconstruction
climate

1. Aerial view of Dir'iyah showing the locations of al-Turaif and other quarters of the city.

THE RECONSTRUCTION OF TRADITIONAL STRUCTURES IN THE AL-TURAIF QUARTER
Dir'iyah, Kingdom of Saudi Arabia

Michael Emrick, AIA*
The Office of Michael Emrick, AIA
P.O. Box 80601
Nashville, Tennessee 37208

Carl Meinhardt, FAIA
The Office of Carl Meinhardt, FAIA
520 Broadway
New York, New York, 10012

The site of Dir'iyah includes both palaces of the rulers and houses of the common people. The vast scale of the ruins, including those of the large palaces, represents an enormous task in the preservation and interpretation of the site. A major problem in researching and analyzing Dir'iyah's structures is the devastation they received at the hands of the Egyptian army. This, in combination with 130 years of neglect and weathering, has left many structures only as wall fragments. As a result of the rapid growth and development occurring in the Kingdom, in Riyadh, and in the new Dir'iyah suburb in particular, there are fewer and fewer comparable surviving structures on which to base research.

Historical Overview

The deserted city of Dir'iyah, impressive today in its ruins, is the foremost physical symbol of the longest ruling dynasty in the Arabian Peninsula, the dynasty of Sa'ud. This family made its beginnings there in 1446, founding Dir'iyah as a farming homestead. Through a combination of successful agriculture and local leadership it steadily increased its influence over adjoining territories. With increased political influence, Dir'iyah grew from a few family houses to respectable township size. Throughout, it maintained its political independence and, by its third centennial, Dir'iyah had become a well-established and respected town in the central Najd.

In 1745, the Saudi rulers entered a new phase of their history. First giving refuge to the fiery preacher and reformer Muhammad bin Abdul al-Wahhab, then joining his cause to promote morality and pious government, the Saudis became leaders of a reformist government which grew over the next seventy years to encompass nearly all of the Arabian Peninsula.

Dir'iyah remained the capital throughout this period of expansion. It underwent its greatest growth at this time, both in terms of buildings and population. By 1810 annual taxes were collected from as far as the Hijaz, Yemen, Oman, and the desert reaches of Iraq and Syria. While most taxes were spent on the burgeoning state's army, as much or more was distributed as welfare. Some funds were also earmarked for buildings in Dir'iyah as well as to house and maintain the ever increasing number of court retainers; Sa'ud bin 'Abdul al-'Aziz had perhaps 1700 in residence at his death in 1814.

At the peak of its expansion the Saudi state suffered a severe setback at the hands of the Egyptian army of Mohammad Ali. For Dir'iyah it was a death blow. Marching first into the Hijaz in 1811 to restore the Ottoman flag to the Holy Cities of Islam (Makkah and Medinah), Mohammad Ali then determined to destroy completely the Sa'ud dynasty that had seized them. In 1818 Dir'iyah fell into Egyptian hands after fierce fighting. The captured Saudi ruler 'Abdullah was sent off to Istanbul and death; Dir'iyah was evacuated and razed to prevent it from ever rising again.

Mohammad Ali's plan failed in one respect; the Sa'ud family he thought thoroughly subjugated rose only a few decades later to rebuild their independent state. Their capital, however, was moved to Riyadh. After abortive attempts to rebuild Dir'iyah immediately following the disaster, the city was ultimately left in ruin, deserted. Today its ruins stand as a living historical testimony of the ancestral home of the Sa'ud family and their first period of rule over the peninsula.

The Development of Dir'iyah

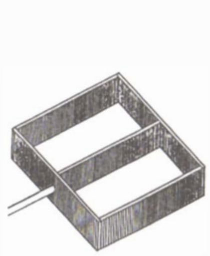
The Najd is a great plain of gravel, striated by sand bars, with occasional outcropping mountains. Settlements are found primarily in the eastern portion, grouped along the Jabal Tuwaiq Escarpment. Dir'iyah is located in the center of this arc, in the Wadi Hanifah.

Al-Dir'iyah is an oasis approximately 20 kilometers northwest of present day Riyadh (see fig. 1). The wadi, a narrow ribbon hemmed in by abrupt cliffs on both sides, flows southeast through the upper part of the oasis, bending east before passing through the main settlements. Date gardens are on a raised step above the valley floor, protected from the floods by a levee of large stone blocks as high as 3 meters.

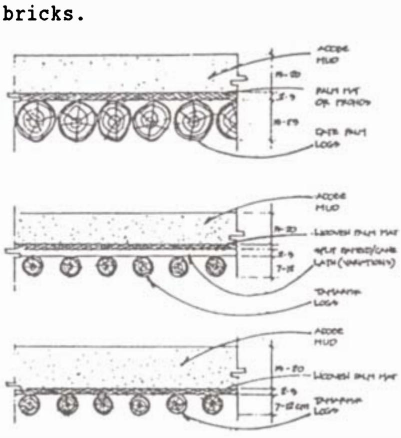
* Author to whom correspondence should be addressed.

2. Plan of the al-Turaif Quarter showing the locations of the Palace of Omar (1), the Subaalat and Mosque of Moudhi (2), and the al-Turaif fortifications (3).

3. Aerial view of the al-Turaif Quarter of Dir'iyah taken in the 1950's.



4. Sketch of the box frame (al Milben) used for making adobe bricks.



5. Sections illustrating typical types of floor/roof construction.

Evolving into an integrated group of hamlets and date groves within and along the wadi, Dir'iyah's fortifications were gradually extended to encompass increasingly larger areas of settlements and agricultural activities. By the late eighteenth century Dir'iyah was enclosed by a perimeter wall over 15 km in length. The evolution and construction of the al-Turaif Quarter of Dir'iyah (see figs. 2, 3) for the Sa'ud family and their retainers indicates the increase of political power and influence they, and Dir'iyah as their capital, came to exert on the Najd.

Najdi Society

Najdi society was the least influenced by non-Arab elements because of its remote location from the coastal areas. But this society was not completely isolated as the Najd was situated on the major trans-Arabian caravan routes connecting the Red Sea, Makkah, and Medina on the west with the Gulf and Syria on the east as well as Yemen in the south. It was, perhaps, the religious attitudes of this area during recent centuries that tended to make this area appear more remote and less open to foreign ideas.

Dir'iyah began to grow and become more cosmopolitan as it attracted supporters of Shaykh Muhammad bin Abdul Wahhab. And as it grew, Dir'iyah became a center of learning, a magnet for merchants, and a focus of people looking for work.

Saudi Traditions and Techniques in the Use of Adobe

Najdi architecture may be termed "traditional" or "vernacular" in that it has been generated by a regional response to climate as well as social and political considerations. Major factors defining this design tradition in the Najd were building materials and available skills. Traditional building changed little between the time of the first Saudi state and the mid-twentieth century. The structures surviving at Dir'iyah thus provide a continuing basis for understanding this vernacular tradition.

The traditional architecture of the Najd is dominated by adobe construction. Yet the structures of Dir'iyah frequently have numerous courses of cut limestone as foundations. Geological circumstances provided the Dir'iyah area with an abundance of stone. The natural layering and fragmenting of the stone wadi cliffs allowed for relatively easy quarrying. The concentrated use of stone indicates that labor was imported from other regions where knowledge of stone construction was more advanced.

There were also specialists who made adobe bricks using rectangular wood frames (*al milben,* see fig. 4) which were set on level ground and filled with wet mud. The clays and sands of the region are particularly well-suited for making adobe bricks and plasters. Adobe was also used as a roofing material. Supported by wood logs (tamarisk and date palm) set close together, the logs were covered by a thick palm frond mat layer which was, in turn, covered by a thick layer of adobe mud to form the roof (see fig. 5). Other specialized craftsmen did the plastering and decorated doors, windows, lintels, and beams.

At al-Turaif extensive coursed stone foundations were used in combination with adobe brick walls. Walls were also constructed with various layering techniques utilizing stone fragments laid horizontally or in herring-bone fashion in adobe mud beds (see fig. 6). Except for the exposed stone foundations, walls were coated with thick layers of adobe and gypsum plasters. Long thin stones were used to frame many of the nonrectangular wall niches and openings, in particular the traditional triangular keel arch found in mosques (see fig. 7). Logs were generally inserted into the walls as lintels for rectangular doors, windows, and niche openings.

Saudi architecture relies on post-and-beam construction. Roof joists were set directly into the adobe walls, while larger beams sat on stone plates set into the walls to distribute the load and to prevent the adobe bricks from crushing. Columns were used to develop large interior spaces (see fig. 8). These consisted of rough-hewn cylindrical stone drums set in adobe mud mortar and finished with a coat of gypsum plaster. Each column had a rectangular flat stone corbel capital that supported the large multiple log wood beams.

Water removal was handled by downspouts placed about the perimeter of exposed roof areas (*mirzam,* see fig. 9). These consisted of half-hollowed tamarisk logs built into the roof construction. Roofs were sloped towards these downspouts, which were notched at the outer end to provide a drip to throw water away from the walls.

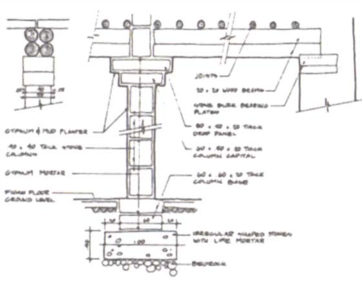
Ventilation openings were of major importance in controlling the climate of the interior spaces. Dir'iyah's buildings exhibit a wide variety of patterns of small triangular and rectangular openings in the upper levels of exterior walls (see figs. 10 - 11). These openings provided ventilation and privacy as well as being decorative. During the winter months the openings were plugged with mud plaster to prevent the entry of winter cold and to help retain heat.

Decorative crenelations (*shurofaṭ mudarrajah,* see fig. 12) were found on parapet walls at the roof level and on courtyard railings. These provide modest decoration on the otherwise stark, massive building forms. Ornament and display were generally restrained because of the prevailing conservative religious attitudes against ostentation. The vast, stark walls were subtly textured by the broad-toothed scrapers that were used to apply the wall plaster. Inverted solid projecting bands of triangular patterns were also used on the exterior surface both to decorate and deflect rain from the tall walls (see fig. 13).

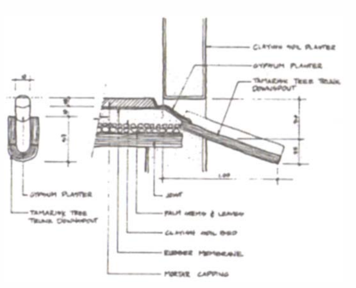
Bright colors, in geometric and stylized patterns, were concentrated on the interior--doors, windows, and ceiling beams. Other interior decorations were reserved for only the most important rooms, particularly the *majlis* (the principal reception room for male visitors). Here it was not unusual to find fine white gypsum plaster with incised or pressed stylized flowers and geometric motifs.

6. Example of horizontal coursed stone used in in wall construction.

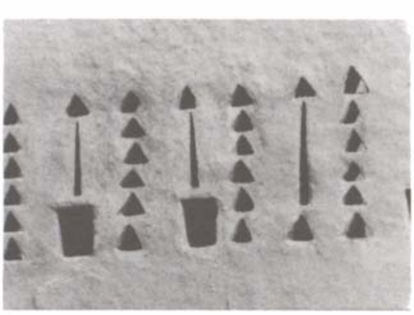
7. Example of stone keel arch construction typically used in mosque and public building construction.



8. Detail of typical column construction showing both footing and beam.



9. Detail of downspout (mirzam) construction.



10. Detail of the wall ventilation pattern on the Sa'ad Palace.

Architecture as a Response to Climate and Culture

The Najdi climate heavily influenced the main architectural forms and choice of materials; the culture affected the overall planning, detailing, and decoration. Regional houses are generally two stories high, contiguous to each other along narrow streets. Where the street plan permits, houses are rectangular; however, it is more common for house forms to be irregular, imposed by the labyrinthine pattern of the streets. Dir'iyah is an example of this organic type of community where large groups of buildings are divided by narrow streets.

While little research has been conducted on Najdi town planning, fortunately Riyadh was documented in the late nineteenth century, and much of the original plan survived until the mid-twentieth century. Dir'iyah, while a ruin, largely survives in plan, enabling a comparison with Riyadh. The two capital cities share a variety of similarities. The concentration of houses was close to or surrounded the open squares that contained both mosques and markets, similar to the design that still survives in many rural towns. The plan of Dir'iyah has been succinctly described by Geoffrey King:

> Al-Dir'iyyah, the former capital of the Al Su'ud, is a special case, for as the center of a great state, its buildings, their numbers, their scale and the extent of the fortifications are all unusual. Nevertheless, on the main citadel, al Turayf, the main features of a Najdi settlement are still observed in what is a well-preserved 18th century town. Thus around the main mosque and an open area cluster the royal palaces and further out, the houses of lesser individuals. The whole was enclosed by walls. The plantations and palm-trees are still situated today below the main town in the wadi. Only its peculiarly strong position distinguishes al-Dir'iyyah from other towns in the area: in other respects it has the same basic features.[1]

This community form had many advantages with respect to both climate and culture. The narrow streets and courtyards provided pedestrians with protection from the sun and sandstorms. Attached buildings also limited the amount of wall surface exposed to the sun. With the fronts of houses on narrow streets, doors and other openings were carefully organized so as not to interfere with those of a neighbor. The result was cooperative communal interaction outdoors as well as privacy indoors for the inhabitants.

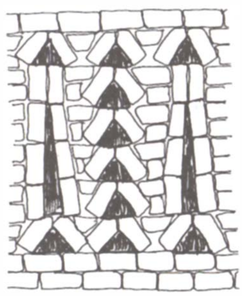
Building materials were also used as climate moderators. The combination of thick adobe walls as above ground shelter surrounding an open courtyard that provided light and ventilation helped keep the inhabitants cool in the summer and warm in the winter.

Equally unique are the cultural and spatial factors fostering a private lifestyle by providing outdoor space within the house--the introverted courtyard (atrium) (see fig. 16). Courtyard houses frequently accomodated an extended family built around single or groups of linked courtyards, they permitted the free growth of the family. Houses were often modified or enlarged to meet the needs of the occupants and were fortified in time of war.

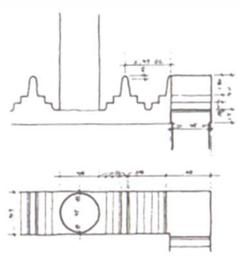
Historical Documentation

Few buildings in Dir'iyah, or any other small Arabian towns and villages, are mentioned in written documents before the mid-nineteenth century. The remoteness of these sites, the lack of a written tradition, and the preference of non-Arab visitors to record and discourse on the religious and social customs and habits rather than on the building arts make the documentation of specific structures virtually impossible until the development of photography in the mid-nineteenth century.

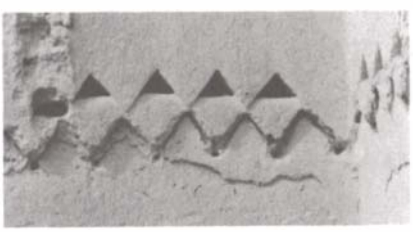
Known graphic documentation includes various sketch plans of towns that accompany the journals and accounts of visitors. Recorded more as a part of gathering political and military intelligence than for any interest in Arabian town planning concepts, only major physical sites and building complexes were noted. Surviving historic photographs include many individuals and groups of people or general views that only occasionally contain glimpses of structures.



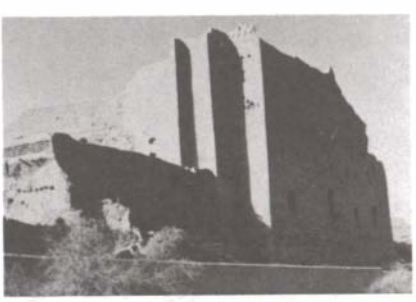
11. Construction detailing of ventilation pattern from the Mishari Palace.



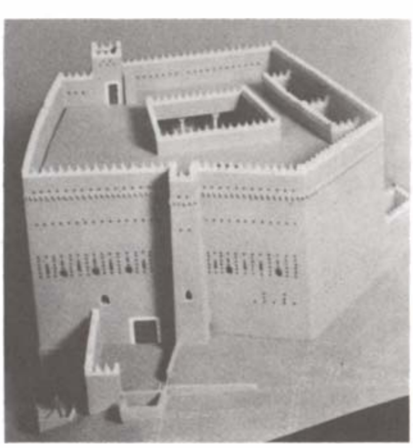
12. Typical decorative wall crenellation design.



13. Example of projecting triangle design used for both decoration and rain deflection.



14. The Palace of Omar as it currently exists as seen from the wadi.



15. Model of the reconstructed Palace of Omar.

Stabilization and Restoration Approaches

The stabilization and reconstruction plans prepared for the various structures were very conservative in their approach. These plans were sensitive to the integrity of the historic structures as well as to the materials and techniques of construction.

Several principles were established to guide the process. First, reconstruction or repair work would not begin until all the problems that had been causing the deterioration of the adobe had been determined, analyzed, and understood. Second, adobe building materials would be replaced or repaired with the same types of materials that were used originally. Similarly, traditional construction techniques would be utilized in the course of stabilization and reconstruction work.

A final principle was to resolve problems and retain original historic materials whenever. It was realized that the structures under investigation were "evolutionary" in nature, and when occupied they received on-going maintenance to renew protective adobe and gypsum plaster coatings. It was necessary to recommend the demolition of structurally unsound components and to reconstruct them completely with new, compatible materials. No uniform approach was possible, but every area of the structures was evaluated with respect to the extent of physical intervention necessary to achieve total reconstruction.

Where components of the structures no longer existed, reconstruction proposals were based on historical evidence or physical evidence noted in contemporary structures to allow for the accurate replication of missing features. The objective was to keep design speculation to an absolute minimum.

Although a wide variety of new materials, in particular surface coatings, additives, and waterproofing agents are available and have been tested, the results to date indicate that most, if not all, of these modern materials result in various forms of chemical changes, discoloration, or are incompatible with indigenous materials. Recommendations specifically ruled out the use of any new materials in the stabilization and reconstruction process, specifying only traditional materials and techniques.

Project Program and Documentation Techniques

Project contracts called for a multiple-phase program consisting of on-site analysis and testing; archaeological investigations; photographic and video documentation; architectural and historical analysis; preparation of four sets of documentary drawings--existing condition, proposed final configuration, demolition, and reconstruction; specifications; and bills of quantity. In addition, the project also called for several summary publications for use in site interpretation.

Archaeological investigations conducted as part of the site documentation were designed to delineate suspected portions of walls and columns. These were sometimes partially extant but were buried under debris from the siege and subsequent weather-related deterioration. Also documented were original finished floor levels. Once these features were determined, the overall clearing of the rooms and courtyards was undertaken.

Rough excavation work was conducted with pick-axe and shovel, occasionally with trowel and brush, and the rubble removed was monitored for the presence of artifacts, a few of which were recovered at each site. Searching for artifacts was not a significant component of the excavations because Dir'iyah's occupants were given the opportunity to remove their possessions prior to the devastation of the site.

The structures were visually and physically inspected to determine the physical condition and any structural problems. A room-by-room inventory and photo documentation was conducted to record material conditions, structural faults, and surviving design components. Also carefully reviewed were surviving examples of traditional building techniques, structural detailing, decorative elements, and finishes.

Our firms were involved in three projects at Dir'iyah--the Palace of Omar, the Subaalat and Mosque of Moudhi, and the walls and towers of the al-Turaif Quarter. Of these three projects only the al-Turaif fortifications have been completed. This project involved three towers, including the Faisal and al-Wasita Towers, two bastions, and several kilometers of walls.

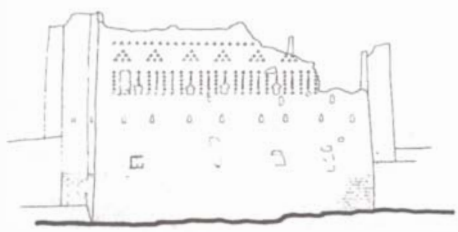
The Palace of Omar bin Sa'ud (see figs. 14 - 19)

The palace stands in a prominent position high atop the wadi. While not the largest of al-Turaif's palaces, it occupies a prominennt site. From the greater extent to which it survived the 1818 siege, the Palace of Omar most likely served as one of a series of strongholds developed throughout the many lines of defense designed into the fortifications of Dir'iyah. The palace's adobe walls rise two stories above the tall stone foundation. The opposite side of the palace faces a narrow lane in a residential quarter of al-Turaif.

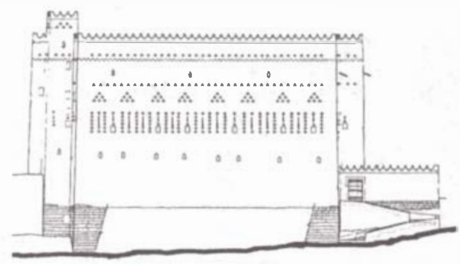
16. Existing condition ground floor plan of the Palace of Omar.

The palace has a five-sided plan built around a nearly square two-story courtyard (see fig. 16). The entrance connects with the courtyard, which served as the principal private outdoor space. Some unresolved research questions concerning this site remain to be resolved: (1) its potential access directly to the wadi below and (2) the design of a suspected service courtyard surrounded by rooms attached to the west side of the main structure.

Omar bin Sa'ud was the son of Imam Sa'ud (the Great) who ruled over the state from Dir'iyah at its height. He was also the grandson of Imam 'abd al-'Aziz, who played a large hand in putting the state together. His older brother 'Abdullah became Imam upon the death of their father in 1813, and it was as a lieutenant of 'Abdullah that Omar fought in the fateful siege and battles of Dir'iyah in 1818.[2]



18. Wadi elevation of the palace as it exists today.



19. Wadi elevation of the reconstructed palace.

17. Reconstruction ground plan of the Palace of Omar.

The Subaalat and Mosque of Moudhi bint Ibn Wahtan (see figs. 20 - 25)

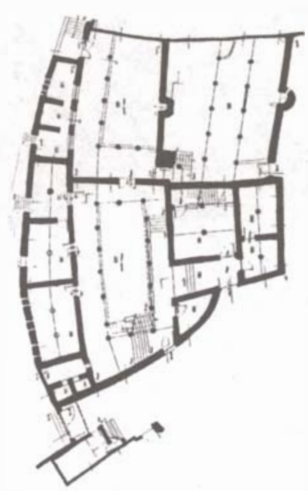
Located at the edge of the eastern residential section of al-Turaif, the subaalat and mosque structure was badly damaged during the 1818 siege. The subaalat, according to tradition, provided lodging for travelling merchants. It was a modest two-story structure built around a long, narrow courtyard. Several doors located along an adjacent lane provided temporary shop space for the merchants. The mosque connected to the subaalat was small and intimate, serving the immediate community around it.

The structure that we see today has been considerably altered over time. Formed from the components of earlier structures, probably one or more residences, the final configuration of this structure made it an unusual hybrid. The mosque itself was altered and rehabilitated during the mid-twentieth century when al Turaif was again inhabited.

20. The Subaalat and Mosque of Moudhi as seen from the wadi.

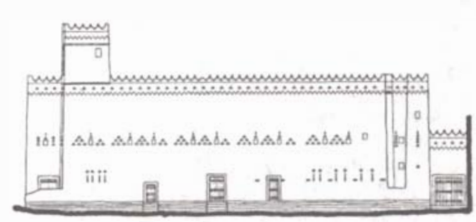
21. Interior detail of the Subaalat of Moudhi.

22. Existing condition ground plan of the Subaalat and Mosque.



23. Reconstruction ground plan of the Subaalat and Mosque.

24. Existing east elevation of the Subaalat and Mosque.



25. Reconstruction elevation of the Subaalat and Mosque.

Moudhi was the wife of Muhammad bin Sa'ud, the first of the Saudi rulers to espouse the reformist cause of Muhammad bin 'Abdul al-Wahhab. Her intervention with her husband resulted in asylum being granted to the reformer and his followers, a fateful alliance upon which the success of the Saudi dynasty and the Wahhabi movement were based.[3]

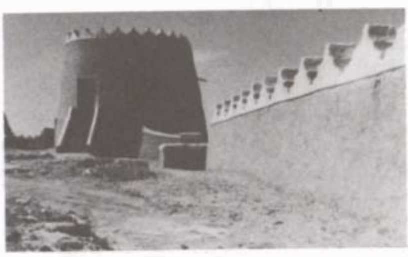
The Al-Turaif Fortification Walls (see figs. 26 - 30)

The al-Turaif walls are one component of Dir'iyah's fortifications and are similar in design to fortifications at other locations in the region. The walls that surrounded Dir'iyah were punctuated by rectangular and circular towers at relatively regular intervals. These towers not only buttressed and strengthened the walls, they also served as observation posts and defensive positions for cannon. Special features of the al-Turaif walls are projecting rectangular bastions for cannons.

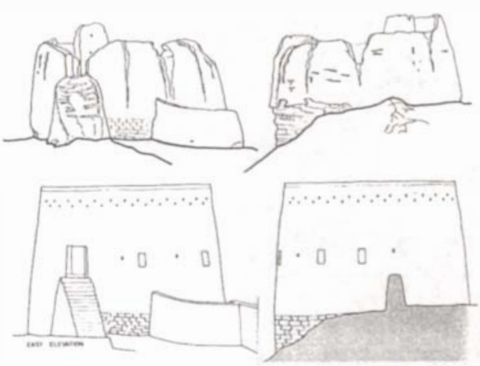
The al-Turaif fortifications are a combination of extensive rough-coursed stone construction combined with adobe brick for parapet walls. These were, nearly everywhere, finished with a coat of adobe plaster. The walls typically have a distinctive batter and vary in thickness. Major walls consist of outer and inner stone layers with an inner cavity of stone and rubble fill.

The walls had a rampart level protected by a tall parapet wall constructed of adobe bricks in which were found numerous small shooting and observation loopholes (*mizghal*). Fortification walls may also have had decorative stepped crenellations (*shurofat mudarrajah*) on the parapets.[4]

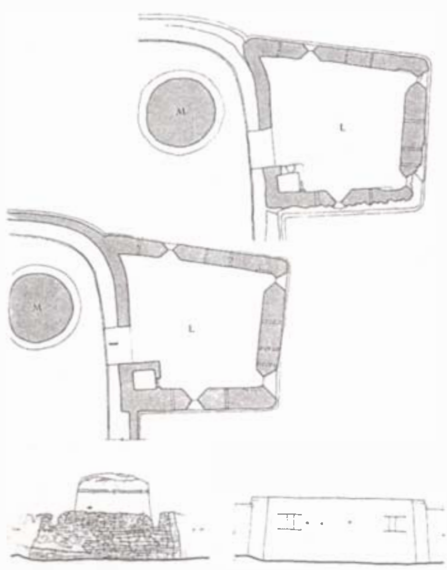
26. Faisal Tower prior to reconstruction as seen from the wadi below.



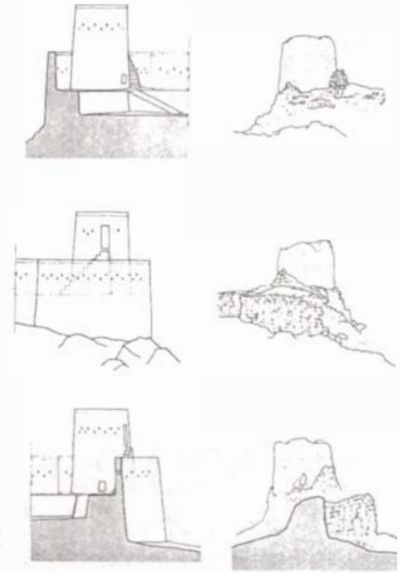
27. The reconstructed Faisal Tower and part of the defense wall.



28. Existing condition (top) and reconstruction drawings (bottom) for the Faisal Tower.



29. Existing condition and reconstruction drawings of a defense tower and bastion at al-Turaif.



30. Existing condition (right) and reconstruction elevations (left) of the al-Wasita Tower at al-Turaif.

Conclusions

With the rapid development and modernization of Riyadh, its suburbs (of which new Dir'iyah is one), and other parts of the Kingdom of Saudi Arabia, traditional historic structures are being demolished at an incredible rate, the intent being first and foremost to modernize the services and infrastructure of the Kingdom. In the midst of this, the preservation of the historic capital of Dir'iyah is being undertaken by the Department of Antiquities and Museums.

The mission of the department is to maintain, document, and, in selective cases, reconstruct significant historic structures at the site in order to interpret the three centuries of history of this site for current and future generations of Saudi Arabians. In interpreting a site of this scale and complexity it is easy to help the visitor to transport himself from the culture of the twentieth century to the reality of an historic city which was once one of the largest cities in the middle of the Arabian Peninsula.

The process of reconstructing significant examples of historic structures not only helps visitors to understand the past history of the Dir'iyah, the Najd, and the Kingdom through its building arts, it also results in new people being trained in the traditional methods of construction, preserving and passing on crafts and techniques to future generations.

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ABSTRACT

This paper is a brief case study of a preservation project at Acoma Sky City, a Native American settlement in New Mexico, USA on the National Register of Historic Places that has been continually occupied for more than 1000 years. A brief history is given, and the difficulties that are encountered when using federal funds to rehabilitate privately owned dwellings, are discussed. Recommendations are made for the planning of the rehabilitation of privately owned contiguous dwellings while maintaining a preservation perspective. Staged funding is recommended to obtain maximum value and minimal re-evaluation of priorities mid-project.

KEY WORDS

Adobe, preservation/rehabilitation, planning strategy, Native American tradition, historic heritage.

ACOMA: A CASE STUDY IN PRESERVATION PHILOSOPHY AND IMPLEMENTATION

Paul G. McHenry, Jr. AIA
Architect
4601 Montaño NW #52
Albuquerque, NM 87120
U.S.A.

Introduction

Acoma is a living monument and one of the unique treasures of North America. Its history and isolation from modern influences provide an unequalled opportunity to experience the past. The very qualities that make it unique also make its preservation more difficult. Preservation work at Acoma is subject to disciplines and pressures that are seldom encountered in preservation activities of this magnitude at other sites.

Acoma is a group of adobe and stone buildings located on top of a 350 foot high sandstone mesa, approximately 55 miles West of Albuquerque, New Mexico. The basic community pattern is comprised of three rows of house blocks, one to three stories high, oriented on an east-west axis. A monumental church is located south of the housing area. A valuable resource for restoration planners is the collection of Historic American Buildings Survey drawings, 1934.[1]

Acoma Sky City Area "C", ca. 1890 Museum of New Mexico Neg. # 16042

History

Although the precise chronological origins of Sky City are not known, is was an established community at the time of the first Spanish contact by Alvarado in 1540 AD. Its origins are believed to date several hundred years earlier, making it one of the oldest continually occupied settlements in North America. The earliest description of Acoma was given by Francisco Sanchez in 1581, where he reported finding "500 houses of 3-4 stories."[2] The 1980 Graham Report SKY CITY PLANNING inventories a total of 369 dwellings, 107 of which were recently constructed.[3] This indicates a 50% decline since 1581.

In 1598, in reprisal for the death of thirteen Spanish soldiers, Vicente de Zaldivar, organizer of the avenging company, ordered amputation of one foot from the body of every Acoma male over 25 years of age, enslaved all the Acoma people for 20 years, and razed the buildings of the community.[4] This severe punishment affected the Acoma community tragically and shocked the Spanish authorities, who later punished Zaldivar for his actions. His cruelty resulted in a distrust of outsiders which understandably persists to this day.

The next significant event was the resettlement of Acoma and the construction of a large church by the Catholic priest Fr. Juan Ramirez between 1629 and 1640. The form and pattern of the house blocks as they exist today were built at that time. The original Sky City dwellings reportedly were located in the vicinity of the present-day church.

Very little archaeological investigation has been done at Acoma, a situation common to most occupied pueblos. The culture and traditions of most pueblo communities make it unlikely that such investigations will ever be feasible unless undertaken exclusively by Indian personnel. The pre-Spanish buildings reportedly were of rubble stone, laid in mud mortar. Although this has not been proven, it seems likely that stone was the primary building material considering that, by most accounts, "adobe bricks" were introduced by the Spaniards. However, if stone was the building material of the 500 dwellings that were destroyed by Zaldivar in 1598, what happened to the stone? No significant accumulation of stone has been found, either in building walls or at the base of the cliff. Reportedly, some, if not all, may have been used in the construction of the retaining wall at the "campo santo" (graveyard) on the east side of the church. The Acomas are very sensitive about the disturbance of burials, so there is little likelihood that any further investigation will be allowed.

The earliest use of adobe bricks at this site was in the construction of the church, where a brick size of 10" x 19" x 3" was used [5]. This same brick size is found in the wall construction of the areas of Acoma presumably built during or after the construction of the church. This dating was further established by tree ring studies by the University of Arizona, which indicated that virtually all timbers in one house block (Area "C") were cut in 1646 [6].

The soil source for the adobes and the site of their fabrication has not been determined. Quite possibly, the bricks were made in the valley below and were transported to the top of the mesa after manufacture. There is very little, if any, naturally occurring soil or water for making bricks on top of any of the nearby mesas, so we may presume that Acoma was the same. Although no precise estimate has been made, hundreds of thousands of bricks were required. Adobe bricks are very heavy (100 lbs per cu. ft.) It would be more practical to carry only the weight of the finished bricks up to the construction site rather than soil and water, which would then evaporate after drying. Soil samples were taken from building walls and plaster, analysed for minerology and compared with several possible soil sources in the vicinity, but the results were inconclusive. Perhaps the variable nature of any given soil source makes precise determination impossible; this factor is another complication in developing adobe restoration techniques.

Preservation Goals

Acoma is a time capsule of a 16th century native culture that has been relatively undisturbed. It must be preserved as intact as possible so that the wealth of information it contains will not be lost. Some features have already been lost through neglect and modification by their owners. New doors and windows, cement stucco, and other modern features represent improvements in the mind of the owners, who may fail to see the historical value of the original structures. When restoring public monuments or property, preservation teams can apply their principles of restoration ethics with free rein. But Acoma is private property, and the owners have the right to make the final determination. The values for preservation of this resource are manifold:

1. Prevent loss of historic examples and the cultural heritage they represent to further the Acoma's understanding of their own heritage and educate other cultures.

2. This resource has great economic value to the Acoma people. Its continued preservation provides tourist dollars, a primary income source for the pueblo. Many village leaders are aware of this, and the cultivation of preservation attitudes can only be accomplished with their help.

3. The age and lack of maintenance of many of these buildings has created a safety hazard to both occupants and tourists which must be mitigated.

4. The construction work required for the preservation and continued maintenance of these buildings represents a source of employment for the Acoma people, and makes use of their natural resources of stone, wood and earth.

5. As there is constant turnover in construction personnel, it is desirable to devise a logical, standardized plan for a system of maintenance, repair and reconstruction which reflects historic detailing. This could be used for future guidance for the Acoma community.

Implementation Problems and Conflicts

For several years, the United States Department of Housing and Urban Development has offered annual Community Development Block Grants for housing rehabilitation to Native American communities on a competitive basis. Conditions of these grants provide that work on historic buildings follow The Secretary of The Interior's Standards for Rehabilitation [7], in order to preserve and protect historic resources.

Acoma is a special case because it is an occupied community owned by individuals, as compared to a ruin or monument that is not privately owned. The grant program under which this rehabilitation was to be done was a Community Development Block Grant, presumably conceived for more conventional housing which would not have the historic restoration complications presented by Acoma. The responsibility for overseeing the application of the "standards" was delegated to the Historic Preservation Division of the New Mexico State Office of Cultural Affairs.

In the past (1983-85), several problems developed during funded projects at Acoma. Asphalt emulsion stabilized (waterproof) adobe bricks were used for reconstruction and repair is one example. Although the Acoma builders believed this material to be a more durable brick than the original plain mud type, the final wall finish was to be of natural mud plaster, which would not adhere to the asphalt surface, and eroded in a matter of weeks. Other non-historic features installed without prior official approval were wall buttresses placed to reinforce sagging historic walls. Window groupings that had no historical justification and modern style doors were installed. In response to these problematic alterations, the Historic Preservation Division required that Acoma Pueblo employ an architectural consulting firm experienced in preservation and skilled in adobe technology. The author's firm, Paul G. McHenry, Jr. and Associates, Architects, was selected to mitigate past mistakes and to provide guidance and supervision for the future reconstruction and rehabilitation of Area "C", one of a number of designated areas at Acoma.

Mud plaster erosion from asphalt stabilized adobe bricks.

Architectural elements without historical background; buttresses and side by side windows.

Preservation standards related to these projects were affected by the following factors:

1. The Acomas are a proud and independent people who strongly resist any efforts to control or influence them, and they view Acoma as their private domain. Outsiders are not welcome except as tourists or personal friends. Many of their religious activities exclude outsiders, and very few outsiders are welcome within the buildings. The crew that prepared the Historic American Buildings Survey noted this fact in 1934 and that access to some of the rooftops was limited as well.

2. Many of the Acomas do not live on the mesa top full time, and have homes in the valley below, closer to their farms and work, so the historic houses are used more for special ceremonial occasions than as primary residences. As a result, individual homeowners were not always readily available for consultation about preservation details for their home, although a growing number of families are living at Acoma on a full time basis. Individual homeowners were not always sympathetic with preservation ideals, and they want to install modern amenities of their own choosing.

3. The affairs of the pueblo are managed by a Governor and tribal Council who are elected each year. The Cacique is the religious leader. It is interesting to note that although the tribal officials are all male, Acoma is a matrilineal society, so title to the home is held by the woman of the family.

4. The budget for rehabilitation as originally conceived by tribal planners was intended for the employment of tribal members, so any expenditure outside the pueblo was strongly resisted.

Resolution

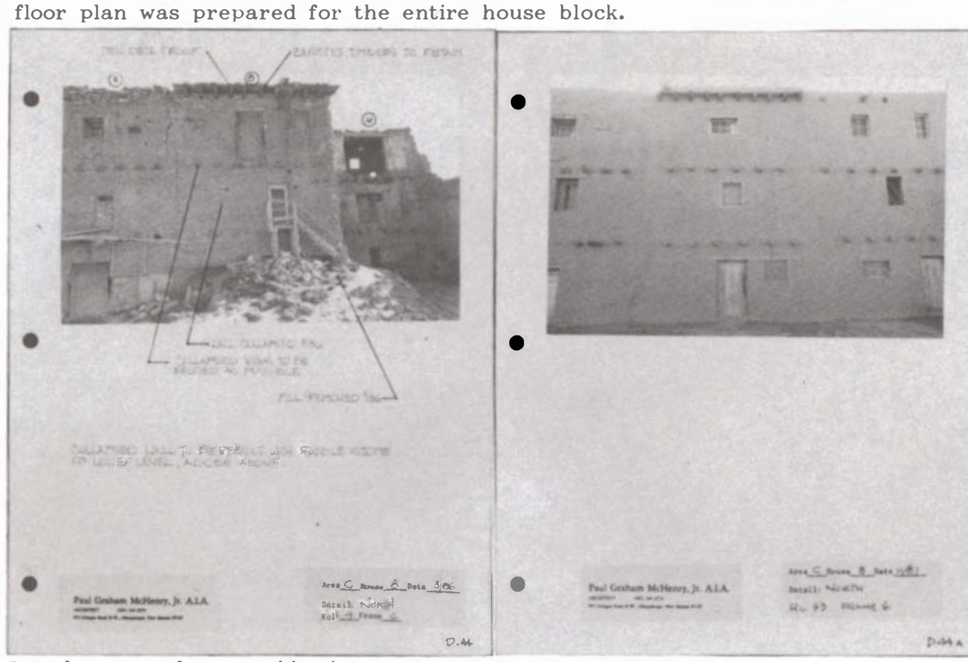
The primary conflict in the implementation of this project was one of attitudes: a resentment by the Acomas when they were told by preservation oversight authorities that they must do the rehabilitation in a certain way or lose their funding; a lack of sensitivity on the part of historic preservation authorities to the needs and desires of the private owners, to which the owners were entitled.

Initially, a common attitude on the part of the Acoma leaders was that they knew more about their building technology than outsiders, and unfortunate past experiences with "expert" consultants had reinforced this attitude. They did not realize that, although many of the construction crew were skilled in modern building techniques, their earthbuilding skills had been diminished or lost through time and lack of use.

The problem of the mud plaster and asphalt bricks could not totally be resolved, but an improved and more durable mixture was developed. Bruce McHenry of the architect's staff, an expert on mud plaster, discovered that the soil mixture being used was faulty: the main ingredient was "blow sand". The rounded particles of blow sand (as opposed to the angular particles of "sharp sand") would not interlock with each another to create a consolidated mass. By the substitution of coarser, more granular sand particles, which the Acoma crew called "gravel", a much more durable mud plaster could be achieved. Through experimentation, demonstration, and the active involvement of the architects, staff, and construction crews, many lost skills were regained by the Acomas and a team effort was created.

A major point of disagreement and conflict was the retention of the earth floors on the upper levels. These were historic features of great interest, and which had value in an archaeological context, but the owners did not want dirt floors. The floors were unpleasant to live with, smelled terrible when disturbed, and were unsanitary, carrying the refuse of centuries. The final result was that many earth floors were removed. Construction scheduling and lack of proper budgeting dictated that only minimal archaeological investigation would be done. The archaeology was done by an Acoma archaeologist with only a few weeks training, and who received only minimal cooperation from the construction crews. The archaeologic investigation consisted of a small number of test pits and the stockpiling of the earth material removed for later examination. Artifacts found were returned to the home owners for their disposal. The conflicts could have been mitigated by additional planning and consultation leavened with sympathetic attention to the owner's needs.

In order to minimize the costs required for architectural planning and documentation and to meet the Standards, an innovative approach was required. A simple photo and drawing scheme was proposed by the architect to create a project "workbook" with pages for each individual house. The photography was done at minimum expense using 35mm black-and-white film. Each photo used for the workbook was enlarged to a 5" x 7" print and mounted on an 8-1/2" x 11" sheet of paper which was incorporated in the work book. Additional photos were taken of significant interior details and elevations after completion to provide full photo documentation. A floor plan and front/rear elevations were drawn approximately to scale for each level of each house, prepared from aerial photos and limited field measurements. These were grouped in sections of the workbook appropriate to each house unit. An overall elevation drawing and floor plan was prepared for the entire house block.



Sample pages from workbook.

Originally each detail required approval by the New Mexico Historic Preservation Division Office prior to construction. The the difficulty in gaining entrance to individual houses, obtaining the advice and approval of the owner, and construction scheduling made this unworkable. Therefore, a plan was adopted to request approval in principle of the overall plan, with smaller details left to the discretion of the architect and the construction foreman.

Additional sections of the workbook included standard details of expected repairs common to several buildings, drawn in an isometric style for easier understanding by the construction crews. A section for historic photos was created with suggested approximate photo points. Before and after photos also proved beneficial. This system accomplished two necessary steps: documentation of condition of the monument, and simple directions for repairs and improvements at minimal cost and complication.

The participation of individual homeowners in determining the nature and extent of preservation of their homes was paramount. As individual homeowners, they are entitled to do anything they wish to do using their own funds. There are no regulations to control the owner's choice of style or architectural elements at this time, although community leaders have debated the merits of such a regulation.

In order to achieve maximum results in historic preservation for this and future projects, it was vital to seek the support of the construction crew leaders. Preservationists take the position that as this work is being done with Federal funds, the Acomas could be told exactly what they must do. What was overlooked was the fact that this was a "rehabilitation" project to improve the safety and livability of these peoples homes, as compared to a "preservation" project, which would have much more stringent disciplines.

Area "C" north side, before rehabilitation.

With the approach taken, most of the preservation goals were achieved, and the substance of the resource preserved. Unfortunately, some historic features were lost or replaced, such as adobe walls, doors, and windows that were considered unrepairable. Salvage was claimed by the owners, who disposed of it as they saw fit. Most of the original dirt floors were replaced at the insistence of the owners. This change was generated for sanitation reasons, and could be partly justified by the fact that these were interior features which would not be seen by the public.

The Secretary of the Interior's Standards for Rehabilitation is a remarkable document in that it wisely anticipates and provides for resolution of conflicts such as were experienced on this project. Key phrases in the ten "standards" include: "...every reasonable effort...,...avoided when possible...,...may have taken place...,...wherever possible...", etc.

Conclusions and Recommendations

1. A clear choice must be made during the planning stages of a historic site project between "Historic Preservation" and "Rehabilitation" standards, which are very different approaches. The former not only implies, but requires heroic measures which can be very costly, and the latter provides some practical flexibility. Perhaps the only suitable subjects for true historic preservation are those owned by a government agency, or whose title and control are held by an entity dedicated to its pristine preservation without regard for personal profit or third party motives.

2. Funding for any preservation/rehabilitation project should be made available in two discrete phases. The first phase should include funding for detailed investigation and determination of probable costs by qualified personnel or consultants. The second phase provides funding for the actual project, and should include contingency allowances. Such dual phase funding would allow a realistic assessment of probable costs and alternatives prior to determination of final goals and costs. Unfortunately, funding for many current projects is allocated prior to the determination of specific goals, and the competition for these available funds can skew the final results unnecessarily.

3. Local zoning laws, regulations or recommendations should be established and put in place by the people who would benefit, so that it would not be viewed as outside interference in local affairs.

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THE STUDY OF ACCELERATED CARBONATION OF LIME-STABILIZED SOILS

Mário Mendonça de Oliveira * - Cybèle Celestino Santiago and Sílvia Pimenta d'Affonsêca
Faculdade de Arquitetura da Universidade Federal da Bahia
Rua Caetano Moura, 121 - Federação
40.210 - Salvador - Bahia - Brasil

ABSTRACT

Traditional mud brick technology represents an attractive alternative in the construction of low-cost structures.

Lime is one of the oldest substances used to stabilize earthen materials. Nineteenth century lime-stabilized mud brick found in Bahia has been subjected to laboratory analysis. Since analysis of lime -- $Ca(OH)_2$-- containing materials is difficult due to the slow time course of the carbonation process, a method of reducing the reaction period from months to a few days has been developed. This process has been used to test adobes stabilized with lime.

KEYWORDS

Soil-lime stabilization, accelerated carbonation, mud brick, earth walling, adobe, restoration of earthen materials.

Introduction

It is commonly assumed by those people who study the history of architecture that wood and mud were the first building materials to be used by men. Mud, which is a very cheap material, has been continuously used in many different and simple ways: by throwing it against a rudimentary frame made of wooden sticks, as amorphous mud bricks, as plano-convex adobe bricks [1], as lath-and-plaster wall, "pisé de terre", clay stuccoes, etc. Although these techniques were sometimes ephemeral, according to Vitruvius they had great prestige (especially in the case of adobes). [2]

The low cost of earthen constructions is important when developing alternative building techniques particularly in third world countries.

The performance of soil building materials depends not only on the composition of the minerals that constitute them but also on the granulometry of the aggregates, on the rate clay/inert materials and on such factors as the percent moisture content of the mixture.

The studies and analysis of ancient earthen materials demonstrate that our ancestors were familiar with the use of that technology. By experience and tradition, they were able to produce materials of good stability with an optimal distribution of particles.

In Brazil, the use of simple building techniques with earthen materials dates from the colonial period (sixteenth century). Contrary to other native peoples in the Americas, Brazilian Indians were not very familiar with earthen materials. They preferred wood and palm leaves as building materials. Old documents contain much information concerning the use of lath-and-plaster and "pisé de terre". These documents describe the preparation of a plastic mixture of clay, aggregate, and water which was then thrown against a frame of horizontal and vertical sticks of wood, tied with liana or, rarely, with leather ropes. This technique is still used today by poor people (who make up the majority in Brazil) living in the country and in the peripheral areas of cities.

Salvador, the first national capital of Brazil, was founded in 1549. At the beginning, a wooden fence protected the city, but as it was very weak, the wood was later replaced with "pisé de terre", a technique as old as the lath-and-plaster wall. Unfortunately, the second wall did not last long in the tropical rains and it too has disappeared.

Friar Jaboatão, a well-known chronicler of early Brazil, has described the walls which surrounded the city of Salvador as "made of good and thick earth wall". [3] Nevertheless, it seems to us that he alone believed in the quality of this wall. Gabriel Soares, another chronicler from Brazil, for instance, wrote that "the walls have crumbled because they had been constructed in pisé de terre". [4]

Luiz Dias, the master of works responsible for the planning and construction of the city of Salvador, did not have much faith in the efficiency of these walls. We reach this conclusion from comments he made in one of the letters he sent to Portugal: "using the dart I had in my own hands I was able to destroy them very easily. He has also pointed out that the walls were much too high considering the fact that they had been made in pisé de terre without lime". [5] This comment confirms that lime was used as a stabilizer since the beginning of colonization. This method of construction was brought by the Portuguese to the colony. The "technological appropriation" [6] of an old tradition is fundamental to our research. In general, there is no reference in the history of architecture in Brazil to the use of lime as a stabilizing element. "The use of the technique of pisé de terre was more diffuse in the states of São Paulo and Goiás [7], but it was also used in Minas Gerais and Bahia. In Salvador (Bahia), it was

* Author to whom correspondence should be addressed

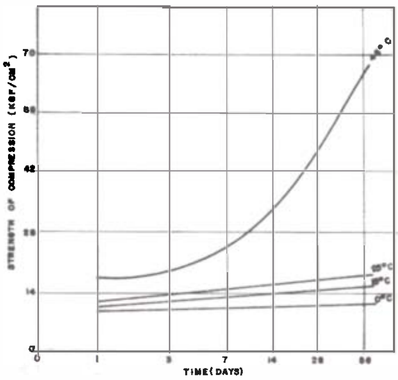

Fig. 1 - Effect of time and temperature in the process of soil-lime stabilization. 5% $Ca(OH)_2$

used primitively in its walls and other constructions. Later, this technique was put aside and replaced by the lath-and-plaster technique, which is simpler to execute. Nowadays, it is very difficult to find craftsmen ("taipeiros") who know the method of building in "pisé de terre".

In ancient times, the use of adobe was also very common throughout Brazil. Even though its use still persists in the construction of low-cost houses, people prefer to build their houses using lath-and-plaster.

Soil Stabilization

The study of soil stabilization in the conservation/restoration of monuments and archeological sites is very important. It is also appropriate to the construction of low-cost buildings. Portland cement was responsible for the introduction of a very efficient stabilizer in construction. On the other hand, its use in conservation must be very restricted. This is because it contains soluble salts, which can be dangerous to the monument. Also because its high strength is incompatible with earth. It is necessary, therefore, to use a stabilizer for coating the tops of walls, ruins, and other earthen structures to increase durability. There are additives of traditional or modern use (cattle dung, sugar, straw, blood, etc.) that can also be employed.

The use of cement has spread since last century. In Brazil, for example, modern architecture is based on the use of this material. In addition to the disadvantages mentioned above, there is also the problem of supply. The opposite is true for lime. It is much simpler to prepare and, in some areas of the country there are numerous lime quarries and still a rudimentary production of the material is possible.

It is interesting to note that in spite of not being completely understood by the specialists until now, the process of soil stabilization with lime is considered by them as technologically and culturally adequate in the conservation/restoration of earthen structures.

It stands to reason that in a single mixture of soil and water -- as is the case with adobes, "pisé de terre", and lath-and-plaster walls -- the reactions are dependent on the activity and surface area of clay particles. The smaller the particles, the more reactive they are. Thus, clay particles are more reactive than larger silt particles. Sand grains are bigger than the latter and are inert. In the case of soil-lime, some characteristic chemical reactions occur. Some of them are directly related to the laminar structure of the clays and to the distance between strata. This means that the reactivity of the product will change as a function of the kind of clay that predominates in the soil and the spaces between the layers.

"In the presence of water, the cations (mainly Ca^{++}, and sometimes Mg^{++}) originating from the lime cause the saturation of the clay minerals in the soil. Thus, the properties that depend on the charge and the superficial status of the particles (limits of consistence) are suddenly modified. In some aspects, the interchangeable cations enjoin the bonds between the clay particles and the way they gather, modifying their hydric-mechanic behavior". [8]

"The reactive phenomenum causes the appearance of silicates, aluminates and aluminum-silicates of hydrated calcium, substances that present cementing conditions. Specialists suggest that some of these reactions happen suddenly". [9]

Other reactions occur after longer periods of time. In all cases, time and temperature have a direct influence on the reactions (Fig. 1).

A symposium on soil-lime was recently held at CEPED. [10] The specialists divided the phenomena of stabilization in two groups:

a) Fast reactions
   - Cation exchange
   - Absorption of $Ca(OH)_2$ molecules
   - Ion crowding

b) Slow reactions
   - Siliceous cementation
   - Aluminous cementation
   - Ferreous cementation
   - Carbonation

We have developed at the NTPR [11] a process of accelerated carbonation in lime-containing mortars. Our intention now is to apply this process to verify how the phenomenum of carbonation contributes to the process of stabilization increasing the mechanical characteristics of the soil. Carbonation is one of the slow reactions that occur when stabilizing a soil with lime. Thus, accelerating this process we will save time when observing the phenomenum.

Time is not as important as temperature (Fig. 1) in the development of mechanical strength in the first phase of the process of lime stabilizing soils (fast reactions). As the slow reactions need years to be completed, the effects of carbonation will only be noticed after a long period. Then, it is very important to our research to speed these reactions in order to get through the first results in a short time.

The Stabilized Adobes from Cows' Island ("Ilha das Vacas") in Bahia

We have been in charge of the restoration of a nineteenth century house located on Cows' Island. During the survey that preceded the restoration of this building, we were lucky to find an internal wall made of mud bricks. This discovery aroused our curiosity because initial inspection suggested that the adobes had signs of a lime additive.

A spot test was conducted in our lab. It proved our field observations to be correct. The bricks contain a very precarious lime that was probably prepared "in situ" by crushing and burning seashells. In the "Recôncavo", an area in the "Todos os Santos" Bay, Bahia, there was a tradition of using seashell lime. [12] This is a product of high quality, although there is the inconvenience of the presence of soluble salts if the material is not well washed. As we have found some pieces of shell within the ancient adobe, we can assume that the shells had not been well burned.

Historical research provides us with documentation on the use of lime-stabilized soil in Bahia (e.g., Mr. Dias' letter). This is the first discovery of an actual sample supported by further laboratory analysis.

Although the text written by Prof. Silvio de Vasconcelos is considered a classic on the history of building materials in Brazil, there is no reference to the use of lime as a stabilizing additive. He mentions other additives, odder than that one: "For that reason, it is possible to find dung (basically from bullock cattle) mixed with vegetal fibers or animal hair, in order to reinforce the mud with an interior frame. There is also the tradition of the use of ox blood as an agglutinant element". [13]

According to the historical record, the stabilized mud bricks we found also belong to the nineteenth century.

The characteristics of the material we have found are the following:

Bulk density - 1,806 g/cm^3

Granulometry:		ASTM	ABNT (Brazil)
Gravel		13%	5%
Sand	Coarse	9%	8%
	Medium	13%	12%
	Fine	22%	34%
Silt		22%	16%
Clay		21%	25%

Classification:
USCS: SC AASHTO: A-6 (3)
USCS: Unified Soil Classification System
AASHTO: American Association of State Highway Transport Officials
WL = 32% (liquid limit)
WP = 19% (plastic limit)
IP = 13% (plasticity index)
Percentage of $CaCO_3$ = 20.54
pH= 8.38. It indicates that almost all the calcium hydroxide used in preparing the bricks had been carbonated, i.e. converted into calcium carbonate by reaction with carbon dioxide from the atmosphere.

The Process of Accelerated Carbonation

It is obvious that the carbonation of calcium hydroxide always presents a problem when performing laboratory analysis. Thus, we have developed in the NTPR a very simple technique for carbonating lime-containing samples. The fundamental ingredients are CO_2 and

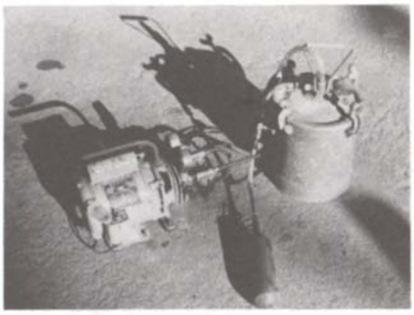

Fig. 2 - First prototype of our accelerated carbonation chamber

Fig. 3 - Second prototype of the chamber

water. In order to accelerate the process of lime carbonation, an hermetically closed carbonation chamber was created (Fig. 2, 3). Our first prototype was a pressure container used for painting, which had a metal frame inside to support the samples. In order to maintain an atmosphere saturated with water vapor, it was necessary to provide a layer of water below the frame. A vacuum pump was used for twelve hours in order to remove the air from inside the pores of the samples. Then the pressure was stabilized allowing the introduction of CO_2. We used gas from fire-extinguishers, so the costs of the equipment and the operation were very low.

The efficiency of the process can be proved through the results below: .

LIME / SAND	REACTION TIME	STRENGTH Kgf / cm^2	
1 : 2	4 months (normal exp.)	7.00	11.78
	6 months (normal exp.)	23.20	11.83
	acc. (15 days)*	64.15	53.24
1 : 3	4 months (normal exp.)	9.34	9.30
	6 months (normal exp.)	18.05	14.72
	acc. (15 days)*	27.55	29.07

* Humid, in a high CO_2 concentration.

Soil from CEPED

WL = 45,2%
WP = 20,7%
IP = 24,5%

SAMPLE	REACTION TIME 12 days	STABILIZER	STRENGTH Kgf/cm^2	OBSERVATION
A	stove (35°C)	---	5,34	
B	stove (35°C)	8% $Ca(OH)_2$	9,40	
C	accelerated-CO_2	8% $Ca(OH)_2$	18,43	acc. 5 days

Analysing the samples before and after the carbonation process, no substantial change in color has been recorded. From our point of view, the small changes that are noticeable will be useful for characterizing the intervention, as is normally required for doing any restoration work.

Conclusions

The use of lime as a stabilizer of earthen structures is admitted with other stabilizers because it is a "technological appropriation" of an old tradition; it makes possible the use of local labor; and it improves the mechanical characteristics of the material.

There should be no substantial changes in texture and color of the adobe if lime is used in a low percentage -- 3 to 8 % -- as recommended by CRAterre. [14]

According to specialists, the function of lime when stabilizing soils is basically connected to the reactions with clay minerals. In addition to this, we have observed that the carbonation process is also remarkable to the increase of mechanical characteristics of stabilized soils, despite the use of small quantities of lime.

Acknowledgements

We thank André Lyra and Prof. Luis Carlos Dourado (NTPR), CEPED, "Laboratorio de Geotecnia" - Engineering School (UFBa), Gilda Sento Sé, Prof. Carter Hudgings and Fernando Santiago Jr. for their collaboration.

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"And there are so many oysters in Bahia and in other parts that it is common to load huge boats with their shells in order to prepare lime. Lime which is prepared from these shells is very good for building purposes. It is also very white".

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ABSTRACT

Curahuara de Carangas is located 4,000 meters above sea level in a remote area of the Bolivian altiplano near Chile. This adobe structure consists of a single long nave and three smaller rooms. The thick walls are supported by massive buttresses. Interior surfaces are covered with Biblical murals in tempera on lime wash. Some are dated 1608; others bear the signature and date, " Ignacio Martine de Lima, 1777."

Local Indians have provided care and preservation for centuries. However economic changes have led to the church's deterioration. In 1984 the Bolivian Institute of Culture, with UNESCO support, began site preservation in a project that incorporated local workers into the church's restoration. The churchyard was cleared; the wood, reed, and thatch roof reconstructed; and the adobe walls stabilized and whitewashed.

The project combined efforts of architects, art conservators, and local craftsmen who are descendants of the original builders. Work was carried out using traditional skills originally used to construct the church.

Murals were consolidated with polyvinyl alcohol and Acryloid B-72 and cleaned with soft erasers. A sensitive approach was taken with respect to exterior structural forms and interior decorative schemes, while meeting the community's need for a functioning church.

KEYWORDS

Bolivian Altiplano, Colonial Architecture, Adobe and Mural Conservation, Acryloid B-72

RESTORATION OF THE SIXTEENTH CENTURY CHURCH AT CURAHUARA DE CARANGAS, BOLIVIA: A CASE STUDY

Carlos Rua and Anton Rajer
1508 South 14
Sheboygan, Wisconsin, 53081
USA

Located on an arid high plain in the western region of Oruro, Bolivia, the sixteenth century adobe church at Curahuara de Carangas lies at 4,000 meters above sea level. The area has been occupied since pre-Columbian times, when the area's population density was higher than it is now.

Decoration and Importance

One great value of the church at Curahuara lies in the fact that its entire interior is decorated with murals. Virtually hundreds of square meters of walls and ceiling are painted in a medium of tempera on lime wash. The murals in the presbytery are dated "1608." Others in the church bear the signature and inscription "Ignacio Martine de Lima 1777." The oldest and most complete group of their type preserved in the South America, the murals constitute an important monument of Bolivian cultural patrimony. Pictorial themes derive from the Bible, such as scenes of the Last Judgment, the Flood, and the expulsion of Adam and Eve from the Garden of Eden. Ceiling decoration consists of portraits of the 12 apostles and Christ in the presbytery above the altar (the 1608 murals) and floral decoration elsewhere (see figure 1).

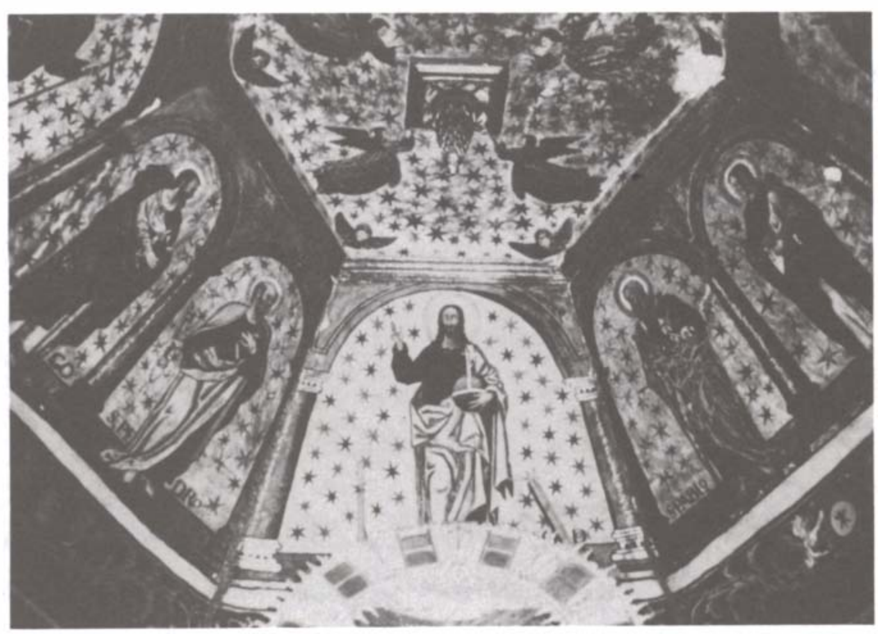


FIGURE 1. Ceiling decoration portrait of Christ flanked by the apostles.

Materials and Construction

Mud brick has been used in this area for centuries, as attested by nearby pre-Incan tombs constructed of the material. The site of the church at Curahuara is slightly sloping, with a 2 percent grade from east to west. Built at the end of the sixteenth century, this is a typical Renaissance church of the early Spanish colonial altiplano period. The interior consists of a single long nave, a sacristy, a baptistry, and a presbytery. A separate bell tower stands within the churchyard (see figures 2, 3).

The thickness of the church's walls varies greatly but tends overall to be approximately 1 meter. Some of the buttressed walls are 4.5 meters thick, including their supports. The standard size of the original bricks is about 30 cm x 60 cm x 6 cm. At the time of construction the exterior and interior walls were covered completely with lime wash. The roof is made of wooden beams with reeds and bamboo affixed to them; thatch forms the outer layer. In addition, the buttress tops were covered with a type of reed "shingles" to reduce weathering.

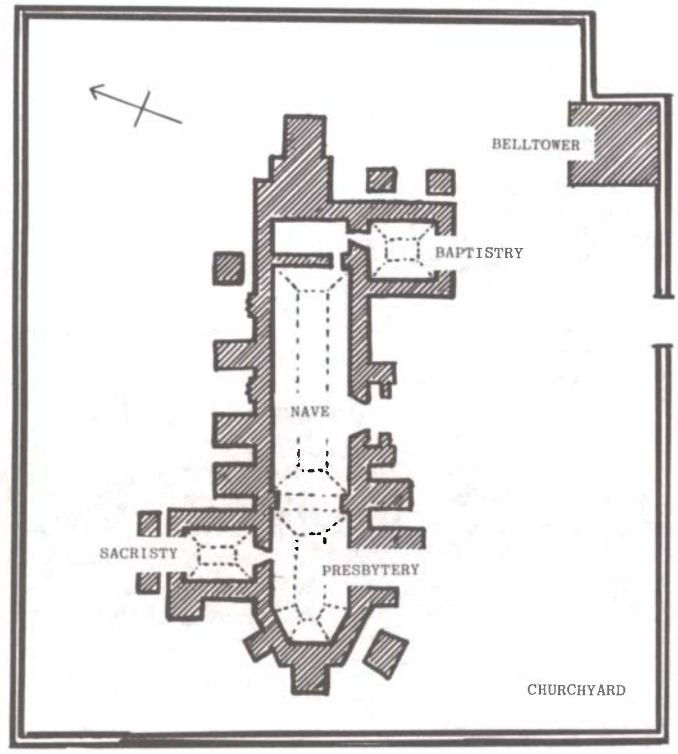


FIGURE 2. Plan of the church at Curahuara de Carangas.

Historical upkeep and restoration strategy

Construction of the church in colonial times was accomplished by workers from ten local Indian communities. Throughout the centuries these same communities were charged with the church's care in perpetuity and have continued it to this day. However, the church has fallen into disrepair in recent decades because of declining population and an exodus from this impoverished rural area. Remaining members of each of the ten communities have taken responsibility for the upkeep of a specific part of the building, such as the entrance portal or the baptistry. This system of care and upkeep was integrated into the recent restoration project: each community was responsible for restoration work on their assigned portion of the building, under direction of the Bolivian Institute of Culture (IBC) architect. Thus this project was unique in that it employed descendants of the original builders to carry out the restoration, using traditional, time-honored skills.

Pre-project planning

Curahuara's isolation necessitated thorough planning before realization of the project. In the early 1980s the IBC, which is charged with cultural patrimony care in Bolivia, began to survey the site. It conducted an inventory of the church's paintings and con-

FIGURE 3. Exterior view of the church at Curahuara de Carangas.

tents, as part of the Bolivian Cultural Patrimony Inventory Project, to be included in the country's national register. The document that grew out of this project strongly recommended emergency conservation work as it appeared portions of the structure were in danger of collapse, and the roof over the baptistry leaked seriously during the rainy season.

The institute sought funding from the West German government through .UNESCO/PNUD (Projecto Naciones Unidas de Desarrollo) for this three-phase project. Economic and technical constraints necessitated extension of the project over a period of five years. The economic constraints derived from limited available yearly funding. The technical constraints were associated with limits on the institute's art conservation staff, the availability of supplies, the complex logistics of transporting materials and staff to the remote site, and the coordination of work with the Curahuara native community.

Timing of each phase of the project had to coincide with the spring and fall dry seasons. The site's only access road is unpaved and is virtually impassable during the rains. Most construction materials had to be brought to the site. The community of Curahuara is adjacent to a small army base. The community is without electricity or running water. IBC staff decided to seek the assistance of the army camp—which shares two walls in common with the churchyard—in the project. The only communications links between Curahuara and the rest of Bolivia are through the base radio. The military also assisted with labor, transport of materials, and other logistics.

Mud brick fabrication

The making of mud brick in the Bolivian altiplano can only be accomplished during short periods in the spring and fall when drying conditions are optimum. It can be made neither in the bitter temperatures of winter—it will freeze and crack—nor during the rainy summer season—it will not dry. The technology of making new bricks to replace damaged ones was provided by local craftsmen, expert in this type of construction, but always with an architect's oversight. Men are primarily responsible for making the brick, though women will assist by gathering straw.

Testing for different textural fractions of the adobe yielded a stratigraphy of four layers. Small pebbles settled to the bottom of the test vial and were covered by a layer of clay. A stratum of sand overlaid the clay, while fragments of straw floated to the top of the water used to fractionalize the adobe sample. These results indicate the adobe was fabricated from at least two types of local soil and amounts of local grasses. Further analysis with standard microscopy could reveal more about the material components of the adobe.

Phases of Treatment

Each of the project's three phases lasted about two or three months. Each phase was designed to be capable of being completed in the projected time frame and also to be complete unto itself, although complementary to the other phases.

Phase I. Phase I began in 1984 and consisted of clearing the churchyard of debris, rebuilding the churchyard walls, conducting archaeological excavations, performing soil tests, and conserving wall murals. Also, emergency reconstruction was conducted on the principal interior arch between the sanctuary and nave; it had collapsed the previous year, as the IBC survey indicated it might, endangering the structural integrity of the roof. (see Figure 4).

Clearing the churchyard was an interesting communal event. Citizens from adjoining communities and military personnel worked together to remove trash and rubble and to reconstruct the churchyard walls. Archaeological excavation at the site was organized through the Bolivian Institute of Culture. Uncovered in one of the test pits was an pre-Columbian tomb with textiles and intact skeletal remains. Other, smaller tombs also were found. The excavations also assisted in determining soil stratigraphy, soil composition, and potential sites for new drainage pipes to carry runoff away from the church.

Interior consolidation of wall murals by IBC staff was planned with the solution of two different technical problems in mind. First, to solve the problem of adhesion between the adobe and plaster layers, polyvinyl alcohol was injected with syringes into the voids behind the plaster lime wash. Then, a 5% solution of Acryloid B-72 in toluene was brushed onto the murals to consolidate the paint layer. IBC staff were careful to wear masks to protect them from solvent exposure. It had been suggested that epoxy

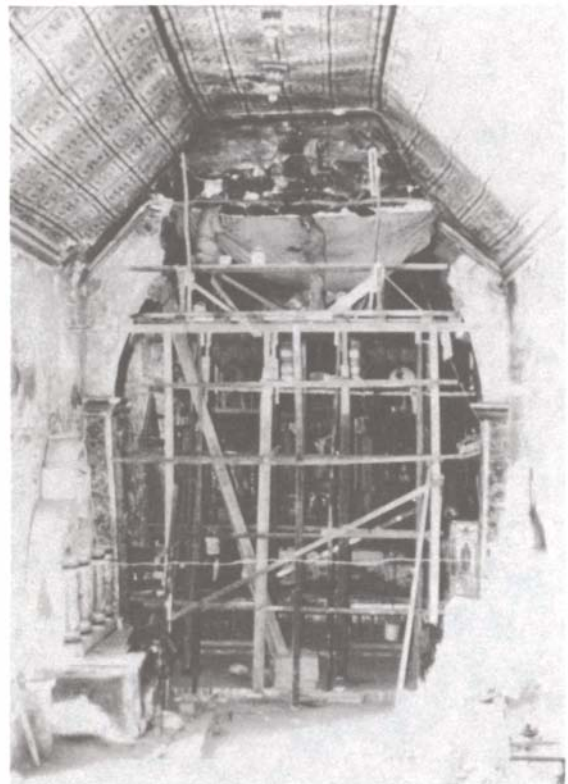


FIGURE 4. Reconstructing the presbytery arch.

might be used to solve the problem of readhering the plaster to the adobe. This idea was discarded because epoxy's high viscosity and quicker drying time made it less suitable than the thinner polyvinyl alcohol, which permitted multiple applications and therefore created better adhesion.

After the surface of the murals dried, IBC staff cleaned them with gum erasers. Owing to constraints of time and resources, no inpainting was performed on the murals, although backgrounds were toned to match surrounding areas.

Reconstructing the presbytery arch formed the most challenging aspect of this phase. Wooden scaffolding and braces were erected to prevent further collapse. An iron rod was inserted between the wall supports to strengthen the walls' integrity and to form a skeleton for the arch, which was rebuilt with mud bricks. The arch was whitewashed and toned to match the surrounding decorative scheme. Because of the site's extensive structural needs, inpainting was confined only to areas in which it was required to reconstruct visual unity. Many areas were stabilized but not inpainted.

Phase II . This portion of the project took place in 1985, when the church exterior was cleaned and resurfaced and the roof replaced. The exterior was swept clean with brooms of local manufacture, then resurfaced with adobe mortar and painted with lime wash. Replacement of the roof involved approximately 100 laborers from the ten neighboring communities, who were employed to make mud brick and cut reeds and grass. Soldiers assisted with the transportation of materials from the lowlands: bamboo and trees of substantial girth do not live in the altiplano, and thus needed to be transported to the site.

Once again, traditional native construction technologies were used. Reeds were gathered by women and children, and heavy construction was done by male craftsmen. Craftsmen prepared new bricks in wooden molds, let them dry and installed them. Bricks were joined with mud mortar and later whitewashed with lime. A few modern materials were used; they complemented and were compatible with the original, locally available and financially feasible ones. For example, wire mesh reinforced the roofing thatch, and zinc flashing directed rain runoff.

Although the roof had been renewed periodically over the centuries—mostly on an emergency basis—its degraded condition mandated it be replaced entirely, including some deteriorated beams, one section at a time. Wooden support beams were set into adobe at the top of the walls. Next, bamboo reeds were secured to the beams; the wire mesh was applied to the reeds as a base upon which to attach the thatch. Interior and exterior views of the completed roof indicated it was identical in appearance to the original.

Phase III. The major effort during this phase of the project, in 1987, was the cleaning and stabilization of the free-standing bell tower, located in one corner of the churchyard adjacent to the army camp. Again traditional technology was used to stabilize mud brick with mud mortar and lime whitewash.

Drainage pipes were installed in the churchyard and drainage stones excavated at the exterior base of the church walls. These flat stones probably date to the construction of the building and were designed as part of the water runoff system.

Future site preservation agenda

The project ended with completion of the 1987 restoration season, although more work remains to be done, such as restoration of the main altar. The local communities, whose ancestors built the church, were again charged with the church's upkeep. Religious ceremonies continue to be performed in the church on a limited basis; Curahuara lacks a permanent priest.

Visiting IBC staff continue regular monitoring of the site. Any earthen architectural artifact requires careful attention and constant care. Recently one large buttress had to be renewed. However, two major problems threaten preservation of the church. As the native population declines, the time-honored system of communities providing its upkeep is endangered. Also, the potential rerouting of the Chile-Bolivia highway would effectively cut Curahuara off from outside traffic which currently passes the town on its way to the Chilean border. Moving the highway would also necessitate moving the military base, which the town depends on in many ways for its survival.

On the hopeful side, the project at Curahuara has served as a role model for other remote colonial adobe sites at Carabuco and Caquiaviri, where similar problems have been encountered, similar treatment methods have been employed, and the strategy of integrating local communities into restoration projects have been used with equal success.

Analytical work on cross-sections of paint layers and identification of materials from the Curahuara site continues. Analysis of the cross-sections will be forthcoming.

Conclusion

The church at Curahuara in the Bolivian altiplano is famed for its early colonial murals, the most complete grouping from this period in all South America. Throughout the centuries native descendants of the builders were charged with its care and preservation, but the church has degraded much in recent decades owing to the economic problems in the region. A recent site survey by the Bolivian Institute of Culture identified needs and proposed international assistance, which was forthcoming through UNESCO. In a three-phase project, IBC staff, local craftsmen, and military workers cleared the site, replaced the roof, cleaned and stabilized the murals, replaced adobe, and whitewashed the walls of the church and free-standing belltower. The project was unique in that it integrated IBC professionals, local craftsmen, and the military. The church has been and continues to be a source of historical importance and community pride at this remote site.

ANALYSES AND CONSERVATION OF PUEBLO ARCHITECTURAL FINISHES IN THE AMERICAN SOUTHWEST

Constance S. Silver
949 West End Ave.
New York, NY 10025
USA

ABSTRACT

The southwestern region (Southwest) of the United States preserves an important patrimony of architectural finishes composed of and executed on earth-based renderings. These finishes, plain renderings (e.g. "plaster") and mural paintings, have been employed extensively by the prehistoric and historic Pueblo peoples (Native Americans) of the Southwest on their complex domestic and ceremonial architecture. This paper summarizes three areas of research on Pueblo finishes, concentrating on the Pueblo III period (A.D. 1100-1300):

1. Laboratory analyses. Samples of Pueblo renderings were analyzed with methods developed by the National Bureau of Standards. Much of the resulting data was unexpected.

2. Simulation of murals to test detachment methods. Simulated Pueblo murals provided models for testing several techniques for detachment of finishes from threatened sites.

3. Pilot conservation treatments. The objective of the pilot conservation treatments was to develop methods for stabilization of finishes on site in the Southwest. Minimally intrusive methods were stressed. A holistic approach to conservation is recommended.

KEYWORDS

Mural painting conservation, detachment of mural paintings, conservation of earthen renderings, analyses of adobe.

Pueblo Finishes: An Overview

The American Southwest includes the states of Arizona, Colorado, New Mexico, and Utah. The region is characterized by deserts and semi-arid steppes traversed by a few rivers and by mountain ranges that support pine forests. Winters are cold and relatively dry. Summers are hot and dry, but heavy rain storms are common. The Southwest lacks many resources. Over the centuries, intensive dry farming and river irrigation at lower altitudes have sustained native peoples.

By 1100 A.D., the prehistoric peoples of the Southwest had developed a complex architecture of earth, cut stone and mud mortar, timber roofing, and architectural finishes composed of earthen renderings. Prehistoric Pueblo culture and architecture culminated in the Pueblo III period (A.D. 1100-1300), exemplified by the remarkable "cliff dwellings," highly developed settlements of domestic structures, four-storey towers, plazas, and subterranean ceremonial kivas, constructed within natural rock shelters (See figs. 1, 2). Both ceremonial and non-ceremonial structures were finished with refined renderings composed of several superimposed strata.

Pueblo kivas were often painted with ritually significant mural paintings. Briefly described, a preparatory coarse-textured rendering (e.g. "brown coat") was applied to the masonry walls of the kiva, followed by a fine-textured finish rendering. The finish rendering was embellished with a variety of techniques, as seen in the Pueblo III kiva of site LA 17360, New Mexico (See figs. 3, 4). Color fields of white and red paint were applied as horizontal bands. Designs were then painted by brush or incised into the plaster. Painted impressions were also made of handprints. New murals were executed by superimposition of new finish rendering onto the existing mural painting, followed by painting.

Kiva murals, their technique of execution and cultural content, were studied extensively by Watson Smith in the 1930s and 1940s.(1) Indeed, Smith's research was so comprehensive that few subsequent anthropological and technical studies were undertaken until those carried out by the author and other researchers over the last decade.(2) This research has indicated that Pueblo builders also developed and employed a formal scheme of architectural embellishment. Although less complex than kiva murals, these finishes include simple renderings, white washes, colored washes (pink and red), bichrome designs (See fig. 5), and painted designs.

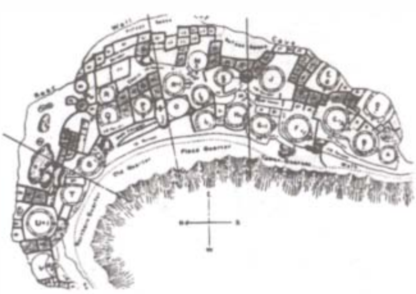
Smith made several important observations about Pueblo finishes. His analyses revealed the Pueblo palette to be a judicious use and mixture of naturally occurring pigments. Although no formal analyses were made of paint media, Smith's ethnographic models suggested many possible sources. Smith also observed that Pueblo architectural finishes and mortar are two different components of a wall; they differ in form, function and physical composition. Mortar is a structural component of masonry. For example, at the site of Awatovi, Arizona, mortar was composed primarily of "clay or adobe," with varying admixtures of sand. It was compact, cohesive, but coarse-textured, with a gray or green tinge. By contrast, the finishes applied to walls, especially in kivas, were composed of a fine-textured, reddish-brown rendering. Smith also observed that this rendering had excellent properties. It cracked and shrank only slightly after drying. While it was not totally waterproof, it did withstand considerable dampness and even some direct rain. However, it also had the capacity to be re-plasticized repeatedly by the addition of water. These observations by Smith pointed to a highly developed and selective use of earthen materials in architecture by Pueblo peoples. Further, the capacity of Pueblo renderings to be re-plasticized suggested minimally intrusive techniques for conservation of finishes on site, as will be described in a following section of this paper.

Pueblo Finishes: Analyses of Component Materials

In 1987, the author examined samples of Pueblo renderings and mural paintings with analytical methods established by the National Bureau of Standards to characterize adobe.(3) These analyses had three objectives: first, to expand understanding of prehistoric Pueblo technologies, specifically to ascertain if Pueblo finishes differ from structural adobe; second, to determine if Pueblo finishes have special properties which have contributed to their longevity and which might be used in conservation treatments; and third, to ensure that simulated murals used for testing detachment methods provided reasonably appropriate models.

The National Bureau of Standards recommends seven analytical methods for structural adobe. Samples were analyzed from sites in Arizona: Escalante Ruin, a prehistoric Pueblo site; Tumacacori, an eighteenth-century Spanish colonial church; soil adjacent to Tumacacori; and Fort Bowie, a nineteenth-century Fort. In 1987, the author analyzed renderings from the following sites: 1. Lowry Ruin, Colorado, mural painting from Kiva B (c. 1100 A.D.); 2. River House Ruin, Colorado, mural from a kiva (c. 1200 A.D.); 3. comparative sample of raw earth from a possible "adobe soil quarry," Mesa Verde National Park, Colorado; 4. comparative sample of a Pre-Columbian painted rendering from Cardal Lur, Peru; 5. comparative sample of nineteenth-century earthen rendering from Mission Santa Cruz, California; and 6. comparative sample of commercial raw adobe from Santa Fe, New Mexico. Due to the small size of the samples, two analyses could not be carried out, identification of soluble salts and evaluation of liquid and plastic limits. Analysis of organic media, omitted by the National Bureau of Standards, was included. The results of the analyses are summarized, including relevant analyses of structural adobe by the National Bureau of Standards.

1. Mesa Verde National Park. Cliff Palace, the largest cliff dwelling in North America.



2. Plan of Cliff Palace (Fewkes)

Analyses of Microfabric

The microfabrics were examined by the following methods: microscopic analyses of cross-sections in reflected light; thin sections in reflected light and polarizing light; and scanning electron microscope (SEM) photographs of cross-sections of rendering and paint.[4]

The Pueblo renderings closely resemble each other, although separated by 160 km and about 100 years. They exhibit a homogenous consistency, in marked contrast to the other samples.

Munsell Color Determinations

The Munsell Soil Color Charts (1975 edition) was used. However, the number of samples was too limited to permit general conclusions about consistency of color.

Determination of pH

A Hach Kit was used.[5] The results are compared to pH analyses of the structural adobes:

National Bureau of Standards Sample	pH
Escalante Adobe	8.19
Fort Bowie	8.72
Tumacacori Adobe	8.12
Tumacacori Soil	8.26

1987 Analyses of Renderings Sample	pH
Lowry Ruin	6.09 +-.02
River House Ruin	7.66
Cardal Lur	7.21
Mesa Verdè "Adobe" Soil	7.69
Santa Fe Commercial Adobe	8.20

The pH levels of the Pueblo renderings vary from slightly acidic to pH neutral, whereas the structural adobes are all somewhat basic, including the commercial adobe from Santa Fe. However, in this regard it is interesting to note that the sample from the possible "adobe soil quarry," Mesa Verde National Park, conforms to the pH range of the Pueblo renderings.

Determination of Particle Size Distribution

Particle size distribution was analyzed by Dr. Nicholas Coch, Department of Geology, Queens College, with state-of-the-art instrumentation.[6] Dr. Coch observed several unusual characteristics of Pueblo renderings:

> All samples had to be run again because of the continuous presence of aggregates in the coarse fractions of some of the samples. These samples were easily the hardest ones I have ever analyzed because of the very strong cementation between particles by iron oxide and clay. This required additional heavy physical disaggregation plus an adjustment of both the chemical disaggregation and the ultrasonic probe disruption of the sediment samples.

The results are compared to particle size distribution studies of the structural adobes:

National Bureau of Standards Samples Sample	Gravel	Sand	Silt	Clay
Escalante Adobe	(not analyzed)			
Fort Bowie Adobe	25	59	9	7
Tumacacori Adobe	5-8	65-80	8-12	8-12
Tumacacori Soil	2	24	26	
1987 Analyses of Renderings				
Lowry Ruin	.00	28.09	58.61	13.30
River House Ruin	.00	19.20	62.03	18.77
Mesa Verde "Adobe" Soil	.08	57.85	25.56	16.51
Santa Fe Commercial Adobe	5.32	41.85	18.27	34.56

The Pueblo renderings are distinctive and anomalous when compared to the other samples. Their particle size distributions are primarily in the silt and clay ranges--although the "clay" range does not automatically confirm the mineralogical presence of true clays.

Mineralogical Composition

X-ray diffraction was used. The Pueblo renderings and samples from the possible "adobe soil quarry," Mesa Verde National Park, tested negatively for the presence of mineralogical clay. These results were so surprising that the samples were tested independently with SEM X-ray analyses (SEM and EDS). Again, the results were negative for the presence of clay. There are two possible explanations. First, the samples may, indeed, contain no clay. Second, and more likely, there is a clay component but it is present in amounts too small to be detected by the X-ray diffraction analyses. That is, in general a mineral phase will not be detected if it comprises less than 10 percent of the total sample. To detect clay, the clay-size category of the particle size distribution should be analyzed separately for the Pueblo renderings.(7)

3. New Mexico, Site LA 17360. View of the kiva and its mural paintings.

Analyses of Organic Media

Histochemical stains were applied to the Pueblo renderings and paint.(8) Positive results for organic media in the paint layers were not unexpected. However, the presence of carbohydrates, lipids and proteins in the rendering from River House Ruin was unexpected:

Sample	Period Acid Schiff (carbohydrates)	Vangiesen Stain (proteins, usually collagen)	Xantho Protein Stain	Sudan Black (lipids)
Lowry Ruin Paint	Positive	Positive	Not Tested	Negative
Lowry Ruin Rendering	Negative	Negative	Negative	Negative
River House Ruin Rendering	Positive	Positive	Positive	Positive

4. Site LA 17360. Detail of the mural paintings.

Simulation of Pueblo Murals to Develop Methods for Detachment

Pueblo mural paintings have been detached by the *strappo* method, which removes only the pigmented layer from the rendering. *Strappo* can be time-consuming in the case of multiple strata, which must be removed individually. Consequently, murals have been lost when they could not be removed in a timely manner from threatened sites. Further, with the *strappo* method the original texture and optical qualities are lost with the destruction of the rendering.

The objective of the experimental program for detachment was to determine if available conservation materials can effect complete removal of rendering and painted strata by the *stacco* method: *stacco* entails detachment of rendering and paint as a unit.

To effect complete removal of a Pueblo mural, the soft, friable and laminated structure of rendering and paint layers must be transformed into a hardened and cohesive unit. Tests on samples indicated that the alkoxysilanes (ethyl silicate), partially polymerized ethyl silicates, and alkyl (alkoxy silanes), provided effective and thorough consolidation with minimal changes in optical qualities. Conservare OH(R) and Conservare H(R) produced the best results. Once consolidated, supportive facings can be adhered to the hardened surface of the mural, preparatory to separation of the rendering from the wall.

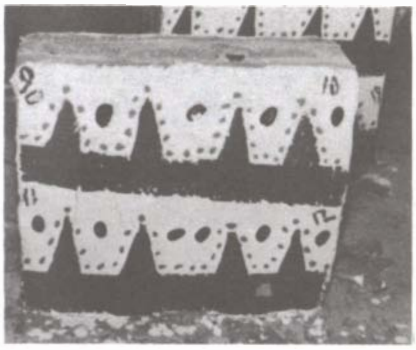
Four cement blocks, each measuring 45 cm by 40 cm, were covered with a rendering made from commercially available adobe. The adobe was sifted through a 1/15 cm screen, mixed with water and sand, and applied by hand in several strata, to create a total thickness of about 1.3 cm. Although the consistency of this rendering did not conform to the analyzed prehistoric Pueblo renderings, it did provide an adequate model for test purposes.

5. Mesa Verde National Park. Spruce Tree House, rendering painted with a bichrome design.

Each surface was divided into four sections, to create a total of 32 individual mural paintings of uniform composition and design, each measuring about 18 cm by 20 cm. Documented Pueblo pigments were used. The pigments were mixed with rabbit skin glue to create a workable paint. A kaolin-white color field was applied. A characteristic "dado" design was painted on the white field in iron-oxide red and yellow, and bone black (See fig. 6)

Unexpectedly large quantities of materials were required. About 36 kg of raw adobe earth were needed to create a satisfactory rendering that would cover 1.5 m^2 in a layer about 1.3 cm thick. About 1.36 kg of kaolin and 90 mL of rabbit skin glue were needed for each 1.5 m^2.

Murals 1-6 were left untreated, as controls. Murals 7-18 were consolidated with Conservare OH. Murals 19-32 were consolidated with Conservare H, which contains a hydrophobe. Various combinations of isolating coatings on the painted surfaces, facing fabrics, and adhesives for facing fabrics were tested. Adhesives and isolating materials included: polyvinyl alcohol; rabbit skin glue; Acryloid B 72; BEVA(R); Soluvar Matte(R); and Blair Spray Fix(R). Facing fabrics included: Japanese tissue paper; surgical gauze; crepeline; and monofilament. Each individual mural was treated with a different combination of these materials.



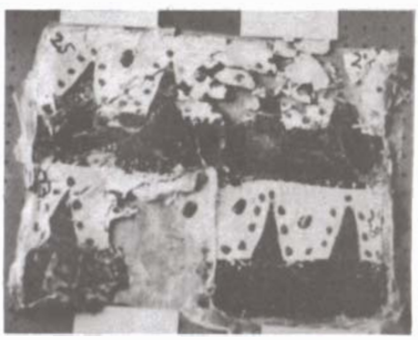
6. Simulated Pueblo mural paintings.

The faced murals were detached by separating the rendering from the block with a thin blade and hammer. The detached murals were adhered to a solid support. The facings were removed with appropriate solvents. The various combinations of materials produced a range of results from excellent (detachment of the mural intact and largely unchanged) to very poor (almost 50 percent loss of rendering and paint). The excellent results for Murals 14 and 28 were particularly interesting because the same isolating layer, Blair Spray Fix, and the same facing adhesive, polyvinyl alcohol, were employed. Conservare OH also increased the resistance of Mural 28 to the water-based polyvinyl alcohol (See fig. 7).

The experimental program indicated that detachment by stacco is possible. However, it has not been tested in the field. Therefore, its performance in the case of very thick, friable and delaminated murals is not clear.

Conservation of Finishes on Site in the Southwest

A series of pilot conservation treatments was carried out in 1981 at Mesa Verde National Park.(9) The objectives of the pilot treatments were to develop methods for the stabilization of deteriorated painted and unpainted Pueblo renderings on site in the Southwest. Mug House Ruin (MV 1229), a Pueblo III site, provided two representative examples: Kiva C, a subterranean circular kiva, and an above-ground wall that is semi-protected by the cliff overhang. Because the pilot treatments were similar, only the treatment of Kiva C is summarized.



7. Simulated Pueblo mural paintings, after detachment.

Kiva C was excavated in 1960, and it has remained exposed. There are about 10 superimposed layers of fine-textured renderings on the rougher preparatory rendering, creating a total thickness of about 2.5 cm. The visible mural painting is a white and red "dado" design.

Between 1960 and 1981, considerable deterioration had occurred. The murals that survived on the walls were very unstable. Several conservation problems were evident: detachment of rendering from wall; delamination between strata; friable rendering; friable rendering and paint; flaking paint; efflorescence of salts; root penetration; burrowing and abrasion by insects and rodents; and surface dirt.

The most serious conservation problem was the instability of the rendering and paint, so severe in some areas that the mural could not be touched without provoking further damage. In considering the rheological behavior of the rendering and paint, it was evident that water would be the most effective material for conservation treatment because it can relax and re-plasticize the brittle and deformed rendering to permit compaction and cohesion of the delaminated strata and their repositioning in plane as a unit on the wall. Water also reactivated the bond between the paint and the rendering. The pilot conservation treatment is summarized:

1. Wet-strength Japanese tissue was attached to the surface of the rendering, both painted and unpainted areas, with water that was applied by brush. The paper acts as a support and ensures that the surface remains protected during treatment. The area was lightly sprayed with water until the rendering had become malleable.

2. A 50:50 mixture of water and isopropyl alcohol was injected as a wetting agent between the rendering and the wall. A 25 percent solids polyvinyl acetate emulsion was injected into areas of detachment between the rendering and the wall, and between the second layer of preparatory rendering and the first layer of finish rendering. The adhesive was not in contact with any of the painted layers (See fig. 8).

3. The treated area was then pressed gently back into plane on the wall. Local pressure was used on the dampened rendering to compact the strata, renewing the cohesive strength and re-establishing continuous contact between paint, rendering and wall. During treatment, the surface of the mural remained generally visible through the Japanese paper, allowing the treatment to be monitored.

4. Simple presses, constructed from plywood and faced with foam rubber, were placed in contact with the treated areas, to maintain drying under pressure for 48 hours. The presses were held in place by wedging them with plywood shafts that were weighted at the ground with large rocks (See fig. 9).

5. After drying, the Japanese paper was removed. Some dirt was removed on the paper, but paint and rendering remained unaffected. With the exception of some very unstable flakes, the treated areas had become a cohesive unit secured to the wall.

6. Unstable flakes of paint were adhered with localized applications of Acryloid B 72, about 8 percent in toluene. Repeated applications of acetone removed surface residues; however, changes in optical qualities, primarily a deepening of tone, would be apparent if large areas were treated with resins.

7. A very friable area of rendering was treated with Tegovakon T(R), an alkoxysilane manufactured by Th. Goldschmidt. Conservare H and Conservare OH produce better results, but they were not readily available in the United States in 1981.

8. Efflorescence of salts were initially removed by light brushing with a sable brush. Tenacious salts were treated with a compress of paper pulp infused with a saturated solution of bicarbonate of soda. The compress remained in place for about 5 hours. Compresses of distilled water followed. About 50 percent of the salts were removed, with no damage to the rendering or paint.

8. On-site pilot conservation treatment. Injection of adhesive after facing with Japanese tissue.

9. Rotted roots were removed by standard mechanical methods, such as brushing.

Kiva C was re-examined in 1985. The treated murals had remained stable. This treatment reflects the author's bias in favor of minimally intrusive methods of conservation. Conservation is primarily effected by renewal of the correct rheology of the rendering through judicious use of water. The mural retains its original Native American character and the original optical qualities remain unaltered. Future conservation treatments are not compromised. The treatments are so simple that they can be implemented by any trained conservator. The cost of treatment is low.

Two caveats are in order. First polyvinyl acetate emulsion has been used extensively in the conservation of mural paintings. However, adhesives that better retain their chemical stability and permit some transmission of water should be developed. The question of biodeterioration of adhesives when used on site also requires further examination. Second, it must be understood that fragile Pueblo renderings and murals cannot be preserved, regardless of conservation treatment, if they remain subject to adverse environmental conditions. In the case of excavated kivas, conservation treatments must be followed by controlled backfilling. Several excellent methods and materials are now available for backfilling.

9. The treated area drying under pressure.

Conclusions and Recommendations

Although only a few samples were analyzed, the results suggest a highly refined and very selective technical tradition of Pueblo finishes. The possible absence of clay and the inclusion of organic media are particularly intriguing. Analyses of a similar mural painting tradition from Buddhist Central Asia resulted in precise identification of the sources of organic media.[10] Similar analyses of a large sample of Pueblo renderings might increase understanding of use of the limited resources of the Southwest by prehistoric Pueblo peoples. It might also be possible to incorporate traditional materials into future conservation treatments, thus maintaining consistent and compatible systems throughout a mural painting or rendering.

All detachment methods result in some damage to a mural. Changes in optical qualities occur. The ensemble of mural and architecture is disrupted. Therefore, detachment is always a treatment of last resort. The methods described in this paper for stacco provide a possible option for removal of murals from threatened sites.

Additional research is required to develop a specific adhesive adapted to reattachment of Pueblo renderings to walls on site in the Southwest. The acrylic emulsions may be good candidates.[11] In this regard, it should be noted that the adhesive need not be extremely strong to be effective. Indeed, an overly strong adhesive could promote mechanical stress. Rather, properties of ageing, biodeterioration and water transmission are more important considerations.

Following development of a more appropriate adhesive, a holistic approach to conservation should be implemented, controlled backfilling being an integral treatment for kivas.

Materials

BEVA. Developed in the late 1960s by Gustav Berger as an adhesive for relining canvas paintings. The basic composition is:

Elvax Resin Grade 150 (Dupont). . . .250 g
Ketone N. Resin (BASF). . . . . . . .150 g
Cellolyn 21 Resin Hercules. . . . . . 29 g
A-C 400 Copolymer (Allied Chemical) . 85 g
Paraffin Oil-Free (65 C° Melt Point) . 50 g

BEVA is available from Conservation Materials Ltd., 340 Freeport Blvd., Sparks, Nevada 89431, USA (702 331-0562).

Blair Spray Fix. Trade name of a nitrocellulose-based fixative. It contains nitocellulose resin, methylene chloride, alcohols, acetates, and ketones. It is made by Blair Art Products, Inc., Twinsburg, OH 44087 USA.

Conservare H and Conservare OH. The basic composition is 2-propanone, 2-butanone and tetraethylorthosilicate. Originally manufactured by Wacker-Chemie, Munich, Germany, these consolidants are available in the United States from ProSoCo, Inc., P.O. Box 1578, Kansas City, Kansas 66117 (913 281-2700).

Soluvar Matte. Soluvar and Soluvar Matte are acrylic resin varnishes, produced in the United States by Liquitex, Binney & Smith, Inc., Easton, PA 18005-0431. The principal component is isobutyl methacrylate polymer.

Tegovakon. Th. Goldschmidt, AG, Essen, Germany, has marketed five stone consolidants: Sandstone Consolidant, a two-component product containing ethyl silicate, methyl (triethoxy)silane, ethanol, and hydrochloric acid and water; Tegovakon, similar to Sandstone Consolidant; Tegovakon H, a two-component mixture of "silicon esters" and water-repellent; and Tegovakon GS, a single component similar to Tegovakon H; and Tegovakon V, ethyl silicate.

Notes

1. Watson Smith, Kiva Mural Decorations at Awatovi and Kawaika-A (Cambridge: Harvard University Press, 1952).

2. Constance S. Silver, "Architectural Finishes of the Prehistoric Southwest: A Study of the Cultural Resource and Prospects for its Conservation" (M.S. thesis, Columbia University, 1987). The author gratefully acknowledges the assistance of Professor Norman Weiss, Columbia University, and Watson Smith.

3. P. W. Brown, J. R. Clifton, and C. R. Robbins, Methods for Characterizing Adobe Building Materials (Washington, D.C.: U.S. Government Printing Office, 1978).

4. Lorraine Schnabel, personal communication to the author, September 2, 1987.

5. Dr. David Spidel, Chairman, Department of Geology, Queens College, Queens, New York. Personal communication to the author, September 23, 1987.

6. Dr. Nicholas Coch, Department of Geology, Queens College, Queens, New York. Personal communication to the author, June 29, 1987.

7. X-ray diffraction was carried out by Gregory Cavallo, American Museum of Natural History, New York City (personal communication to the author, July 17, 1987). The results were verified with SEM X-ray diffraction (SEM and EDS) by Dr. Robert Koestler, Metropolitan Museum of Art, New York City (personal communication to the author, September 4, 1987). The author gratefully acknowledges review of these data and suggestions regarding the relationship between quantity of mineral and detection by X-ray diffraction by Richard Coffman and Neville Agnew, Getty Conservation Institute (personal communication to the author, April 9, 1990).

8. McCrone Associates, Inc., personal communication to the author, September 9, 1987.

9. The pilot conservation treatments at Mesa Verde National Park were supported by four institutions. The National Museum Act (Grant FG-107214000) provided financial support. The Museum of New Mexico was the sponsoring institution. The National Park Service made available protected sites. Technical in-kind support and consultation by Paul M. Schwartzbaum were provided by the International Centre for Conservation, Rome (ICCROM). The author was project director.

10. V. J. Birstein, "On the Technology of Central Asian Wall Paintings: The Problems of Binding Media," Studies in Conservation 29, No. 1 (February 1975): 8-19.

11. M. W. Phillips, "Experience in the Use of Acrylic Plaster Adhesive," Case Studies in the Conservation of Stone and Wall Paintings, IIC Bologna Congress, 21-26 September, 1986, 34-37.

ABSTRACT

A methodology for the conservation and restoration of earthen structures is proposed.
This methodology encompasses the study of the physical environment, historic values, the state of the building and the evaluation of the architectural typology and architectural significance. These elements are taken into account in a cyclic approach to balance between the different kinds of values that are important in the definition of the intervention.
In this way the technical problem of conservation of earthen structures is embedded in a global evaluation that is appropriate for the preservation of the monument.

KEYWORDS

Methodology, conservation, earthen architecture, restoration.

MÉTHODOLOGIE DE LA CONSERVATION ET DE LA RESTAURATION DES MONUMENTS EN TERRE.

Koenraad Van Balen
ingénieur architecte
Centre d'étude pour la conservation
du patrimoine architectural et urbain
K.U.Leuven
Kasteel van Arenberg
B-3030 Leuven, Belgium.

Introduction.

La lecture de différentes méthodologies proposées pour la conservation des constructions en terre montre que celles-ci se limitent en général à un point de départ où le problème technique de la conservation des matériaux est abordé (1). Ceci mène en général à des solutions techniques qui perdent de vue le cadre architectural et social, tant pour l'évaluation du problème posé par la conservation que pour les possibles solutions.

Pourtant il y a des personnes qui se sont intéressées à l'étude des traditions culturelles avec le but de pouvoir comprendre la tradition architecturale afin de maintenir la main-d'oeuvre, la connaissance du savoir-faire. Ceci peut aussi être utile au conservateur pour la compréhension de l'architecture dans laquelle il intervient ainsi que pour la sauvegarde de la tradition de l'entretien. Ce dernier point est reconnu comme étant de très grande importance pour la sauvegarde du patrimoine en terre (2). Seulement il ne semble pas encore incorporé dans les politiques de sauvegarde, à part que en termes généraux. L'étude des techniques d'entretien et leurs applicabilités dans la conservation semble par contre négligée. Pour un grand nombre de conservateurs ces techniques sont beaucoup trop vigoureuses, bien qu'appliquées pendant des dizaines d'années. Hélas il faut dire que l'efficacité de ces techniques diminue fortement quand les intervalles des travaux deviennent si importants qu'on ne se souvient plus du dernier entretien.

L'intervention doit clairement se distinguer des éléments originaux, comme il est mentionné à juste titre, conformément à la Charte de Venice, dans les différents colloques qui ont précédé celui-ci (3). Mais dans le cas des objets architecturaux ce type d'intervention ne peut satisfaire que quand on tient compte de la dimension architecturale. Pour cette raison nous proposons une lecture et une analyse plus approfondies de la dimension architecturale avant de définir le type d'intervention.

Ce dilemme que pose la conservation du patrimoine architectural - préférence pour l'objet archéologique ou pour le chef-d'oeuvre architectural - se pose par exemple clairement dans l'ancienne ville de Buda.

Il me semble donc qu'il faut ajouter à la proposition faite à Ankara (1980): "... la préservation de l'intégrité de l'architecture en terre comme un tout qui comprend les concepts et techniques traditionnelles qui étaient utilisés à l'origine et continuent à être utilisés aujourd'hui ..." la dimension architecturale.

Pour pouvoir maîtriser ces différentes "dimensions" une approche est proposée et commentée par la suite.

Une méthodologie.

L'intégration de problèmes techniques dans un contexte plus vaste de conservation a été étudiée pour des problèmes de consolidation structurelle (4) et des problèmes analogues d'évaluation de risques dans la protection du patrimoine contre les incendies et d'autres risques naturels (5). Il nous a paru utile d'élaborer une approche similaire pour cette conférence.

Le point de départ de cette méthodologie est que chaque problème technique se trouve dans un vaste contexte qu'il faut analyser profondément. Pour cela une approche pas à pas est proposée qui distingue les phases suivantes: L'ANALYSE; LE DIAGNOSTIC, LA THERAPIE et LE CONTROLE.
Poursuivons ces différentes phases afin d'éclaircir nos idées.

NOTES.

1 par exemple les méthodologies présentées lors du premier cours pilote sur la préservation du patrimoine architectural en terre, Grenoble, du 28/10 au 4/11/1989.

2 colloque précédent sur la conservation des constructions en terre en Iran (1972, 1976).

3 New Mexico (1977), Rome (1987)

4 Lemaire R., Van Balen K. (Editors), Stable-Unstable,

Structural consolidation of ancient buildings, Leuven University Press en M&L, 1988, Leuven;

Van Balen K., "Stabiliteitsherstel in monumentenzorg (Structural consolidation in monument conservation.)", in Monumenten en Landschappen, jg.5, nr.2, 1986, Brussel;

Van Balen K., "Benadering en verantwoordelijkheden bij stabiliteitsherstel (Approche et responsabilités dans la consolidation structurelle)" (conférence lors de la journée d'étude: Monument en stabiliteit (Monument et stabilité); Gent, België.

5 Van Balen K., De Witte E., Buelens R., "De beveiliging van kerken en hun kunstbezit (La protection d'églises et leurs biens meubles)" in Monumenten en Landschappen, jg.5, nr.4, 1986, Brussel

Van Balen K., "L'influence des catastrophes -les incendies- sur l'évolution des bâtiments en pan de bois en Flandre", (conférence au Cours intensif européen sur la protection et la conservation du patrimoine culturel dans les zones à risques sismiques; deuxième cours; Ravello, Italie. *Centre Européen de Ravello en collaboration avec l'Instituto di Formazione del Mesogiorno (FORMEZ)* décembre 1987).

6 voir les théories de Norberg-Schulz.

1. L'ANALYSE.

Un monument historique doit être analysé dans ses différentes dimensions. Il s'agit d'un objet architectural qui reflète une histoire et donc l'analyse historique doit être étudiée. Il s'agit d'un conglomérat de matériaux et donc le comportement de ces matériaux doit être connu. L'architecture nous dévoile aussi une typologie de construction qui ressort de l'histoire de l'architecture et est la réponse envers les différentes restrictions comme le climat, la présence de matières premières, une technologie acquise dans la période de construction et des différentes interventions ultérieures.

L'architecture elle-même est porteuse d'une signification (6), elle est un "symbole" qui doit être compris dans le contexte de la société qui l'a créé, mais elle devient, comme monument historique, un symbole pour notre société d'aujourd'hui.

La phase de l'analyse envisage donc d'effiler ces différentes dimensions afin de pouvoir les estimer et les confronter dans le diagnostic où les grandes lignes de l'intervention doivent être définies.

L'analyse tiendra, entre autre, compte des pas suivants:

a. l'étude de l'environnement dans lequel se trouve l'objet de l'étude, la situation géographique, le climat, le microclimat (urbanistique), la situation dans un réseau urbain, la disponibilité de matières premières, la technologie acquise par la société.

b. l'étude historique du bâtiment basé sur des sources écrites, iconographiques mais aussi des témoins dans la construction même. Cette étude nécessite donc un relevé précis et détaillé du bâtiment.

c. l'étude des matériaux: leur composition originale, l'origine des matières premières employées, leur état de conservation, l'emplacement mutuel, les dégradations qui témoignent de leur incompatibilité (fissures, dégradation plus accentuée dans la zone de contact,...), les caractéristiques physiques et structurels (porométrie, isothermies, ...) des matériaux. Dans le cas des constructions en terre la connaissance de la structure interne du matériau ainsi que les caractéristiques des terres employées pour la fabrication est de grande importance.

d. le comportement mécanique des constructions portantes en terre doit être étudié en tenant compte du système global de la structure et pas seulement des matériaux isolés. Par exemple le comportement d'une paroi en terre renforcée de pannes de bois lors d'un tremblement de terre, ne peut s'expliquer que par la compréhension de l'interaction des différents matériaux.

Les éléments cités ci-dessus semblent assez évidents et font l'objet de la plupart des études préalables, mais nous voulons insister ici que cette approche ne peut satisfaire que si les éléments suivants sont aussi inclus:

e. l'architecture reflète aussi une typologie de construction qui à son tour reflète la connaissance du savoir-faire d'une société à une certaine période. Ceci est déja en soi une dimension intéressante qui vaut l'étude. Certaines de ces typologies sont la cumulation de la connaissance acquise pendant des siècles, des réponses aux restrictions posées par l'environnement et les dégradations qui en suivent. La protection des parois en terre par des grands toits en surplomb dans les régions pluvieuses en est un exemple. La protection des parois en terre par des enduits, qui sont souvent renouvelés pendant les travaux d'entretien, en est un autre.

f. typologie et matériau sont liés entre eux dans la conception initiale du bâtiment et donc dans une approche de conservation. Le conservateur approchera donc avec beaucoup de retenue le bâtiment en respectant la typologie.

Dans différentes régions du monde, souvent les pays en voie de développement, la technologie ancienne a été conservée et on trouve aisément la main-d'oeuvre pour entretenir ces constructions de la même manière que cela a été fait pendant longtemps. La sauvegarde de la technologie, dans ce cas, est possible par la poursuite de la tradition d'entretien.

Dans beaucoup de pays -dits civilisés- cette main-d'oeuvre n'est plus disponible et on a perdu la notion importante de l'entretien régulier. Le problème de la conservation des bâtiments devient alors différent: la sauvegarde de la technologie ne peut alors qu'être garantie par la conservation minutieuse de ses témoins dans des circonstances pénibles créées par le manque d'entretien!

La conservation d'un monument historique nécessite souvent la mise en valeur de la signification dont il est porteur. Cette dimension doit être étudiée afin de pouvoir décider comment se fera l'intervention. Peut-être faudra-t-il une intervention architecturale afin de rendre plus lisible aujourd'hui la signification dont il s'agit.

2. LE DIAGNOSTIC.

Le diagnostic est en effet la confrontation et la synthèse des résultats de l'analyse. Il faudra résoudre différents dilemmes. Je vous en présente quelques-uns.

a. faut-il consolider une ruine de murailles en adobe sans restaurer ces éléments typologiques qui ont été conçus, mais qui n'existent plus, pour la protection des parties supérieures des murs (voir par exemple les surplombs des toitures ou les enduits)?

b. doit-on réemployer comme élément structurel un mur en adobe qui apparemment est lézardé par la perte de cohésion du matériau même et par des fissurations dues à des tassements différentiels? La valeur historique de ce mur sera appréciée différemment s'il porte des traces uniques pour l'histoire ou s'il peut être refait à neuf sans changer vraiment la valeur historique du bâtiment.

c. dépendant de la valeur unique de l'élément sur lequel il faut intervenir, une technique de consolidation et de conservation peut être exécutée pour autant que cette technique offre assez de garantie. Par contre si la valeur monumentale de cet élément architectural ressort de son aspect global cet élément pourrait être refait avec des techniques traditionnelles, même améliorées.

d. beaucoup de constructions en terre ont pu survivre tout au long des décennies, des centenaires par l'entretien qu'elles ont subi régulièrement. Cet entretien de nos jours est souvent négligé et beaucoup de ces bâtiments fragiles en terre sont dans des situations déplorables. La restauration devient alors un travail d'entretien accumulé et ajourné qui devient alors plus radical que la poursuite de travaux d'entretien normaux aurait causé. Ceci peut clairement être illustré à Quito, où la vulnérabilité du patrimoine est accrue par manque d'entretien après les tremblements de terre.

e. la perte de la main d'oeuvre spécialisée et du savoir-faire traditionnel est une hypothèque sur la poursuite des travaux d'entretien tellement nécessaire. Ne faut-il donc pas d'abord parler de la conservation de la main-d'oeuvre et du savoir-faire avant d'aborder le problème de la conservation des bâtiments mêmes?

En résolvant les dilemmes il faudra définir les objectifs précis de l'intervention. Ceci aussi bien au niveau architectural qu'au niveau technique : quelles sont les exigences auxquelles les interventions doivent satisfaire pour garantir une sécurité suffisante pour la protection de l'unicité de l'objet et de la sécurité acceptable pour la société. Ces objectifs s'expriment en termes précis comme par exemple une résistance mécanique de X MPa, une progression de déformation limitée,...

3. LA THERAPIE ET LE CONTROLE.

Dans cette phase seront définis les travaux qui doivent être exécutés. Ils seront décrits et exécutés tenant compte des objectifs définis par le diagnostic. Nous lions directement cette phase au contrôle qui est le "feed-back" vers les phases précédentes.

7 par exemple les expériences à Pueblo Benito avec des constructions en terre; T. Rutenbech, Monitoring structural movements in historic stone masonry buildings in Preprint of the proceedings of the International Technical Conference on Structural Conservation of Stone Masonry, Athens, Greece, October - November 1989.

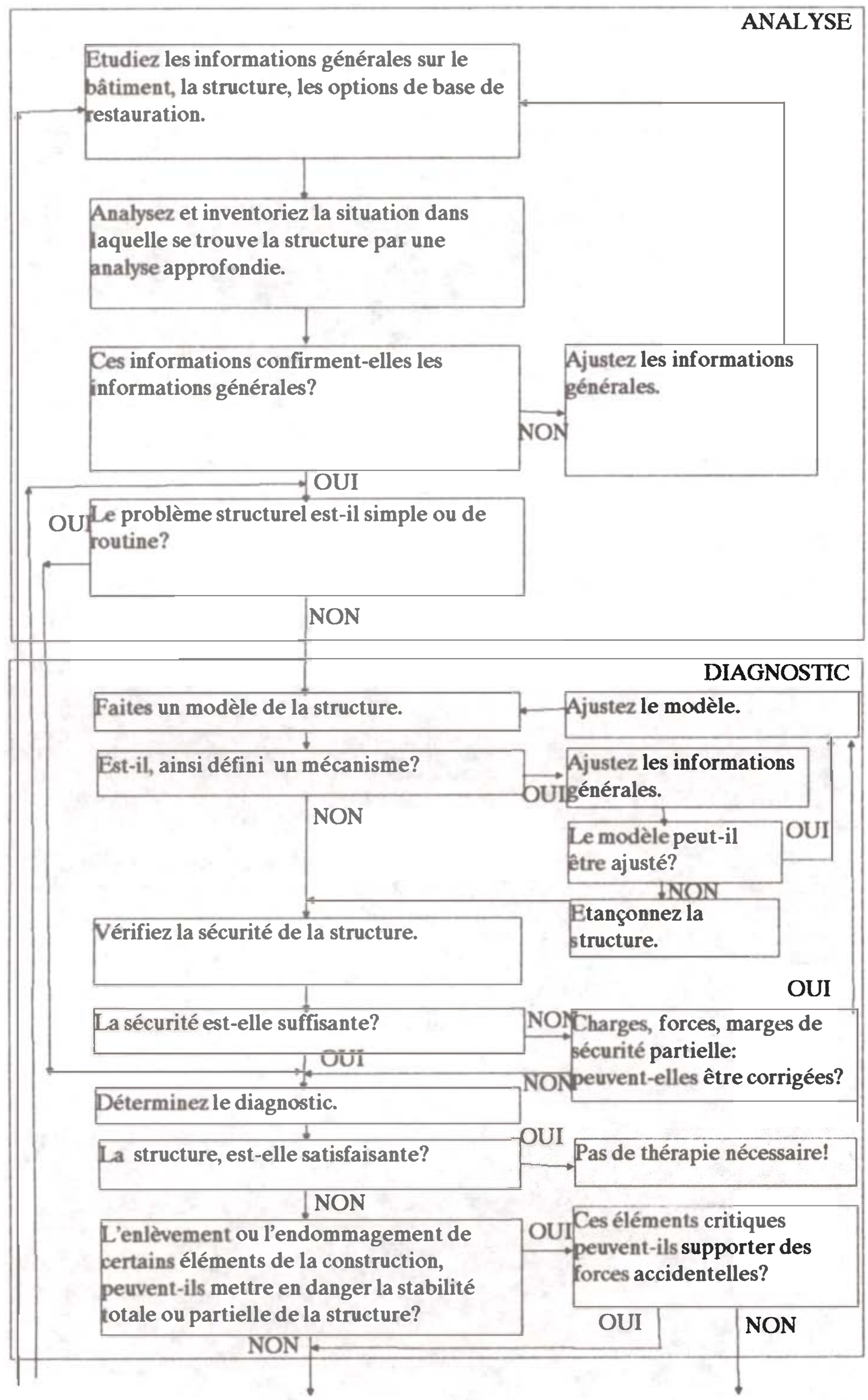
Le contrôle permet en cours d'exécution d'évaluer la thérapie. Les critères d'évaluation sont définis par le diagnostic mais il faut aussi tenir compte de l'incertitude inhérente liée à l'analyse. On constate par exemple lors de l'intervention que les préalables de l'analyse ne sont pas confirmés, ou pire encore, contredits. Il faut alors retourner à la phase de l'analyse afin de revoir quelles sont les implications des nouvelles données sur les décisions prises. Ainsi la méthodologie se présente comme un parcours avec recouplages, chaque nouvelle donnée sera relatée aux valeurs ressortant de l'analyse.

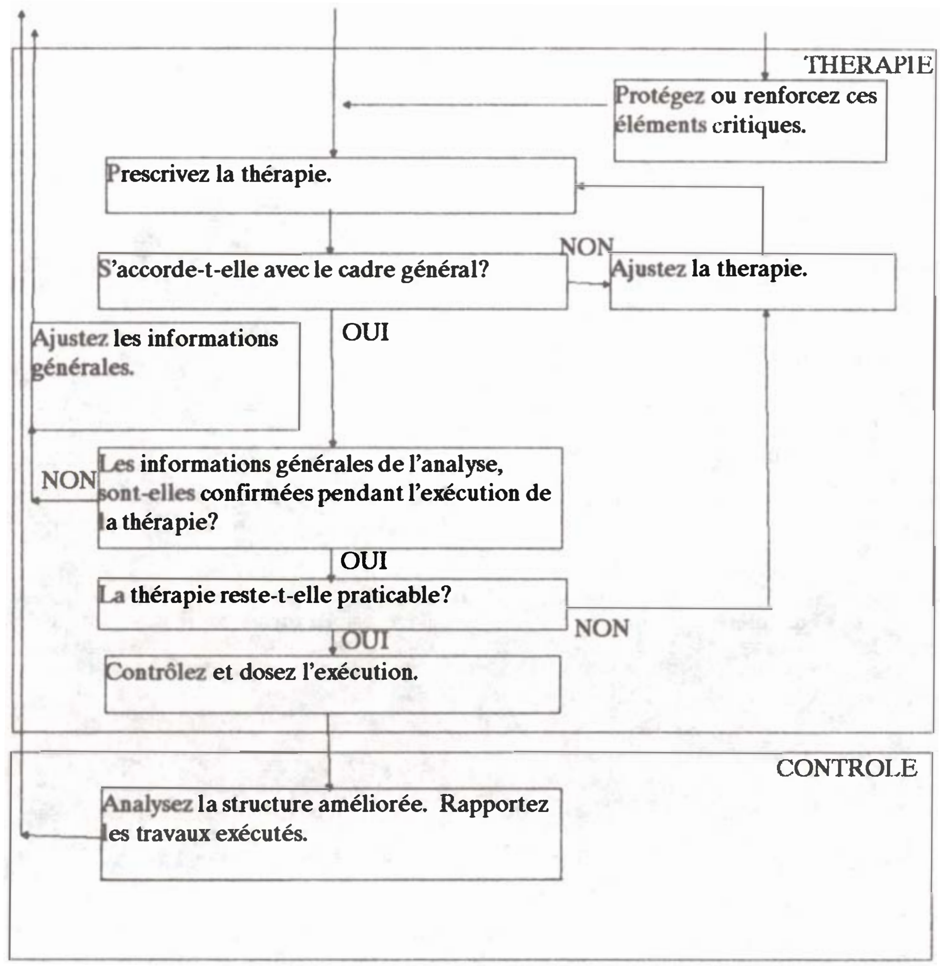
Cette procédure nous donne aussi la possibilité de limiter les travaux excessifs dus aux incertitudes.
Prenons par exemple un mur porteur qui, suite aux charges qu'il porte, subit une déformation croissante. Cette déformation croissante est une mesure pour le manque de stabilité (7) et des calculs devront donner des indices sur les marges de sécurité, qui à leur tour définiront les caractéristiques à donner à la maçonnerie pour qu'un niveau de sécurité acceptable soit atteint. Ces caractéristiques seront comparées aux prestations des techniques qui peuvent être employées et on choisira une méthode qui interviendra le moins possible. Nous savons que dans la méthode de calcul beaucoup de facteurs d'incertitude sont compris et nous devrons essayer de les éliminer le plus possible. Ceci peut se faire par une amélioration de la connaissance du comportement des matériaux ainsi que par l'emploi d'un modèle plus approprié au problème à résoudre. Si pour des raisons de sauvegarde de l'authenticité, une intervention minimale est proposée, un système de contrôle de déformation peut nous aider à évaluer l'effet de l'intervention. Une première intervention peut alors être exécutée et évaluée avec le système de "surveillance". Si ce système de contrôle montre que l'intervention est satisfaisante, même si le calcul avec toutes ses marges d'incertitude n'aurait pas pu le démontrer, une garantie est offerte et l'intervention est minimalisée. Si par contre le système de contrôle ne nous donne pas satisfaction sur les travaux exécutés, parce que par exemple la croissance des déformations n'est pas satisfaisante, une seconde intervention peut être proposée. Ainsi une intervention en cascade peut être exécutée avec chaque fois des étapes minimales qui évitent chaque exagération.

Cette approche que nous avons employée pour l'église de Notre Dame à Ninove en Belgique, montre qu'il est possible d'éviter des interventions qui ressortent de l'incertitude de notre connaissance du comportement des matériaux et du manque d'exactitude des modèles de calcul.

Il s'agit donc de définir, pour chaque type de problème qui se pose dans le bâtiment, les paramètres qui reflètent au mieux l'efficacité de l'intervention. De plus si ce paramètre peut être mesuré avec des techniques non destructives, un système optimal de surveillance peut être établi.

Le schéma des différentes étapes pour résoudre de cette manière un problème de stabilité peut être résumé par le graphique suivant. Pour des problèmes avec les matériaux, des schémas analogues peuvent être élaborés.


ANALYSE
Etudiez les informations générales sur le bâtiment, la structure, les options de base de restauration.
Analysez et inventoriez la situation dans laquelle se trouve la structure par une analyse approfondie.
Ces informations confirment-elles les informations générales?
NON
Ajustez les informations générales.
OUI
OUI
Le problème structurel est-il simple ou de routine?
NON
DIAGNOSTIC
Faites un modèle de la structure.
Ajustez le modèle.
Est-il, ainsi défini un mécanisme?
OUI
Ajustez les informations générales.
NON
Le modèle peut-il être ajusté?
OUI
NON
Etançonnez la structure.
Vérifiez la sécurité de la structure.
OUI
La sécurité est-elle suffisante?
NON
Charges, forces, marges de sécurité partielle: peuvent-elles être corrigées?
OUI
NON
Déterminez le diagnostic.
La structure, est-elle satisfaisante?
OUI
Pas de thérapie nécessaire!
NON
L'enlèvement ou l'endommagement de certains éléments de la construction, peuvent-ils mettre en danger la stabilité totale ou partielle de la structure?
OUI
Ces éléments critiques peuvent-ils supporter des forces accidentelles?
OUI
NON
NON



Conclusion.

La conservation des monuments en terre n'est pas seulement un problème technique qui a comme but de conserver ou restaurer au mieux le matériau.

L'approche proposée veut mettre en évidence l'importance des différentes dimensions de la conservation architecturale qui toutes doivent être prises en considération quand des décisions sur l'intervention doivent être prises.

L'évaluation des valeurs historiques ainsi que l'évaluation des problèmes techniques sont déjà aujourd'hui le sujet de beaucoup d'études préalables aux interventions.

La connaissance et, surtout, l'interprétation à l'égard de la conservation des typologies de construction et la conservation des méthodes d'entretien ainsi que de la main-d'oeuvre sont souvent négligées.

L'étude de ces typologies nous apprend beaucoup sur la durabilité des techniques - y compris les détails architecturaux - suite à une expérience beaucoup plus longue qu' avec les produits modernes. Elle nous aidera à intervenir plus scrupuleusement et d'envisager des solutions architecturales appropriées pour des problèmes même techniques.

ABSTRACT

Within the social framework of Peruvian reality, the importance of housing built with mud and other traditional materials in the region as well as the need of using improved technologies in seismic and rainy areas is presented. A description is contained herein of characteristics, advantages and disadvantages of earthen buildings as well as technical recommendations which have been developed after extensive research programmes and subsequently implemented over the last 15 years in low-cost housing in seismic areas. Recommendations include construction with mud, rammed earth and quincha (bahareque), as well as mud plasters and painting. Many of these recommendations have been included in the Seismic Peruvian Code.

KEYWORDS

Construcción Sismo-Resistente, adobe, tapial, quincha (bahareque), recomendaciones.

KEYWORDS

Seismic-resistant construction, adobe, rammed earth, wattle and daub, quincha, recommendations.

CONSTRUCCIONES DE TIERRA, EN EL PERU DE HOY

Julio Vargas Neumann* y Juan Bariola Bernales
Pontificia Universidad Católica del Perú
Departamento de Ingeniería
Apartado 1761, Lima
PERU

En los últimos 25 años, en el Perú se ha producido un abandono de atención al interior del país, especialmente en la Sierra, y un proceso de migración escalonada del campo a la ciudad.

Como resultado de este proceso, la velocidad de incremento poblacional en las principales ciudades de la Costa, es mucho mayor que la de crear soluciones habitacionales. El déficit anual es de 100,000 unidades. Tugurización y asentamientos urbano-marginales, son notorios en dichas ciudades. Procesos de invasión de terrenos privados, fiscales y públicos, han ido presentándose en forma creciente.

Los precios de la construcción aumentaron a un ritmo mucho mayor que el poder adquisitivo. La obra que construye el Estado, no puede ser adquirida por la población.

Sin embargo, la necesidad e inseguridad de los sectores marginales, los conduce a construir con mucho esfuerzo, utilizando sistemas informales de autogestión y autoconstrucción. La pujanza de este sector lo convierte en el constructor del 75 a 80% de la actividad actual.

Es obvio que frente a este panorama hay que desarrollar dos actividades fundamentales: apoyar los procesos informales existentes y difundir soluciones de muy bajo costo.

No es fácil regresar a soluciones tradicionales. Es necesario conocer la historia, las tradiciones sociales, los problemas poblacionales y sus prioridades, para luego diseñar la solución más adecuada a cada comunidad. Sin lograr una verdadera motivación, es mejor no intervenir apoyando el proceso.

La construccion en tierra, indudablemente de una tasa costo/calidad baja, es una solución en el Perú de hoy.

se estima que el costo de una vivienda rústica de tierra autoconstruida e incluso autogestionada, no sobrepasa de 15 dólares por metro cuadrado y el de una de quincha, 40 dólares. El casco habitable en albañilería de ladrillo, cuesta en la misma región 80 dólares por metro cuadrado y una vivienda terminada de clase media, 200 dólares.

En general, en adelante nos referiremos a las construcciones de adobe, salvo mención expresa.

Las construcciones de tierra, como las de cualquier otro material, tienen una serie de ventajas y desventajas. En función de ellas y de las características ecológicas de cada zona, resulta el mayor o menor uso de este tipo de edificaciones.

Entre las ventajas se puede enumerar las siguientes:

- Simplicidad de ejecución.
- Economía.
- Aislamiento térmico y acústico.
- Producción sin consumo de energía.

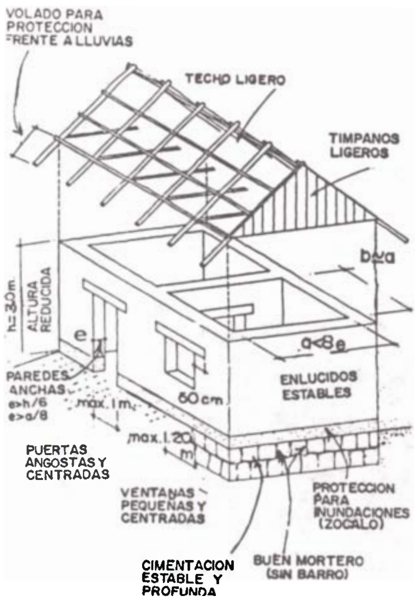
Los mayores inconvenientes podrían ser:

- Durabilidad (erosión, humedecimiento, etc).
- Fragilidad frente a desastres naturales (sismos e inundaciones).
- Disminución de las áreas efectivas debido al grosor de los muros.
- Aceptabilidad social.

La tecnología moderna ha desarrollado en las últimas décadas, materiales nuevos, propios de países industrializados. Menos esfuerzo se ha invertido en la solución o control de las deficiencias de los materiales primitivos o naturales, más propios de los países del Tercer Mundo.

*Autor a quien debe ser dirigida la correspondencia.

Una revisión del listado de ventajas y desventajas presentado, nos permite concluir que las primeras son cada vez más importantes en el mundo de hoy; y las segundas son superables con el auxilio de nuevos conocimientos técnicos y programas educativos de apoyo estatal.



- CONSTRUCCIONES DE UN PISO
- HABITACIONES CASI CUADRADAS ($a \simeq b$)
- DISTRIBUCION SIMETRICA DE MUROS
- VANOS PEQUEÑOS
- DISTANCIA MAXIMA ENTRE CONTRAFUERTES 8

CONFIGURACION ADECUADA

Gráfico 1

Por estas razones, tal vez como consecuencia de alguna ley natural, se podría afirmar que las construcciones de tierra volverán a imponerse en el futuro.

Para lograr la utilización masiva de la construcción con tierra en una sociedad actual latinoamericana, en primer lugar, es necesario desarrollar la información técnica que permita competir al material, con los existentes en el mercado actual.

Esto significa el conocimiento del material en sí y también desde el punto de vista arquitectónico y estructural en base a estudio e investigación que permita desarrollar normas, manuales de diseño, textos, panfletos de difusión práctica, material didáctico a diferentes niveles de formación e información para la educación continua de los especialistas.

Desarrollado lo anterior, al igual que otros materiales, la tierra podrá ser seleccionada por comparación de resultados y costos, por facilidades de diseño, construcción y uso.

Las áreas más rezagadas de estudios, son sin duda las asociadas al comportamiento sísmico y a la durabilidad frente a la humedad o al agua.

Recomendaciones Técnicas

Las recomendaciones que se presentan, son aplicables a las construcciones de tierra en general, pero están especialmente orientadas a la vivienda popular, pretendiendo mejorar la calidad de la construcción espontánea, informal o masiva que es la que mayores pérdidas de vida y daños produce frente a los eventos sísmicos.

No incluye por tanto las soluciones que usan estabilizantes (cemento, cal, asfalto, etc.) para mejorar la resistencia o durabilidad, ni refuerzos utilizando materiales costosos (concreto, acero, etc.) para mejorar su comportamiento dinámico.

Las recomendaciones son el resultado de extensos programas de investigación realizados en los últimos 15 años y fase fundamental para las etapas de Difusión e Implementación (ver notas 1 a 6).

a) Suelos de Fundación: La fragilidad y poca resistencia sísmica de las construcciones de adobe, obliga a limitar los posibles emplazamientos de las construcciones a aquellas áreas asociadas a subsuelos firmes o relativamente firmes.

b) Cimentación: Los cimientos y sobrecimientos para los muros podrán ser de piedra o ladrillo asentados por un buen aglomerante (cemento, cal, yeso, etc). En vista del elevado costo del cemento u otros aglomerantes, su uso debe ser mínimo (como mortero para adherir las unidades). (Ver graf. 1).

El refuerzo vertical nace en el sobrecimiento, para facilitar la construcción del cimiento.

c) Otras Características Apropiadas: Desde el punto de vista del comportamiento sísmico, las construcciones de tierra son peligrosas, ya que los métodos tradicionales no tienen siempre en cuenta que el material es pesado, poco resistente y frágil.

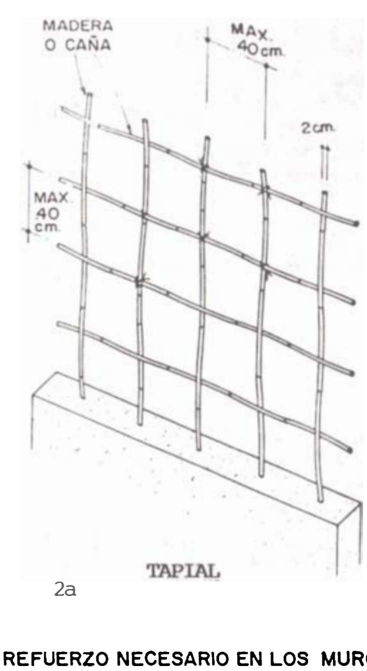
La tecnología moderna debe tender precisamente a aligerarlas, concederles resistencia y ductilidad.

Los techos y tímpanos deben ser muy ligeros, así como la altura de las paredes debe ser mínima.

En la construcción de los muros de adobe, no debe usarse suelos sin suficiente arcilla (ver prueba de resistencia seca). Debe añadirse arena gruesa o paja para controlar o evitar fisuraciones, especialmente en el mortero de junta (ver nota 7).

Por razones sísmicas, todas las construcciones de tierra deben tener refuerzos de material de alta resistencia a la tracción y compatibles con el material (madera o caña).

d) Refuerzos: El refuerzo más efectivo para los muros es el de caña o madera, constituyendo mallas amarradas en los nudos y colocadas al interior de los muros en una o dos capas verticales según el espesor de los mismos (Ver graf. 2a, 2b, 2c).

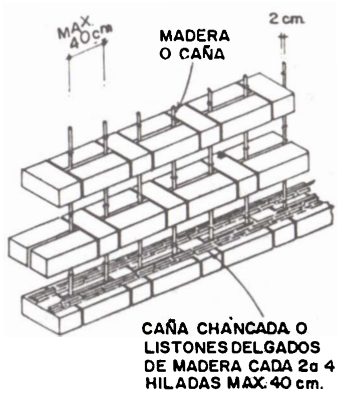


2a

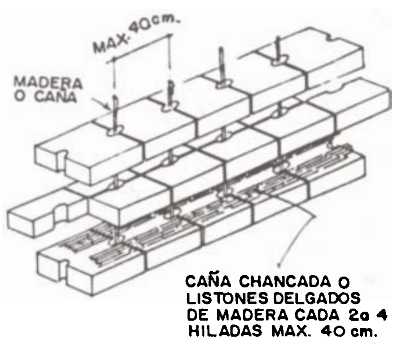
REFUERZO NECESARIO EN LOS MUROS DE CONSTRUCCION DE TIERRA

Gráfico 2

2b



2c



ADOBE
REFUERZO NECESARIO EN LOS MUROS DE CONSTRUCCION DE TIERRA

Gráfico 2

En las construcciones de bahareque o quincha constituyendo marcos de mayor sección, rellenas con mallas secundarias de menor sección (Ver graf. 3a, 3b).

En todos los casos las mallas y marcos deberán estar firmemente conectados a la cimentación y a la viga collar superior que se describe más adelante.

En los nudos y encuentros, las maderas o cañas se unen amarradas con hilo de pescar (nylon) o sustitutos de existencia local (cueros, soguillas, etc).

Conviene colocar una capa de refuerzo horizontal a la altura de los dinteles de puertas y ventanas (bajo los dinteles). Los dinteles deben tener todos el mismo nivel y suficiente longitud de apoyo a cada lado de los vanos.

Los refuerzos horizontales que se encuentran en las esquinas, deben trenzarse y amarrarse eficientemente entre sí.

Todos los muros deben llevar una viga collar continua en la parte superior de los mismos.

Una buena solución es la mostrada en el graf. 4.(ver al final)

La viga collar superior estará unida a la cimentación a través del refuerzo vertical, tal como se vió en el graf. 2, para garantizar el trabajo integral de los muros.

Los dinteles de los vanos también deben ir fijados a la viga cadena superior, para impedir una vibración desordenada. Para ello se puede usar unas cuantas tablitas de madera (Ver graf. 4).

Nótese que en los encuentros de esquina o en T, los refuerzos cubren los contrafuertes o proyección de las paredes. Esta disposición facilita la interconexión de las paredes y de la viga cadena y mejora el comportamiento global.

e) Techos: Los techos tienen dos partes principales: la estructura y la cobertura.

El conjunto debe ser ligero y estar bien conectado entre sí y a los muros.

La estructura descansará sobre la viga collar colocada en los muros o en elementos longitudinales de madera, para distribuir la carga. Se evitará apoyar las vigas sobre la zona de los dinteles y si es inevitable se reforzará adecuadamente dichos dinteles.

La estructura no debe generar empujes laterales sobre los muros y debe garantizarse su propia estabilidad lateral.

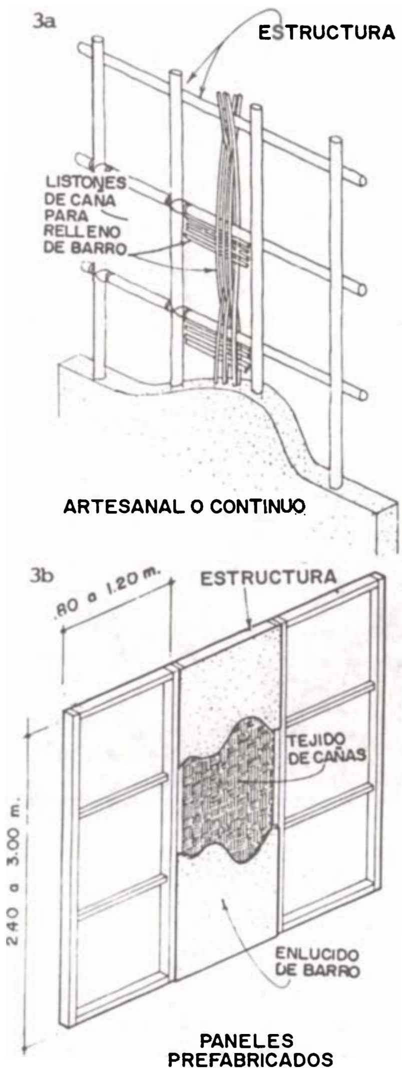
La cobertura garantizará la impermeabilidad del techo. Si se usa algún tipo de paja, se recomienda colocar enlucidos de barro mezclado con algún impermeabilizante o estabilizante.

f) Muros de Adobe o Bloques: Tanto en el bloque cortado como en el moldeado, los bloques más resistentes corresponden a los suelos plásticos o arcillosos. Sin embargo, la resistencia del bloque juega un papel secundario en la resistencia de la mampostería, en la cual son críticas las juntas entre bloques.

Para garantizar la adhesión entre bloques y mortero, debe evitarse la microfisuración de éste. Las condiciones de secado del mortero son muy severas por la velocidad del proceso al ponerse éste en contacto con los bloques ávidos de humedad y por la restricción a la contracción de secado. Esto produce la microfisuración mencionada y la debilidad de la mampostería. Este conocimiento no es tradicional y debe ser cuidadosamente difundido (ver nota 7).

Si el barro de la junta, que normalmente es el mismo utilizado en el bloque, tiene suficiente arcilla de acuerdo a la prueba de resistencia seca, entonces debe observarse si tiene problemas de fisuración. Si los tiene debe añadirse al mortero preferentemente paja, en la mayor cantidad posible siempre que permita una trabajabilidad aceptable (cerca de 1:1 en volumen). También se puede alternativamente, añadir arena gruesa. La proporción adecuada viene dada por la prueba de control de fisuración.

En suelos arcillosos conviene remojar los adobes unos minutos, antes de asentarlos y mojar la capa anterior de bloques antes de colocar el mortero de junta. En suelos arenosos no conviene el remojado. Sólo conviene mojar la capa anterior de bloques.



CONSTRUCCIONES DE TIERRA CON ESTRUCTURA DE MADERA O CAÑA

Gráfico 3

Debe llenarse cuidadosamente las juntas verticales del mortero.

Los bloques utilizados deben estar bien secos para evitar futuras retracciones.

Las dimensiones de los bloques no son muy importantes para la resistencia, ni tampoco el aparejo o disposición de los bloques entre sí.

g) Muros de Tapial: Las construcciones de adobe adquieren resistencia activando la arcilla del suelo por humedecimiento, las de tapial lo hacen por compactación, utilizando menores porcentajes de humedad.

Existiendo arcilla, la mayor resistencia se obtiene con mayor humedecimiento y compactación. Hay sin embargo, por un lado, limitaciones prácticas para limitar el humedecimiento: la factibilidad de poder golpear y compactar el suelo y la excesiva deformabilidad al desencofrar; por otro lado, existe el problema de la fisuración.

Para controlar la fisuración se exige el uso de bajos porcentajes de humedad (del orden de los óptimos en la prueba de Proctor o menores) y el control de la cantidad de arcilla añadiendo a los suelos arena gruesa. Si la cantidad de arena gruesa es excesiva, se disminuye la resistencia peligrosamente. Se recomienda hacer pruebas de muros con distintos porcentajes crecientes de arena, hasta que se controle tolerablemente la fisuración.

La compactación o número de golpes del muro, es función del peso y forma de la herramienta. A mayor compactación, mayores resistencias. Pero llega un momento que la eficiencia no progresa. Se recomienda una compactación normal, que no produzca que pedazos de barro se queden adheridos al encofrado cuando éste se retira. Se recomienda 50 golpes cada 1000 cm^2 con un mazo de 8 a 10 kgs de peso. La altura recomendable para los bloques varía entre 50 y 80 cms, pero es muy importante que las capas de compactado no sean mayores de 10 cms.

La mejor forma de garantizar el monolitismo en las paredes de tapial, es echar paja y bastante agua en las subjuntas de compactado (cada 10 cms).

Asimismo, entre bloques o mejor dicho entre capa y capa de tapial (cada 50 a 80 cms), es necesario echar bastante agua antes de colocar el material superior y compactarlo.

La colocación de piedras, grava o paja entre capa y capa de tapial, no es necesaria, ni útil.

La utilización de paja en la mezcla de barro en cantidades excesivas (mayores de 1:1/4 en volumen) es contraproducente pues disminuye la resistencia.

h) Construcciones de Tierra con Estructuras de Madera o Caña (Quincha): El comportamiento sísmico de este tipo de construcciones puede llegar a ser muy bueno, si es que se observan cinco puntos fundamentales:

- Buenas conexiones entre los elementos de madera o caña, de forma de garantizar un comportamiento integral. Las conexiones normalmente son hechas con clavos. El número y dimensión serán suficientes pero no excesivos como para rajar los elementos. También pueden concebirse uniones amarradas con cueros, soguillas, etc.

- Rigidez lateral en base a algunos elementos oblícuos de arriostre en el plano de la estructura, de manera de disminuir la deformabilidad y por tanto la fisuración del material de relleno de la estructura (normalmente barro).

- Preservación de los elementos de madera y caña, especialmente en la parte embutida en la cimentación, que debe ser de concreto, piedra o ladrillo, estos últimos asentados con morteros de cemento, cal o yeso.

- Adicionalmente es recomendable que el material de relleno consista en mallas de madera o caña de menor sección, sobre las cuales se coloca una capa de barro con paja (1:1 en volumen) por cada cara, a manera de relleno y enlucida. Muchas veces esta malla es tejida entre sí, e incluso alrededor de la estructura principal.

- Tanto en las viviendas construidas como sistema continuo, como en las de paneles prefabricados, debe colocarse una solera o viga continua superior que tiene doble misión:
  Garantizar un trabajo integral de todas las paredes;y
  Distribuir adecuadamente las cargas del techo.

Sólo después de fijar esta viga cadena superior y el techo (cuando se ha terminado de clavar), deberá ser colocado el relleno de barro, para evitar que éste se desprenda o fisure con los golpes propios del clavado de los elementos.

En el caso de paneles prefabricados, los marcos de los paneles pueden llegar a tener secciones muy reducidas y económicas (1" x 3" ó 1" x 2"). La conexión entre paneles se efectúa con clavos, pero las maderas o cañas tejidas para recibir el relleno de barro, puede no ser clavada.

i) Enlucidos y Pinturas: La finalidad de los enlucidos y pinturas es brindar protección y durabilidad a los muros, además de las razones estéticas.

Los enlucidos en base a aditivos naturales, pueden estar conformados por dos capas. La primera de alrededor de 1 cm, conformada por una mezcla de barro con paja (1:1 en volumen) y un aditivo natural que aumente la resistencia húmeda del barro para impedir su fisuración durante el proceso de secado, que es paralelo a la adquisición de resistencia seca. El aditivo natural ayuda a resistir las tensiones de retracción de secado restringido. La segunda y final, es compuesta por barro de material fino que cuando está casi seco, debe ser frotada enérgicamente con pequeñas piedras redondeadas y lisas de la mayor dureza posible.

Se recomienda como aditivo natural el uso de jugo de cactus mezclado con agua (60 kgs de cactus para 40 litros de agua) para mezclar con la tierra de la primera capa, hasta obtener una trabajabilidad razonable.

Existe otros aditivos naturales de acción semejante, tales como la resina de algarrobo, o el agua del hervido del árbol de banana, etc.

Aunque no siempre se puede disponer de bitumen y tampoco es económico, es posible utilizar enlucidos preparados en base a este material.

Las pinturas deben preferentemente ser insolubles en agua para proteger a los muros de las lluvias.

Se utiliza lechadas de cal, de cemento, de yeso, aceites y también extractos de plantas.

Generalmente, las pinturas modernas de origen químico o sintético, tienden a formar barreras contra la humedad pero sólo proporcionan protección temporal, pues se desprenden.

Conclusiones

- La situación socio-económica de ciertos países latinoamericanos es tal, que requiere soluciones de vivienda de muy bajo costo, como la de construcción con tierra (adobe, tapial, quincha, etc).

- El proceso de desarrollo de programas de construcciones con tierra, exige previamente estudio, investigación, difusión del conocimiento, elaboración de normas, discusión técnica internacional, etc., para que el material pueda competir técnicamente con materiales más resistentes y costosos.

- El esfuerzo realizado en investigación en el Perú, Guatemala, México, etc., debe ser continuado y complementado con las fases de discusión y divulgación, de manera de lograr que el material sea aceptado por la comunidad profesional internacional primero y por los gobiernos y usuarios después.

ANEXO

Prueba de Resistencia Seca

Se fabrican tres o más bolitas pequeñas de suelo de aproximadamente 2 cm de diámetro. Una vez secas (a las 24 horas) se aplasta cada bolita entre los dedos pulgar e índice. Si las bolitas son tan fuertes que ninguna se puede romper, el suelo tiene suficiente arcilla para ser usado en la construcción con adobe, siempre y cuando se controle la microfisuración del mortero debida al secado. Si algunas bolitas se rompen, el suelo es inadecuado, ya que le falta arcilla y deberá descartarse.

Prueba de Control de Fisuración

Se fabrica por lo menos ocho emparedados, con morteros hechos con mezclas en proporciones gradualmente decrecientes de suelo y arena gruesa. Se recomienda que las proporciones suelo/arena gruesa, varíen entre 1:0 y 1:3 en volumen. El emparedado con el menor contenido de arena gruesa que, al abrirse a las 48 horas, ya no muestre fisuras visibles en el mortero, indicará la proporción suelo/arena más adecuada para la construcción con adobe, de mayor resistencia.

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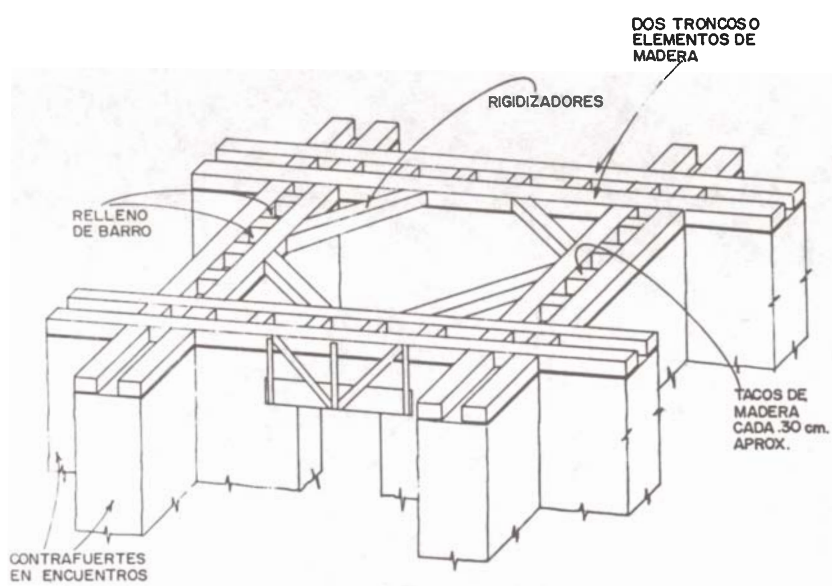

VIGA CADENA SUPERIOR

Gráfico 4

Site Preservation

THE HOUSE THAT JUAN BUILT: AN ARCHAEOLOGICAL PERSPECTIVE ON ADOBE ANALYSES

Jeffrey L. Boyer
Staff Archaeologist
Office of Archaeological Studies, Museum of New Mexico
P.O. Box 2087
Santa Fe, New Mexico 87504-2087
U.S.A.

ABSTRACT

Architecture often comprises one of the most conspicuous features on archaeological sites. However, archaeologists have generally not paid the same attention to architecture as to other human artifacts.

Using data from the Trujillo House (LA 59658), a 19th century Hispanic homestead near Abiquiu in the Rio Chama Valley, the Office of Archaeological Studies of the Museum of New Mexico is exploring the utility and potential of adobe analyses in archaeological research. Analyses of adobe building materials from the site show that the adobe was made on-site using local materials. The very sandy soil was made sandier by the addition of coarse sand to the adobe, producing adobe that was weaker than the native soil. Comparison of material from a post-1880 borrow pit with adobe from the structure shows significant differences with adobe from rooms probably pre-dating the pit, thus clarifying the construction sequence of the house.

Analyses of adobe from the Trujillo House show potential for providing information on changing frontier settlement, site formation processes, and the use of local and regional construction materials.

KEYWORDS

Hispanic architecture, archaeology, adobe, particle size, plasticity, soluble salts.

Introduction

Because architecture often comprises the most conspicuous feature of an archaeological site, archaeologists have been forced to study architecture as they would any other human artifact. However, while archaeologists have developed a wide variety of techniques to study artifacts such as ceramic sherds, stone tools, and glass or metal items, we have typically not studied architecture as a human artifact.

The Office of Archaeological Studies of the Museum of New Mexico is incorporating analyses of adobe building materials into archaeological data recovery projects in north-central New Mexico. The research design for the Abiquiu Project (MNM Project 41.405) involves investigating the development of Hispanic and Puebloan sociocultural frontiers. Using data from this and other projects, the Office of Archaeological Studies is exploring the potential of adobe analyses for illuminating patterns of local and regional material use, settlement, site formation processes, and for testing oral tradition.

The Trujillo House (LA 59658)

In 1988, the Office of Archaeological Studies conducted archaeological data recovery investigations at four sites in the Rio Chama Valley immediately east of the village of Abiquiu (Fig. 1). The sites were recorded during an archaeological inventory survey of U.S. Highway 84 prior to planned reconstruction activities.(1)

One of these sites was described as "a dense refuse deposit measuring roughly 23 by 10 m... Although no structures were observed, noticeable vegetation changes suggest areas of occupation. The dense trash deposit is characteristic of domestic refuse, suggesting a historic residential occupation."(2) Data recovery at this site included archival and ethnohistorical research as well as extensive archaeological excavations.

Archival research revealed that the site was located on lands once belonging to the family of Jose de Uribarri, a *genizaro* who settled in Santa Tomas de Abiquiu in 1754. Although the family history is somewhat cloudy due to the nature of the church baptismal and marriage records, it appears that Uribarri's great-granddaughter, Juana Maria Jaramillo, married one Juan Esteban Trujillo. The year of their marriage is not clear, but their first child was born in 1838. The land was sold in 1872 and again in 1884, but Trujillo continued to maintain his residence there. An 1894 map of the Abiquiu area shows the "house and land of Juan Trujillo" at the location of the archaeological site. The house was apparently abandoned soon thereafter.(3)

Excavations at the site confirmed the archaeological survey and archival information by revealing the remains of an eight room, C-shaped adobe structure and a deep trash-filled pit (Fig. 2). The house measured 34.5 m long by 10.5 m wide and faced northwest. The wall remnants were no taller than 50 cm in the center of the house and were missing at the north ends of Rooms 1 and 7, due both to highway construction and to the subsequent burial of a telephone line along the right-of-way fence.

The Trujillo House was constructed of adobe bricks. In some portions of the structure, the bricks could be defined along the top and sides of the wall remnants. However, natural deterioration of the adobe meant that individual bricks could not always be defined. The walls were plastered with one or more layers of adobe plaster and were then covered with very thin layers of gypsum whitewash known locally as *jaspe*. *Jaspe* is not a Spanish word and may have been borrowed from Jicarilla Apaches who frequented the area in the 18th and 19th centuries.

The most common features in rooms were fireplaces, which were typical Hispanic corner fireplaces except that only two fireplaces were actually built in room corners. The other fireplaces were built in artificial corners formed by short wing walls. In each case, the wing walls created a barrier between the fireplace and the door leading into the room, probably protecting the fireplaces from drafts and so increasing their efficiency.

Besides doors, only two other features were recorded in the house. A dismantled *banco* (bench) was found in the northeast corner of Room 1 and an undefined feature was found in Room 7.

The trash-filled pit was located about 6.5 m north of the structure and was identified during survey as a dense scatter of surface artifacts. Excavation revealed a pit 1.6 m deep and 5.4 m in diameter that had been dug into sterile, natural soil.

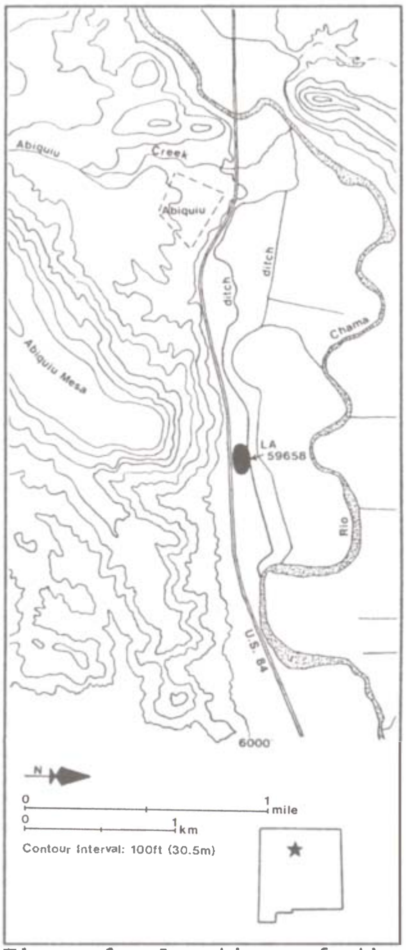

Figure 1. Location of the Trujillo House (LA 59658).

Adobe Building Materials at the Trujillo House

A. Samples and Analytical Methods

Five adobe brick samples and six adobe plaster samples were collected from the Trujillo House (Fig. 2). In addition, two samples were collected from the midden pit, intended to provide control data for the analyses. One sample was collected from the south side of the pit about .5 m below present ground surface. The second sample was collected from the bottom of the pit.

Of the 13 samples, 11 were selected for analyses. These included both samples from the midden pit, the five brick samples, and four plaster samples. Table I lists the proveniences and types of these 11 samples.

The liquid and plastic limits of each sample were determined using methods outlined by Teutonico.(4) Particle size analyses of seven samples were conducted using a sieve stack ranging from 2 mm to .075 mm and the sedimentation-hydrometer method for particles smaller than .075 mm.(5) Finally, Teutonico's qualitative methods were used to test for water soluble salts in seven samples.(6)

B. Analytical Results

1. Particle Size The percentages of coarse and fine sands, silt, and clay in the control sample, three brick samples, and three plaster samples are presented in Table II. Fine sand constitutes the primary ingredient in each sample, ranging from 54 to 75 percent. Coarse sand is the most diverse ingredient, ranging from 1 to 24 percent. Silt ranges from 12 to 24 percent, while clay is present in amounts ranging from 0 to 12 percent.

The control sample from the midden pit contains a very low percentage of coarse sand, a high percentage of fine sand, a moderate percentage of silt, and the highest percentage of clay. The most similar adobe sample is from the hearth floor in Room 3, which is also low in coarse sand and high in fine sand but is much lower in clay. The other samples contain between 3.3 and 6.7 times as much coarse sand as the control sample, while their relative clay contents are 27 to 60 percent less. The brick and plaster samples from Room 2 have the highest clay contents. Sample 4 from Room 4 is aberrant because no dispersing agent was used in processing the sample. Probably for that reason, the percentage of coarse sand is much higher than in the other samples and no clay was recorded.

In order to compare the Trujillo House samples with modern construction standards, the percentages of coarse and fine sands and of silts and clays were combined. This data is presented in Figure 3, which shows the percentages of sands and silt/clays in comparison to standards set by the U.S.D.C. National Bureau of Standards (7) and Section 2405 of the Uniform Building Code.(8) The midden control sample (sample 1) falls near the bottom of the NBS standards for sand but near the middle of the range for silt/-clay. The adobe samples fall below the midpoint of the standards for both sand and silt/clay, indicating that the adobe samples have slightly less clay than recommended, important since clay acts as a binder in adobe.

A different picture is obtained, however, when the samples are compared to the Uniform Building Code standards. The percentages of sand are at or above the midpoint of the range for sand while the percentages of silt/clay are well below the midpoint of the range for silt/clay. This suggests that the adobe samples contain more sand and less clay than recommended standards; since clay is the binder, these sandy adobes would be relatively weak, perhaps weaker than the natural soil.

2. Plasticity Liquid and plastic limits were calculated for all

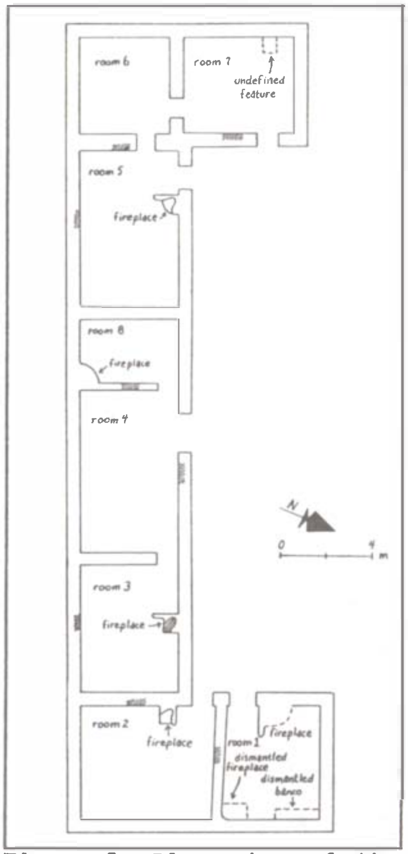

Figure 2. Plan view of the Trujillo House showing features and adobe collection locations (////).

11 samples. The results of these tests are presented in Table II. Figure 4 graphically shows the relationship between the liquid and plastic limits for each sample. It is important to note that only the control sample and two plaster samples have positive indices. All other indices are negative. However, even the positive indices are quite low, indicating that the soil, both natural and as adobe, is essentially non-plastic. This is probably due to the relatively high sand and low clay contents.

Interestingly, the midden floor sample resembles the adobe samples much more closely than it does the control sample. In fact, the plasticity of the midden floor sample is almost identical to that of the wall dividing Room 4 into Rooms 4 and 8 and is quite similar to the samples from Room 2 and from the hearth in Room 3. Although this sample was collected as a control, it appears that it may actually be adobe rather than natural soil. This could not be confirmed by particle size analysis as time did not permit additional tests.

As noted above, the plaster samples from Rooms 5 and 7 are the only adobe samples with positive indices. The brick samples from these two rooms, although possessing negative indices, have the highest indices of the remaining adobe samples. These facts set Rooms 5 and 7 in a cluster of indices well below that of the control sample but above the other adobe.

The sample from Room 4 is singular in its very low index. This sample also had the most diverse liquid limit test figures, perhaps pointing to material diversity within the sample.

3. Soluble Salts The results of the qualitative tests for soluble salts in seven samples are presented in Table II. Tests for the presence of nitrates could not be carried out because the lab lacked the necessary acids and reagents. However, it may be presumed that nitrates are present where nitrites are found. The data show that the midden floor sample contained the widest range of salts, including sulfates, chlorides, nitrites, and carbonates. Only carbonates were strongly present and the identification of sulfates was tentative.

Two samples are similar to the midden floor sample in the presence of salts-sample 2 from Room 2 and sample 3 from the hearth in Room 3. Sample 6 from Room 7 may also be similar but the presence of chlorides could not be positively identified. The remaining samples are similar to each other but not to the midden floor sample.

In general, soluble salts are not strongly present in any of the samples. This may have to do with the high sand content of the soil and adobe, which would facilitate draining water away from the adobe walls rather than holding it in the walls where salts would be deposited.

4. Plaster Layers In addition to the materials analyses, the six plaster samples were visually inspected to determine the number and thickness of plaster layers and number of layers of *jaspe*. Two samples show only one plaster layer; both are from Room 2. The average thickness of six fragments from the west wall is 13.6 mm, while the fragment from the north wall is 22 to 24 mm thick. One *jaspe* fragment from the west wall has six layers, each less than .25 mm thick.

Plaster samples from Rooms 3 and 5 show two plaster episodes. Three fragments from the two rooms may point to a third plaster layer. The evidence from Room 3 consists of possible remnants of *jaspe* on the interior surface of one fragment, while the evidence from Room 5 consists of a thin discontinuous layer on the exterior of one fragment from the south wall and a third exterior layer on a fragment from the west wall. However, six other fragments from the south and west walls of Room 5 have only two layers. Consequently, evidence of a third plaster layer is not substantial and may point to incomplete replasterings of those rooms.

Two fragments from Room 7 point to three plasterings. One fragment has three distinct layers, while the second has two layers with a remnant of *jaspe* on the interior surface.

Interpreting the Results

The potential of adobe materials analyses in archaeological research rests in the ability of the analyses to provide data relevant to research issues. The adobe material from the Trujillo House has yielded information useful in addressing at

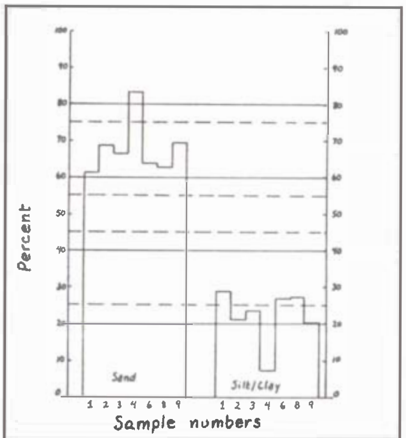

Figure 3. Comparison of Trujillo House adobe with modern construction standards. Solid lines: United States Department of Commerce National Bureau of Standards; Dashed lines: Uniform Building Code.

least three major research questions.

A. Where Was The Adobe Made?

Comparison of the samples taken from the side and bottom of the midden pit reveals that the samples are very different. This is most obvious in Figure 4, where it can be seen that the midden floor sample is quite similar to adobe samples from Room 2, the hearth in Room 3, and the wall separating Rooms 4 and 8. In contrast, the sample taken from the side of the midden pit is a different color than the adobe samples, has different percentages of particle sizes, and a higher plasticity index than the adobe samples and the midden floor sample. This strongly suggests that the control sample from the side of the midden is natural soil. The midden floor sample, on the other hand, was actually adobe that was left in the bottom of the mixing pit.

This is significant for several reasons. First, it identifies the midden pit as an adobe borrow/mixing pit. It seems clear that this feature was initially excavated in order to provide adobe for the house and that, subsequently, the large hole was filled with domestic trash. While we suspected this to be the case, we would not demonstrate it until completion of the adobe analyses.

Second, identification of the borrow pit demonstrates that the Trujillo House adobe was made of local, on-site materials. While this may seem a conclusion too obvious to mention, its significance lies in contrast to an oral tradition from the Taos area to the northeast. Oral tradition in the Taos area maintains that, while adobe was sometimes made on-site historically, there are deposits of clay and sand that were and still are considered to be optimal for adobe. Further, tradition maintains that this "good dirt" was sought by adobe-makers throughout the Taos Valley. This indicates a preference for non-local materials and for regional use of materials from specific locations. This kind of regional use is still being practiced by those in the Taos area who plaster their interior walls with *tierra blanca*, a micaceous kaolin soil found in one deposit in the foothills south of Taos. However, the "good dirt" adobe deposits are located on the Taos Pueblo Indian Reservation and on private lands and are no longer available for general use. Begrudgingly, Taoseños are now forced to make adobe on-site. How accurate the tradition is in showing regional use of specific resources, or whether it actually reflects popular dissatisfaction over the splitting up of the land and the reluctance of landowners to allow access to their lands, is not presently clear. However, it could be tested with analyses of adobe from historical and archaeological contexts. This points out the need for a regional approach to collection and analysis in order to assess the use of local versus regional material sources.

B. How Was The Adobe Made?

Comparison of the adobe samples with the control sample shows that the primary difference between adobe and natural soil at the Trujillo House is that the adobe has a higher coarse sand content and a lower clay content. This suggests that the adobe was made by adding coarse sand to the natural soil. While this may have served to add larger particles to the mix that might act like temper in pottery, its effect was to decrease the relative content of clay, the actual binder in the adobe. The result of this procedure was to produce adobe that was actually weaker than the natural soil due to its high sand and low clay content. This weakness is reflected in the plasticity of the samples. Whereas the natural soil has a positive, albeit low, plasticity index, the plasticity of the adobe is consistently lower and even negative, demonstrating that the adobe from the site is essentially non-plastic. Interestingly, in each case where plaster and brick samples from the same room were analyzed, the plaster has a higher index than the brick, suggesting that the plaster was slightly stronger than the bricks.

The exception to this procedure is the sample from the hearth in Room 3. In this case, the amount of coarse sand is actually lower than the natural soil, while the fine sand is higher. This suggests that the adobe used to plaster the hearth was made by adding fine sand to the mix. While this probably contributed to a finer, smoother plaster, it still decreased the clay content.

There is evidence of historical continuity in the making of weak adobe in the Abiquiu area. In 1982, the New Mexico Bureau of Mines and Mineral Resources published the results of a survey of modern commercial adobe-makers in New Mexico.(9) The survey included several tests of sample bricks. Among the traditional adobe-makers whose bricks were tested for compressive strength, modulus

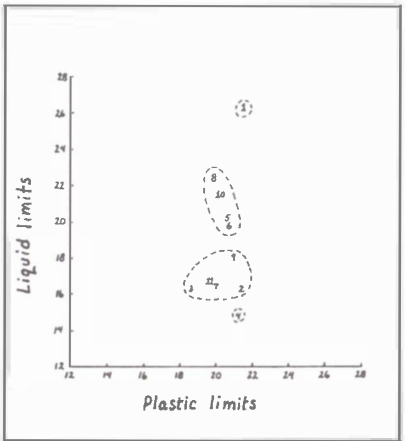

Figure 4. Plasticity, Trujillo House adobe. Each number refers to a sample number.

of rupture, water absorption, and moisture content was one adobe yard in Abiquiu. While the Uniform Building Code (New Mexico State Building Code) requires an average compressive strength of 300 psi, the adobes from Abiquiu averaged only 196 psi. Of the 47 other adobe-makers whose bricks were tested, only three provided samples with lower compressive strength, and two of those were damaged in route to the testing facility. Clearly, the sandy soils of the Abiquiu area are not conducive to making strong adobe.

C. What Was The Construction Sequence Of The Trujillo House?

Wall thicknesses indicate that rather than being built as a single building, the Trujillo House grew as a series of four units over a period of time. Rooms 1 and 2 constituted one unit. The wall separating these two rooms directly abutted the exterior walls rather than being built into the exterior walls and was made of bricks laid end to end so that it was narrower than the exterior walls, which were made of bricks laid side to side.

Rooms 3, 4, and 8 also constituted a single unit. The walls surrounding these rooms were thick exterior walls, including the wall separating Room 3 from Room 2. As with Rooms 1 and 2, it appears that a large room was built that was subsequently divided by narrow interior walls. This is supported by wall abutment patterns, in which plaster on the south wall of Rooms 3, 4, and 8 continued behind the wall abutments separating the rooms. In addition, the adobe floor continued under the two dividing walls.

Room 5 was added to the west end of the Room 3-4-8 block as a single unit. The wall between Rooms 8 and 5 was a thick exterior wall and there was no continuity of plaster or floor between the rooms as there was in Rooms 3, 4, and 8. Rooms 6 and 7 were built as a single unit and subsequently subdivided. Plaster on the west walls of Rooms 6 and 7 was continuous behind the wall abutment separating them. The dividing wall was narrower than the surrounding exterior walls.(10)

Though it is plain that the structure grew by accretion, the actual sequence was difficult to discern as natural deterioration of the adobe had obscured some wall abutments. For instance, it was clear that a thick exterior wall separated the Room 1-2 unit from the Room 3-4-8 unit, but whether it was originally the east wall of Room 3 or the west wall of Room 2 was not clear.

Comparison of the samples demonstrates that there were distinct similarities between the adobe from the midden floor and that from three locations in the house - Room 2, the hearth floor in Room 3, and the wall dividing Rooms 4 and 8. This is seen clearly in the plasticity and salts tests. Analyses of the artifacts from the six cultural strata in the pit strongly suggest that the artifacts were deposited in the pit after about 1880 or perhaps slightly earlier.[11] This suggests that modifications made to the house using adobe from the pit also date from the last years of the occupation. Therefore, it may be conjectured that Room 2 was built late in the site's history, probably during the last building episode. This is supported by the plasticity data and the soluble salts, as seen in Figure 4 and Table II. It is also supported by the plaster layer data, from which it is seen that Room 2 is the only room with a single plaster layer, in contrast to Rooms 3, 5, and 7, where two and three plasterings are evident. Since it is clear that Rooms 1 and 2 were built as a unit, this unit was probably the last portion of the house to be built.

As noted above, plaster on the southern wall of Room 4 demonstrates that this wall and, therefore, Room 8 were built after construction of Room 4. It may be conjectured that the wall dividing Room 4 into Rooms 4 and 8 dates from the same late building episode that produced Rooms 1 and 2. This is supported by the plasticity data, which points to a strong similarity between the midden adobe and the Room 4/8 wall.

Finally, although Room 3 had evidence of two or three plastering episodes and so was perhaps one of the older rooms, the fireplace was apparently remodeled or at least replastered at the same time that Rooms 1 and 2 were built and Room 8 was divided from Room 4.

Using wall thickness data and the results of materials analyses, the following scenario may be postulated for the construction sequence of the house. Rooms 3 and 4 were built as the original house, perhaps as early as the late 1830s. Sometime later, Room 5 was added to the west end of the house. It remained a separate unit as no door was made to connect it to Room 4. Rooms 6 and 7 were built as a unit on the west side of Room 5 and connected to the latter by a door, resulting in a larger, three-room unit on the west end of the house. The presence of two and three plaster layers in Rooms 3, 5, and 7 suggests that the house grew to that size fairly rapidly and remained in that form until about 1880, being subjected to the same maintenance activities. Sometime around 1880, Rooms 1 and 2 were built as a unit on the east end of the house, Room 4 was subdivided into Rooms 4 and 8, and the fireplace in Room 3 was remodeled or replastered. Finally, between that time and the time of abandonment about 1894, Room 1 was extensively remodeled.

Conclusions

Analyses of adobe building materials have yielded significant information on construction processes at the Trujillo House. The analyses demonstrate that the adobe used at the site was made on-site. Further, a large trash-filled pit was positively identified as a borrow/mixing pit, clarifying processes of site formation.

The natural soil at the Trujillo House is not well suited for adobe, although it falls within modern construction standards. If the Trujillos had used the natural soil alone, the adobes might have been stronger. However, by adding additional sand, the relative clay content of the soil was decreased, making it weaker and non-plastic.

Finally, the analyses have been critical in determining the construction sequence of the house by providing data which, when linked with artifactual studies, allow us to assign dates to construction episodes and to portions of the structure. As a consequence, the growth of the house from its original two rooms to its final eight is better understood.

These data are important in themselves with specific reference to the Trujillo House. However, they raise questions about material use and site formation processes that require a regional perspective. What are the quarry sources for *jaspe*? If the use of *jaspe* represents regional use of a specific material, why does the adobe reflect use of on-site materials? Are there no regional sources for better adobe soil? How does the size of a dwelling reflect the length of occupation? What is the relationship between dwellings and other features on a site? A body of regional data will show the utility of adobe materials analyses in addressing regional archaeological issues.

The Trujillo House data have important implications for conservationists as well. Material compatibility between original adobe and that used for stabilization, reconstruction, or maintenance could best be ensured by using materials from the same for similar sources. This should reduce the risks of differential weathering, moisture absorption, and weight-bearing strength. However, identification of material sources and construction techniques raises an issue of the desirablilty of identical materials in conservation. Were the Trujillo House to be stabilized or reconstructed, the conservationist would need to consider whether such weak adobe would be suitable in the face of long-term maintenance and stability needs. Finally, there is the consideration of the use of materials from different sources in the same structure, which would require both identification of the various sources and assessment of material compatibility and suitability for use throughout the structure. These concerns point to the need for regional data collection and suggest an important partnership between archaeology, ethnohistory, and conservation.

Table I. Sample numbers, proveniences, and types, Trujillo House adobe.

Sample	Provenience	Type
1	Midden pit, south wall, .5 m below present ground surface	Natural soil control
2	Room 2, west wall	Brick
3	Room 3, hearth floor	Plaster
4	Room 4, north wall	Brick
5	Room 5, west wall	Brick
6	Room 7, east wall	Brick
7	Rooms 4 and 8, wall	Brick
8	Room 7, east wall	Plaster
9	Room 2, north wall	Plaster
10	Room 5, south wall	Plaster
11	Midden pit floor	Adobe

Table II. Summary of analytical results, Trujillo House adobe.

Sample	Particle Size in %[a]				Plasticity in %[b]			Salts[c]			
	cs	fs	s	cl	ll	pl	pi	s	ch	n	c
1	3.56	67.72	16.59	12.12	26.30	21.49	4.81				
2	16.55	62.28	14.02	7.14	16.25	21.49	-5.24	-	+/-	+	++
3	1.60	74.56	18.77	5.07	16.30	18.50	-2.20	-	+/-	+/-	+
4	24.01	68.90	7.10	0	14.70	21.20	-6.50	-	-	+/-	+
5					20.23	20.64	-.41	-	-	+/-	+
6	13.30	60.66	19.63	6.54	19.70	20.63	-.93	+	?	+/-	+
7					16.60	19.96	-3.36	-	-	+/-	+
8	17.74	54.90	24.06	3.28	22.50	19.94	2.56				
9	11.97	67.82	12.94	7.27	18.00	21.00	-3.0				
10					21.60	20.13	1.47				
11					16.75	19.78	-3.03	+/-	+	+	++

[a]Particle Size - cs:coarse sand; fs:fine sand; s:silt; cl:clay.
[b]Plasticity - ll:liquid limit; pl:plastic limit; pi:plasticity index.
[c]Soluble Salts - s:sulfates; ch:chlorides; n:nitrites; c:carbonates; ++:strongly present; +:present; +/-:indications inconclusive, perhaps present; -:not present; ?:un known.

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The Protection and Conservation of the Adobe Structures at Paquimé, Casas Grandes, Chihuahua, Mexico

Roy B. Brown, *
Centro Regional Chihuahua
Instituto Nacional de Antropología e Historia
Juárez y Carranza
31000 Chihuahua
México

Beatriz Sandoval and Haydee Orea M.,
Dirección de Restauración del Patrimonio Nacional
Instituto Nacional de Antropología e Historia
Ex-Convento Churibusco
Xicotencatl y General Anaya S/N
Col. Churibusco, México D. F.
México

* Author to whom correspondence should be addressed.

Abstract

The archaeological site of Paquimé, Casas Grandes, is located in the grasslands of northern Mexico. Paquimé is a prehispanic rammed earth city that reached its heyday in the fourteenth century. Discussion centers on the factors contributing to the deterioration of adobe at Paquimé and the steps that have been taken to preserve the building known as Unit 6. The conclusion presents comments on the steps that need to be taken to insure the site's conservation and protection.

Keywords:

ARCHAEOLOGY, PAQUIMé, CONSERVATION, PROTECTION, ADOBE, RAMMED EARTH

Introduction

Five hundred to a 1000 years ago the site of Paquimé near Casas Grandes, Chihuahua, Mexico, dominated northwestern Chihuahua (Phillips 1989). The early pit houses were replaced by wattle and daub compounds which in turn were replaced by rectangular, single story, rammed earth compounds. These compounds were transformed into the apartment blocks which dominate today's vista.

Apart from the construction techniques, the diagnostic architectural complex includes a freshwater-cum-drainage system colonnades, sleeping nooks, stylized hearths, turkey and macaw pens and "T" shaped doorways. The walls are made in standard widths roughly equivalent to 25, 40, 80 and 120 cm. Non-habitational areas include rubble core/stone veneer ceremonial structures such as platform mounds and "I" shaped ball courts (Di Peso 1974; Di Peso, Rinaldo and Fenner 1974).

Paquimé, lies in the Chihuahuan grasslands of the Basin and Range Province of western North America at 30° 25′ N: 107° 52′ W, at 1485 m above sea level. It is about 20 km east of the Sierra Madre Occidental. Paquimé sits on the first terrace of the western bank of the Casas Grandes river.

The climate is arid (300 mm) and extreme (Cetenal 1977; Córdoba *et al.*, 1969; Schmidt 1975, 1983). Most rain falls in torrential summer storms. The extreme summer temperatures surpass 40° C while the extreme winter temperatures dip below 17 °C. Spring winds, westerlies and souwesterlies, reach peak velocities > 17 m/sec. Winter northers reach velocities > 13 m/sec. Soils are shallow, immature and calcareous.

Between 1958 and 1961 Charles Di Peso, Director of The Amerind Foundation led the Joint Casas Grandes Expedition in collaboration with the National Institute of Anthropology and History, a branch of the Mexican government (Contreras 1958; Di Peso 1960, 1966, 1968, 1974; Di Peso, Rinaldo and Fenner 1974).

The four principal factors leading to the deterioration of Paquimé are water (rain, run-off, and capillary action); wind abrasion; expansion and contraction due to temperature changes; and, abrasion etc. due to visitors.

The three main criteria for the development of a research strategy and a management plan are the need to protect the site's scientific worth, educational value and esthetic integrity.

Material presented in this paper without specific attribution is derived from Di Peso (1974) and Di Peso, Rinaldo and Fenner (1974).

Cultural History

Di Peso provided a three period, nine phase chronology based on dates derived from radiocarbon, tree-ring, and obsidian rehydration measurements. Subsequent work has modified the chronology (Dean and Ravesloot 1988; Le Blanc 1980; Lekson 1984). Phillips (1989) proposes an alternate chronology that eliminates some phases and combines others:

Tardio Period;	San Antonio de Padua Phase	AD 1660-1686
Medio Period;	Paquimé, Diablo and Robles	AD 1300-1450
	Buena Fé Phase	AD 1150-1300
Viejo Period;	Perros Bravos Phase	AD 1075-1150
	Pilon Phase	AD 975-1075
	Convento Phase	AD 975- 600

The Viejo Period: The Viejo Period reflects the expansion of the local population as pit-house villages grew and were replaced by rectangular wattle and daub surface compounds. The beginning of this period was related to the downfall of Teotihuacan and the end was related to the rise of Tula (Di Peso 1974).

The Medio Period: Casas Grandians managed to accumulate large quantities of shells, copper bells, metates, etc. and produced large quantities of macaw and turkey feathers. These products were exchanged for cosmic legitimization (Rathje, Gregory and Wiseman 1978).

The Tardío Period: The Tardío Period includes the post climax occupation around Paquimé and the first Spanish intrusions.

Construction Techniques

Since everyone knows what adobe is, adobe is different things to different people (Judd 1977). In this paper we will consider adobe to be a mixture of clayey soils and sand that have been used in construction (Judd 1977). The ideal percentage of clay should be under 20%, while the sand should surpass 45%.

As clay dries, it shrinks, looses its lubrication water and sets in a particular shape. Once the adobe had been set, subsequent addition of water will rehydrate and "melt" the clay. To protect their form most adobe structures are roofed and plastered. When the protection is lost, water penetrates and re-initiates the re-hydration process which results in "adobe rot".

At Paquimé the basic construction material is the local soil which naturally has a high proportion of montmorillonite clay and caliche. No organic matter was added to the soil.

Since cracking was slight, it seems as if the walls were made with a fairly dry mixture of water, mud and gravel. Non-load bearing walls were about 25 to 30 cm wide while load-bearing walls were about 40, 80 or 120 cm wide. The thinner walls supported single story structures while the thicker walls supported multi-storied structures. Although sixteenth century documents mention six or seven floors (Obregon 1986), archaeological evidence suggests there were only three or four.

Both interior and exterior walls were plastered. First the wall core was covered with a layer that provided a level surface for the application of the finishing layer. This penultimate layer plays two very important rôles. Firstly, it creates a smooth and uniform surface that increases the adhesion of the final layer. Secondly by adsorbing any irregularities in the outer surface of the core it reduces the mechanical and hydraulic stresses that tend to crack the final layer.

Conservation and Preservation

The Degradation of Adobe at Paquimé: The four principal factors leading to the degradation of adobe at Paquimé are water (rain, run-off, and capillary action); wind abrasion; expansion and contraction due to temperature changes; and, abrasion etc. due to visitors.

Water is the number one enemy of adobe and rammed earth buildings. Water is the original "plasticizer" and as such permits the shaping of clay. Once dried clay maintains its shape until it is rehydrated and returned to the plastic state. Rehydration may be the result of a single event or the continual wetting due to rain, dew, etc.

Water at Paquimé is mainly derived from rain. Torrential storms wash away any loose material leaving a new surface to be subjected to yet an other drying cycle.

Capillary action takes place in any porous material that finds itself in contact with another material with a higher percentage of liquid water. It must be remembered that the clays in the adobe provide a large area to store water and facilitate evaporation. In adobe walls in arid environments, the capillary action is re-enforced by the establishment of a vapour front which would seem to wick the water further up the walls, with a resultant increase in coving.

Paquimé is subjected to spring and early summer winds with peak velocities in excess of 17 m/sec (60 kph). The particles in the wind work like a sand blaster abrading the walls. The impact of these winds can be clearly seen in the asymmetrical wear of exposed walls. In general terms, the amount of material eroded from the western face of exposed north-south walls is more than twice that of the east face. This wind driven asymmetrical erosion is not found in protected walls.

The winds also help to wick out the moisture in the walls and increase the amount of damage attributed to "capillary action". The continual expansion and contraction due to temperature changes results in the chronic destruction of the most basic mechanical bonds. As previously noted ambient summer temperatures in the shade exceed 40°C while winter temperatures fall below -17°C. In the summer the temperatures of surfaces exposed to direct sun light will vary more than 40°C each day. This results in a small but not insignificant expansion and contraction cycle (Luis Torres, personal communication). In the winter the formation of ice crystals within the adobe also creates pressures that break the mechanical bonds.

Paquimé received over 17,500 visitors in 1989 and like the sand particles in the wind, they slowly but surely abrade whatever they touch. While it is hard to measure the impact of the individual visitor, the wear and tear can be easily detected month by month. The sucessful installation of a visitors trail has greatly reduced this damage.

Properly cared for adobe is a strong and long lasting material, but exposed to the elements it quickly melts and looses its structural properties. The individual and combined damage of water, wind abrasion, temperature changes and visitor induced abrasion are chronic and insidious since they take advantage of the weaknesses created by each other.

Conservation: In 1988 the National Institute of Anthropology and History, in collaboration with the government of the State of Chihuahua, undertook the restitution of Unit 6. Unit six is a single story rammed earth structure to the north west of the main living quarters. Unit six was previously restored by Eduardo Contreras in 1981.

The first step was to gather all the available documentary and photographic evidence that would facilitate the job. Based on Di Pesos' monumental work (Di Peso 1974; Di Peso, Rinaldo and Fenner 1974) a profile of each room was developed and converted into the work sheet used to evaluate each rooms' condition.

The second step was the application of sacrificial superficial layers of "new old adobe" that would cover and protect the original wall stubs. "New old adobe" is the material that was washed into the rooms as the buildings eroded and then was removed as fill during the excavation.

The wall stubs were scrapped to remove loose material, gently wetted down and covered with "new old mud". The "new old mud" was forcefully flicked on with a small mason's trowel. A 30 cm grid of yellow polypropylene strings and knots were placed within the first layer of the "new old mud". This grid will inescapably delineate the joint.

After the "new old mud" covered the old wall stub, the workman applied considerable pressure to create a smooth surface and float the fines to the surface. Then, indentations were made with the point of the trowel. These indentations helped stop cracks and improved the adhesion of the next layer. The workmen preferred to use their fingers.

When the first layer was quite dry, a second layer, and then a third, etc. were applied as necessary to bring the wall back to the dimensions specified in Di Pesos' reports.

An alternative approach is effective in some cases of advanced erosion. Walls were re-built using forms that simulated the original construction technique (Contreras 1985). These forms were positioned in the manner suggested by Contreras (1985) and filled with "new old mud". The forms were removed once the mud was dry enough to stand on its own. After each section was dry, the planks were raised and another section built. Once the wall was close to the dimensions specified (Di Peso, Rinaldo and Fenner 1974), one or more layers of mud were flicked on.

The use of forms is ideal only in specific situations. Forms are successful only in reconstructing walls from low stubs. Attempts to apply this technique to walls that have been heavily eroded laterally, but not vertically, have not met with success. As the new material dries, it tends to lose adherence and draw away from the old wall. There needs to be sufficient mass, at least 20 cm of "new wall", above the stub to bind the material applied to the sides.

Steps To Be Taken: The most important steps to be taken are the development of long term maintenance and protection programs. The success of a maintenance program depends on the financial commitment to semi-annual inspections that include both photographic and written documentation. Such semi-annual inspections are the key to site preservation since they provide the information needed to evaluate what techniques and actions have been successful as well as anticipate the budgetary needs in the short, medium and long term.

The protection program needs to addresess the different problems faced in protecting the different facets of the cultural heritage. Such a protection program needs to enlist the support of the general public, help them appreciate the pace that at which their history is being destroyed and create a conciencious force that strives to protect archives, historic buildings and archeological sites, etc.

The work done at one site has little meaning if everything else is forgotten. Steps must be undertaken to protect the plain as well as the dramatic. The general public pays for the protection of cultural resources and the public should know what it gets for its money. As government agencies we are no more than the custodians of the public interest. If there is no public interest, we are custodians of little more than a collection of anachronims.

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ABSTRACT

The mud and brick wall remnants at Fort Selden State Monument, New Mexico, U.S.A. were stabilized 1972, 1974, and 1985. The techniques employed included the placement of caps on wall tops, repair of basal erosion, establishment of drainage slopes to prevent the accumulation of water next to walls, preservation landscaping, and construction of visitor trails. These efforts have retarded, but not stopped, the deterioration of the site. It is suggested that research be directed toward the burial of cultural resources as a long-term preservation method, and it is recommended that sites should not be excavated and left exposed for purposes of public display and interpretation.

KEYWORDS

Preservation

Predictive Modeling

Resource Burial

Earthern Architecture

Display and Interpretation

Fort Selden, Administration Building, 1867. Photographic Archives: Museum of New Mexico.

Fort Selden, Company Quarters, 1867. Photographic Archives: Museum of New Mexico.

Fort Selden, Company Quarters and Post Hospital, 1886. Photographic Archives: Museum of New Mexico.

FORT SELDEN RUINS CONSERVATION

Thomas J. Caperton
New Mexico State Monuments
Museum of New Mexico
Box 2087
Santa Fe, New Mexico 87503
U.S.A.

Location

Fort Selden is located in the semi-desert country of New Mexico in the southwestern United States, 85 km (53 mi) north of the Mexican border on the Rio Grande.

Historical Background

The post was established to protect visitors in the valley of the Rio Grande from Indian raids and bandits. The adobe fort was constructed in the late 1860s by soldiers from the garrison, military prisoners, and civilian employees.

The flat-roofed structures comprising Fort Selden were arranged about a rectangular parade ground, they included the Officer's Quarter's, Company Quarters, Administration Building, and the Post Hospital. Beyond the perimeter of the parade ground were the corrals, the Commanding Officer's Quarters, and the Trader's Store. Fort Selden was constructed to hold a complement of about 200 men.

According to military specifications the outer walls were .61 m (2 ft) thick and the inner walls, which did not support roof beams, were .30m (1 ft) thick. The outer walls had rock foundations and the interior walls had mud brick foundations. The walls were 3.05 m (10 ft) high from floor to ceiling with a .61 m (2 ft) parapet above the roof. The roofs consisted of peeled cottonwood logs (vigas) overlayed with small cottonwood poles (latillas) which were placed side by side. On top of these were a layer of willows placed crosswise, and on the willows a thick layer of hay and a 8.9 cm (3 1/2 in) layer of mud mixed with cut straw. On top of this was a layer of tamped dry earth and, finally, a 8.9 cm (3 1/2 in) layer of mud. Most of the exterior walls were not rendered, while the interior of the buildings were coated with a lime plaster.

There were continual problems with the upkeep of the mud brick buildings. During one period of particularly heavy rain, tents were pitched inside the rooms to protect the inmates and their possessions. In 1871 the Post Commander commented: "The buildings and quarters are sufficient for the present garrison, and have been well built from the material afforded by the country (adobe) but that material ... disintegrates so fast during the summer rains that constant repairs are needed to preserve the buildings for decay and ruin" (Cohrs, Caperton, 1983: 6).

The post was abandoned in 1891. The roofs, windows, and other salvageable material was reportedly given to a contractor in payment for removing the bodies from the post cemetery.

Environmental Data

Fort Selden is located at an elevation of 1126 m (3990 ft) above sea level. Temperature and precipitation has been recorded at a station 20.9 (13 mi) from the site since 1870.

The average annual maximum temperature (1870-1983) is 24.7° C (76.4° F), the average minimum temperature is 6.6° C (43.9° F). There are an average of 97 days a year with temperatures over 32.2° C (90° F) and 100 days with the temperatures at or below freezing. The mean annual precipitation is 21.60 CM (8.49 in). The rainy season is from July 1 to September 10. The months of July to September receive 54% of the annual rainfall.

Preservation Efforts

The former fort was acquired by the New Mexico State Monuments, a bureau of the Museum of New Mexico, in 1972. There is a visitor center with a full time staff at the site. Preservation projects were instituted at the monument in 1972, 1974, and 1985.

Walls Caps

During the historic occupation of the post, lime plaster was used to form a simple cap on the walls. Erosion problems at another nineteenth century fort in New Mexico were addressed by placing wide wooden planks on top of the walls to protect them and form a drip edge. The planks were held in place by additional mud bricks.

During the 1972 stablization effort at Fort Selden some of the wall remnants were capped with mud bricks which had been amended with a polyurethane resin (Pencapsula). The amended bricks were relatively impermeable and this may have resulted in the accelerated erosion of the wall fabric immediately below the cap. The bricks were laid in line with the walls with no drip edge. In some cases several courses of historic bricks were removed to form a base for the new material. The result of this work was a flat-topped unnatural appearance to the walls. The amount of original fabric removed would probably not have been lost from natural weathering processes for several decades.

Workman preparing eroded wall base for insertion of new adobe bricks, 1974. New Mexico State Monuments.

The amended bricks were removed in 1974 and the walls were coated with about 2.54 cm (1 in) of unamended mud to form a protective cap.

The walls were capped with unamended mud again in 1985. Narrow strips of red plastic sheeting were placed between the cap and original surface at 0.9 m (3 ft) intervals to act as indicators when additional maintenance work is required.

The unamended cap lasts about one year. The rapid deterioration of the cap is the result of the relatively wide wall surface which is exposed to rain and snow. Some of the walls which were not capped have eroded to a characteristic rounded or pointed top which tends to shed water and on which snow does not readily accumulate. While the unamended cap is an effective and aesthetically acceptable preservation technique, if well maintained, investigation should be made into the use of amendments that would retard erosion without having adverse effects upon other portions of the wall remnants. The use of shelters to protect the exposed mud brick walls might be a more effective preservation technique than capping. Careful consideration must be given to the design of the shelters so that they do not create adverse physical effects upon the wall remnants.

Workman contouring new adobe bricks to fit profile of historic wall, 1974. New Mexico State Monuments.

Wall Bases

Many of the wall bases at the monument exhibited typical basal erosion caused by rising damp, leaching of salts, wind carried abrasives, and to some extent, rodent infestation.

In 1974 the walls that exhibited advanced basal deterioration were repaired by inserting mud bricks into their base. The eroded areas were prepared by cutting them into a rectilinear form with a flat base to accept the new mud bricks which were set in unamended mud mortar. The square edges of the bricks were trimmed to match the contours of the historic walls.

Walls which exhibited less basal erosion were repaired with successive layers of mud plaster.

Adobe wall before stabilization, 1974. New Mexico State Monuments.

Drainage Slopes

Slopes were established to prevent the accumulation of water next to walls. The exterior and interior ground surfaces of the rooms were, as practicable, brought to the same level by lowering or raising the fill. This may prevent problems with the transference of moisture through the wall from the area of greater to lesser fill. The ground surface was then sloped away from the walls to facilitate water run off.

In those cases where there was severe and extensive basal erosion, earth berms were established against the walls to provide structural support. The berms were compacted and sloped away from the walls to prevent the accumulation of water next to them. The basal erosion pattern will reoccur at the juncture of the wall and top of the berm.

Drainage within room blocks was generally facilitated by channeling the water through doorways or gaps in the walls to the exterior of the structure. In cases where this was not possible, the interior of the rooms were contoured to encourage the puddling of water in the center where it would evaporate.

Adobe wall after stabilization, 1974. The ground surface has been raised to provide wall support and graded to facilitate water runoff. New Mexico State Monuments.

Preservation Landscaping

Several species of natives grasses that do not require watering after establishment were planted on the parade ground and the perimeters of the post. The grass may reduce the amount of wind carried particles that blast the wall remnants of the post during sandstorms. Vegetative growth is discouraged in the rooms for it is felt that it might retain moisture which would enter the walls.

Visitor Trails

Distinct trails were established through the fort and visitors are requested to stay on them. Them recudes impact on the walls from public use.

Predictive Modeling

In 1989 photographs from the occupational and post-occupational periods of the fort were compared with present-day photographs by Kevin McDougall and John

Preservation landscaping. Grass was planted on the parade ground to reduce the amount of wind carried abrasives. The trees replicate the historic landscape, 1985. New Mexico State Monuments.

Drainage contours to prevent accumulation of water next to walls. The grade is established to the center of this roadway. After snow, 1974. New Mexico State Monuments.

Officer's Quarters before stabilization, 1974. New Mexico State Monuments.

Officer's Quarters after stabilization, 1980. New Mexico State Monuments.

Jensen of the University of Queensland, Brisbane, Australia to dtermine if photogrammetry can be used to determine the erosion rate of cultural resources. McDougall and Jensen stated that it is possible to extract data from which the deterioration rate of adobe buildings could be determined. Predictive modeling possesses the potential to be an invaluable tool for both preservationist and site managers.

Resource Burial and Public Presentation of Cultural Resources

Low-lying walls at Fort Selden which were not of salient interest to visitors were draped with a soil membrane (geotextile) and covered with earth.

Resource burial is the most effective means of preservation known today. Sites should be recorded prior to burial and copies of the data placed in time capsules on the site. The resource could remain covered for generations and the time capsules might insure the survival of archival data. In cases where there are substantial above ground remains the resource should be covered to the greatest extent possible. Thus, a good portion of the site will remain relatively intact. Site burial has the additional benefit of discouraging vandalism.

The mud brick remains of Fort Selden are preserved by the State of New Mexico for purposes of display and interpretation. Such public programming can conflict with preservation efforts. Decisions regarding the presentation of the site may have a significant impact upon the cultural resource.

In many cases, extensive ruins in the southwestern United States which are open to public visitation have been stabilized in the same form that they were found after archaeological excavation. The resources did not exist in this condition, as a roofless ruin without room fill, during any period of their history. The walls, and other features, if left exposed, deteriorate rapidly. After several decades of weathering and/or repair the original fabric of the resource becomes enextricably altered. A fantasy historical environment may be created is this process continues. The preservation design ultimately may destroy the historic integrity of the resource.

Alternative forms of resource presentation and interpretation must be implemented. For example, sites can be effectively interpreted in a museum setting without sacrificing the integrity of the resource. Portions of a site might be excavated and enclosed in a structure with a controlled environment.

CONCLUSIONS

The preservation design of the mud brick wall remnants at Fort Selden, New Mexico included the placement of unammended mud caps on walls, filling of areas of basal erosion with mud bricks, establishment of drainage slopes to prevent the accumulation of water next to walls, preservation landscaping, construction of trails for site visitors, and resource burial. These techniques have, at best, extended the life expectancy of the ruins and hopefully have not had a deleterious effect upon the resource.

To date there is no panacea for the ills associated with the conservation of adobe cultural resources, and some procedures have resulted in their further degradation. The exploitive presentation of historic sites should be reconsidered in light of the fact that the original fabric of the resources is often sacrificed or lost for reasons of public programming.

The most effective preservation techniuqe for earthen ruins is burial. It is recommended that research be directed toward the burial of sites, alternative methods of presentation and interpretation, and the investigation of erosion rates.

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ABSTRACT

In the "l'Ile district of Martigues (Bouches-du-Rhône - Southern France), important rescue archeological excavations have taken place during a twelve-year period (1978 - 1989) ; this work has shed much light on our knowledge of architecture and daily life in Southern Gaul during the Iron Age. Because of its exceptionally good state of preservation, the site has clearly demonstrated the importance of earthen materials in construction techniques and has provided a good insight into the domestic lay-outs within the two successive protohistoric villages found there.
In addition, this archeological work has led to a project aimed at presenting some of the earthen buildings of the first village, this through both restoration and reconstruction.

KEY WORDS

Archeology - Reconstruction - Earthen architecture - Domestic lay-outs - Earthen objects - Iron Age - "L'Ile" district of Martigues - France.

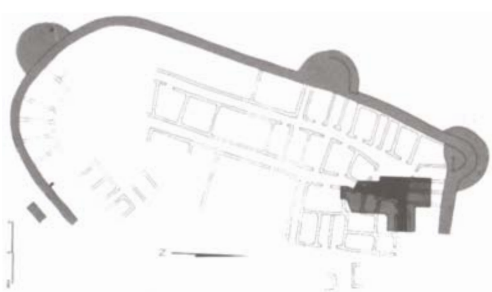

FIG. 1 Plan du premier village protohistorique (début Ve - début IIe s. av. J.C.) et implantation de la "Vitrine Archéologique". Dessin N. Nin.

FIG. 2 Fouille de l'espace concerné par la préservation archéologique. Place d'angle, rues et maisons du premier village. Photo Jean Chausserie-Laprée.

L'ILE DE MARTIGUES A L'AGE DU FER : UN VILLAGE EN TERRE

Histoire et préservation du site.

Jean CHAUSSERIE-LAPREE
Archéologue de la Ville de Martigues
Mairie de Martigues, BP 101
13692 MARTIGUES CEDEX - FRANCE

Introduction

De 1978 à 1989, le quartier de l'Ile à Martigues, petite ville de Provence Occidentale, a été le théâtre d'importantes fouilles archéologiques motivées par une opération de rénovation urbaine. Les principaux résultats de cette recherche concernent l'installation au début du 5ème siècle avant J.C. d'un habitat urbanisé qui est à l'origine de l'agglomération actuelle.

Entre le début du 5ème siècle et la fin du 2ème siècle avant J.C. deux bourgades protohistoriques se sont succédées au milieu du chenal qui relie l'Etang de Berre à la Méditerranée. Grâce à des conditions de sédimentation particulières -exhaussement du sol, submersion partielle, incendies répétés- les structures bâties des deux villages ont été remarquablement conservées. Elles offrent un large panorama des techniques architecturales et des pratiques domestiques en vigueur dans le Sud de la France durant l'Age du Fer, et soulignent l'importance de la terre crue dans la construction, l'aménagement intérieur, l'entretien et la décoration des maisons (1).
La qualité des vestiges qui a permis d'établir l'histoire des techniques architecturales protohistoriques utilisées sur ce site est à l'origine du projet de conservation et de mise en valeur de l'habitat in situ. Toutefois les problèmes liés au contexte urbain actuel, à la remontée de la nappe phréatique et à la nature des vestiges interdisaient une conservation en plein air. Le choix s'est donc porté sur une conservation en rez-de-chaussée de l'un des immeubles nouvellement construits. Ainsi derrière une "vitrine archéologique" est aujourd'hui présentée au public une partie du quartier nord-ouest du premier village gaulois. Huit habitations sont partiellement conservées et occupent, avec les trois rues et la place qui les desservent, une superficie de 70 M2 (voir fig. 1-3).

Un double parti de présentation a animé la réalisation de ce projet :

- la restauration des vestiges immobiliers dans leur état initial met clairement en évidence le plan d'urbanisme et l'architecture vernaculaire de cette agglomération. La superposition de murs d'époques successives trahit également le principe de sédimentation du site.

- la reconstitution intégrale de plusieurs maisons donne une image inédite de ce type d'habitat. La variété d'utilisation et l'adaptabilité du matériau terre trouvent ici une illustration que la seule conservation des murs n'aurait pu fournir.

On trouvera donc l'association des deux thèmes principaux traités dans cette conférence : l'histoire et la tradition de l'utilisation de la terre dans l'habitat d'une part, la restauration et la préservation des sites de l'autre.

TECHNOLOGIE PROTOHISTORIQUE DE L'ARCHITECTURE EN TERRE

Dans les deux villages l'architecture de terre se rencontre à tous les niveaux de la construction domestique (murs, toitures, sols, placages, aménagements intérieurs etc...) et se présente, en fonction de chaque utilisation, sous une forme et une technologie différentes.

LES MURS : LE PRINCIPE GENERAL DE CONSTRUCTION

Porteurs ou cloisons, les murs sont constitués de deux parties :
- une base en pierres liées au mortier de terre
- une élévation de terre crue

On trouve ici un modèle issu du monde hellénique et largement répandu sur les habitats protohistoriques du Sud de la France dès le début du 6ème siècle avant J.C. (2) (Voir fig. 4).

La base en pierres :
La fonction de la partie basse en pierres n'est pas identique selon qu'il s'agit de constructions initiales ou de reconstructions. Dans le premier cas la nature meuble du sous-sol rendait nécessaire une fondation enterrée destinée à protéger la base de la maçonnerie de l'affouillement. Quand le mur est rebâti sur une ancienne construction ruinée, la fondation devient un simple soubassement, à peine enterré, qui asseoit la partie en terre et l'isole des remontées capillaires d'humidité. La hauteur de ce socle, généralement peu importante (0,30 m à 0,50 m) peut atteindre 1 m sur certains murs de façade plus exposés aux chocs et à l'érosion (voir fig. 5).
Quelles que soient les périodes, la technique de construction est une maçonnerie porteuse à deux parements en moellons irréguliers montés en opus incertum et liés avec un mortier de terre.

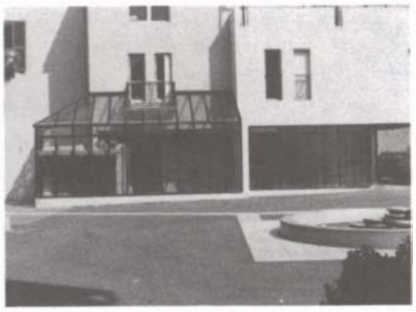
FIG. 3 Vue extérieure d'ensemble de la "Vitrine Archéologique". Photo J.C-L.


FIG. 4 Mur de fond d'une maison du premier village (IVème s. av. J.C.) Elévation d'adobes sur soubassement de pierres. Photo J.C-L.


FIG. 5 Fondation d'orthostates et soubassement de pierres d'un mur de façade du premier village (Vème - IVème s. av. J.C.) Photo J. C-L.


FIG. 6 Murs d'adobes effondrés dans une maison du premier village (IVème s. av. J.C.) Photo J.C-L.


FIG. 7 Mur associant briques crues et poteau central en bois (IIIème s. av. J.C.) Dessin N. Nin.


FIG. 8 Bouchage d'une porte selon la technique de la bauge (IIIe s. av. J.C.) Photo J.C -L.

Sa largeur moyenne (0,50 m) est un peu supérieure à celle de l'élévation en terre. L'arase supérieure des pierres est recouverte d'une chape de terre argileuse qui prépare le lit de pose des briques ou du pisé et assure adhérence et répartition égale des charges.

L'élévation en terre crue :
Une soixantaine de murs possédaient encore une élévation en terre en place. S'y ajoutent les nombreuses parois abattues dont l'analyse permet d'évaluer la hauteur des constructions. Celle-ci témoigne de l'inexistence d'étage que renforce l'absence de dispositifs spécifiques, telles les montées d'escaliers présents sur certains sites préromains ibériques ou provençaux (3) (voir fig. 6).
Trois modes principaux d'utilisation de la terre crue ont été mis en évidence : l'adobe, la bauge et le pisé. La documentation recueillie a précisé nos connaissances sur les périodes d'apparition de ces différentes techniques durant l'Age du Fer du Midi méridional. Elles ont aussi permis de saisir les modalités de mise en oeuvre de la terre et d'en tirer les enseignements pratiques pour l'opération de reconstitution.

L'adobe

La technique de l'adobe est la plus répandue. Présente dès la création de l'habitat, elle perdure jusqu'à sa destruction définitive.
Les briques sont obtenues par la mise en forme d'un mélange de terre, de stabilisant végétal et d'eau dans un moule rectangulaire. Malgré des déformations importantes dues aux oscillations de la nappe phréatique, aux tassements et à la mauvaise qualité des matériaux, une étude métrologique a pu être menée qui dénote la variété des longueurs des briques selon les périodes.
On constate aussi la grande disparité chromatique des adobes. Outre des sources d'approvisionnement diversifiées, ce phénomène témoigne de la réutilisation de terre à bâtir provenant de murs ruinés (4) (voir fig. 4 et 7).
L'appareil transparait grâce au mortier de liaison que distingue une couleur plus claire et une consistance très argileuse mal appropriée à la confortation des ouvrages. Il respecte généralement la règle de recouvrement des joints verticaux. Quelques constructions cependant laissent voir des coups de sabre responsables de graves malfaçons. Les maçonneries de briques révèlent aussi l'absence fréquente de liaison structurale des murs entre eux, qui trahit un rythme de construction original. Le premier mur édifié est le refend dont la longueur fixe l'alignement de façade et l'emplacement de la superficie de la maison peut-être en fonction de lots définis à l'avance. Ce procédé très rudimentaire tire sans doute son origine de la faible superficie des maisons, parfois dépourvues de façade (10 à 20 m2).

Trois murs porteurs en briques sur soubassement de pierres montrent l'association d'adobes et de poteaux en bois placés au centre de la maçonnerie (voir fig. 7). Cet appareillage mixte qui s'apparente aux constructions à pans de bois, est tout à fait original pour notre habitat et se distingue radicalement de la technique du torchis qui caractérise, dans le Sud de la France, des périodes plus anciennes et des zones moins influencées par les apports étrangers.

La bauge

Rare, la technique du façonnage direct et manuel de la terre touche des portions limitées de murs et paraît réservée à des situations architecturales particulières : bouchage d'une porte ou réfection d'une ancienne maçonnerie de briques. Son association aussi bien avec la pierre qu'avec l'adobe révèle sa liberté de modelage et sa facilité de mise en oeuvre (voir fig. 8).

En outre le matériau très composite de la bauge, riche en vestiges domestiques, indique un prélèvement et une préparation de la terre à bâtir dans l'habitat lui-même. Bien qu'occasionnelle, la bauge attestée dès le 4ème siècle avant J.C. semble préfigurer la technique du pisé qui se développe au 2ème siècle avant J.C.

Le pisé

Les murs massifs deviennent majoritaires dans le second village où ils apparaissent représentatifs d'une technique véritablement novatrice. Reposant sur un soubassement de pierres plus large (0,50 - 0,60 m) le matériau terre présente une coloration et une composition à peu près uniformes. C'est un mélange de sables, limons et argiles plus hétérométrique que les briques. Dans certains cas, des pierres dessinent des lignes horizontales interprétées comme des niveaux intermédiaires entre deux banchées de terre. Faute de vestiges attestant l'emploi de coffrage, ce sont les rares indices matériels d'utilisation du pisé. De plus la période d'apparition à Martigues de ce mode d'architecture correspond à son introduction sur d'autres sites méridionaux proches (Entremont, Marignane). Le pisé apparaît ici comme un transfert de technologie italique de même que la brique avait été empruntée au monde grec quelques siècles plus tôt (5) (voir fig. 9 et 10).

LES SUPERSTRUCTURES

C'est le domaine le moins bien connu puisque aucun élément s'y rattachant ne nous est parvenu en place. Encore avons-nous la chance que ce village ait subi trois incendies qui ont fossilisé des fragments de superstructures effondrées.

FIG. 9 Murs de façade en pisé du deuxième village (IIe s. av. J.C.) Photo J.C-L.

FIG. 10 Elévation en pisé d'un mur du deuxième village (IIe s. av. J.C.)

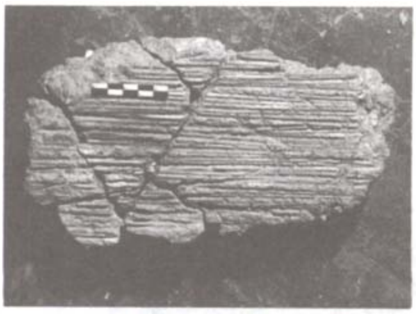

FIG. 11 Fragment de la couverture d'un toit-terrasse. Empreintes de roseaux sur la face inférieure. Photo G. Xuereb (Martigues Communication)

FIG. 12 Partie nord-ouest du premier village recouverte par la nappe phréatique. Photo J.C-L.

FIG. 13 Maçonnerie de pierres et de briques avant restauration. Superposition de deux murs successifs. Photo J.C-L.

Mais il est difficile de distinguer les vestiges de la toiture de ceux qui peuvent provenir d'un niveau intermédiaire. S'il parait acquis que cet habitat n'a pas comporté de maisons à étages, plusieurs observations nous incitent à restituer l'existence de mezzanines ou demi-plans partiels. D'abord l'exiguité des pièces que leur encombrement extrême rendait inutilisables sans le recours à un espace de vie supplémentaire. Mais également les nombreux objets retrouvés en position renversée dans les strates supérieures des couches de destruction, les poteaux implantés près des murs qui ne pouvaient servir de support à la toiture ou les planchers découverts carbonisés sur le sol.
De la toiture proprement dite, nous possédons assez d'éléments pour en restituer la composition et la forme. Obéissant à un modèle courant dans le Sud de la Gaule et en Espagne, elle est en terrasse et formée de deux parties : la charpente et la couverture.
La charpente, assemblée sans pièce métallique, se compose de solives de pin ou de chêne disposées dans le sens de la largeur et reposant directement sur le sommet des murs. Elles sont parfois relayées, au centre de la pièce, par une poutre principale seulement perçue grâce au trou ou à la base de poteau qui lui sert de support.
La couverture est faite d'un lit de roseaux arrangés à plat sur lequel est damée une couche de terre crue. Elle nous est connue par les nombreux fragments cuits accidentellement, offrant une face inférieure striée d'empreintes de végétaux, l'autre plane et lissée (voir fig. 11). Cette couche est un mélange de sables, argiles, graviers et fibres végétales, présentant les traces de multiples recharges, témoins d'un entretien permanent, qui finissent par former une épaisseur de terre allant jusqu'à 0,20 m, ce qui induit une charge importante de l'ordre de 300 à 500 kg/m2 (6).

LA VITRINE ARCHEOLOGIQUE : RESTAURATION ET RECONSTITUTION DE L'HABITAT

La présentation proposée dans la "vitrine archéologique" où sont préservées des structures d'habitat du premier village protohistorique, met en évidence, dans les élévations , la technique de l'adobe sur soubassement de pierres. La mise en oeuvre a eu recours aux techniques de construction originelles et respecte les principes architecturaux énoncés plus haut. Exclusivement manuelles, la préparation de la terre et la fabrication des briques ont été reproduites avec les moyens les plus simples. Un millier d'adobes aux modules en vigueur aux 4ème et 3ème siècles avant J.C. ont été réalisés dans des moules prismatiques en bois à compartiment simple. Par ailleurs la conduite, simultanément à ces travaux, d'une opération de fouille touchant le second village, nous a offert un approvisionnement en sédiments appropriés à nos besoins en matériau.
Enfin, pour éviter, dans l'architecture, tout désordre lié à la présence de la nappe phréatique sous-jacente (voir fig. 12), nous avons enterré avec du sable les structures les plus profondes et protégé les vestiges par un système d'étanchéité et de drainage adéquat (chape de béton et feuille de plastique) (7).

LA RESTAURATION

Dans la moitié sud du local où les vestiges archéologiques sont présentés dans leur caractère originel, l'état de dégradation des maçonneries a rendu indispensable une reconstruction des éléments qui avaient souffert des intempéries durant la fouille et des travaux d'édification de l'immeuble contemporain.

Après relevé et démontage, les structures ont été rebâties soit avec leurs matériaux propres quand ils pouvaient être réutilisés (pierres) soit avec un matériau similaire dans le cas des briques, du liant et des enduits. Les parties reconstruites ne l'ont pas été exactement à l'identique, les murs montrant souvent des pathologies structurales récentes sans rapport avec la réalité archéologique. Ainsi avons-nous décidé de restituer l'état des maçonneries au moment de leur découverte en mettant en valeur les phases de construction successives (voir fig. 13 et 14).
A cause des contraintes techniques les murs restaurés ne représentent que les dernières périodes d'occupation du village primitif. Ils montrent le remontage de la maçonnerie de pierres la plus récente (fin 3ème siècle avant J.C.) sur la portion conservée de l'élévation en adobes du mur antérieur (milieu 4ème - milieu 3ème siècle). Par souci pédagogique ils sont dénués d'enduit protecteur. Une attention particulière a été portée sur les joints qui révèlent l'appareil. Toutes les fissures de retrait intervenues après la pose du mortier ont été bouchées et la surface des joints lissée.

LA RESTITUTION

A l'extrémité nord du local, les vestiges protohistoriques n'avaient pas la même qualité architecturale, les travaux de fondation de l'immeuble moderne ayant endommagé les murs en élévation.
Nous avons donc entrepris de les rebâtir entièrement et de recomposer cette partie du village à partir des données de fouilles ou de références ethnographiques.
La présence d'un pilier d'angle du bâtiment actuel a interdit de respecter exactement le plan-masse des maisons. L'exiguité des espaces intérieurs exposés nécessitait de modifier légèrement l'implantation primitive des maisons pour masquer cette intrusion contemporaine en l'englobant dans un mur de refend (voir fig. 15 et 16).

FIG. 14 La même maçonnerie après restauration. Photo J.C-L.

FIG. 15 Stockage des adobes en vue de la reconstitution de l'îlot nord. Photo J.C-L.

FIG. 16 Masquage par le mur de briques crues d'un pilier d'angle en béton de la "Vitrine Archéologique". Photo J.C-L.

FIG. 17 Elévations et superstructures reconstituées de 4 maisons du premier village gaulois de l'Ile de Martigues. Photo J.C-L.

FIG. 18 Elévations de briques crues sur soubassement de pierres. Parements dénués de revêtement. Photo J.C-L.

Au total cinq habitations ont été partiellement reconstituées. Situées de part et d'autre d'une ruelle et donnant sur la placette d'angle, elles composent un petit ensemble qui recrée l'image urbaine de cette agglomération protohistorique (voir fig. 17).

Murs, sols et enduits

Dans la continuité des vestiges de la partie sud du local, la maison d'angle est dépourvue d'enduit extérieur. Au-dessus du soubassement originel en pierres restauré, l'élévation restituée montre un appareil soigné d'adobes maçonnées avec un mortier argileux selon la règle de recouvrement des joints verticaux. La façade donnant sur la place a été percée d'une petite fenêtre dont la présence répond à une triple motivation : donner une prise de lumière à l'ouest, permettre une meilleure intégration de la maison au dispositif urbain de la place et démontrer, notamment par l'absence de linteau, la résistance mécanique de la terre crue quand elle est correctement mise en oeuvre (voir fig.18).

A l'inverse, les élévations des maisons qui forment la façade nord de la ruelle sont enduites intérieurement et extérieurement, conformément aux observations de terrain. A l'intérieur, ces revêtements ont un rôle autant fonctionnel qu'esthétique. Fréquemment restaurés, ils présentent, pour un même niveau d'occupation, jusqu'à trois ou quatre recharges correspondant aux réfections du sol avec lequel ils viennent se confondre. Cette accumulation masque les différentes épaisseurs du mur. Très fins et appliqués en surface sous forme de badigeon, ils concourent à éclaircir les pièces. Incontestablement ces revêtements participent à l'embellissement de l'espace intérieur de la maison dont ils suppriment les angles vifs (8) (voir fig. 19).
A l'extérieur, les enduits étaient plus dégradés du fait de leur exposition aux intempéries et aux chocs. Le projet de reconstitution insiste sur cet aspect par une composition différente et une apparence moins homogène qui atteste leur usure (voir fig. 20).
Nous fondant sur des témoignages anciens et actuels nous avons renforcé cet enduit de fibres végétales qui améliorent sa résistance à l'érosion. Un badigeon fin de terre argileuse lissée l'imperméabilise (9) (voir fig. 21).

La mise en oeuvre des briques a respecté les principes architecturaux antiques même quand ils ne répondaient pas à une construction dans les normes. Seule une maison a vu son angle nord-ouest édifié selon les règles strictes de l'appareillage d'angle avec un chaînage régulier de briques, par mesure de sécurité. Partout ailleurs il n'y a pas de liaison structurale des murs de refend avec les murs de façade qui viennent s'appuyer contre eux. Cette absence de chaînage est encore aggravée, dans l'îlot nord, par le percement de nombreuses portes que la taille des maisons contraint presque toujours à placer près d'un angle malgré les risques de flambement du trumeau ou du mur de refend lui-même que cela comporte (voir fig. 22 et 23).

Niches, étagères et banquettes

Certains dispositifs ont été introduits pour pallier les problèmes de rangement du petit mobilier qui abonde dans chaque maison. Il s'agit d'étagères constituées d'une planche appuyée sur des piquets de bois fichés dans la maçonnerie, de niches réservées dans l'épaisseur du mur, dont les formes et les dispositions ont été empruntées à des exemples actuels du pourtour méditerranéen (10). Ces aménagements permettent de disposer les objets qui ne trouvent pas au sol de place appropriée (voir fig. 24).
Ils trouvent un complément dans les banquettes basses qui courent sur le sol le long des murs. Faites d'une rangée de briques crues maçonnées sur une ou deux assises, elles sont solidaires du mur et du sol par l'enduit argileux qui les recouvre.
Dans un espace domestique multifonctionnel, leur rôle a pu être divers : étagères basses permettant d'isoler du sol des réserves alimentaires, tables de travail pour la préparation des repas, supports d'objets fragiles ou encore banquettes pour s'asseoir (voir fig. 25).

Les superstructures

Ne disposant d'aucun espace intérieur complet nous avons opéré ici de façon didactique, sélectionnant pour chacun d'eux un type d'aménagement. Ainsi pour l'habitation vue en coupe à l'angle nord-ouest de la vitrine, on a privilégié l'hypothèse d'un demi-plan restreint servant de support à deux grands silos en torchis. Ancré dans le mur et soutenu au sol par un poteau d'angle, il est constitué d'un plancher en pin recouvert de quelques centimètres de terre (voir fig. 26). La deuxième maison est dotée d'une mezzanine couvrant toute la largeur de la pièce. Zone de stockage pour des vases à provision et lieu de repos, ce niveau intermédiaire, soumis à de plus lourdes charges, a nécessité le recours à des bois plus importants. Il s'accompagne d'un système d'accès composé de pièces de bois plantées en escalier dans le mur (voir fig. 19 et 27).

La reconstitution des toitures a également tenu compte d'autres observations de terrain : absence de terre effondrée au pied des murs, stockage de matériel domestique en terrasse qui suppose l'existence, au-dessus des murs, de rebords de toiture hauts de 0,10 à 0,20 m permettant de retenir la terre, de mieux contrôler l'évacuation de l'eau avec des gargouilles et de servir de protection pour les gens et le mobilier.

FIG. 19 Espace intérieur d'une maison reconstituée. Badigeon d'argile blanche et aménagements domestiques. Photo G. Xuereb (Martigues Communication).

FIG. 20 Façade de l'îlot nord reconstitué. Parement revêtu d'un enduit de terre argileuse. Photo G. Xuereb (Martigues Communication).

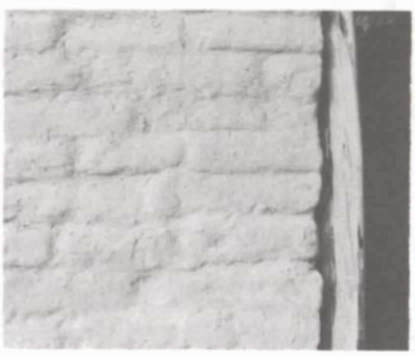

FIG. 21 Détail d'un enduit extérieur renforcé de végétaux. Photo J.C-L.

Ils jouent aussi un rôle esthétique rendu ici par les différences de niveaux entre les toitures et les acrotères d'angle. Bâtis en terre façonnée, ils devaient être régulièrement restaurés par suite de l'érosion et du ruissellement. Le badigeon de couleur claire appliqué en surface, en augmentant la réflexion solaire, contribue à une meilleure isolation thermique des toitures (voir fig. 27).

Le mobilier en torchis

Omniprésente dans l'architecture, la terre crue est aussi un élément essentiel de la vie quotidienne à travers un type de mobilier qui envahit littéralement l'espace domestique, à savoir les récipients et objets en torchis. Préservés grâce aux incendies qui les ont fossilisés, ils constituent, à Martigues, un répertoire unique pour tout le bassin méditerranéen protohistorique (voir fig. 28).

La matière qui les compose est un mélange d'argile et de végétaux auquel devaient sans doute être ajoutés des excréments animaux si l'on se réfère aux exemples actuels. Leur montage se fait par tranche de 7 à 10 cm et le modelé qui reste souvent apparent, frappe par la liberté des formes et la variété des combinaisons (11).

Ce mobilier recouvre deux fonctions principales : le stockage des provisions et la cuisson des aliments.

On trouve d'abord des silos ou vases de réserve pour les céréales, fruits séchés etc... Grandes jarres cylindriques, carrées ou rectangulaires, récipients bas en forme de jatte droite ou carénée, ils sont montés à l'intérieur de la maison, à leur emplacement définitif et reposent sur un socle isolant de pierres ou d'adobes ou sur une étagère qui les protége des prédateurs et de l'humidité (voir fig. 26).

Outre ces vaisseaux solidaires du sol ou de leur support, de nombreux autres vases en torchis, mobiles pour la plupart, complètent en les diversifiant les modes de conservation des denrées alimentaires. Il est enfin un autre élément, essentiel, fabriqué en terre crue : le four, composé de quatre parties indépendantes dont l'assemblage aboutit à un objet complexe. Placé près de la porte et lié à une plaque à feu, il diffère des fours en dôme traditionnels qui servent à cuire les galettes par une utilisation sans doute multifonctionnelle, pouvant répondre aux principaux besoins culinaires : cuisson des mets bouillis et du pain, boucanage des viandes et poissons, torréfaction des céréales (voir fig. 29,30 et 31).

Enfin comme matériau de base, la terre crue est présente au sein même de l'unité domestique à travers les couronnes de torchis, stockées en pile, qui constituaient probablement des pains d'argile prête à l'emploi pour la fabrication ou la réfection de ces objets (voir fig. 32).

Conclusion

La préservation des vestiges d'habitat en terre, mise en oeuvre dans la "vitrine archéologique", a tenté de concilier réalité archéologique et intérêt muséographique. Adapté aux contraintes techniques du site, le programme réalisé a voulu rendre compte de ces deux aspects distincts en proposant d'une part la restauration sur place des bâtiments tels qu'ils nous étaient parvenus, d'autre part la reconstruction de plusieurs maisons afin de tenter de redonner une apparence originelle et vivante de ce fragment d'agglomération gauloise.
Avec cette première expérience menée dans le Sud de la France une attention particulière a été portée sur la présentation des modèles architecturaux originaux encore peu ancrés dans l'imagination collective où la terre crue, sous des formes multiples, joue une rôle fondamental.

FIG. 22 Construction d'un mur de refend sans chaînage avec la façade. Photo G. Xuereb (Martigues Communication).

FIG. 23 Le même ensemble une fois édifié et recouvert d'enduit. Photo J.C-L.

FIG. 24 Niches et étagères murales dans une maison reconstituée. Photo G. Xuereb (Martigues Communication).

FIG. 25 Banquette basse en terre dans une maison du second village (IIe s. av. J.C.) Photo J.C-L.

FIG. 26 Demi-plan restreint servant de support à des silos en torchis. Photo J.C-L.

FIG. 27 Vue extérieure en coupe de deux maisons reconstituées. Toits terrasses et mezzanines. Photo J.C-L.

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(4) Pour une étude sédimentologique et granulométrique du matériau terre sur des habitats protohistoriques méridionaux, voir l'étude de Philippe Boissinot dans " Le village protohistorique du quartier de l'Ile à Martigues ". Documents d'Archéologie Méridionale, 10 (1987) pp 66 - 68. Voir aussi :

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P. Poupet et C.A. de Chazelles, "Analyses archéologiques et sédimentologiques des matériaux de terre crue de l'architecture protohistorique de Lattes, provenance et technologie", Lattara, 2 (1989) pp 11 - 32.

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(8) L'emploi de pigments naturels minéraux et végétaux comme décoration a dû être utilisé si l'on se réfère à des exemples antiques (Lattes, Baux de Provence, Glanum, sites ibériques) ou actuels (maisons de Kabylie)

- P. Poupet et C.A. de Chazelles, "Analyses archéologiques des matériaux de terre crue" p 27 - 28.
- P. Arcelin et O. Buchsenschutz, " Les données de la protohistoire" p 24.
- M. Abouda, " Maisons Kabyles : espaces et fresques murales". éd. AXXAM (1985), 108 p.

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FIG. 28 Mobilier en torchis (silos rectangulaires, couvercles, jattes etc...) dans une maison incendiée du 1er village (IVe s.av. J.C.) Photo J.C-L.

FIG. 29 Four complexe en torchis effondré à l'angle d'une maison incendiée du premier village gaulois (IVème s. av. J.C.) Photo J.C-L.

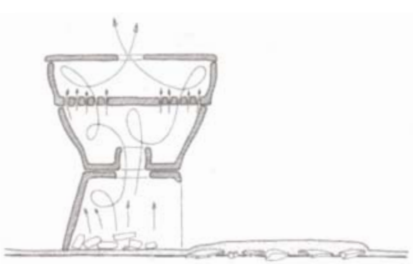

FIG. 30 Dessin schématique du four complexe. Dessin L. Domallain.

FIG. 31 Reconstitution du four en torchis. Photo J.C-L.

FIG. 32 Couronnes d'argile disposées à l'angle d'une maison du premier village gaulois (IVe s. av. J.C.) Photo G. Xuereb (Martigues

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THE SLUMPING OF THE GREAT KNOB: AN ARCHAEOLOGICAL AND GEOTECHNIC CASE STUDY OF THE STABILITY OF A GREAT EARTHEN MOUND

Thomas E. Emerson
Illinois Historic Preservation Agency
Old State Capitol
Springfield, Illinois 62701

William I. Woods
Department of Geography and Earth Science
Southern Illinois University at Edwardsville
Edwardsville, Illinois 62026

ABSTRACT

Monks Mound or the "Great Knob"--located at the prehistoric site of Cahokia in Illinois, across the Mississippi River from St. Louis--is the largest earthen mound north of Mexico. After centuries of stability several major slumping episodes have occurred at the Great Knob in the last five years. Archaeological and geotechnical investigations have indicated that the mound was structurally engineered to resist internal slumping but that recent shifts in groundwater levels have damaged the internal structure leading to instability. Numerous engineering solutions for stabilization were examined but all were found to impact severely the visual, archaeological, or architectural integrity of the mound. In the final evaluation it was determined that passive management was the best current approach.

KEYWORDS:

Archaeology, prehistoric earthen mound, stabilization, passive management, drainage

Introduction

About one thousand years ago, the aboriginal peoples of southwestern Illinois reached their cultural climax and greatest elaboration with the rise of the Middle Mississippian culture. This period saw the development of temple mound centers, hierarchical political and religious organization, large-scale trade, and full-time agricultural subsistence patterns. One of these temple mound centers and its society far exceeded the rest in size and complexity. This is the site of Cahokia, located just across the Mississippi River from St. Louis, Missouri, in the expansive American Bottom floodplain of Illinois (see fig. 1).

Cahokia's size is impressive--the habitation and ceremonial areas are thought to cover at least 13 km2 and include over one hundred and twenty mounds (see fig. 2). Dominating the site is the Great Knob or Monks Mound, a large, multiterraced platform mound (see fig. 3) located within the central ceremonial precinct. This structure holds the distinction of being the largest earthen mound north of Mexico. It measures about 291 m north-south, 236 m east-west, and 33 m in height [1].

Today, about 7,500 ha of the site, including the central ceremonial precinct and many of the mounds, are owned by the State of Illinois and managed by the Illinois Historic Preservation Agency (IHPA). The Cahokia Mounds Historic Site is listed on the National Register of Historic Places, is a National Historic Landmark, and is on the World Heritage List.

The Great Knob Slump

Since its first depiction in the early nineteenth century, Monks Mound has sustained only slight surficial modification due to direct human alterations and sheet, rill, and gully erosion. In the mid-1950s, and again in the late 1960s, two minor slope failures took place. The effects of these were readily patched and none of the movements were viewed as seriously endangering the mound as an architectural monument. However, in February 1984 a moderate slope failure along the eastern mound edge called into question the future stability of Monks Mound. The State began joint archaeological [2] and geotechnic [3] studies of this east face slump. Virtually while this work was in progress, in April 1984, a massive slope failure occurred on the western face (see fig. 4). This slump was larger than all previously known examples and over the subsequent few months showed no signs of naturally stabilizing as the other slumps had done.

At this point, there was intense pressure from both State and Federal organizations to make immediate emergency repairs to the slump areas. Fortunately, we were able to argue convincingly that so little was known about the internal structure of the mound or the causes of the slope failures that it would be premature to undertake any emergency actions until more information could be gathered.

Research and Philosophy

At that point, the IHPA expanded its research to address the entire issue of mound slumping. This research had three immediate goals: (1) to determine the cause of the current slope failure; (2) to design a way to arrest this process; and, (3) to evaluate the impact of these actions on the architectural and archaeological integrity of the monument. The geotechnical aspect of the study was performed by Mathes Geotechnical Services, Inc. [4] and was a continuance of their earlier work on the east slump. The archaeological portion of the study was conducted by the Contract Archaeology Program, Southern Illinois University at Edwardsville (SIUE) and focused on the compilation and synthesis of all previous historical and archaeological information available on the Great Knob [5], as well as a limited program of test excavation and mapping on the west slump [6].

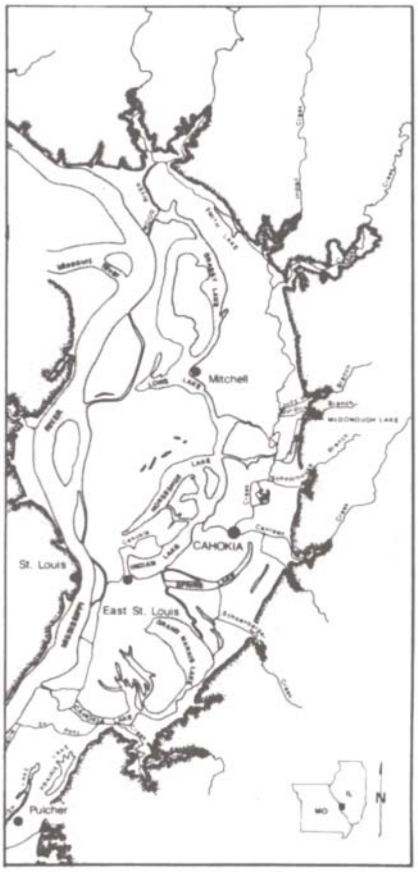

Fig. 1 - Map of the American Bottom showing the locations of Cahokia and the major Mississippian mound groups.

As these studies went forward, a parallel process was undertaken to assess the philosophical and ethical implications of any proposed stabilization and restoration effort. In May 1985, the IHPA convened a working meeting including international, national, and regional experts on resource management as well as leading scholars on Cahokia research to discuss the issues of restoration, stabilization, investigative excavations, and public interpretation. There was strong unanimity that stabilization rather than restoration was the goal. However, there was a basic dichotomy in the participants' approaches to the treatment of the Great Knob. These differences resulted from each individual's perception of the mound as primarily an "architectural monument," a "database," or a "public interpretive resource." Those perceiving the mound as architecture strongly urged the construction of a large surrounding berm to preserve its form. Researchers focusing on the informational aspect suggested excavations to retrieve information that might be lost during the slumping process. Those responsible for interpreting the site to the public were concerned about any approach, e.g., massive berming, that drastically modified the visual fabric of the mound and surrounding area. Out of this diversity of opinions, the discussants argued for a solution that preserved the Great Knob's visual and architectural integrity, minimized the loss of archaeological information, and was long-term in nature.

Background

The Great Knob is underlaid by natural submound deposits that are associated with a relict channel bar complex of the Mississippi River, as well as more recent slackwater sediments and overbank deposits of Cahokia Creek, the major drainage in the American Bottom. Although matrix textures of these materials are predominantly sands, loamy silts and clays are also present, particularly in near-surface positions. These natural deposits are superimposed by premound anthropogenic accretions of varying thickness.

It is hypothesized that construction began during the late Emergent Mississippian period (A.D. 950) with the bulk of the present mound completed by the end of the initial phase of the Mississippian period (A.D. 1050). This would include the vast majority of the fill to the north of the so-called first terrace. Subsequent additions continued throughout much of the Mississippian period until ca. A.D. 1250 or earlier. These additions consisted of a sequence of veneer caps on the third and fourth terraces, completion of the first terrace, and also of secondary mounds on the southeastern corner of the third terrace and the western end of the first terrace [7]. Elite buildings, free-standing walls, and large posts have been identified through excavation [8-11]. They are associated with the uppermost planar surfaces. Toward the end of the Mississippian period a domestic structure was present on the first terrace secondary mound with refuse distributed around its periphery, indicating the greatly diminished ceremonial status of the facility [12].

A number of coring and excavation projects have demonstrated that the mound is composed entirely of readily available earthen materials [13-21]. Furthermore, it is evident that there were decisions made as to the selection

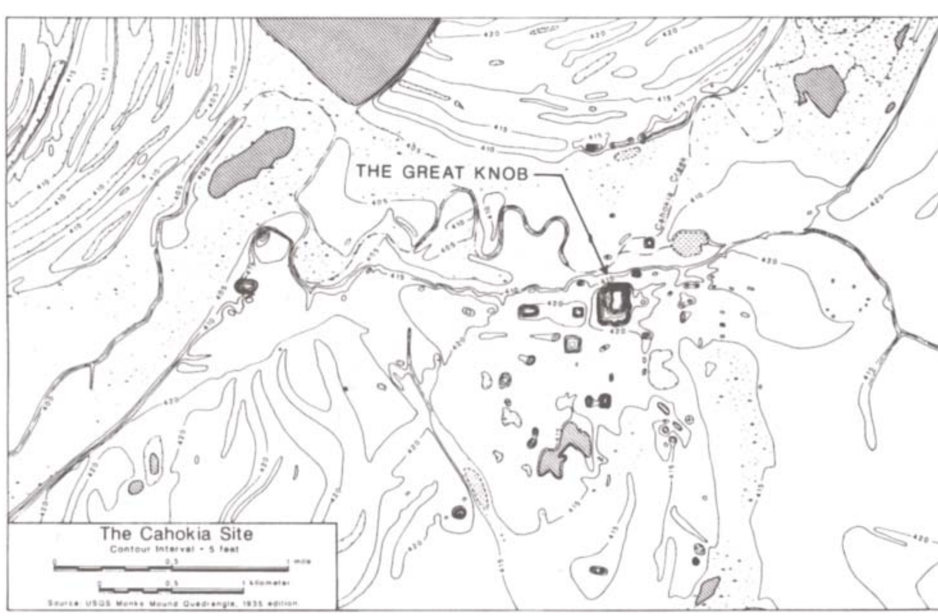

Fig. 2 - The location of the Great Knob within the Cahokia Site.

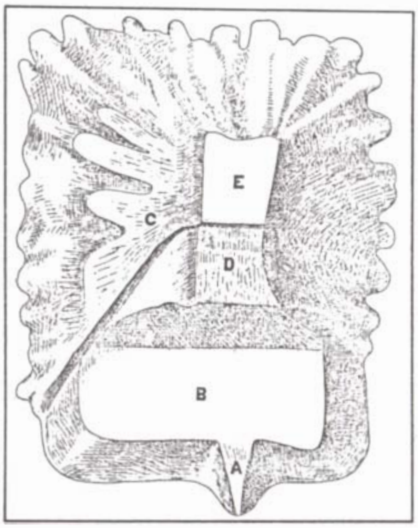

Fig. 3 - Late nineteenth century depiction of the Great Knob.

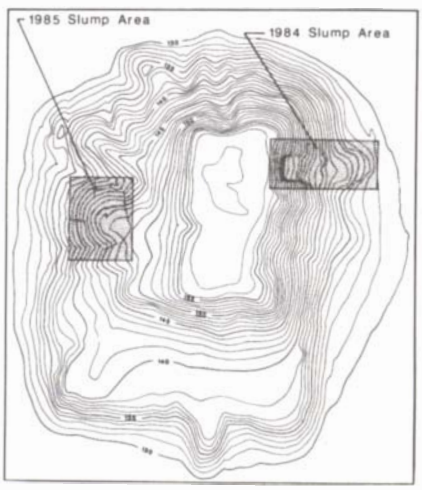

Fig. 4 - Topographic map of the Great Knob with slumps indicated.

and placement of materials within the mound. Indeed, far from being just a pile of dirt, the Great Knob was constructed with mechanical and engineering considerations in mind; in other words, detailed planning was used. Internally, a series of massive silty-clay to clayey-silt fill units were emplaced, with upper surfaces sloping to the exterior. In most cases these were covered with coarser materials that would have functioned as internal drains to remove atmospheric water before infiltration into the core sediments. Puddled clay facings may also have been present to facilitate runoff. Retaining buttresses were incorporated into the internal structure of the mound, as well as being emplaced externally along the southern and western peripheries [22-24].

The efforts expended on engineering suggest an understanding of the problems inherent in earthen constructions of this magnitude in humid, mid-latitude climatic regimes. The basic problem concerns the materials themselves. A significant portion of the mound mass is composed of smectite clays with a high shrink-swell capacity and low hydraulic conductivity. When wet, these clays displace more volume than in the dry condition, while they contract and tend to crack upon drying. The consequences of repeated episodes of drying and wetting are obvious: They produce great instability. Given a high local water table and an annual average of over 65,000 m3 of precipitation on the surface of the mound, continual water control was essential for maintenance.

The degree of success of the prehistoric engineering can be measured by the long-term stability of the mound. With the exception of the prehistoric slumping evidenced by the two east lobes on a side where no buttressing was present, for a millennium no major failures occurred in spite of the instability of materials and enormous mass and surface area of structure. The question is why is it failing now?

In the judgement of the authors, the most likely scenario suggests that the rapid sequence of recent failures is associated with modern changes in groundwater levels. From the 1940s to the early 1960s, water use by local industries was of such a magnitude that groundwater tables in the entire northern portion of the American Bottom were lowered drastically to the point where many wells went dry. By the late 1960s, water tables began to rise again due to recycling and industrial closings and within a decade were approaching their former levels. In response to the initial dropping of the water table, the lower core of the mound dried out for the first time, where previously it had been wetted by capillary action to a height of up to 10 m. Consequently, this portion of the core contracted and probably developed cracks at numerous locations. This shrinking of the core would also have disrupted the integrity of higher parts of the construction, including the drains and massive fill units. The expansion of the core due to rewetting exacerbated this problem. With the internal drains no longer functioning efficiently and cracks in the clay core, massive fill units, and clay caps, intrusion and retention of atmospheric water increased dramatically. As a result of this instability, failure and slumping occurred. The prehistoric planning that had been successful for centuries had not taken into consideration modern changes in the water table.

Proposed Stabilization Remedies

Analysis of the geotechnical engineering data indicated three areas in which action could be taken to stabilize the current mound configuration: (1) reduce the internal seepage pressures; (2) modify the mound geometry; and/or, (3) mechanically restrain the slope [25]. Having established the broader parameters within which to frame a specific remedy to the slope failures, more detailed methods of intervention were investigated for possible use [26]. Each of these methods incorporated one or more of the three stabilization principles noted above.

A number of solutions were based on the concept of "toe-loading" of the slump in which weight is physically added to the outward end of the slope to resist movement. These methods varied from a complex benching program to simple toe-loading. Benching the mound would begin with the addition of fill to create a base berm at least 15 m in width. Sloping fill would be added to form the base for another berm higher up slope and so forth up the mound sides. A granular drainage blanket would be placed under the fill to ensure drainage. A variation on this program would simply add fill to the mound surface to lessen the angle of the face thus creating a flattened, more stable, slope. While having a high success potential, these solutions would create a severe impact on the mound's visual appearance. A modified version of these techniques would simply be the addition of a toe-berm, about 15 m wide and 6 m high, around the base of the mound. While the visual effect would be lessened, it would leave the upper parts of the mound subject to localized slumping.

Other proposed methods of restraining the movement of the mound base involved the construction of retaining walls. Tied-back retaining walls are held in place by anchors drilled back into the mound, while a more conventional wall would be dug into the ground around the base. Both types would require the addition of fill to protect the upper mound slopes, impede already poor drainage, and involve a great disturbance of archaeological village deposits around the mound as well as of the mound matrix. The visual impact of retaining walls, however, could be kept to a minimal level.

Mechanical restraint of the slope could also be achieved by physically "nailing" the mound matrix in place or by replacement of some matrix. This could be done by driving or drilling pilings or piers through areas of slope failure or potential failure. Such structural features could range from ca. 1-m-wide crushed stone columns to 5-cm cylindrical rods or angle iron. A more drastic measure would be to excavate and remove large portions of the lower mound fill and replace it with crushed rock, both to strengthen the structure and assist in drainage. The advantage of nailing or matrix replacement techniques is that they have no visual impact on the mound and some, such as those including crushed stone, also facilitate internal drainage. Yet the internal damage to the archaeological integrity of the mound would be severe in most instances.

From the inception of the slope failures it had been clear that the primary source of the problem was water saturation of the mound matrix. A number of proposed solutions thus incorporated water removal techniques as either a primary or secondary aspect of their program. Primary drainage techniques included the use of dewatering well points, interceptor trenches and drains, stone trenches, horizontal drainage tunnels or wicks, and sand or wick drains. The most ambitious program called for the installation of numerous well points, both in and around the mound, to remove groundwater thus relieving the internal pore pressure. Such a solution would incur long-term operating expenses, involve disturbance of the mound and adjacent cultural deposits for electrical and mechanical system installation, would not strengthen the areas of slope failure, and would probably have to be used in conjunction with some method of mechanical restraint.

The excavation of deep interceptor trenches into the zone of the failure plane which would be filled with crushed stone and contain drain pipes would accomplish two purposes. The crushed stone would strengthen the slope while the drains would remove excess water. It is also possible that simple stone-filled trenches without drains would serve the same purpose. As in many other methods, the impact on the archaeological deposits and mound matrix would be very high.

Other dewatering methods that were more sympathetic to the archaeological integrity of the site included the installation of vertical or horizontal sand or wick drains. Sand drains are simply 15-cm-wide, sand-filled bore holes that pass through the slope failure plane and serve to carry off excess water. A fairly new methodology avoids the necessity of drilling through the use of a sheath to insert synthetic wick drains into the soil. The wick drains are only 10-cm-wide and 1.2-cm-thick. Like the sand drains, they serve to carry off excess water from the mound interior. Both of these dewatering techniques appear to have the advantage of being low-impact solutions to the problem of excess groundwater. Unfortunately, neither addresses the need to strengthen the areas of present or future slope failures.

In evaluating the possible implementation of any of these proposed solutions, priorities needed to be established to guide our decision-making process. It was clear from the outset that preservation in place through stabilization was our mission. Given this context, more specific priorities can be summarized as follows: (1) The solution cannot negatively impact the archaeological integrity of the mound or associated village area, (2) should minimize visual impacts, (3) must have a sound geotechnical basis and a very high probability of success, (4) should address both the current and future causes of slumping, and, (5) must be economically justifiable.

In addition, it was clear from the geotechnical studies that though the slumping was primarily due to excess pore water pressures acting on the failure surface, our lack of knowledge about the groundwater conditions along that surface could not ensure that drainage alone would be a sufficient remedy. The engineers recommended that some form of mechanical stabilization be used in combination with a drainage technique for greater reliability.

Based on these priorities techniques such as stone piers and columns, retaining walls, matrix replacement, and interceptor trenches were rejected because of the excessive disturbance to the archaeological deposits and the large amount of mound matrix that would need to be removed. The negative visual impact of the addition of large amounts of fill and drastic changes to slope angles ruled out benches, slope flattening, and toe berms. Well point dewatering was considered to be too expensive and of uncertain value due to the low rates of hydrologic conductivity within much of the mound matrix.

The use of a system of wick drains and small diameter soil pin pile patterns appeared to be a potential solution. This combination seemed to answer all of our needs with a minimal impact on the archaeological resources, i.e., no visual impact, sound engineering addressing both the removal of excess water and providing mechanical restraint, and economic feasibility. Further detailed planning of this system was authorized.

Both the wick drains and pin piles are new techniques in the United States with few contractors having the expertise or equipment to perform the work. To be most resistant to deterioration, pin piles consisting of epoxy-coated steel rods or angles are placed in predrilled 15-cm holes and pressure grouted with 3000-4000 psi concrete. Maximum efficiency is gained when piles are clustered in specific locations tied together at the surface with a 1.2- x 0.9-m concrete cap. These clustered pin piles must achieve a density of one per lineal 0.3 m of cap and must reach below the mound fill into the natural subsurface clays and sands, i.e., over 15 m in some cases. At least two continuous walls of pin piles would be necessary to stabilize the current slump areas. The data on hand were not sufficient for the engineers to indicate a more specific pattern for the wick drain installation beyond that of an arbitrary grid layout containing about 1,000 wick drains. Major construction berms would have to be placed on the mound face to enable the equipment to place the pin pile wall system and wick drains. Estimated cost for stabilization of the major west slump was approximately one million dollars and seven hundred thousand dollars for the smaller east slump.

Conclusions

The archaeological research at the Great Knob made it apparent that the mound was essentially completed in the short time span between A.D. 950 and A.D. 1050 and was largely comprised of massive fill units rather than small additive layers. It was also discovered that an internal system of buttressing and drainage planes, as well as external buttresses, had been included as part of the original mound design. The examination of the historical documentation had important results. Despite existing folklore suggesting that past erosion, deforestation, cultivation, and other factors had dramatically altered the mound's shape, our study showed there had been little change since its depiction in the early 1800s.

The engineering study collected information from a number of sources including cores, backhoe trenches, and psiometer and inclinometer tests. This study collected data on groundwater content and distribution, matrix material characterization, mound stability, and prehistoric construction techniques. Unfortunately, the data were not specific enough to determine the precise cause of the slope failures, although it was clear that the ultimate problem was water saturated soil. Based on this general information, a series of engineering solutions were proposed to stop the slumping. These proposed methods were in turn evaluated as to their impact on the Great Knob as an archaeological database and architectural monument.

The issues taken into consideration in determining a course of action included the importance of the mound as a data source on prehistoric culture history and construction techniques, as "monumental architecture," its interpretive and symbolic value in presenting the site to the public, and its visual importance as part of the prehistoric and modern cultural landscape. Our primary dilemma in determining a course of action focused on the fact that all of the engineering options to "save" or "preserve" the mound appeared to have a more negative impact than following a "no action" course. In comparably evaluating these often conflicting values we believe that, for the moment, the preferred approach is to manage passively the slumping until a permanent solution to the problem can be found. In the meantime, the IHPA has continued to monitor the slump zones both visually and instrumentally. In the almost five years since the initial onset of the massive west slump there has been no movement. Given this apparent stabilization it is evident that, in this instance, the passive management decision, when coupled with extensive supporting engineering, archaeological, and historical documentation, has been successful.

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CHAN CHAN: APORTES PARA LA CONSERVACION DE LA ARQUITECTURA DE TIERRA

Arql.ANA MARIA HOYLE
Independencia 572 - Trujillo
PERU

ABSTRACT

The purpose of this paper is to inform you of our recent experiences in the use of organic aglutinating substances as an alternative to the use of plastic chemicals in the preservation of the earthen architecture at the site of Chan Chan, the capital of the Chimu Empire (9th - 15th C. A.D.). The subjects addressed will be surface consolidation, structural reinforcement, and the protection of the tops of walls.

KEYWORDS

Chan Chan, Conservation, Adobe, Perú.

INTRODUCCION

A partir de 1974, el INC y la UNESCO, han efectuado labores de conservación en Chan Chan. Por falta de recursos técnicos y financieros éstas han sido, en su generalidad, llevadas a cabo a nivel empírico en el mismo monumento, sin tener la posibilidad de realizar un control sistemático y riguroso, ni los análisis físico-químicos in situ. Igualmente, estas limitaciones no han permitido implementar programas integrales de conservación y prevención. No obstante, la experiencia de campo ha aportado conocimientos y soluciones al problema de conservación, con resultados muy positivos que son materia de este documento.

FACTORES DE DEGRADACION

Un complejo conjunto de factores de degradación se presentan interactuando permanentemente en Chan Chan (1). Su proximidad al mar (1000 m. de distancia) favorece una fuerte concentración de sales higroscópicas transportadas por los vientos y depositadas sobre las estructuras (0.54% ClNa-0.09% SO3Na) (2); éstas también se encuentran contenidas en los materiales de las edificaciones (0.84% ClNa/0.74% SO3Na prom.) (3) y en el subsuelo (36.48/67.53 milhimos/cm) (4). Las sales se activan con la humedad relativa ambiental (84%) (5), las precipitaciones pluviales (garúa, lluvias) y la fluctuante napa freática, que, en combinación con los cambios térmicos, causan daños irreversibles en el monumento: Formación de costras, eflorescencia y cristalización de sales y finalmente exfoliación. Además, la humedad ambiental favorece la formación de líquenes, y las precipitaciones pluviales, particularmente las cíclicas de carácter torrencial, producen severos efectos erosivos y causan empozamientos al interior de los recintos. Además, debido a la ausencia de una barrera rompevientos natural la violenta acción erosiva eólica desvasta mayormente cabeceras y paramentos de cara al litoral.

Finalmente, a estos factores se añaden, la mala calidad de albañilería de ciertas estructuras, un suelo de soporte débil con resistencia diferencial en algunos sectores (basado fundamentalmente en rellenos artificiales de basura y desechos de construcción) y las vibraciones imprevistas de los movimientos tectónicos que han causado más de un derrumbe y trituración de muros. (6)

CONSERVACION DEL MONUMENTO

Antecedentes

Los programas de conservación se orientaron a controlar el proceso de deterioro y la acción de los agentes naturales teniendo los siguientes niveles de intervención (7):

a. Refuerzos estructurales.

b. Protección de cabeceras de muros como punto crítico en la preservación de estructuras mediante la aplicación de una capa de mortero estabilizado compuesto de: Arena gruesa y tierra (2:1) y Mowilith DM-1H (Acetato de Polivinilo en Solución) al 5% y 10% en agua. El objetivo fue obtener una capa poco permeable, resistente a la erosión pluvial y al temperismo, complementado con planos inclinados para facilitar el discurrimiento pluvial hacia sectores del muro menos comprometidos con decorados en relieve.

c. Consolidación a nivel de fijación de enlucido-muro y relieve-enlucido, mediante Mowilith DM-1H al 5% en agua; y la fijación de superficies y policromías con Silicato de Etilo 40 disuelto en alcohol etílico de 96% y ácido clorhídrico. Previamente se había experimentado con soluciones acrílicas, Acetatos de Polivinilo, Metracrilato, Nylon Soluble, etc.

d. Instalación de una red de drenaje para la evacuación rápida y eficaz del agua pluvial.

Las lluvias torrenciales del año 83 sometieron a la más dura prueba este tratamiento, el que en su generalidad arrojó una respuesta favorable. La capa de protección de cabeceras impidió la absorción y filtraciones de humedad al interior de las estructuras y anuló la acción de las sales depositadas en ellas. Las superficies tratadas a base de Silicato de Etilo 40 no presentaron erosiones. De otra parte, se evitaron daños por humedad capilar debido a un eficaz funcionamiento de la red de drenaje instalada en el Templo Arco Iris. Sin embargo, los consolidantes químicos de naturaleza plástica presentaron inconvenientes:

a. Su empleo en superficie formó una película impermeable por efecto de una rápida evaporación, que finalmente se exfolió debido a la acción de la humedad y las sales contenidas en la estructura.

b. En las cabeceras de muros se crearon varios problemas. La impermeabilidad de esta capa anuló la capacidad de respiración del muro y evaporación de la humedad contenida, produciéndose activación de sales higroscópicas bajo ésta con deterioro del original. Su rigidez y poca capacidad de absorción, formó, de un lado, una resistencia diferencial con el original; y del otro, un incremento de la velocidad del discurrimiento pluvial, que, acentuado por los declives naturales o artificiales, produjo una severa erosión en el punto de contacto entre ambas superficies y determinados sectores de las estructuras.

Intervención 1987-89

La experiencia prevista nos condujo a reformular algunas acciones de la intervención y a plantear nuevas alternativas, particularmente en relación al tipo de consolidante; partiendo de la consideración que el tratamiento no debe anular las propiedades de permeabilidad de las estructuras, y debe contar con resistencia al intemperismo. De tal manera, era preciso emplear un consolidante con propiedades de cohesión, plasticidad y resistencia a la compresión y que permita mantener la porosidad de los materiales.

Los criterios de intervención, además de los predichos inicialmente, incluyeron:

a. Considerar el carácter irreversible de los consolidantes químicos de naturaleza plástica y su efecto en la estructura molecular del barro.

b. Emplear sustancias consolidantes compatibles con la naturaleza del barro y las condiciones básicas de un adecuado tratamiento de conservación.

c. Orientar la intervención hacia un tratamiento mecánico de protección y prevención contra agentes naturales.

1. Materiales

Como sustancia consolidante, optamos por emplear mucílago de tuna (Opuntia ficus indica) usado tradicionalmente en las construcciones de tierra y en la restauración de Chan Chan en los años 60. Previamente apreciamos que esta sustancia ha tenido una buena respuesta como aditivo en morteros para recomposiciones de frisos en Tschudi, y no ha producido problemas de alteración del material.

Los mucílagos son ésteres de ácido sulfúrico (polisacárido complejo), contenidas en las células vesiculares de los tejidos parenquimáticos de la Tuna. Son insolubles al agua, pero tienen capacidad de absorverla y retenerla; en contacto con ésta forman soluciones viscosas. Complementariamente las pectinas que se relacionan íntimamente con ellas y las gomas, forman sustancias coloidales que se convierten en jaleas. (8)

Esta sustancia mucilaginosa, tiene propiedades de conglomeración, además inhibe y selecciona gérmenes, por lo que su uso favorecería la consolidación de materiales y se evitaría la formación y proliferación de bacterias y líquenes.

La extracción de mucílago se efectúa de la siguiente manera: 350 gr. del interior de la hoja cortada, remojada en 0.5 lts. de agua natural durante 24 hrs. Esta sustancia se mezcla con agua natural al 5%-10% a fin de rebajar su densidad y lograr su aplicación y buena penetración en el muro (3 cm. promedio). Su tiempo de utilidad se extiende a sólo 48 hrs. a partir de su remojo inicial; pasado este tiempo, sus células entran en estado de descomposición y pierde el 85% de su viscosidad.

Esta sustancia, en solución al 5%, ha sido empleada como consolidante y como aditivo para morteros, en las proporciones siguientes:

Cuadro 1

TIPO DE MORTERO	PROPORCIONES MATERIAL (*)					
	Arcilla gr.	Tierra gr.	Arena Fina gr.	Arena Gruesa gr.	Confitillo (Piedra 5 ml.) gr.	Mucílago 5% lt.
- Resanes enlucidos a	-	333	666	-	-	0.25
- Resanes enlucidos b	333	-	999	-	-	0.25
- Resanes enlucidos c	-	333	-	666	-	0.25
- Asentado de Adobes	-	333	-	666	-	-
- Estuco	-	333	-	666	333	0.25
- Capa Protec. Cabeceras	-	333	-	666	333	0.25

(*) Proporciones estimadas con un margen de error al 10%

2. Tratamiento:

Los niveles y procedimientos de la intervención continuaron siendo los mismos, con modificaciones parciales que se indican en cada rubro.

a. Refuerzos Estructurales:

Tuvieron los siguientes lineamientos: Consolidar y estabilizar la estructura colapsada o en proceso; anular la exposición del interior de la estructura a los fenómenos del intemperismo; y, crear barreras rompeviento y clausura de accesos no originales como medida de prevención ante la fuerza erosiva eólica y el tránsito indiscriminado del turismo.

El procedimiento consistió en la limpieza de los escombros y la eliminación de los materiales salinos y sueltos. Se efectuaron calzaduras de las bases, además de recomposición de los vacíos y reforzamiento de cabeceras. Los paramentos fueron elevados hasta alcanzar el nivel de éstas, dejándolos aptos para el tratamiento de protección. Se utilizaron adobes de forma y composición semejante a los originales, y la técnica de albañilería siguió el patrón arqueológico empleando mortero según las proporciones dadas en el Cuadro 1. Las superficies de las partes agregadas fueron cubiertas con un estuco que incluye confitillo y mucílago (Cuadro 1), con lo que se obtuvo una superficie bastante plástica y rugosa que se integra, sin confundirse con el original.

La intervención también consideró la reposición de secciones de paramentos desplomados, mediante el uso de puntales que iban devolviéndolas paulatinamente a su posición original. Se utilizaron llaves de amarre de algarrobo y adobe (según el caso), además de mortero, con el propósito de fijarlos a la estructura sólida.

Como medida de prevención contra la acción eólica, se levantaron algunos muros orientados de Este a Oeste, hasta la altura de la evidencia arqueológica; de tal manera se devolvió la barrera rompeviento original que protegía un importante sector decorado del palacio Tschudi.

b. Protección de Cabeceras de Muro :

Intervención destinada a controlar filtraciones, excesivo humedecimiento, erosión pluvial, penetración de sales higroscópicas y la abrasión eólica en las cabeceras originales. Además de los criterios referidos anteriormente al uso de consolidantes, la intervención se orientó a anular los fuertes planos inclinados, adecuando las cabeceras de manera tal, que permitan una distribución homogénea del agua de lluvias, con una absorción y discurrimiento normal en toda la extensión de la estructura, eliminando con ello, su concentración y fuerza erosiva.

El procedimiento consistió en la preparación de la superficie original luego de la eliminación de materiales sueltos, costras, y el material del tratamiento anterior. Se extranjeron las sales con papetas de papel absorbente humedecido con agua destilada y alcohol al 5%, y se consolidaron las superficies con mucílago al 5%. Posteriormente se aplicó la capa de protección, consistente en uno o dos tendidos de adobes modernos, y sobre ésta, el mortero de barro con mucílago al 5% (Cuadro 1). Una vez deshidratada, se cubrió la superficie con un aguaje de arcilla bastante líquida, con el objeto de eliminar la porosidad gruesa producida por la presencia del confitillo; así como para uniformizar el color de la superficie del conjunto trabajado. Esta capa, de naturaleza reversible, es la que resistirá los embates de la naturaleza, previniéndose, así, la degradación del original.

En los casos de muros decorados con rombos, solamente se colocó una capa de adobes, siguiendo el diseño de la decoración, y únicamente en donde se presentaron buenas condiciones de estabilidad y resistencia estructural. Esta capa, actuando literalmente como una cubierta, reemplaza al mortero de protección, siendo también, totalmente reversible.

c. **Consolidación de Enlucidos y Relieves:**

Considera la adherencia de estucos y relieves desprendidos o en proceso al muro soporte; y, el resane de grietas y vacíos.

Efectuamos inicialmente la limpieza general de las superficies, retirando el material grueso de escombros, las chorreras y adherencias finas acumuladas por deslizamientos de barro. Las sales se eliminaron con la misma técnica descrita para las cabeceras. Los desprendimientos fueron adheridos al muro mediante inyección de mucílago en solución al 5%-10%; y también insertando mortero con mucílago bastante licuoso.

De otra parte, las grietas y vacios fueron resanados con mortero (Cuadro 1) aplicado en dos capas y humedeciendo previamente el área con mucílago. La primera con arena gruesa, dejando una textura irregular a fin de facultar la adherencia de la segunda; y luego ésta, con materiales finos, a la que se le dió un acabado de textura regular luego de la deshidratación.

d. **Protección de Estructuras:**

La medida adoptada para evitar la degradación por factores medio-ambientales y también de orden turístico, fue la protección de los paramentos de banquetas y las rampas con un muro moderno a distancia de 0.20 mts. respecto al original, y una capa de adobes, respectivamente. De otra parte, los pisos arquitectónicos fueron protegidos con su propio material de escombro, cuyas superficies se adecuaron con planos inclinados hacia puntos centrales alejados de las estructuras a fin de que el agua evacúe hacia espacios abiertos y no se acumule contra los muros. Esta intervención es complementaria a la red de drenaje.

COMENTARIO

Llegar a conclusiones sobre la respuesta del tratamiento general y el comportamiento del mucílago a los tres años de la intervención, es bastante prematuro. Sin embargo, informaremos sobre los resultados de corto plazo bajo condiciones climatológicas normales.

Los refuerzos estructurales han solucionado problemas de estabilidad de muros, y se ha logrado una efectiva protección de la estructura interna expuesta por derrumbes y otros. De otra parte, la protección de paramentos con muros modernos, ha garantizado la prevención de daños por intemperie y permitido satisfacer exigencias de orden turístico, por cuanto se mantiene la configuración arquitectónica del sector intervenido.

El tratamiento de las cabeceras ha sido optimizado, aunque no se presenta como una solución concluyente. La ventaja de esta técnica en su conjunto, es que mantiene la permeabilidad del muro, debido a que el mucílago no altera la porosidad de los materiales. De esta manera, la inevitable migración y cristalización de sales contenidas que se produce en el nivel superior de las cabeceras afectará solo los materiales modernos que pueden ser fácilmente reemplazados.

La anulación de los planos inclinados ha permitido evitar la concentración y evacuación peligrosa del agua y las fuertes erosiones en determinados puntos de la estructura, habiéndose dado mas bien, una absorción homogénea en toda la superficie de las cabeceras debido a su capacidad de permeabilidad; facultad que, agregada a la ausencia de rigidez, ha evitado las erosiones a nivel del contacto entre la capa de protección y la superficie original, así como también un discurrimiento acelerado y total del agua pluvial que conllevaría acumulaciones en las bases de muros y una consecuente acción capilar.

El inconveniente que presenta este mortero en el tratamiento de estructuras,es su relativa resistencia a la erosión pluvial. Las mezclas que incorporaron mucílago como mordiente respondieron mejor a las lluvias estacionales normales; sólo se presentaron leves erosiones con un mínimo de pérdida de material fino. Por lo tanto debemos preveer su poca resistencia frente a lluvias de carácter torrencial que deberá ser salvada con elementos eventuales de protección (techumbres portátiles, plásticos, etc.).

En cuanto al tratamiento de superficies, la adherencia de enlucidos y relieves al soporte ha dado resultados positivos . Los resanes de grietas y vacíos han complementado la adherencia de superficies y subsanado posibles filtraciones al interior de los muros. En lo que respecta a la consolidación de las superficies, solamente se efectuó un ensayo en el Palacio Tschudi consistente en la aplicación de mucílago al 5% con brocha directa. Inicialmente se produjo un cambio de color, sin embargo en un corto tiempo fue retornando paulatinamente a su tono original.

En general, el tratamiento de estructuras y superficies con mortero mucilaginoso, ha demostrado buena resistencia a la abrasión eólica. Queda por experimentar lo correspondiente a sus cualidades patológicas en la generación de bacterias y líquenes.

Como corolario final indicamos que el mucílago es compatible con el adobe de Chan Chan. Como sustancia consolidante no forma películas impermeables, cohesiona y da resistencia a los materiales. Además permite reiterar la aplicación de la sustancia en la misma zona tratada, así como el empleo de otro consolidante. Estas cualidades son favorables debido a que el mucílago pierde sus propiedades de cohesión luego de un tiempo (no conocido), obligando a repetir el tratamiento.

En vías a mejorar el tratamiento en relación a la resistencia del consolidante, se han venido desarrollando pruebas de laboratorio con mucílago al 5,10,20,30, 40 y 50% en agua, mediante diversas técnicas de aplicación, sobre adobes salinos y sin contaminación. En principio se observa una buena receptividad de la sustancia en ambos. A medida que se aumenta el porcentaje del mucílago, se incrementan la densidad de la solución y la resistencia de la superficie. Pero, la absorción es más lenta (alcanzando siempre 3 cm. promedio) y se produce una alteración inicial del color. Estas muestras toleraron también la penetración de solución de Silicato de Etilo 40, y se comprobó, una vez más, la inalteración de la porosidad, debido a que fue posible la extracción de sales contenidas mediante papetas. En la búsqueda de soluciones, ambos consolidantes bien pueden utilizarse en niveles de tratamiento complementario. Estas pruebas aún están en observación.

En lo que a medidas de prevención se refiere, seguimos considerando de prioridad la instalación de un sistema de drenaje por el potencial pluvial cíclico que ocurre con una frecuencia de 7 a 25 años, no obstante, aún subsiste el problema de su implementación por los restos arquitectónicos y culturales subyacentes. Solo ha sido posible la instalación de pozos colectores en el sector de tumbas del palacio Tschudi, debido a la inexistencia de vestigios culturales bajo éstas.

De otra parte, la instalación de una barrera rompevientos vegetal propuesta en la zona de la playa para contrarrestar la acción eólica, no traería efectos favorables al monumento. La velocidad y fuerza eólica contraída por la mecánica de su desviación ocasionaría mayores daños. Solo sería efectivo si se implementa una serie de barreras a través de la zona urbana arqueológica, lo cual obviamente es imposible. En este sentido, hemos optado por recomponer las grandes murallas perimetrales, e interiores de los palacios (orientadas E-W) a manera de rompevientos, que han aminorado significativamente la fuerza y acción erosiva eólica.

CONCLUSIONES

1. El tratamiento a base de Mucílago de Tuna Brava, se asume como una alternativa al uso de consolidantes de naturaleza plástica, por sus propiedades de aglutinamiento, porosidad y plasticidad.

2. Se debe precisar un mantenimiento minucioso y permanente del monumento como una de las medidas preventivas de mayor importancia para su conservación.

3. Implementar un programa integral de conservación y prevención permanente, que debe considerar la instalación de laboratorios para análisis físico-químicos in situ, que promueva el conocimiento de la problemática de Chan Chan y garantice soluciones mas eficaces para su conservación.

Reconocimiento: Participaron en el trabajo expuesto el equipo técnico del INC-LL: Rest. Héctor Suárez, Rest. Carlos del Mar, Rest. Carlos Castañeda, Arql. Arturo Paredes y Arql. Antonio Murga; contando con la asesoría del Químico Prof. Carlos Cano del INC-Cusco, y las recomendaciones del Rest. Ricardo Morales G., a quienes extendemos nuestro agradecimiento.

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ABSTRACT

Ancient Panjikent (AD 5-8th cent.), situated some 55 km east of Samarkand, has been under excavation from some forty years. An excavated area of some 6 hectares, has yielded a town with hundreds of two-storied houses, a ruler's palace, two temples, streets, and bazaars encircled by city walls. The mud-brick and adobe (pakhsa) buildings of Panjikent which originally reached a height of some 10-12m (preserved up to about 7m), were decorated with murals and sculptures that have now gained worldwide recognition. There exist enormous problems of conservation and exhibition at Panjikent. These involve the creation of an open-air museum, like that at Pompei, where visitors may be introduced to the town as a whole. This fascinating work and the resolution of these problems would greatly benefit from international cooperation.

KEYWORDS

Sogdian civilization, Silk Route, dead city,open-air museum.

PANJIKENT; A PRE-ISLAMIC TOWN IN CENTRAL ASIA

Dr.Boris Marshak
The State Hermitage Museum
191065 Leningrad
USSR

Panjikent is one of the most important Central Asian archaeological sites. The city of Panjikent is in Tadjikistan (the Tadjik Soviet Socialist Republic) and is situated some forty miles east of Samarkand. Panjikent exists today and is located on the Zerafshan river. Ruins of early medieval Panjikent were discovered on the hills south of the modern town. (Belenizki, 1980;Azarpay,1981;Belenizki,Marshak,1971).

Since 1946 about a half of the city datable to the eighth century A.D. has been excavated by Soviet archaeologists. Panjikent was founded in the fifth century. Some buildings (part of defensive city walls and two large temples with their spacious yards) were constructed towards the mid-fifth century A.D. There are also some houses of the sixth to seventh century A.D. The walled town (excluding the citadel) encompassing an area of 13.5 hectares was very crowded with narrow streets framed with rows of shops and even vaulted alleys. Houses of wealthy people were two to three stories and had many rooms and principal halls, resembling miniature palaces. Now the height of their ruins reaches 6 to 7 meters.

One third of houses were once adorned with superbly executed paintings and no less skillful wood carving. About 722 A.D. some houses were burned by the Arab conquerers and wooden beams, panels, statues became carbonized.

Panjikent demonstrates the highest point of development of the pre-Islamic culture of Sogdiana. Sogdian merchants controlled trade and commerce along the "Silk Route" the main artery of communication between the West and the East. The excavations of Panjikent have a world importance because it is now the most studied town along the ancient silk roads.

Walls of all buildings and vaults of some ground floor rooms were constructed with mud bricks and pisé (or using a local term pakhsa). After excavation of these walls it is very difficult to preserve them. Panjikent was declared to be open-air museum more then ten years ago. Thousands of tourists from many countries are visiting the site. However, we are at very beginning of the work of establishing a real museum.

Fig.1. Façade of the 7th house dismanteled from additional mud-brick masonry (early 8th century).

Fig.2. Vaulted alley with the walls from pisé divided into large blocks.

Fig.3. Ground floor room with its vault. Early 8th century.

I am an archaeologist and not a technical specialist and so in my paper I want only to show our problems for challenging the specialists who. I hope, can solve them. There are some destructive natural agents like rain and snow, ground water with salts and instability of half-ruined constructions. Now we must remove all sculptures and murals painted upon clay plaster. The Hermitage restorers have their own methods of conservation and removing of Panjikent murals, clay sculptures and burned wood carvings. They use PBMA for reinforcing the murals before removing and paraffin to strengthen charcoal (Kostrov,1954).

Another problem is an esthetic one. It seems necessary to be very careful with introducting modern roofs of concrete, plastic, glass and metal for protection of ruins because these materials inevitably destroy the effect of a dead city resembling Pompei.

There are three ways to present the structures to the public:

1. As ruins protected from further destruction without elements of the reconstruction.
2. As partly reconstructed buildings (with artificially reinforced construction and wall materials) which would be open for visitors.
3. As roofed buildings with museum exhibits inside open to guided tours.

There are also so awkward objects as the unpaved streets and the city walls (their height is about 7 meters in present condition).

The experience of more than forty years of excavations has shown us that the walls were practically invulnerable if protected from the effects of moisture. The walls of the main hall of Temple I built in the fifth century were in good condition until 722 A.D. The hall had only three walls and was opened to the columned portico facing the outside. The unfired clay reliefs dating from the 6th century A.D. in the portico of Temple II also were in good condition until the early 8th century. Now for protecting a wall we use only some rows of additional mud brick masonry above its remnants and the additional clay plastering of its lower part.

For walls which are to be excavated later we must use several methods of protection including new masonry above ruins, chemical reinforcement of old bricks and plasters, insertion of special framework into constructions and special drainage systems. During restoration of the buildings which had been excavated decades ago it would be possible to reconsruct the damaged surface using documentary drawings and photographs. In

Fig.4. Lobby with two doors and two windows for the stair-case. Early 8th century.

Fig.5. Room with pisé walls. Half-columns were carved in pisé blocks. Early 8th century.

Fig.6. Two-storied house. Below a vaulted ground floor room. Early 8th century.

Fig. 7. Ornamental mural.6th century.

Fig.8. Lion-throne of the Goddess Nana. Clay statue. 7th century.

this case it would be also useful to make new bricks and plaster from clay with some kind of modern special long-lasting mediums. It could be dangerous to keep murals and sculptures in situ which may be replaced with modern replicas because now we have no way to make originals strong enough in the climatic conditions of Central Asia. In Panjikent there are dry hot summers and cold snowy winters. It would be useful to search for the best way of preparing exact and long-lasting copies from modern materials.

Our problems are too sophisticated to be solved without collaboration with our foreign colleagues. The great importance of the site itself and the possibility of testing many scientific approaches and technical means must be stressed. I think it would be beneficial to establish an international conservation program for Ancient Panjikent, the main artistic center of the Silk Route civilizations.

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ABSTRACT

In Northen Yemen, one of the traditional types of construction, based on on-site fashioned earth, called zabour, is going to disappear because of economic reasons, more particularly the high cost of manpower.,

Special studies have been carried out about the wall of Sanaa, the capital of Yemen, in order to have this type of construction renewed. The studies aimed at modernizing this process though keeping its specificity (the elaboration is handmade in a very unsophisticated way). The tedious part of the work, consisting of kneading the earth, has been removed thanks to the use of a mixer. The quality and the durability of the product are guaranted by the use of a hydraulic stabilizer and to the measure of the quantity of water used for kneading. The laboratory studies carried out in Yemen proved that it was possible to reach a dry or wet resistance of about 3MPa.

This new technology is the result of an on-site experiment, which has enabled us to define recommendations for the manufacture of zabour on-site.

KEYWORDS

Zabour, Yemen, Laboratory and on-site experiments, Dry and humid resistance, Modernisation of a technologie,

RESTAURATION DES MURAILLES DE SANA'A, YEMEN DU NORD
AMELIORATION DU ZABOUR', METHODE TRADITIONNELLE DE CONSTRUCTION EN TERRE

Myriam Olivier, Ali Mesbah et Willy Adam,
Laboratoire Géomatériaux
ENTPE, Ecole Nationale des Travaux Publics de l'Etat
69 518 Vaulx-en-Velin Cedex, France

Introduction

Le gouvernement de la République Arabe du Yémen a lancé depuis plusieurs années des opérations de restauration de la vieille ville de Sana'a. Après mise au point des projets et les marchés, les travaux sont suivis par le "Bureau Exécutif pour la Sauvegarde de la Vieille Ville de Sana'a", organisme dépendant directement du Cabinet du Premier Ministre du Yémen. Il est aussi important de noter que la ville de Sana'a a été classée *"Patrimoine de l'Humanité"*, en 1980, par l'UNESCO. Les chantiers de restauration de bâtiments publics, de mosquées et de maisons sont très nombreux. De même, des opérations sont en cours relatives à l'assainissement, aux pavages des rues et au ramassage des ordures ménagères.

La reconstruction d'une partie des murailles de Sana'a fait partie des projets du Bureau Exécutif. Le début de leurs destructions est postérieur à 1962. Ensuite le développement de l'urbanisme, associé au non-entretien du reste des murailles, ont entraîné soit leur destruction totale, soit leur disparition partielle entre les bâtiments. Il faut aussi déplorer l'utilisation du Wadi[2] comme voie de circulation, ce qui a causé en 1982, la destruction d'un magnifique pont construit en continuité avec la muraille. Seule une partie de la muraille reste visible et à peu près accessible. C'est celle qui fait l'objet du projet de restauration. Elle va du Wadi jusqu'à 100 m environ de la porte de Bab El Yémen, et mesure environ 400 m.

L'une des techniques utilisées pour la construction de la muraille, le zabour, est actuellement sur le point de disparaître, supplantée par la construction en parpaings de ciment. Les connaissances empiriques accumulées depuis des siècles sont entre les mains de maîtres-maçons (les Ustas), âgés, pour la plupart, de plus de 70 ans. Cependant, pour conserver à la muraille son aspect originel, il a été décidé d'utiliser cette technique, mais en essayant de retrouver scientifiquement les bases de cette technique. La participation française s'est donc située sur un plan purement scientifique et technique et n'a donc pas eu pour objet de remettre en cause les options déjà choisies concernant la politique de restauration et de reconstruction. Celle-ci a été de plusieurs ordres : transformation du projet architectural d'origine en dossier technique, étude expérimentale en laboratoire de la fabrication et de la stabilisation du *Zabour*, transposition des résultats d'études sur le site (méthodologie de suivi du chantier de fabrication et mise en oeuvre du *Zabour*, introduction de l'utilisation d'un malaxeur) et introduction de notions de suivi de chantier (comparaison des quantités prévues à l'estimatif et réalisées, contrôle de qualité,...). Ce sont essentiellement les quatre derniers points qui seront présentés dans cet article.

Contexte de la restauration

Décider de restaurer ce mur a soulevé l'alternative suivante : reconstruire en place une muraille similaire à celle qui existait 200 ou 300 ans auparavant, ou essayer de conserver, dans leur état actuel, les vestiges de l'ancienne muraille. La première solution a été retenue par le Bureau Exécutif et a été appliquée pour l'élaboration du projet.

Les études ont débuté en 1986, grâce à la participation de la République Démocratique de Corée (Corée du Nord) qui a, d'une part, effectué un lever topographique très précis du mur actuel et des constructions avoisinantes et d'autre part, réalisé un premier projet de restauration de ce mur, ne prenant en compte que l'aspect extérieur de la structure. En juin 1988, l'ENTPE a été sollicitée par les Ministères Français des Affaires Etrangères et de l'Equipement, afin de fournir au Bureau Exécutif pour la Sauvegarde de la Vieille Ville de Sana'a un appui technique pour la réalisation des pièces techniques du Dossier de Consultation des Entreprises et pour le suivi des travaux. Celui-ci a consisté en la mise à disposition, auprès du Bureau Exécutif et de l'entreprise retenue, d'un ingénieur du Laboratoire, Willy ADAM, de mars à décembre 89, pour résoudre les problèmes de chantier et pour réaliser les études nécessaires à la mise en oeuvre concrète du *Zabour*, et en deux missions de suivi effectuées, en juin et décembre 1989, par Myriam OLIVIER.

Le projet

1. L'état actuel : La muraille de Sana'a est construite suivant un profil très spécifique au Yémen du Nord. Mais son aspect originel est difficile à imaginer à partir de son état actuel. Cependant, il est possible de trouver, au Yémen des structures identiques, en bien meilleur état. C'est le cas du mur d'enceinte de Saada, ville du nord, en limite du désert.

Le corps de la muraille est constitué de deux murs de *zabour*, montés sur une maçonnerie très résistante, et enserrant un remblai argilo-sablonneux. Un "garde corps"extérieur est réalisé en *zabour* sur une hauteur qui devait être d'environ 1,5 à 2 m. La largeur utile du dessus du mur varie de 3 à 5 m.

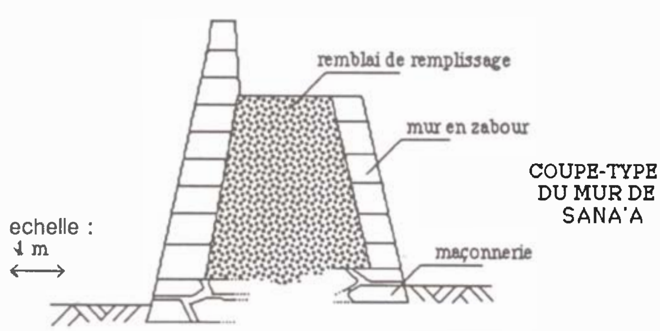
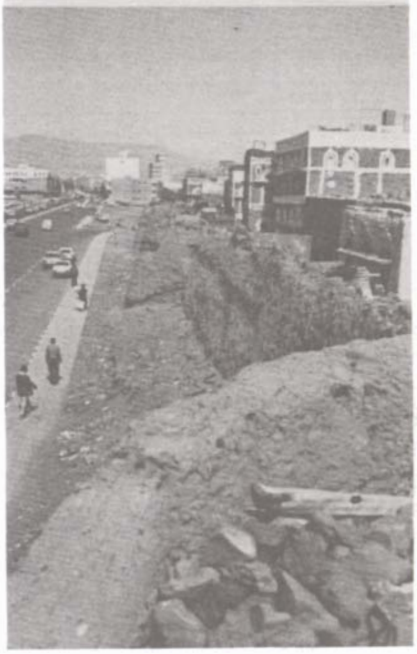


figure 1 : coupe type originelle du mur de Sana'a

Le *zabour* est la principale technique traditionnelle de construction en terre du Yémen du Nord. Le sud du pays utilise également la technique de l'adobe et surtout la construction en pierre. Il consiste à fabriquer des boules de terre argileuse, très humides, puis à les mettre en place à l'avancement, sur le mur, extérieur du mur



de façon à réaliser des "boudins" carrés de section 60x60cm environ. Ceux-ci sont relevés aux angles des murs, de façon à créer un chaînage vertical, donnant ainsi un aspect rayé aux constructions locales qui atteignent couramment des hauteurs de 20m.

2. Présentation du projet : Comme on le verra plus loin, cette technique artisanale est lente à réaliser et très consommatrice de main d'oeuvre. Or, le niveau de vie local s'étant fortement élevé lors des dix dernières années, cette technique a tendance à disparaître au profit du béton et du parpaing de ciment, jugés plus modernes, plus économiques et plus fiables.

Dans le cadre du projet de restauration de la muraille de la Vieille Ville de Sana'a, le laboratoire Géomatériaux de l'Ecole Nationale des Travaux Publics de l'Etat a réalisé une étude sur la technique traditionnelle du zabour en vue de mettre au point les spécifications techniques relatives à sa préparation et à sa mise en oeuvre sur chantier. Le but visé n'était pas d'introduire une technique nouvelle dans ce pays mais, à partir de celle qui existe déjà, de proposer des améliorations pour arriver à un produit fini fiable, homogène, résistant, ayant une bonne tenue à l'eau et pouvant être préparé et mis en place par les artisans locaux sans difficultés majeures.

Outre les aspects laboratoire et réalisation expérimentale sur le site, nous avons travaillé à la mise au point du projet initial, pour y introduire les contraintes de site et tenir compte des matériaux employés. C'est pourquoi, tout en essayant de respecter l'aspect originel du mur, le projet actuel présente quelques modifications avec la muraille ancienne. Ainsi :

- en raison de l'urbanisation qui s'est développée à l'intérieur du mur depuis 1962, la largeur originelle du mur a dû être modifiée. Les écrits anciens signalent que "quatre cavaliers pouvaient galoper de front sur le mur", ce qui correspondrait à une largeur de 5 à 6 m, et est corroborée par l'emprise du mur que l'on distingue encore au nord de la ville. En revanche, sur la partie sud, objet des travaux, l'épaisseur résiduelle du mur varie, sur la majeure partie du tracé, à la base de 2 à 5 m et en haut de 2 m à 30 cm (!). Aussi, afin de ne pas trop empiéter sur les propriétés bâties, la largeur finale en tête de mur ne dépassera que rarement 1,5 m. De plus, pour éviter de détruire certaines maisons directement fondées sur le mur, celui-ci sera par endroits, déplacé de 0,5 à 1 m vers l'extérieur,

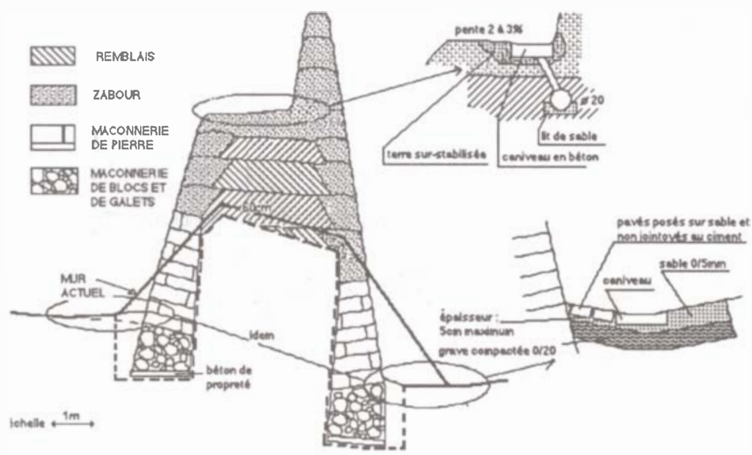


figure 2 : coupe type du projet de restauration du mur de Sana'a

les cours, à l'intérieur du mur

- un soubassement en pierres équarries a été prévu à la base du mur comme cela existait sur l'ancien mur. Ces pierres sont en basalte, matériau qui a déjà été utilisé pour restaurer le mur il y a environ 150 ans comme on le voit sur une partie encore visible du Mur Sud. Il faut cependant noter que le mur d'origine avait probablement une fondation en pierres sédimentaires blanches comme on le voit sur le bord du Wadi. Ce type de pierre est plus facile à tailler, mais est en revanche plus érodable.

- dans tous les cas, la technique de construction de la maçonnerie est identique à celle utilisée pour le mur d'origine, à savoir : pierres bien équarries à l'extérieur et maçonnerie plus rustique à l'intérieur. Cependant celle-ci a été faite avec un mortier de ciment, au lieu d'un mortier de terre (technique ancienne) afin de garantir une meilleure tenue dans le temps de la structure restaurée.

Fabrication traditionnelle du zabour

La préparation et la mise en place du Zabour s'accompagnent d'un rituel assez impressionnant quand on y assiste pour la première fois. Si le malaxage de la terre peut être assimilé à une danse bien rythmée où pieds et mains s'altement pour mélanger intimement la terre, la pose du Zabour par contre est une valse où les boules de terre montent et descendent à une cadence régulière. L'harmonie des gestes, le rythme, les chants d'accompagnement montrent que les artisans se plaisent à faire ce travail et exécutent un numéro de leur folklore.

Mis à part l'aspect cérémonial, la préparation de la terre est une opération longue et fastidieuse. La terre disposée en grand tas est tout d'abord arrosée d'eau et abandonnée ainsi pendant 3 à 4 jours. Ce temps est nécessaire pour permettre à l'eau de s'infiltrer, de cheminer à travers les pores du sol et d'imbiber toute la terre du tas. Après cette période d'humidification commence la phase proprement dite de malaxage. Le tas de terre est pétri, étalé avec les pieds, remis à nouveau sous forme de tas en ramassant des mottes de la périphérie et en les lançant vers le milieu du tas. Ce cycle d'étalement - rassemblement de la terre se renouvelle jusqu'à ce que le matériau atteint le niveau de plasticité, de cohésion désiré. Vient ensuite la formation des boules de terre ; chaque artisan récupère une petite motte de terre, la pétrit plusieurs fois sur une surface lisse et dure et la met pour terminer en boule. On se retrouve ainsi, en fin de préparation avec un tas de boules de terre qui ressemble à des petits pains attendant la cuisson.

Place maintenant à la valse des boules de terre. L'USTA (maître-maçon) se positionne dans la zone de travail, attrape une à une les boules de terre qui lui sont lancées par les ouvriers, les oriente et les projette dans la partie de l'ouvrage à réaliser. Tout se déroule rapidement à une cadence rythmée sur le chant d'accompagnement. Au fur et à mesure que s'accumulent les boules de terre, la bande de Zabour se dessine et prend forme. Quand un morceau de la bande est prêt, l'USTA arrête momentanément le jeu des boules, comble en tassant avec la main les creux qui se sont formés et achève la finition des parois extérieures, en la polissant avec la main.

malaxage de la terre et fabrication des boules de zabour

mise en place du zabour par l'Usta

Modernisation de la technique

Cette présentation sommaire de la technique de fabrication du Zabour au Yémen montre clairement qu'elle s'accompagne d'un délai considérable entre le début de la préparation de la terre et sa mise en place effective. Pour le chantier de la muraille de Sana'a où environ 2000 m^3 de Zabour doivent être réalisés, cette technique traditionnelle, si on devait la maintenir telle quelle, entraînerait un allongement excessif de la durée du projet, un coût de production du m^3 de Zabour exorbitant et un alourdissement de la gestion du chantier. Aussi a-t-il fallu l'adapter pour la rendre plus opérationnelle.

1. Le malaxage : La première innovation apportée réside dans la mécanisation de la préparation de la terre. Au malaxage manuel, on a substitué un malaxage mécanique[3]. Les résultats enregistrés sont très intéressants du point de vue économique et technique :

- Réduction importante de la main-d'oeuvre et gain de temps. Avec 3 personnes (1 technicien et 2 ouvriers), il a été possible de préparer des gâchées de 0,01 m^3 en 6 à 8 minutes. Chaque gâchée comprend un malaxage à sec des constituants solides (terre-sable-ciment) pendant 2 minutes puis un malaxage humide avec l'ajout d'eau. Cette dernière est toujours versée sous forme de pluie. La méthode manuelle traditionnelle demande 45 minutes pour malaxer le même volume, après avoir pré-humidifié la terre pendant plusieurs jours. Une fois les quantités fixées et après que les ouvriers se soient fait la main, la préparation de la terre devient pure routine, reproductible en série. Ils retrouvent alors l'appréciation visuelle d'un maçon expérimenté.

- Meilleur contrôle du dosage en eau et meilleure qualité du malaxage. Alors que pour une préparation traditionnelle la teneur en eau varie d'un endroit à un autre du mélange (au laboratoire, pour de faibles quantités de terre malaxée manuellement, on a observé des variations de 5 points de teneur en eau), le malaxage mécanique permet une répartition uniforme de l'eau dans le mélange. Les petites variations enregistrées (de l'ordre de 0,5 à 1 point de teneur en eau) viennent des phénomènes d'évaporation dus au temps écoulé entre la fin du malaxage et la mise en place de la terre et surtout, du pétrissage de la terre pour la confection des boules. Elles ont peu d'influence sur la résistance finale. (voir figures 7 & 8).

2. La stabilisation au ciment : L'autre innovation vient du fait qu'un liant, du ciment en l'occurrence, a été ajouté à la terre pour la stabiliser. Au Yémen, jusqu'à présent, aucune tentative en ce sens n'a été faite. Pour protéger la terre brute contre les intempéries, les artisans préfèrent épaissir les ouvrages, ce qui entraîne souvent un surdimensionnement des éléments structuraux. Avec la stabilisation au ciment, il a été possible d'obtenir un matériau aux bonnes caractéristiques mécaniques et parfaitement résistant aux intempéries (voir § VI).

De plus, la méthode traditionnelle de préparation de la terre n'est plus appropriée, car il est effectivement impossible de faire "macérer" la terre stabilisée plusieurs jours à cause du phénomène de prise assez rapide en présence d'un stabilisant. D'où l'intérêt supplémentaire de l'introduction du malaxage mécanique. Les études ont été réalisées avec 0, 4, 6, 8 et 10% de ciment, qui sont des valeurs courantes pour la fabrication de mortiers de terre. Pour les travaux, c'est finalement une stabilisation à 6% de ciment qui a été retenue.

3. La mise en oeuvre du zabour : Le dernier point concerne la réalisation même du mur. Pour assurer le transfert des études de laboratoire sur le chantier de construction et s'assurer de la bonne coordination entre les techniciens du Bureau Exécutif et l'Usta (maître-maçon), un essai de mise en oeuvre sur le site a été réalisé les 11, 13 et 14 décembre 1989. Le travail expérimental sur site s'est fait progressivement. Au début de l'expérimentation, l'ensemble des opérations de dosage, de malaxage et de mise en oeuvre étaient suivis par W.ADAM et M.OLIVIER. Puis, petit à petit, elles ont été déléguées à l'ingénieur du chantier et au technicien du Bureau Exécutif. Lors du troisième essai expérimental, l'ensemble des opérations a été réalisé par les Yéménites, avec un parfait consensus entre les différents intervenants (entreprise, Bureau Exécutif et Usta).

Cette phase a ainsi permis un excellent transfert de données expérimentales et de technologie sur un site réel et a donné aux différents intervenants l'occasion de retrouver la maîtrise d'une technique traditionnelle grâce à une approche scientifique des problèmes. L'expérience acquise lors de cette expérimentation demande cependant a être confirmée par une mise en oeuvre rapide sur le mur lui-même. Malheureusement, le report de cette phase à 4 ou 5 mois fait perdre une grande partie des acquis de l'entreprise et de l'Usta.

Etudes faites en laboratoire

1. Principe des études : La détermination des paramètres de chantier a été faite à partir d'essais de laboratoire réalisés au Yémen, en liaison avec le laboratoire du Ministère des Travaux Publics et celui de la Faculté d'Ingénieur de l'Université de Sana'a. Après avoir examiné la préparation traditionnelle du Zabour et identifié les paramètres de base (granulométrie et composition des matériaux, liants, teneur en eau, mode de malaxage, mode de mise en place, cure) qui s'y rattachent, des séries d'éprouvettes ont été préparées en faisant varier ces paramètres. Elles ont ensuite été soumises aux essais suivants : compression simple, tenue à l'eau lors d'essais de remontées capillaires et essai d'immersion complète.

A partir des résultats obtenus, il est possible d'évaluer l'influence, sur les caractéristiques mécaniques (résistances à sec et humide) du Zabour, du mode de préparation de la terre (malaxage manuel, malaxage mécanique), de la teneur en eau de fabrication, de l'ajout de ciment et des conditions de cure.

2. Choix des matériaux : Au Yémen, il n'existe pas un matériau type pour la préparation du Zabour. Les artisans se contentent de prélever la terre qui se trouve immédiatement à leur portée. Ainsi, suivant le savoir-faire de l'Usta et suivant le type de sol disponible, la qualité du Zabour varie d'une région à une autre : on peut facilement passer d'un Zabour compact, résistant et dur comme un rocher à un Zabour fissuré, friable au simple toucher et lessivé par les intempéries.

L'un des points importants du travail a consisté à choisir, pour la restauration de la muraille, une terre permettant d'optimiser les caractéristiques mécaniques et le comportement du Zabour . A cet effet, 8 carrières situées aux alentours de Sana'a ont été visitées et leurs échantillons soumis à des essais d'identification. Nos investigations se sont limitées, pour des raisons économiques, à la région de Sana'a. Les résultats obtenus ont été analysés et comparés à ceux obtenus sur deux échantillons de Zabour retenus pour leur qualité. L'un provenait de la région de Saada et l'autre directement de la partie de la muraille en bon état de conservation. Parmi ces carrières, deux ont retenu particulièrement notre attention. Des difficultés pour acquérir des terrains de la première carrière nous ont conduit à choisir finalement la seconde (carrières de Beit Mulkat et celle de Beit Al Saal'a).

Le matériau provenant de Beit Al Saal'a est un 0/50 mm. Les résultats des essais d'identification font apparaître pour ce sol, un déficit assez important en sable. Pour y remédier, on a mélangé cette terre


vue du mur expérimental en zabour (janvier 1990)

avec un sable propre provenant de la région de Saada, dans la proportion de quatre volumes de terre de Beit Al Saal'a pour un volume de sable. Les gros éléments du sol ont été également écartés afin d'éviter la formation de billes pendant le malaxage (tendance de la terre à s'agglomérer autour des cailloux) et l'apparition de zones d'hétérogénéité dans le Zabour. Les matériaux d'origine et remanié ont donné les résultats suivants :

- courbes granulométriques et sédimentométriques (voir figure 3).
- essai normalisé au bleu de méthylène (uniquement sur le matériau remanié) :
sur le (0 / 0,1 mm) VB = 2,38, soit sur le sol total, (0 / 16 mm) VB = 1,22
- limites d'Atterberg :

matériau brut	WL = 31,8	Wp = 20,3	IP = 11,5
matériau remanié	WL = 30,6	Wp = 22,7	IP = 8

D'après la classification RTR[4], la fraction 0 / 16 mm se situe, pour le matériau brut en A2, et pour le matériau remanié en A1. D'après la classification LCPC[5], le matériau brut est une argile peu plastique, et le matériau remanié un sable argileux.

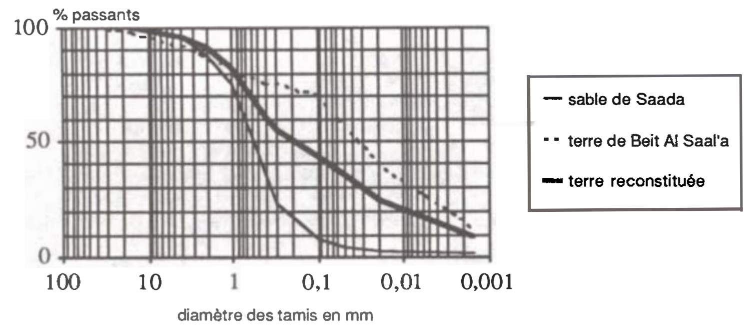


figure 3 : courbe granulométrique des matériaux utilisés


Vues des travaux de maçonnerie en cours

3. Déroulement des essais

3.1 Confection des éprouvettes : Les éprouvettes ont été confectionnées avec de la terre malaxée suivant les deux techniques mais l'accent a été surtout mis sur le malaxage mécanique. Dans les deux cas, une fois achevé le malaxage, on a fabriqué les éprouvettes en utilisant un moule en métal (ø=9,5 cm et h=12 cm). La terre déposée à l'intérieur du moule n'a été ni compactée ni compressée. Dans le cas des préparations "assez sèches" (teneur en eau comprise entre 23 et 26 %), une petite tige métallique a été utilisée pour tasser légèrement la terre et pour éviter la formation de trous à l'intérieur de l'éprouvette. Au-delà de 27 %, la terre malaxée s'apparentait davantage à une boue et il n'a pas été nécessaire de la tasser. Le démoulage des éprouvettes se faisait immédiatement après leur fabrication. Pour éviter des phénomènes de collage ou adhérence dans la zone de contact terre-moule, on a pris soin d'intercaler entre la terre et la paroi intérieure du moule huilée au préalable, un plastique assez rigide. Les éprouvettes ont été pesées et mesurées pour calculer leurs densités sèches à partir de la relation : $\gamma_d = Ph / (S \times (1+w)$,

où :
- Ph est le poids humide de l'éprouvette en gr
- h, sa hauteur en cm
- S, sa section en cm^2
- w, la teneur en eau du matériau

Les éprouvettes en terre non stabilisées ont été conservées à l'air libre et celles stabilisées au ciment, sous une bâche en plastique polyane bien fermée. L'influence du type et de la durée de la cure sera évaluée par la variation des résistances en compression simple.

3.2 Essai de résistance à sec : Des essais de résistance en compression simple à sec, après conservation des éprouvettes, ont été réalisés à 5, 10, 15 et 30 jours afin d'étudier l'influence de l'âge sur la résistance du Zabour. Seules les éprouvettes fabriquées à partir du Zabour traditionnel ont été écrasées à plus de 30 jours. Afin d'obtenir des essais homogènes, avant l'essai proprement dit, on a interposé un système antifrettage entre l'éprouvette et les plateaux de la presse.

3.3 Résistance humide : Cet essai est réalisé sur un matériau généralement âgé de 15 jours qui a été pendant au moins 24 heures soumis à un essai de remontées capillaires. Pour les éprouvettes stabilisées, une partie a été soumise à l'essai de remontées capillaires immédiatement après la cure sous la bâche, tandis qu'une autre a été mise à sécher à l'air libre 1 ou 2 jours avant l'essai. Pour deux séries d'éprouvettes, la conservation sous bâche a duré uniquement 5 jours ; ensuite, elles ont été mises à sécher à l'air libre pendant 10 jours avant l'essai de capillarité.

3.4 Essai de remontées capillaires : Les éprouvettes ont été posées sur un lit de sable, puis soumises à une pression capillaire très faible entretenue par la circulation d'eau dans un tissu épais, déposé sur le sable et dont les bords baignaient dans deux récipients contenant de l'eau.

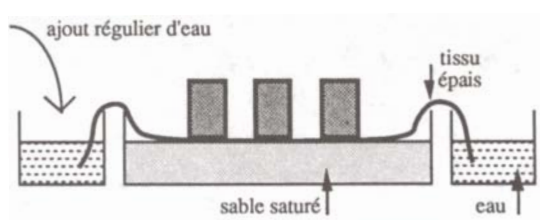


figure 4 : essai de remontées capillaires

Les récipients étaient disposés de manière à ce que le niveau de l'eau et la surface supérieure du lit de sable soient dans un même plan horizontal. Un contrôle suivi tout au cours du déroulement de l'expérience a permis de maintenir constant le niveau de l'eau dans les récipients. Le poids des éprouvettes a été relevé régulièrement pour calculer la quantité d'eau absorbée par le matériau.

4 Influence de la teneur en eau de fabrication

4.1 Variation de la densité sèche : D'une manière générale, il n'existe pas une relation bien nette entre densité sèche et teneur en eau. Les courbes obtenues pour les teneurs en eau étudiées (23 %<w< 34 %) montrent que la densité sèche a tendance à diminuer avec l'augmentation de la teneur en eau. Ceci s'explique : pour ces teneurs en eau, le matériau non stabilisé est proche de la saturation et les densités sèches obtenues se calent sous la courbe de saturation : $\gamma_d=\gamma_s/(1+w.\gamma_s/\gamma_w)$, notée en trait plein sur les figures 5 et 6. Les points correspondants aux teneurs en eau très élevées se situent au dessus de cette courbe, ce qui est dû aux écoulements d'eau libre observés lors du démoulage des éprouvettes.

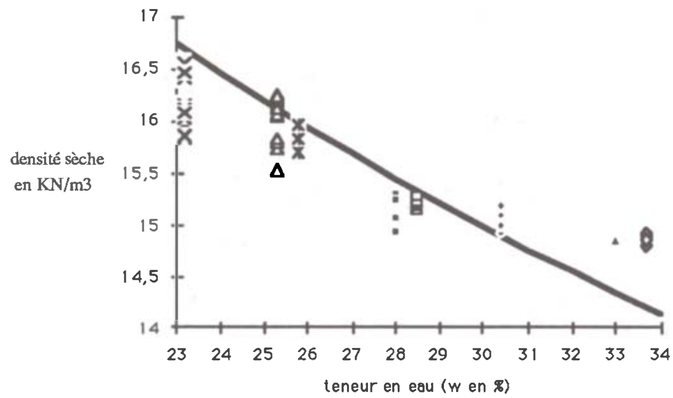


figure 5 : (densité sèche / teneur en eau) pour le matériau non stabilisé

On observe également une grande variation des valeurs de densité sèche à teneur en eau constante (par exemple, pour le matériau stabilisé à 6 % de ciment, γ_d varie de 1,40 à 1,59 pour w=24,8%). Ces résultats peuvent s'expliquer par le fait que la quantité de terre introduite dans le moule lors de la fabrication d'une éprouvette varie d'une éprouvette à une autre, surtout à teneur en eau faible, et comme aucune force n'a été utilisée pour compresser la terre, la répartition des vides, le tassement et la cohésion finale de l'éprouvette s'en trouvent modifiés.

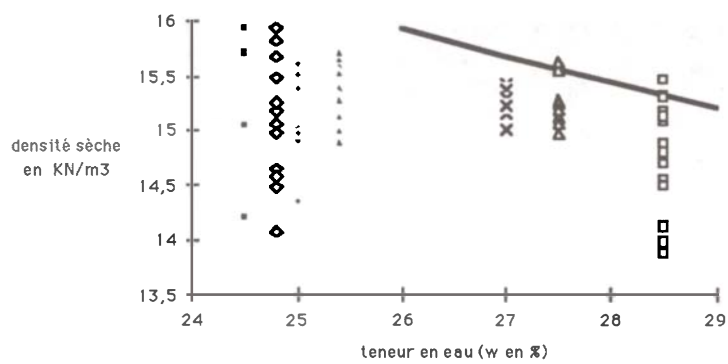


figure 6 : (densité sèche / teneur en eau) pour le matériau stabilisé à 6% de ciment

En comparant les valeurs de densité sèche pour le matériau brut et le matériau stabilisé, on constate qu'on obtient de plus fortes valeurs de densité sèche pour le matériau brut que lorsqu'il est stabilisé. L'ajout du ciment entraîne une baisse de densité, car la chaux libre présente dans le ciment entraîne une floculation quasi instantanée des argiles, qui s'oppose à la mise en place du matériau. On se trouve alors avec un pourcentage de vides plus élevé avec les matériaux stabilisés .

4.2 Résistance en compression à sec : Pour le *matériau non stabilisé*, les valeurs les plus élevées en résistance sont enregistrées pour les teneurs en eau "faibles" (w<26 %). Pour ces valeurs, le matériau est légèrement compacté et non moulé, mais sa mise en place est difficile et la dispersion des résultats est grande. Quand la teneur en eau croît, on retrouve la même tendance que pour la densité sèche, à savoir la résistance tend à diminuer.

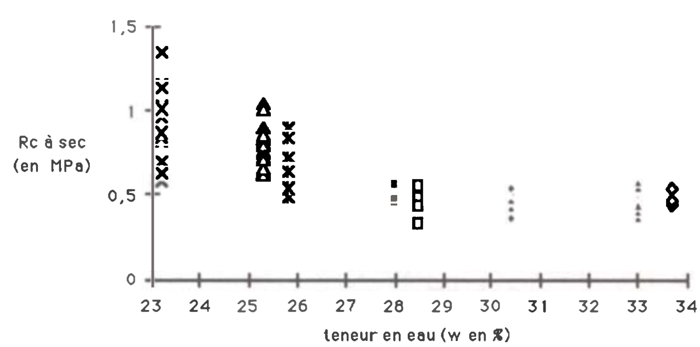


figure 7 : (Résistance à sec / teneur en eau) pour le matériau non stabilisé

L'*ajout du ciment* en faible proportion entraîne un gain de résistance considérable. Pour le matériau brut, la résistance se situe autour d'une valeur moyenne de 0,8 MPa, alors qu'après stabilisation à 6% de ciment, elle est aux alentours de 3 MPa ; soit 3,5 fois plus élevée.

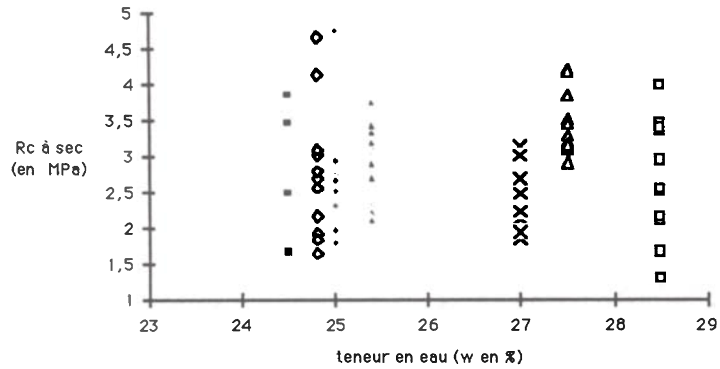


figure 8 : (Résistance à sec / teneur en eau) pour le matériau stabilisé à 6% de ciment

4.3 Résistance en compression après essai de remontées capillaires : L'influence bénéfique du ciment apparaît très nettement pour les résistances humides. Alors qu'après l'essai de remontées capillaires, le matériau brut présente des résistances quasi nulles (Rc humide ≈ 0,03 MPa), le matériau stabilisé à 6% de ciment garde une tenue excellente (Rc humide ≈ 3 MPa). De plus, on observe dans ces conditions, un retrait, donc une micro-fissuration, très faible. Pour 4% de ciment, la résistance humide diminue (Rc humide ≈ 2 MPa) et le matériau devient plus érodable, ce qui nous a amené à choisir, pour le chantier, une stabilisation à 6% de ciment.

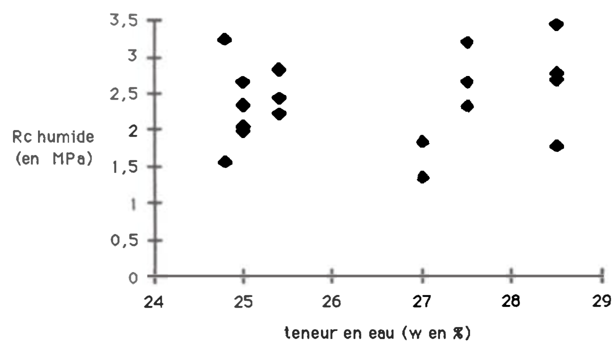


figure 9 : (Résistance Humide / teneur en eau) pour le matériau stabilisé à 6% de ciment

4.4 Conclusion sur les conditions de suivi de chantier : Il ressort de cette analyse que la teneur en eau à elle seule, ne suffit pas pour caractériser le Zabour et prévoir son comportement. Les recommandations écrites ont donc été établies pour assurer une bonne qualité du matériau et de la structure neuve. Elles ont pour principaux objectifs de garantir l'homogénéité de la fabrication et une résistance minimale du zabour. Elles concernent la durée et le mode de malaxage, l'ajout d'un stabilisant, la teneur en eau et surtout le mode de mise en place du zabour. Tous ces paramètres visent à obtenir la meilleure adéquation entre résistance et densité sèche. Sur la figure 10, les ❒ correspondent aux résistances sèches, les Δ aux résistances humides pour la teneur en eau retenue (27<w< 27,5%), alors que les ■ et ▲ correspondent aux autres teneurs en eau.

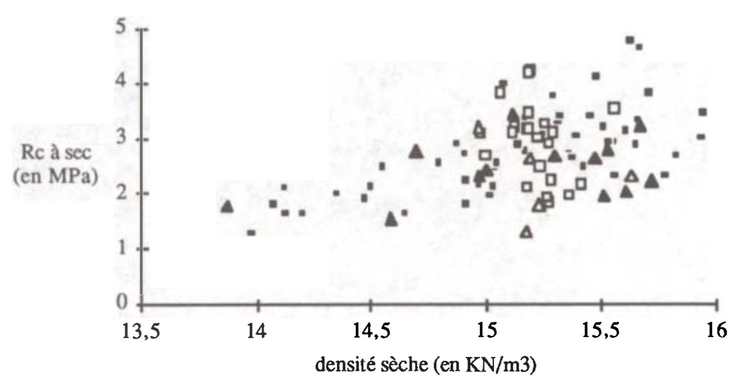


figure 10 : courbe (Résistance / densité sèche) pour le matériau stabilisé à 6% de ciment

Expérimentation sur site

1. Réalisation de l'expérimentation : Le transfert des résultats de laboratoire au chantier lui-même s'est fait au cours d'une expérimentation grandeur nature, en collaboration avec l'entreprise et les Ustas yéménites. Cette phase très importante et très intéressante a permis :

- d'effectuer les réglages du malaxeur pour obtenir une bonne homogénéité du matériau,
- établir une méthode simple de calcul et de dosage sur chantier des quantités de sable, de terre et d'eau, méthode qui pourra être mise en oeuvre par l'ingénieur de l'entreprise yéménite
- optimiser les temps de fabrication et de mise en oeuvre du *Zabour* pour limiter les phénomènes de prise anticipée du *Zabour* stabilisé au ciment,
- établir une relation de confiance avec l'Usta chargé de la mise en oeuvre du *Zabour* - celui-ci avait en effet l'habitude d'utiliser un matériau plus humide et non stabilisé - et l'amener à modifier légèrement son mode de travail afin de limiter ensuite les risques de fissuration par retrait.

D'autre part, lors de cet essai, deux types de ciment Portland, l'un gris, l'autre blanc ont été utilisés afin d'évaluer l'influence de la couleur du ciment sur l'aspect extérieur (variation de couleur surtout) du *Zabour*. Après 2 ou 3 mois de séchage à l'air libre, la couleur finale étant stabilisée, le Bureau Exécutif pourra effectuer son choix quant au type de ciment à utiliser pour stabiliser le *Zabour* du mur.

2. Recommandations pour l'exécution du Zabour : Cette expérimentation en site réel a permis de montrer les étapes où se situent les différences de fabrication et mise en oeuvre entre le *Zabour* traditionnel et "moderne", et ainsi de faire apparaître les points délicats et le suivi à effectuer.

2.1 Qualité du Zabour : le paramètre principal est la teneur en eau du mélange terre-sable-ciment. La teneur en eau optimale est de 27 %, pour le corps du mur. Pour effectuer le lissage de l'extérieur du mur, il est nécessaire d'augmenter très légèrement (+0,5%) cette teneur en eau.

2.2 Temps de fabrication : la mise en place d'un second malaxeur s'est avérée indispensable car, lorsque la teneur en eau est optimale, il faut de 6 à 8 mn pour fabriquer une gâchée de Zabour, alors que la fabrication et la mise en place des boules de *Zabour*, avec l'équivalent de ce matériau, par les aides de l'USTA, ne prend de 4 à 5 mn.

2.3 Mise en place du Zabour : afin de limiter la fissuration dans le mur, due au séchage de la terre et au retrait lors de la prise du ciment, il est nécessaire de s'assurer que le minimum de vides subsiste après mise en place des boules. Pour cela, les points suivants sont à surveiller :
- les boules doivent être placées directement à la jonction de la tranche de *Zabour* en cours de fabrication et la tranche précédente, il est, en effet, insuffisant de simplement repousser ce *Zabour* pour le mettre en place ainsi qu'on procède traditionnellement,
- des rainures devront être réalisées dans l'ancien mur afin de faciliter l'adhérence du nouveau *Zabour* sur celui-ci. De même que précédemment, les boules de *Zabour* devront être lancées directement dans le creux entre l'ancien et le nouveau mur,
- à la fin d'une phase de travail, il faudra également terminer le *Zabour* par une forme en escalier afin de favoriser ensuite l'adhérence avec le nouveau *Zabour*.
- une cure de 15 jours du zabour sera réalisée en disposant une bâche sur le mur.

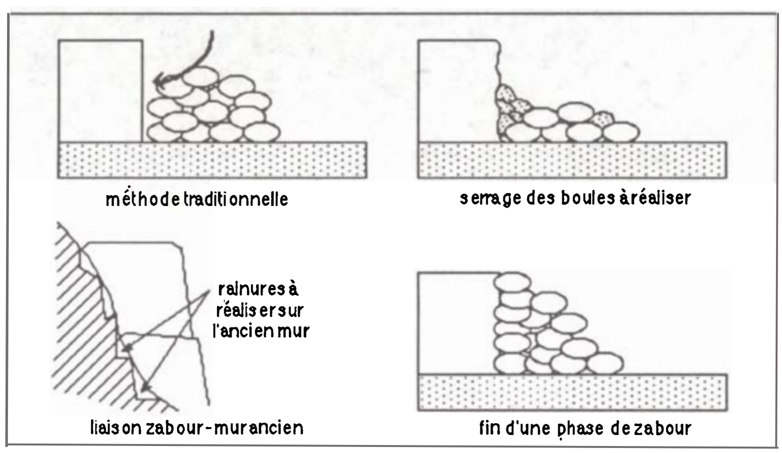


figure 11 : Mise en place du Zabour

Etat d'avancement des travaux

Les travaux d'exécution du mur ont débuté en août 89 par le nettoyage des abords extérieurs du mur. Ce n'est que courant septembre 89 qu'ont démarré les travaux de fondation et de maçonnerie. Fin décembre 89, ces travaux étaient achevés sur près du tiers de la longueur totale du projet (400m).

En avril 1990, les maçonneries de la base du mur sont réalisées sur 90% à l'extérieur du mur, mais les travaux à l'intérieur du mur restent difficiles à entreprendre car ils se déroulent en domaine privé. Le mur expérimental en zabour se comporte très bien, mais le zabour n'a toujours pas été commencé sur le mur lui-même.

Les photos des pages suivantes montrent le site des travaux ainsi que les conditions dans lesquelles ils se déroulent.

Conclusions

Ce chantier montre qu'une technique très traditionnelle peut être modernisée pour s'adapter aux conditions économiques actuelles. De plus, les études de laboratoire ont amené l'appui technique nécessaire pour transformer les connaissances empiriques des Ustas, en connaissances scientifiques quantifiables, vérifiables sur chantier, et qu'il est possible d'introduire dans un Cahier des Charges. Ce point est un point-clé dans la diffusion ou la réhabilitation d'une technique terre, car elle permet de garantir à la fois le maître d'oeuvre et l'entrepreneur en établissant contractuellement les objectifs recherchés et les moyens à mettre en oeuvre pour les atteindre.

Zabour : technique traditionnelle de construction en terre, très spécifique au Yémen Nord. Elle consiste à réaliser des boules de terre argileuse, à l'état plastique, qui seront ensuite projetées sur le mur par le maçon de façon à former un "boudin" carré de 60 cm environ de côté. La construction en place de murs formés d'une succession de ces boudins donne l'allure caractéristique des maisons du Yémen du Nord.(voir §IV)

[2] Wadi : lit asséché d'un fleuve temporaire

[3] malaxeur thermique : SED - CMD 250 LC, modifié ALTECH (05 200 Embrun, France)

[4] RTR : Recommandations pour les Terrassements Routiers

[5] LCPC : Laboratoire Central des Ponts et Chaussées

Consolidation Studies

ABSTRACT

The Getty Conservation Institute, in association with the Museum of New Mexico State Monuments, began a field-test program early in 1988 at Fort Selden State Monument in southern New Mexico. The purpose is to evaluate, using adobe test walls, various preservation materials and techniques. These include chemical consolidants (mainly diisocyanates, and silanes); techniques of application of consolidants (spraying, brushing, bulk infiltration), surface and depth treatments; drainage, shelter designs and materials, reburial techniques for archaeological sites, and some structural reinforcing materials and methods. Accelerated aging through water spray has been used on the walls and their condition has been monitored stereo-photographically. This paper presents the experimental design. Some preliminary results are given in subsequent papers in the present preprints.

KEYWORDS

Adobe, consolidation, site stabilization, site shelters, isocyanates, silanes, outdoor accelerated aging, stereophotographic monitoring.

THE GETTY ADOBE RESEARCH PROJECT AT FORT SELDEN. I. EXPERIMENTAL DESIGN FOR A TEST WALL PROJECT

Neville Agnew
Getty Conservation Institute
4503 Glencoe Ave. Marina del Rey, CA 90292
U.S.A.

Introduction

At the end of 1986 a three month pilot research project was undertaken at the Getty Conservation Institute (GCI) laboratories into the use of various chemical consolidants and other protective measures for the conservation of historic and archaeological adobe. While adobe was the primary focus of this research, it was implicit that the findings could have application to other earthen structures as well, and to outdoor heritage sites in general. The report on this work [1] and subsequent research over a nine month period showed that there was sufficient promise in chemical consolidants to warrant their field testing. The consolidants that tested most satisfactorily against deterioration by water and salts were aliphatic diisocyanate prepolymers and commercially available alkoxy and alkylalkoxysilanes. Preliminary results have been published [2-5]. Physical measures of protection and reinforcement of adobe structures were also planned in a comprehensive program of field testing.

The present paper describes the research design and implementation of the continuing field testing at Fort Selden. Preliminary results of the field testing are given elsewhere in the present publication. After the first phase of research a collaborative program was established at Fort Selden State Monument, where the Museum of New Mexico State Monuments (MNMSM) had already established a test wall facility. By late 1987 the design of the experimental system had been completed and construction of the test walls was finished in February 1988. Integral aspects of the design of the field project were an accelerated weathering (water spray) system, and regular temperature, moisture, and stereophotographic monitoring. Treatment of the test walls was completed by the end of May 1988 and testing began August 1, 1988 with the start of spraying.

The Need for Adobe Preservation Research

A significant component of the world's architectural heritage is built of earth, and the problem of preservation and protection of earthen structures is one of world-wide concern. In the late 1960's an Iraqi-Italian Center for the Restoration and Preservation of Monuments, with the collaboration of ICOMOS and ICCROM, was set up to study the preservation of unbaked brick. Its brief was to:

"systematically undertake collection of data, chemical and physical analysis of the bricks, research into the causes, concomitant and otherwise, of their degradation and be able to suggest methods most suited to give lasting results" [6].

Four international meetings on adobe were organized under the auspices of ICOMOS (Yazd, Iran in 1970, 1976, Santa Fe, USA in 1977 and Ankara, Turkey in 1980). The recommendations of the United States ICOMOS - ICCROM Adobe Preservation Working Session in Santa Fe in 1977 [7] called for (among other things) research into:

- Surface and subsurface drainage of mud-brick structures.
- Chemical surface treatment and consolidation.
- Injection and grouting techniques for consolidation or weather-proofing.
- Structural stabilization and reinforcement materials and methods.

In addition the ICOM-ICOMOS mudbrick symposium in Ankara in 1980 [8] recommended:

- Design studies be made of low-cost shelters that afford protection against direct erosion by rain or melting snow, provide thermal insulation but avoid the "greenhouse effect" and preferably be permeable to water vapor; and that shelter design concepts be tested in the field.
- Pilot field projects be undertaken to test conservation systems on entire structures.

In his introduction to the 1980 Ankara symposium on mudbrick preservation Torraca [9] noted the following points and problems for which a satisfactory solution was not yet in sight:

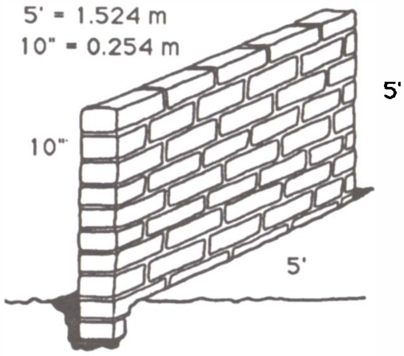


Figure 2. Schematic diagram with depth of test wall foundations and typical test wall dimensions.

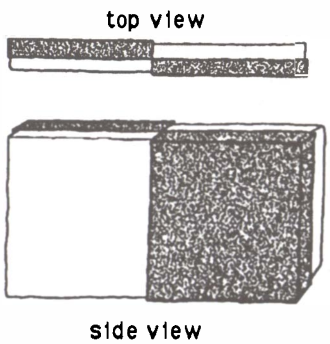


Figure 3. Schematic diagram of diagonal plastering of opposite sides of adobe test walls. The wall shown for the side view is one of the half walls.

•The long-term reliability and efficacy of partial protection methods including chemical treatment, capping and coating were questioned on the basis of recent experience and the high cost of these processes.

•Shelters open on the sides are effective at intercepting rain (and so stop this most damaging factor), but they allow a slow process of crust formation to occur. This is probably due to humidity/temperature cycles which are intolerable for decorated surfaces.

•There is a trend to either complete physical protection (by enclosures or reburial) or reliable maintenance routines.

Clifton [10] has reviewed the status, to 1976, of adobe preservation technology. He concluded that the successful preservation of adobe depends on effective protection of structures from the elements, especially water. He emphasized the need for analysis of the unique set of deteriorative factors operating at each different structure on site; the selection of preservation materials and standardized test methods; and pointed out the unlikelihood of the existence of a single universal preservation material process. Finally, he emphasized the importance of documenting and monitoring preservation processes that have been implemented. The research design presented here and the materials chosen for field testing address most of the concerns listed above - though not necessarily comprehensively in each case.

Deterioration of Adobe and Preservation Approaches

Much has been written about the effects of environmental factors, particularly water, on earthen structures. These include weathering by rain and snow, capillary rise of moisture into structures, migration of soluble salts, moisture-induced swelling and shrinking cycles as the material is melted, dries and so on. These and other deteriorative factors such as temperature, freeze-thaw cycles, wind erosion, and biological and human factors have been discussed [10, 11].

Likewise, the pros and cons of various treatment options involving chemical and polymer systems have been debated. In particular the question of penetration by surface applications and permeability of the treated surface has been one of concern [12]. For these reasons a variety of treatments, including spray, brushing and bulk-infiltration using a gravity-fed reservoir system were included in the design.

Test Wall Construction

After completion of an archaeological survey of the area for the test walls at Fort Selden, and final approval of the test wall design, construction began in December 1987. Figure 1 shows the plan view of the test wall site along with some individual wall treatment / experimental conditions. The standard test wall was 1.52 x 1.52 m by approximately 0.25 m thick (5 x 5 feet x 10 inches) constructed from nominal sized bricks 35.5 x 25.4 x 10 cm (14 x 10 x 4 inches). Wall foundations were 20.3 cm (8 inches), or two adobe bricks into undisturbed earth (Fig. 2). Diagonally opposite sides of the walls were mud-plastered (Fig. 3).

Figure 4. Photograph showing chemical consolidant being applied to adobe test wall by spraying.

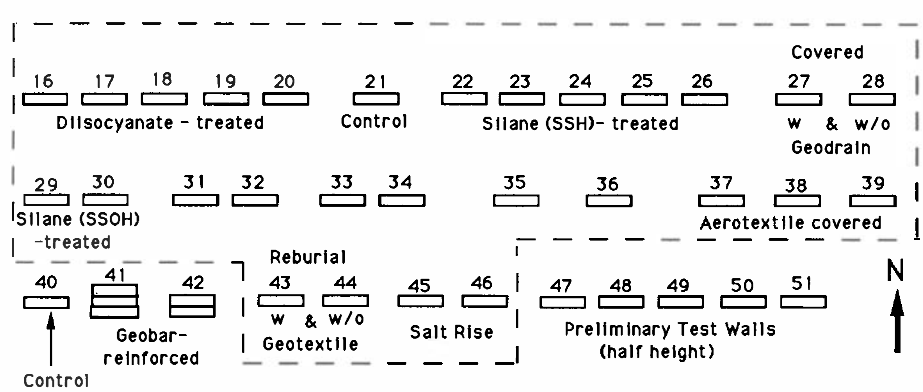


Figure 1. Map view of test walls at Ft. Selden, N.M. showing wall number and type of treatment / experiment. Area enclosed by dashed line represents walls subjected to accelerated (water spray) weathering.

Chemical Treatments

Chemical preservation is the application of a substance, usually a polymer in solution or a monomer which converts in situ into a polymer, and confers its properties of durability, strength (consolidation), weather resistance and so on.

Figure 5. Photograph showing chemical consolidant being brushed onto adobe test wall.

Figure 6. Photograph showing adobe test wall being treated with chemical consolidant using bulk infiltration technique.

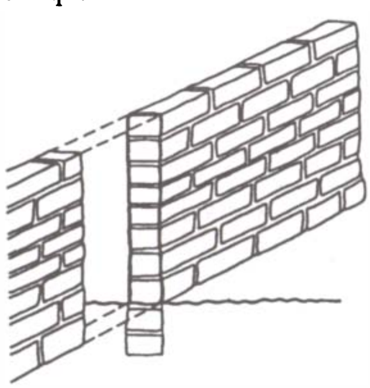


Figure 7. Schematic diagram of pattern of consolidation for walls treated by single surface coating.

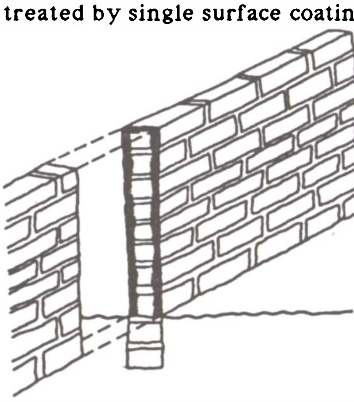


Figure 8. Schematic diagram of pattern of consolidation for walls using multiple surface coatings.

From the extensive literature on the preservation of adobe by chemical treatment, from the evidence of the present research, it has been possible to define the requirements of an hypothetical "ideal" system which will minimally alter the inherent properties and appearance, yet confer durability. These have been reported [3].

Consolidants - Application Techniques

Consolidant solutions were applied to the test walls by spray, brush and from reservoirs with infiltration tubes into the core of the wall (bulk infiltration) as shown in Figs. 4-6. Five basic patterns of consolidant application .were used. These are: surface coating (using minimal material); multiple surface coating (wet-on-wet) to achieve good depth of penetration; bulk infiltration to fully permeate the test wall; surface coating together with basal infiltration of the wall footings; and partial infiltration of the top and bottom of the wall and footings, with only light surface treatment on the vertical face. These patterns are depicted schematically in Figs. 7-11 which were chosen to provide as full a range of treatment responses to the perceived patterns of erosion of adobe walls.

Control Walls

A series of control walls is incorporated into the experimental design. Thus, there is a master control wall (#40, used also for thermal monitoring) that is not treated, nor sprayed, but exposed only to natural weathering; a control wall not treated but sprayed (#21) to monitor the effect of spraying on natural adobe. For the geodrain and simulated reburial test walls there are control walls without drains and without geotextile (#27 and #44, respectively).

In general, each wall can be referenced to one (or more) other wall(s) in which only one variable has changed, for example, the isocyanate (DN3390) - treated series (#16-20) is compared directly with the silane (Conservare SSH) - treated series (#22-26), and each series can be compared with the sprayed control (#21) and the master control wall (#40). Likewise, the effect of physical protection of adobe against spraying (simulating rain) by using knitted synthetic fabric ("aerotextile") as a shelter material can be judged by comparing the sprayed control wall (#21) with a sprayed, sheltered wall (#39).

Accelerated Weathering

It can take a long time for results from field testing under natural conditions to become apparent. To avoid such delay an accelerated weathering water-spray system at Fort Selden was used. The results of an artificial testing regime such as the present one are comparative only and are not intended to be absolute, nor will they necessarily relate in a quantifiable way to natural weathering. However, the results do allow certain valid conclusions to be drawn when judging one process against another and when suitable controls are included in the design.

Important criteria to be decided when initiating a spray regime are: frequency of spraying, time of day of spraying, volume of water per spray cycle, force of spray jet, uniformity and pattern of spray impinging on the wall. Also, local rainfall and meteorological conditions need to be recorded, as these obviously add to the weathering rate.

The initial spray program at Fort Selden proved to be too aggressive and after two months was stopped during a particularly wet summer. The initial spray program comprised two 15 minute cycles daily (at 0900 and 1600 hr). Each nozzle sprayed approximately 22 liters of water per cycle. Thus, the total water load per wall per two cycles daily was 88 liters, or over the two months of initial spraying approximately 1400 gallons. ·During this summer approximately 64 mm (25 inches) of rain also fell. Several walls (#30, 32, 46) collapsed during storms - presumably because of wind load on nearly saturated walls and footings.

Monitoring --- Photographic, Temperature and Moisture

A protocol for stereophotographic recording of the condition of the test walls has been developed. This comprises 6 x 6 cm format stereopairs taken at night with standardized lighting to avoid the variable effects of daylight . Approximately once monthly one side only (to minimize the cost) of each test wall is photographed. A single batch of film is used and standard processing of the negative is carried out. It is intended that quantitative information will be derived from the negatives by digitization and image processing. Fig. 12 shows a single contact print of one of a stereopair.

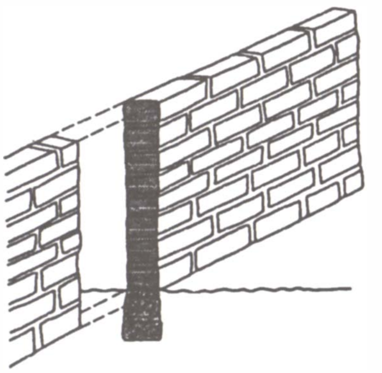


Figure 9. Schematic diagram of pattern of consolidation for walls treated by bulk infiltration.

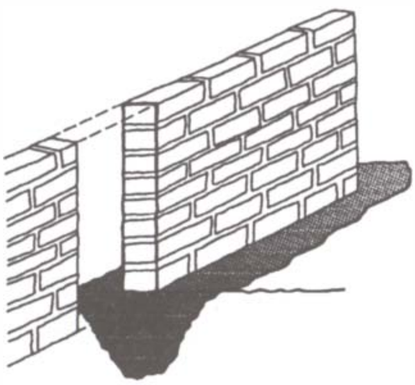


Figure 10. Schematic diagram of pattern of consolidation for walls treated by surface coating & basal infiltration.

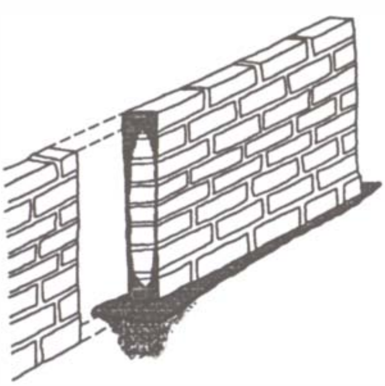


Figure 11. Schematic diagram of pattern of consolidation for walls treated by surface coating and partial infiltration at top and base.

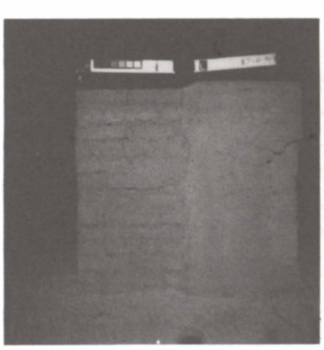


Figure 12. Contact print of one of a pair of stereophotographs taken of test wall #20 (DN3390-treated). Note cracking of outer plaster surface from accelerated (water spray) weathering.

Surface and interior temperatures of the master control wall (#40) are monitored for 24 hours at a time on a seasonal basis using thermocouples and a 16-channel data logger system. This system is shown in Fig. 13. Thermocouples are embedded on the surface and at depths of 2.5 cm and 12.5 cm on the east and west faces of the wall both on the adobe brick and the mud-plaster surfaces.

Moisture monitoring in selected walls (the control wall, geodrain walls, and others such as the basally infiltrated walls) is done using a calibrated resistivity meter and preset pins. Results so far are of doubtful value. Occasionally moisture determinations have been done by coring and use of a calcium carbide meter. Core holes are sealed afterward with silicone rubber plugs.

Protective Structural Experiments

As stated previously the resolutions of the 1980 Ankara conference on mudbrick [7] proposed lines of research on shelters and temporary low-cost protection. However, the design, construction, aesthetics, cost and long-term effects of shelters have not received much attention until recently. In the protection of adobe sites from the weather, shelters have an important role.

There are three important criteria that should be considered in research into shelter design and materials. These, in order of importance, are effectiveness, cost, and visual or aesthetic impact on the scene. Effectiveness should cover all the desirable requirements mentioned above for site protection; cost is obviously important, especially in remote or poor areas, and the aesthetic appeal is relevant where a site is on show to visitors. All shelters will intrude on the landscape to some extent, but a sensitive design will clearly find more acceptance that one at odds with the structure it is protecting. Adobe is especially demanding because of its earth color, rounded and weathered contours and the fact that often it can be overpowered by modern materials such as steel which lends itself to rectilinear design and construction.

A synthetic, knitted shadecloth (or "aerotextile"), originally developed for the horticultural industry, was chosen for evaluation as a shelter material. Fig. 14 shows the structure of the 70% shade density grade. Shelter designs usually try to totally protect easily weathered material like adobe. The basic premise in proposing this open-weave textile for testing was that in many cases a completely water-proof shelter may not be needed, particularly if the adobe site can be treated, as part of the site protection program, with a chemical preservative.

The advantage in testing this aerotextile for shelter use are:

•It breaks the force of rain and will prevent snow from accumulating on the structure.

•It has a wind attenuation factor of 60-70 percent (for the 70 percent density fabric, as shown in Fig. 15). It thus breaks the force of the wind, without any possibility of creating dangerous turbulence which is always a hazard with shelter roofs and walls that are solid. It will also cause wind-borne sand to be deposited if side screens are used.

•The textile is available in a range of "shade densities" of 40, 50, 70, 90 percent light reduction.

•It can be used to ameliorate thermal stress on fragile or heat-susceptible structures (e.g., east-facing walls) when an appropriate shade density is chosen.

•It will inhibit growth of vegetation on sites by cutting down light. In many ruins growth of weeds and robust plants causes great damage through invasive root systems. Thus it will also cut down on the need for expensive maintenance and herbicide treatment.

•It is inexpensive; has a 25-year guarantee in any outdoor situation (the polymer is UV-stabilized polyethylene) and is light in weight and easily transported. It could find application in remote areas and in third-world countries where relatively unskilled labor could be used in construction.

•Being light in weight, open-weave, and tear-proof it does not demand the use of massive (and costly) support structures but can be constructed on light tubular steel and wire framework. Methods of fixing the textile to free-standing frame-works are well established. In addition, conventional shelters of steel, bricks or concrete are normally supported by robust pillars, the installation of which pose a threat to a site both in the excavation of post holes and in the use of heavy machinery for the handling and erection of the structure.

•It allows circulation of air and thus avoids the stagnant microclimates characteristic of totally enclosed protective shelters.

•It is available in a variety of colors, beige, brown, black, green, white --- the beige probably being most suitable for an adobe site.

•If handled sensitively in shelter design it need not intrude unduly on the

Figure 13. Photograph of control wall (#40) with thermocouples hooked up to data logger for exterior surface and internal temperature monitoring.

Figure 14. Structure of aerotextile material with 70% shade density.

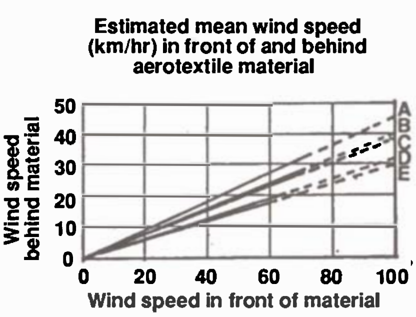


Figure 15. Graph showing effect that different density grades of aerotextile material has on mean wind speed. Curves A, B, C, D, E correspond to density grades of 40%, 40%, 50%, 70%, and 80%, respectively. Solid line represents measured wind speed, dashed line represents predicted wind speed. (Information provided by Technisearch, Melborne, Australia).

historic landscape of the site it is protecting.

There are apparent disadvantages in the use of this material:

• Being open-weave it is not water-proof.
• It is not fire-proof and is easily vandalized.
• It will tend to sag slightly between supports and cause drips at particular points. These will erode holes in adobe.

The main disadvantage of the textile, that of being non-waterproof, can probably be overcome by treatment of the material being protected with a chemical preservative; deep surface impregnation rather than bulk infiltration may be sufficient.

Technology transfer of existing materials - such as aerotextiles and geotextiles (as discussed in the next section) - from the horticultural and civil engineering fields respectively, to applications in adobe site-preservation research, indeed, heritage sites in general, has many clear benefits. The development work has been done and the materials are being marketed internationally and have proven acceptance and durability. Furthermore, they are often available in a range of grades which allows matching with site requirements. Thus, by comparison with steel-roofed constructions, material such as aerotextiles would appear to have great advantages in cost-effectiveness, ease of erection, and aesthetic acceptance with minimal intrusion on the historic site landscape. Two aerotextile shelter designs were used at Fort Selden and are shown in figure 16. These are an A-frame shelter (walls #38 & 39) and a puckered hexagonal ring structure (wall #37).

Ground-Water Control and Water-Proofing Foundations.

The problem of ground-water control has been reviewed thru 1979 by Clifton and Davis [13]. These authors also discuss the possibility of water-proofing foundations and underlying soil and conclude that the approach appears worthy of evaluation in field testing.

In general, ground-water control is best handled by installation of drainage systems. Trials are being carried out at Fort Selden on drains of advanced design. These are less intrusive of soil (and archaeological deposits) around the base of adobe structures than traditional gravel-filled drains (Fig. 17). Stripdrain and Cordrain are such drains. They consist of a non-woven polyolefin geotextile sheath, as a filter to prevent clogging, surrounding a dimpled plastic core (40 mm wide in the case of Stripdrain). This material is superior to conventional slotted agricultural drain-pipe on the following counts:

• It is more efficient as a filter in preventing blocking.
• It is able to intercept water flow in several subsoil layers and enables drainage of high volumes.
• It is tolerant to grade inconsistencies over long lengths.
• It can be installed in narrow trenches with minimal excavation of subsoil.
• It is stiff vertically and can bridge small variations in the trench base.
• It is flexible and can be bent around corners.

Reburial

Many authorities consider reburial of an excavated site - adobe as well as other categories of archaeological sites - as the only responsible measure when protection and preservation are not possible [14]. Adobe sites, in particular, deteriorate rapidly on exposure as previously stated [14]. Yet little work has been done on the effectiveness or otherwise of reburial as a preservation method. Soil disturbance on excavation increases permeability, and if the excavation material is used as backfill the percolation of water and access of air is increased. Thus, reburial may, in some instances, cause unwitting accelerated deterioration.

A common practice in reburial is to use a layer of clean sand as a marker in the event of future re-excavation. In remote areas sand is not always available and transport costs may be high. Sand is ineffective in covering and delineating vertical surfaces that are being reburied. These considerations have prompted consideration of the need for assessment of geotextiles as a reburial shroud for adobe (and other) structures. This fabric is available in different weights and is used as the external sheath in the geodrain systems already discussed. The fabric is permeable and will not create wet, anaerobic conditions around structures that plastic sheeting - which has been used on some sites - may cause. It will conform to the profile of a structure and provide physical protection on both burial and re-excavation.

Two walls (#43, 44) have been used for this experiment, in which half the

Figure 16. Photograph showing adobe test walls (#38, 39) protected by A-frame, aerotextile-covered shelters, and (#37) by hexagonal shaped 'puckered' shelter with aerotextile roof.

Figure 17. a) Close up ot geodrain showing black plastic core and white geotextile fabric. Manufactured under the name Cordrain, by Nylex Corp., Australia. b) Photograph showing geodrains in place and being buried by author.

wall was built below grade (see Fig. 18). The experimental wall was draped with Mirafi 140 NS geotextile and then buried until only the top of the wall showed. The control wall was was not draped but was similarly buried. Both walls have been water sprayed.

Structure Reinforcement

Damaged adobe sites may result from weathering or seismic activity. The effectiveness of synthetic internal reinforcing bars ('geobars') on test walls at Fort Selden is being assessed. The bar is a rigid, fiberglass rebar 12.5 mm in diameter, externally ribbed. It is non-rotting and non-corroding. Test wall configurations similar to that shown in Fig. 19 are being tested. Two methods of inserting the rods have been used. In both a 13 mm pilot hole is first drilled into the adobe wall. This is then filled with water and the resulting mud is extruded using a 50 mm auger bit (with extensions as necessary). The geobar is inserted and in one case the hole is filled with mud, in the other polyester resin was poured to fill the hole, thus giving a 50 mm diameter rigid rod. Two walls (#41, 42) were reinforced with the geobars; however wall #42 has collapsed leaving one geobar-reinforced wall for evaluation.

Conclusion

The Fort Selden field experiment was designed and set up as a large-scale outdoor laboratory experiment to assess certain treatments as a preliminary to real-site implementation. In order to achieve results within a reasonable time frame an accelerated weathering spray system was used. Results of two and a half years of combined natural and artificial weathering are appearing. It is expected that final comparative evaluation of the various measures implemented on the test walls will be possible by the end of 1991.

Acknowledgements

The author acknowledges with gratitude the contributions of his co-workers at the GCI, Dr. Charles Selwitz, Richard Coffman, & Dr. Frank Preusser. Special recognition is due James Druzik (GCI) and Thomas Caperton (MNMSM) who helped initiate the project. Michael Taylor (NPS formerly with MNMSM) who worked on site in May 1988 with the author and has been an active collaborator throughout. Frances Gale of Pro So Co also worked on site applying the Conservare H & OH consolidants generously donated by her company. Mobay Corporation has unstintingly supported the project through donations of diisocyanate prepolymers, and Mike Jakstis of Mobay has provided much useful guidance. Paul G. McHenry Jr. (designer of the test site) and his sons Bruce (construction) and Jamie (photomonitoring) have likewise been integral components. The Fort Selden staff, especially Jose Guzman and Elva Melendez have provided help whenever it has been needed. Thomas Moon developed the photodocumentation protocol.

Note: Technical specifications and plans for the construction of the test walls and the spray system are available from P. G. McHenry, Jr., 834 Griegos Rd. NW, Albuquerque, N.M. 87107.

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Figure 18. Photographs showing geotextile-covered and uncovered walls (#43, 44, respectively) a) prior to burial, and b) after burial.

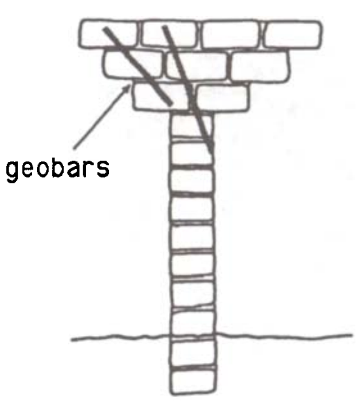

Figure 19. Schematic diagram of test walls containing structural reinforcing elements.

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ABSTRACT

Treatment of adobe with hexamethylene diisocyanate-derived polymers and silanes increases compressive strength and consolidation, and enhances resistance to disaggregation by water. To better understand the modifications of the properties of natural adobe, the effects of treating individual components of adobe (clay, silt, and sand) with chemical consolidants were examined. Several different clays (Na- and Ca-montmorillonites and kaolin) were treated with isocyanate and silanes as were mixtures of clay and quartz sand, quartz sand alone, and adobe. X-ray diffraction (XRD) analysis, scanning electron microscopy (SEM), grain size analysis, water sorption analysis, and compression testing were used to evaluate the effects of the chemicals on consolidation, modification of compressive strength, and resistance to disaggregation by water in clays, sand-clay mixtures, and adobe. The results of these evaluations indicate that the clay type plays a significant role in the properties of isocyanate- and silane-treated adobe.

KEYWORDS

Adobe, clays, compressive strength, consolidation, isocyanates, silanes, water repellency, x-ray diffraction analysis

TABLE 1: Evaluation of Compression Tests on Sand:Clay Plugs

Clay type (Letter refers to figures 1 and 2)	Mean Stress & (Std. Deviation) at Failure) in MPa	Mean Modulus & (Standard Deviation) in MPa
KGa-2 (A)	0.099 (0.027)	11.124 (4.305)
KGa-2 (B)	2.695 (0.380)	116.563 (35.335)
KGa-2 (C)	3.220 (0.918)	147.491 (64.594)
KGa-2 (D)	2.196 (0.180)	124.931 (42.099)
KGa-2 (E)	1.827 (0.200)	92.169 (15.699)
SAz-1 (A)	0.131 (0.037)	10.776 (5.418)
SAz-1 (B)	1.104 (0.212)	74.167 (19.838)
SAz-1 (C)	2.878 (0.308)	181.605 (68.047)
SAz-1 (D)	1.400 (0.226)	99.407 (27.434)
SAz-1 (E)	0.931 (0.140)	87.423 (25.340)
SWy-1 (A)	0.015 (0.003)	1.648 (0.819)
SWy-1 (B)	0.099 (0.041)	13.748 (8.042)
SWy-1 (C)	0.297 (0.297)	20.353 (3.791)
SWy-1 (D)	0.458 (0.059)	45.501 (10.837)
SWy-1 (E)	0.365 (0.027)	27.221 (5.356)

THE GETTY ADOBE RESEARCH PROJECT AT FORT SELDEN II. A Study of the Interaction of Chemical Consolidants with Adobe and Adobe Constituents

Richard Coffman, Charles Selwitz and Neville Agnew*
Getty Conservation Institute
4503 Glencoe Ave. Marina Del Rey, CA 90292
(*) Author to whom correspondence should be addressed

Background and Introduction

This study was initiated by our interest in chemical and physical methods of preservation of historic and archaeological earthen structures, specifically adobe. Many cultural structures are constructed of adobe, which easily loses structural integrity when wetted. Preliminary laboratory work dealt with the interaction of various chemical consolidants with adobe [1]. After isocyanates and silane esters were shown to be successful in consolidating adobe, work focused on the interaction of those consolidants with pure clays, since these are the components most affected by wetting. This phase of research involved studying the effects of specific chemical consolidants (isocyanate [hexamethylene diisocyanate (HDI)-derived polymers] and silanes) on pure clays. The results showed that treatment of clays with isocyanates and silanes markedly increased the clay's water repellency but did not consolidate the clay [2]. Although chemical treatment inhibits water uptake and partially binds the clay particles together, it does not prevent failure of individual clay particles when subjected to deformational stress.

Materials and Methodology

After failing to consolidate pure clays by chemical treatment the next step was to make an *artificial* adobe by combining three parts quartz sand (with a uniform particle size of 0.5 mm) with one part clay. This mixture resembles a "typical" adobe and, when wetted, resulted in a workable, coherent, artificial adobe material. Three sets of artificial adobe were made using three different clays obtained from the Clay Minerals Society, Source Clay Minerals Repository at the Department of Geology, University of Missouri, Columbia, Missouri. The clays are:

A) SWy-1, Na-montmorillonite, Crook County, Wyoming ;
B) SAz-1, Ca-montmorillonite, Apache County, Arizona ;
C) KGa-2, Kaolin, Warren County, Georgia.

Test plugs were manufactured by combining the sand:clay mixture with water to form a viscous slurry that was poured into small (22 mm x 40 mm) cylindrical molds. Plugs of adobe were manufactured in a similar fashion by disaggregating adobe blocks obtained from Ft. Selden, New Mexico, then reconstituting the material with water into a viscous slurry and recasting it in the cylindrical molds. Pure quartz plugs were also made by grinding the quartz sand to obtain a variable size range distribution. This was then sieved and recombined in the following proportions: <45 μm = 5%, 45 μm to 75 μm = 5%, 75 μm to 180 μm = 10%, and >180 μm = 80%. This material was then mixed with water and poured into the molds. After the molds were filled they were placed in an oven set at 50° C to dry. The resulting sand:clay, adobe, and quartz plugs were removed from the molds and given time to equilibrate with the ambient laboratory conditions (22° C, 40-50% RH).

After equilibration to a constant weight, the plugs were treated with either an isocyanate or a silane. The isocyanate (an HDI-derived prepolymer) is manufactured commercially by Mobay Corporation under the name Desmodur N-3390™ (DN-3390™) and is produced as a 90% concentration in an aromatic hydrocarbon and *n*-butyl acetate mixed solvent. Treatment required diluting the DN-3390™ with a 2:1 xylene:methyl ethyl ketone (MEK) solvent mixture to form solutions with concentrations of 5% to 25%. The silanes were tetraethylorthosilicate (TEOS, $(C_2H_5O)_4Si$), with and without methyltriethoxysilane (MTEOS, $CH_3(C_2H_5O)_3Si$), which is added to achieve water repellency. According to the manufacturer these contain 75% active solids in an acetone-MEK solvent and are produced by ProSoCo Inc. under the name Conservare Stone Strengthener H™ (SS-H, with MTEOS) and Conservare Stone Strengthener OH™ (SS-OH, without MTEOS). The silanes do not require additional mixing with solvents. The isocyanate polymerizes in situ by reacting with water inherently present in the clays to form urea linkages with release of carbon dioxide. The silanes polymerize by hydrolysis with atmospheric and in situ moisture, which creates a network Si-O polymer that ties into and

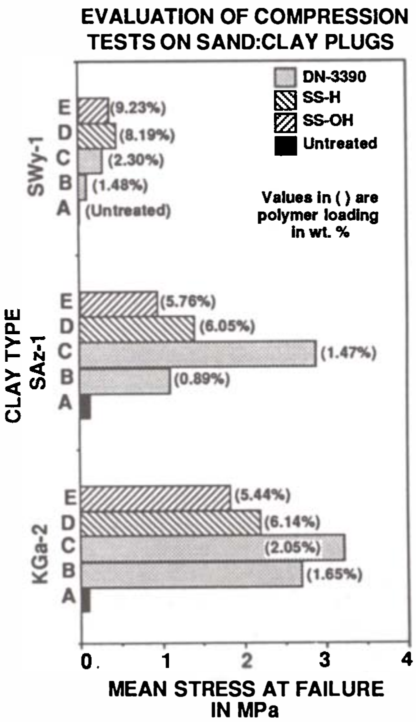

Figure 1. Results of compression tests showing mean stress at failure for untreated and isocyanate- or silane-treated sand:clay plugs.

TABLE II : Evaluation of Compression Tests on Adobe, and Quartz Plugs

Plug Type (Letter refers to figures 3 and 4)	Mean Stress & (Std. Deviation at Failure) in MPa	Mean Modulus & (Standard Deviation) in MPa
Adobe (A)	0.976 (0.170)	93.199 (46.338)
Adobe (B)	3.218 (0.668)	281.166 (118.678)
Adobe (C)	4.167 (0.877)	274.915 (53 243)
Adobe (D)	4.679 (0.667)	338.661 (50 280)
Adobe (E)	8.070 (2.236)	399.022 (97.507)
Adobe (F)	12 082 (3.342)	511.326 (78 337)
Adobe (G)	5.862 (0.884)	471.561 (15.782)
Adobe (H)	5.667 (0.723)	463.604 (88.198)
Adobe (I)	1.466 (0 431)	89.511 (14.219)
Adobe (J)	2.306 (0 318)	173.542 (41.451)
Adobe (K)	2.558 (0.595)	199.973 (19.150)
Adobe (L)	2.482 (0.474)	187.213 (18.090)
Quartz (A)	0.051 (0.015)	9 029 (6.807)
Quartz (B)	3.469 (1.401)	246.830 (156 099)
Quartz (C)	1.700 (0 391)	110.561 (58.729)
Quartz (D)	0.517 (0.134)	45.776 (15.154)

crosslinks the substrate being treated.

Each plug was treated with 3 to 6 ml of solution, then covered to inhibit solvent evaporation and permit thorough penetration of the consolidant into the plugs. After treatment and curing, the plugs were tested for compressive strength, resistance to disaggregation in water, and porosity. A set of untreated plugs was also tested to develop baseline values. Compressive strength determinations were obtained using an Instron Universal Testing Instrument, model 4201, with a 500 Kg capacity compression load cell. The samples were tested using a crosshead speed of 5 mm/minute with a sampling rate of 10 points per second. Water repellency and resistance to disaggregation by water was determined by submerging the sand:clay, and adobe plugs in water for approximately 48 hours. The plugs were removed from the water and weighed, placed in an oven at 50° C for a minimum of 48 hours, reweighed, and placed back into water. The plugs went through ten wet-dry cycles or until they began disaggregating. Mercury injection porosimetry was used for porosity measurements on small pieces (approximately one to two cubic centimeters) of treated and untreated adobe samples.

The relationship of isocyanate solution concentration and number of applications with depth of penetration and consolidation was also examined. Three isocyanate solutions (DN-3390™ + MEK) were mixed in concentrations of 25%, 12.5%, and 6.25%. Each solution was brushed onto a 16 cm x 10 cm area of an adobe block, from Ft. Selden, New Mexico, in 1, 2, 4, 8, and 16 coat applications. The treated blocks were wrapped in plastic, cured for two weeks, then uncovered and cut in half. One half was archived for future study while the other half was placed in a large container of water to wash away the unconsolidated portion.

Experimental Results

The results of compression tests for the sand:clay (*artificial* adobe) plugs are shown in table I and figure 1. Untreated *artificial* adobe plugs failed at low stress levels (0.02 MPa to 0.13 MPa) in the following order of decreasing strength, SAz-1 > KGa-2 >> SWy-1. Chemical treatment markedly increased the compressive strength of the plugs and altered the strength relationships to the following, KGa-2 > SAz-1 >> SWy-1. Both isocyanate- and silane-treated plugs exhibited between a six- to thirty-two-fold increase in compressive strength, based on mean stress values. Plugs made with clay SAz-1 exhibited a twenty-two-fold increase in compressive strength when treated with isocyanate, and a ten-fold increase when treated with the silanes. Treatment with the silanes resulted in a thirty-fold increase in compressive strength for those plugs made with clay SWy-1, whereas isocyanate treatment only resulted in a twenty-fold increase. Both isocyanate and silanes caused comparable increases in the compressive strength of plugs made with clay KGa-2.

Table II and figure 2 show isocyanate treatment of the adobe plugs resulted in a three- to twelve-fold increase in compressive strength over untreated adobe. Treatment with either silane resulted in a six-fold increase in the compressive strength relative to untreated adobe. For most of the adobe samples tested the silane-treated plugs exhibited a greater compressive strength than the isocyanate-treated plugs. However the silane loading of 4.3%-4.5% was greater than the loading on any of the isocyanate-treated samples (see figure 2). In spite of this, an isocyanate loading of 3.2% resulted in a greater increase in compressive strength than was observed for the silane-treated samples. This, together with the results in table I and figure 1, indicate that at equivalent loadings the isocyanates would be superior to the silanes for enhancing the compressive strength of *artificial* and natural adobe.

Table II and figure 2 also show that wet, isocyanate-treated adobe has a compressive strength similar to dry, untreated adobe. Isocyanate-treated adobe subjected to multiple wet-dry cycles is weaker than a similarly treated adobe not exposed to wet-dry cycling, although it still remains stronger than the initial untreated adobe. The compressive strength of untreated and treated pure quartz plugs is also presented in table II and figure 2. Isocyanate treatment increased the compressive strength of the quartz plugs eighty-fold, whereas silane treatment resulted in a ten- and thirty-three-fold increase (SS-OH and SS-H, respectively).

Figure 3 demonstrates how chemically treated sand:clay and adobe plugs withstood disaggregation in water relative to untreated plugs, and to each other. Untreated adobe and plugs made with quartz sand and clay SAz-1 or KGa-2 (Ca-montmorillonite

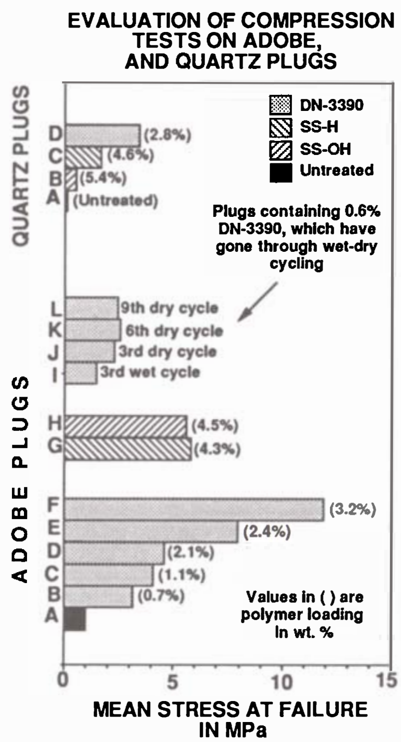

Figure 2. Results of compression tests showing mean stress at failure for untreated and isocyanate- or silane-treated adobe, and quartz plugs.

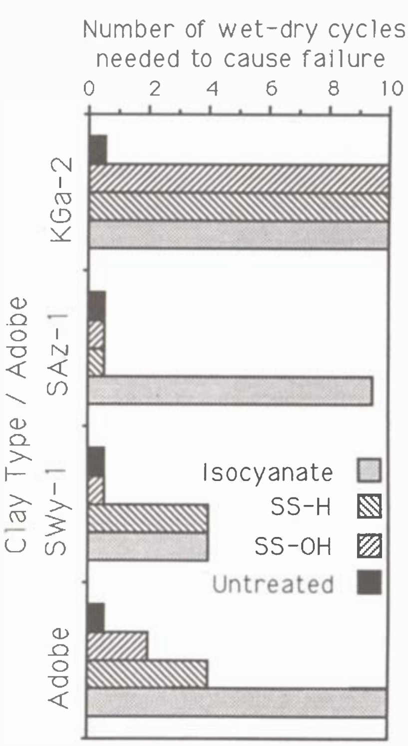

Figure 3. Graph showing relationship between clay type or adobe, type of chemical consolidant, and number of wet-dry cycles needed to initiate disaggregation.

and kaolin, respectively) disintegrated as soon as they came in contact with water. The plug made with clay SWy-1 (Na-montmorillonite) did not disaggregate; instead it absorbed water and swelled into a gelatinous mass. Figure 3 also shows that plugs made with kaolin were very resistant to disaggregation by water once they had been chemically treated, regardless of the type of consolidant used. Isocyanate treatment provided excellent resistance to deterioration by water for the adobe plug and only slightly lesser protection for the sand:clay plug made with clay SAz-1 which deteriorated during the tenth wet-dry cycle. However, the isocyanate and SS-H had limited success in preventing disaggregation of the plugs made with clay SWy-1 which began disaggregating after four wet-dry cycles. In contrast, SS-OH provided very little protection against deterioration by water for the sand:clay plug made with clay SWy-1. Neither of the two silanes provided protection for plugs made with clay SAz-1. However, both silanes were partially successful in protecting the adobe plug against rapid deterioration by water, with SS-H outperforming SS-OH.

The evaluation of polymer concentration and number of applications with depth of penetration revealed that the deepest penetration was attained by applying sixteen coats of the most dilute (6.25%) solution. Figure 4 shows the difference in depth of penetration between natural adobe blocks treated with the 6.25% solution and the 25% solution. Sixteen coats of the 6.25% solution consolidated approximately 920 cc of adobe, while similar applications using concentrations of 12.5% and 25% resulted in consolidation of 680 cc and 470 cc of adobe, respectively.

Porosity measurements, using mercury injection porosimetry, were made on a number of treated and untreated adobe plugs. The porosity of untreated samples varied, ranging from 13% to 25%. Porosity measurements of the treated plugs also fall within this range. Because of this, no difference in porosity was distinguished between untreated and treated samples. However the small volume of the test specimens is probably insufficient to ensure statistical homogeneity, and air voids could easily account for the wide range of values

Discussion

Tables I and II and figures 1 and 2, show that the compressive strength of adobe is far greater than that of sand:clay plugs. This is believed to be a function of the grain size distribution and composition. Natural adobe is made of particles with a wide grain size distribution ranging from pebble- or granule-size down to clay-size. Therefore the particles are closely packed with abundant grain-to-grain contacts, minimal pore space, and good cohesion. In addition, much of the adobe material is composed of hard, resistant particles such as quartz or feldspar. When this material is treated with isocyanate or silane esters, a particle-to-particle bond is formed by the polymer which glues the mass together and enhances the cohesiveness of this naturally strong, coherent material. In contrast the sand:clay plugs contain material with two distinct grain sizes: sand-size and clay-size. The sand-size quartz particles are very strong and coherent particles that provide most of the structural strength of the plugs. However, the clay particles, which are inherently weaker, act primarily as binder or filler between the quartz grains. Compared with adobe, this type of mixture has fewer grain-to-grain contacts, more pore space, and is an inherently weaker material that can fail easily. The difference between adobe and sand:clay plugs is shown in figure 5. When sand:clay plugs are treated with isocyanate or silane esters the polymer bonds to the quartz grains and to the outer surfaces of the clay particles. However polymer cannot penetrate between individual clay layers and plug failure occurs by delamination of the clay layers when subjected to deformational stress.

The effect of grain size and composition is further demonstrated by the enhanced compressive strength of consolidated pure quartz plugs, as shown in figure 2 and table II. The initial strength of the plugs, which is similar to that of sand-clay plugs, is due to the quartz grains and a weak cohesion between the variable-sized particles. However, the compressive strength of treated pure quartz plugs more closely approximates the compressive strength of treated adobe plugs. This is probably because the initial strength of the quartz particles is enhanced by the supporting silica-polymer network.

This research shows that the treatment of sand:clay and adobe plugs with isocyanate and/or silanes results in consolidation and enhances the ability of the plugs to resist rapid deterioration by

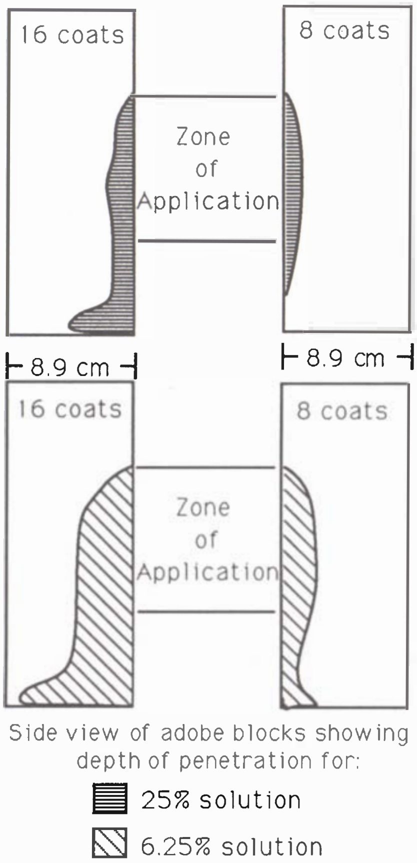

Figure 4. Cross-sectional views of adobe blocks showing depth of consolidation for a 6.25% solution (diagonal pattern) and a 25% solution (horizontal pattern) of isocyanate using 8 coats and 16 coats.

Figure 5. Schematic representation of sand:clay and adobe plugs showing differences in grain-to-grain contacts, packing and porosity.

exposure to water. In sand:clay plugs, the degree of resistance to deterioration appears to be controlled by the clay mineralogy and type of consolidant used. Isocyanate attaches itself to polar sites that cover the basal surfaces of montmorillonites [3,4]. Polar sites are also present on the surface of quartz and kaolin particles in the form of a water film. This provides numerous attachment sites that enable the isocyanate to form strong bonds between clay and quartz particles. Silanes attach by ligand exchange with OH molecules that occur on the basal surface of kaolin particles and on the edges of montmorillonites [4]. Although ligand bonding of the silanes is stronger than the van der Waals and ion-dipole forces of the isocyanate bonding, the sheer number of polar attachment sites appears to allow the isocyanate to develop a stronger overall bonding than the silanes [4]. Because silanes do not develop a strong enough bond bridging quartz and montmorillonite particles, plugs made with those materials are easily deteriorated by the physical movement of clay particles as they hydrate and dehydrate. This explains why silanes did not perform well on montmorillonite-bearing plugs, but did perform well on kaolin-bearing plugs. In contrast, isocyanate develops a bond strong enough to prevent or diminish the deterioration of the sand:clay plugs by the hydration-dehydration action. This permits the isocyanate to perform better at protecting the plugs against deterioration by water.

The lack of difference in porosity of untreated and treated samples is probably because neither isocyanate nor the silanes are heavily loaded into the samples. These polymers form thin films over the surfaces of the clay and sand particles instead of filling the pore spaces with polymer, which is commonly the case with some chemical consolidants. If sufficient polymer was applied, a porosity distinction would be recognized because the pores would become clogged. However, this could be as or more destructive to adobe than leaving it untreated. Isocyanate inhibits deterioration by water but allows water to pass through the adobe, thereby preventing water from becoming trapped in the adobe and causing internal damage. This also explains why the isocyanate works so well on adobe.

Increased penetration and consolidation as a function of solution concentration and number of applications is also related to the above. At high concentrations the polymer solution becomes too viscous to permit adequate penetration into the adobe. By applying multiple coats of dilute solutions the polymer can penetrate deeper into the adobe substrate. If more concentrated solutions were used, the polymer could become concentrated at or near the surface. This would result in the surface becoming sealed against additional treatment and could also trap water introduced through capillary rise from the ground. This, in turn, could cause accelerated deterioration of the interior of the adobe and lead to premature collapse of the adobe wall or structure.

Summary

Isocyanate and silanes have been shown to enhance adobe's resistance to disaggregation by water, as well as increasing compressive strength. However, the adobe's composition and grain size distribution are important factors to consider when deciding which consolidant to use. It appears that adobes containing kaolinite are effectively consolidated with silanes, whereas those adobes containing montmorillonite, and/or mixed-layer clays, respond better to isocyanate.

Successful treatment is also related to the polymer solution concentration, and depth of penetration. High polymer concentrations, or inadequate penetration, could result in the development of a polymer-rich outer skin. This could cause accelerated deterioration of the adobe by separation of the treated, outer layer from the untreated inner core. This type of phenomenon has been observed on several isocyanate-treated test walls at Ft. Selden, New Mexico, where the consolidated outer surface has detached from the rest of the wall. This is believed to be a result of the difference in the coefficients of expansion, upon wetting, between the untreated and treated portions of the adobe. This type of behavior was not observed for silane-treated test walls, possibly because the silanes permit more expansion of the adobe than does the isocyanate. This indicates that to successfully treat adobe, or earthen structures, it is necessary to insure deep penetration and prevent development of a rigid, non-expandable outer skin.

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ABSTRACT

Silane esters and polyisocyanates were applied to adobe test walls in various concentrations and solvent mixtures by spraying, brushing, multiple coating, and bulk infiltration. After one month's curing they were subjected to an accelerated weathering regime of two water spray cycles per day for two months, and subsequently they were allowed to weather naturally. The walls were evaluated visually according to a numerical rating system. Isocyanates provide very effective stabilization by a combination of brushing and bulk infiltration, but there must be a suitable network of accession holes for deep delivery of polymer, and the amount of consolidant must be optimized. The silane ester formulation, Stone Strengthener H, is easier to apply and gives good consolidation without discoloration; but the treated walls show erosion not seen with isocyanate treated walls. Old, aged adobe may require a rehydration before either consolidation can be done.

KEYWORDS

Adobe, brushing, bulk infiltration, consolidation, dilution effects, isocyanates, mud brick, rehydration, silanes.

THE GETTY ADOBE RESEARCH PROJECT AT FORT SELDEN III: AN EVALUATION OF THE APPLICATION OF CHEMICAL CONSOLIDANTS TO TEST WALLS

Charles Selwitz*, Richard Coffman, and Neville Agnew.
The Getty Conservation Institute
4503 Glencoe Avenue.
Marina del Rey, California 90292
USA

Introduction

This study is concerned with the evaluation of chemical consolidants used to stabilize old, weathered adobe of historical interest. Adobe test walls were treated with different chemicals by a variety of application strategies and after curing were subjected to a daily schedule of direct water spraying for two months. This is very severe treatment for adobe. It provided highly accelerated weathering and enabled us to evaluate materials and procedures in a relatively short time period.

Test Wall Evaluation

In the winter of 1988, twenty-five adobe walls were constructed at Fort Selden, New Mexico. Bricks, 30 centimeters (12 inches) square and 10 centimeters (4 inches) thick, were made from local clay-bearing soil which contained 91% sand and 8% silt and clay. The clay consisted of roughly equal amounts of kaolinite, illite and smectite. These bricks were made into east-west running walls 150 centimeters (five feet) long and tall and 30 centimeters thick, with a mortar of the same composition. The walls stood on two layers of adobe brick below grade. On each side a surface "plaster" coating made from the same mortar was trowelled over the right half of the wall, i.e., an area 150 centimeters (5 feet) in height and 75 centimeters (2.5 feet) in width. The walls were allowed to weather naturally for several months and in May were treated with a number of consolidants. After treatment they were wrapped in polyethylene sheeting and allowed to cure for one month and then subjected to water spraying for two months. On each side a nozzle four feet from the wall delivered 22 liters of water over a 15 minute period twice a day as a dispersed spray. In addition, these outdoor walls experienced an unusually rainy New Mexico summer. Photographs of northern and southern exposures of some of the walls treated with DN 3390 or silane esters are provided in the left columns. They can be matched with descriptions of treatments in Tables 3 and 4.

Chemicals and Application Procedures

Most of the studies focused on two types of consolidants: polyisocyanates and silane esters. Most of the isocyanate studies were done with DN3390, is an isocyanurate trimer of hexamethylene diisocyanate. It is supplied as a 90% concentration in a mixture of n - butyl acetate and aromatic hydrocarbons. Stone Strengthener H (SSH) is a mixture of methyl triethoxysilane and tetraethoxysilane (ethyl silicate) in a ketone solvent, and it contains dibutyltin dilaurate as catalyst. The active component in Stone Strengthener OH (SSOH) is ethyl silicate. The isocyanates were given to us by the Mobay Chemical Company while SSH and SSOH were donated by ProSoCo and applied to certain test walls by their personnel.

Both types of chemicals seem uniquely suited for adobe because they cure by mechanisms that involve water inherently available in clay. The silane esters hydrolyze to a silicate network that can crosslink appropriate siliceous functionality in the adobe while polyisocyanates readily link up and consolidate in the presence of water through polyurea formation.

Application was generally done by brushing, but spraying or bulk infiltration were used in a number of cases. Bulk infiltration is a procedure in which holes are drilled into the adobe wall and funnels are used to supply the consolidant; This insures that impregnation at a substantial depth is obtained. Where bulk infiltration is used, surface application of consolidant by brushing is also employed.

Generally, no two walls were treated by exactly the same procedure. Treatment of wall 18 with DN3390 by a combination of bulk infiltration and brushing gave the best stabilization, and its description may be illustrative. Four evenly spaced 19 millimeter diameter holes were drilled across the top to a depth of 30 centimeters. Similarly four holes, one meter above the base, evenly spaced horizontally on the south side and one hole at each end, were drilled downward at 45° angles. Also a series of holes was made at 15 centimeter intervals around the base. A solution of 9 liters of DN3390 in 27 liters of methyl ethyl ketone and 27 liters of toluene was prepared. Funnels were used to deliver 12 liters of this solution through the top holes, 8 liters through the side holes and 28 liters to the base holes. Twelve liters were brushed on the surface in five coats, and an additional 3 liters was applied around the base. The treated adobe was then tightly wrapped in polyethylene film for four weeks.

* To whom correspondence should be addressed

Evaluation of the effectiveness of consolidation was done as soon as the spraying was concluded, then three months later, and finally after an additional twelve months. Subjective quality ratings, ranging from zero for a collapsed wall to ten for an unblemished wall, were made separately for brick surfaces (Table 1) and adobe mud coated surfaces which are described as "plaster covers" (Table 2). Separate rating systems were needed because walls with plaster coats tended to deteriorate by having the cover pull away from the surface while the brick surfaces cracked and eroded. At the conclusion of spraying, one of us (CS), who was not involved in the treatment, created the rating system by a general, overall survey of the test walls. The evaluation was carried out by an examiner (CS) who did not know the procedures that had been used on the particular wall being rated. The Getty Conservation Institute's overall program at Fort Selden looked at a number of stabilization approaches, including the use of inserted rebars, protective geotextiles and reburial procedures, but this presentation will consider only the evaluation and comparison of chemicals used for consolidation.

TABLE 1

RATING ON ADOBE WALL

RATING VALUE	DESCRIPTION
10	No sign of deterioration of any kind
9	Single, small crack
8	Several minimal cracks
7	Wall looks strong, intact but many cracks
6	Poorer than 7
5	Extensive cracking
4	Extensive cracking, some erosion
3	Extensive cracking, heavier erosion
2	Material fallen from wall
1	Extensive amount of fall-off
0	Collapse

TABLE 2

RATINGS ON PLASTER COVER

RATING VALUE	DESCRIPTION
10	No sign of deterioration
9	A few cracks, no sign of separation
8	More cracks - a suggestion of separation
7	Partial separation, not visible, but discernable by tapping - modest cracking
6	Extensive pulling away discernable by tapping, not visible, heavier cracking
5	Partial separation is visible
4	Total separation is visible
3	Plaster is ready to Fall off
2	Parts of plaster cover has fallen off
1	The plaster cover has completely fallen off
0	The wall has collapsed

Results with the Isocyanate, DN3390

The results of this study are summarized in Table 3, which is concerned with the isocyanate DN3390, in Table 4, which examines the consolidation of adobe with silane esters, and in Table 5 which compares different types of isocyanates. Results which describe the effectiveness of DN3390 are developed by comparing the ratings of five treated walls (16 through 20) with an untreated wall. The untreated wall, wall 21, had all but washed away by the time spraying had ended, but the treated walls were relatively intact and standing (Table 3). There was considerable variation in the quality of these consolidated structures. Wall 18 was essentially unchanged while wall 19 was badly cracked and eroded. The critical difference between the walls was the use of bulk infiltration which provided very deep penetration. Wall 18 had access holes drilled across the top, in the midsection and around the base and the largest amount of consolidant, 9 liters, was used. The second best wall, wall 20, had infiltration holes only across the top and along the base and employed much less consolidant, 3 liters. This wall received a rating of 28 (out of a possible maximum of 40) versus a value of 37 for wall 18. The plaster layer on the south side of wall 20 had pulled away, not at the top but in the lower part of the wall. These findings suggest that good results can be obtained with less consolidant but that broader placement of infiltration holes is important. In the walls where only brushing was used, and where there was no direct deep placement of consolidant, results were poorer. There was more cracking and breaking off of adobe. Generally, the peeling away of the plaster coat was a more critical and noticeable problem than the deterioration of the brick surface.

Studies were made on the depth of penetration achieved by brushing. Samples of adobe powder were obtained at measured distances from the surface by drilling. In laboratory studies, these were brought to constant weight at 150°C to drive off water and then heated at 600°C in air to burn off the polymer. Weight and concentration of polymer were then determined by difference. A sample result for wall 17 is shown in Figure 1. This wall had 4 liters of DN3390 brushed over the top and sides, which is a relatively large amount. Typically polymer concentrations between one and two percent are found within the outer inch of adobe. Very much less occurs between one to two inches from the surface, and essentially no polymer can be found any deeper. We did notice in other studies that when large amounts of solution are used on upper surfaces, polymer is found deeper into the brick at lower levels of the wall.

Wall 21 North

TABLE 3

COMPARISON OF THE CONSOLIDATION OF ADOBE WALLS WITH DN3390 USING DIFFERENT AMOUNTS OF ISOCYANATE AND DIFFERENT APPLICATION STRATEGIES[A]

WALL	AMOUNT OF DN3390			DELIVERED IN LITERS			SUMMARY OF RATINGS				
				INTERNAL BULK DELIVERY[B]			NORTH		SOUTH		
	TOTAL	Brushed on Top & Sides	Applied To Base	TOP	MIDSECTION	BASE	BRICK	PLASTER	BRICK	PLASTER	TOTAL RATING
16	3.0	2.0	1.0	0	0	0	5	5	7	5	22
17[C]	4.5	4.0	0.5	0	0	0	7	4	8	4	23
18	9.0	1.7	0.5	1.7	1.1	4.0	10	9	9	9	37
19	4.5	1.5	0	0	0	3.0	5	4	4	2	15
20	3.0	1.0	0.5	0.6	0	0.9	9	4	7	8	28
21	none	0	0	0	0	0	1	1	1	1	4

A. All runs (except 17) at 12.8% DN 3390 in equal volumes of methyl ethyl ketone and mixed xylenes. No catalyst was used.

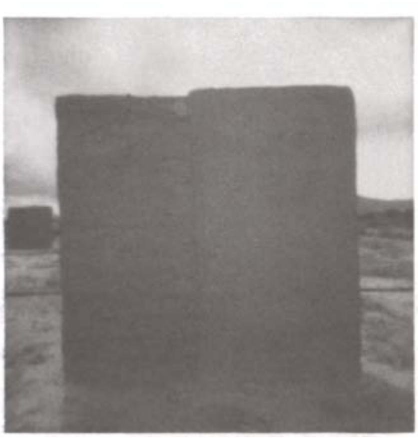
B. Material delivered into deeply drilled holes by using funnels.

C. Approximately one-third of the DN 3390 was at 6.4% concentration.

Wall 21 South

Wall 19 North

Wall 19 South

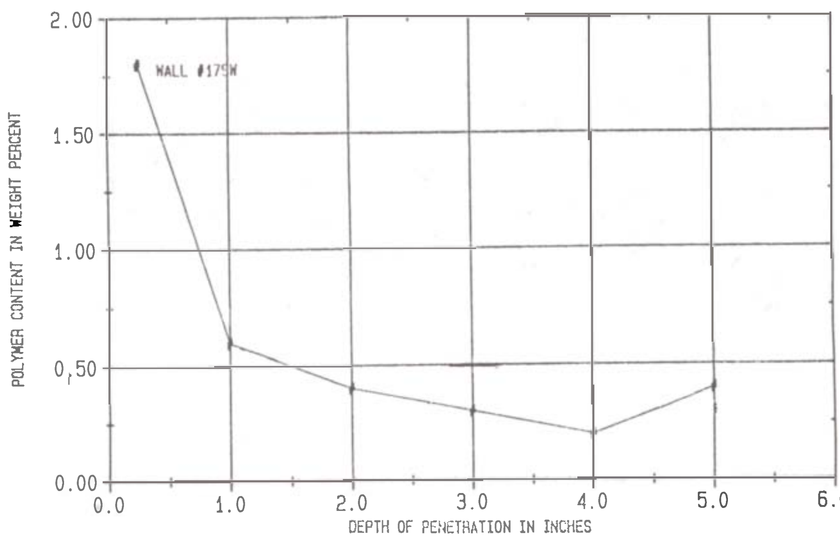


Wall 18 North

FIGURE 1

POLYMER CONTENT DETERMINATIONS

WT. % DN3390 -vs- DEPTH OF PENETRATION



POLYMER CONTENT FOR WALLS # 17SW

The runs in Table 3 show that, in general, better results are obtained with brushing when more consolidant is used. Our results also indicate that it is better practice to apply more solution at the upper sides and top rather than to drench the base. This is confirmed by comparing walls 17 and 19. In each case 4.5 liters of DN3390 were delivered. In wall 17, 4.0 liters were put onto the top and sides and 0.5 liters to the base. For wall 19, 3.0 liters were put into the base by bulk infiltration, and only 1.5 liters were used on upper surfaces. Wall 19 showed the poorest consolidation of any of the walls treated with DN3390. Overall the studies show that the isocyanate can provide effective consolidation of adobe, but there must be a suitable network of accession holes for bulk infiltration of polymer and the amount of consolidant must be optimized.

Results with Silane Esters

Eight test walls were used to examine the ability of silane esters to stabilize adobe. Table 4 outlines the results where SSH was used on five walls, SSOH on two walls, and SSH in a different solvent, mineral spirits, on a single wall. All of these systems used 0.5% dibutyltin dilaurate as catalyst. In six of the series, application was by brushing or by a combination of brushing and bulk infiltration. This was done in a manner to attempt to replicate the application procedures used with DN3390. In two cases the silane esters were delivered to the wall by spraying.

TABLE 4

COMPARISON OF THE CONSOLIDATION OF ADOBE WALLS WITH SILANE ESTERS USING DIFFERENT AMOUNTS OF CONSOLIDANT AND DIFFERENT APPLICATION STRATEGIES

WALL	SILANE[A] ESTER	METHOD OF DELIVERY	TOTAL	AMOUNT DELIVERED IN LITERS BY BRUSHING TOP & SIDES	BASE	BULK INFILTRATION TOP	MIDDLE	BASE	RATINGS NORTH BRICK	PLASTER	SOUTH BRICK	PLASTER	TOTAL
22	SSH	BRUSHING	19.5	8.8	0.7	0	0	0	5	6	7	7	25
23	SSH	SPRAYING	18.5	18.5	0	0	0	0	6	7	7	7	27
24	SSH	BULK[B] AND BRUSHING	45	13	2	6	10	14	7	7	6	8	28
25	SSH	BRUSHING	22	10	12	0	0	0	7	6	7	8	28
26	SSH	BULK AND BRUSHING	18.5	7.5	1.5	6.5	0	3.0	4	6	5	8	23
29	SSOH	SPRAYING	18.5	18.5	0	0	0	0	5	5	4	0	14
30	SSOH	BULK AND BRUSHING	18.5	11.5	2	10	0	5	0	0	0	0	0
31	SSH[C]	BRUSHING	9.5	8.8	0.7	0	0	0	8	7	8	8	33

A. All runs (except 31) in polar, ketonic solvent. All runs contained catalyst.

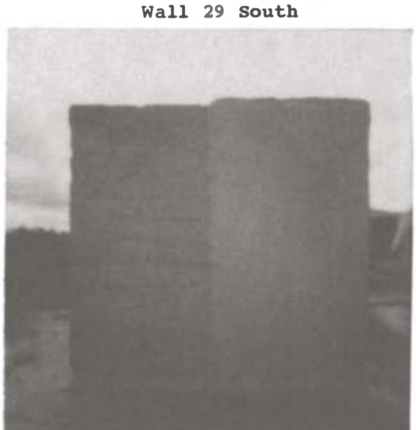
B. Bulk indicates material was delivered into deeply drilled holes by using funnels.

C. In mineral spirits

Wall 18 South

Wall 29 North

Wall 29 South



Wall 25 North

In general it was found that SSH was effective while SSOH was not. This is not unexpected since the major property difference provided by the two is water repellency. The formulation containing methyl triethoxysilane gives a surface that rejects water, while the formulation without the alkyl silane, the SSOH, does not, and this makes a critical difference when attack is by spraying water. There seemed to be little difference between walls that were treated by spraying, brushing or the combination of brushing and bulk infiltration. The walls treated with SSH retained their original light tan color and showed no pulling away of plaster coats. We attempted to determine why these layers peeled away from some of the isocyanate treated walls but did not, in any case, do so when the consolidant was SSH. Thermal expansion studies done by thermomechanical analyses showed no differences between samples treated with DN3390 and SSH. However, comparison of swelling coefficients by the same procedure suggests that adobe treated with SSH is less rigid; this may explain the difference. We do not have the technology to measure low polysiloxane concentrations in adobe and thereby obtain the depth of SSH penetration. The general correlation of non-peeling with the amount of consolidant suggests that stability is also a matter of getting sufficient material deeply enough into the structure.

The SSH treated walls all received a good total rating that appears to be independent of the amount of consolidant used or the method of application. This is in obvious contrast to results obtained with DN3390. The low viscosity of the silane esters enables large amounts to be applied with ease and to achieve good penetration, which is an important advantage. The total quantity of the consolidant itself applied in the silane ester tests ran from 9.5 to 45 liters, a range that was totally above that of the 3 to 9 liters used in DN3390 runs. This may explain why results with the isocyanate tests were more dependent on the amount of consolidant and the method of application.

The main problem with walls treated with SSH and a major difference in the results obtained with isocyanates was their tendency to show surface erosion. Originally the adobe brick walls had a relatively smooth appearance. After treatment with isocyanates and subsequent exposure to water, the surfaces generally still retained a flat, even quality. They were darker and, depending on the amount of DN3390 applied, sometimes were cracked. The surfaces had become hardened but were otherwise structurally unchanged. In contrast, the silane ester treated surfaces were grainy and eroded and in some cases showed ruts and cracks. This difference in behavior is probably generally true in stone consolidation, i.e., where silane esters are compared to thermoset resins like epoxies and isocyanates for the stabilization of sandstone and limestone, but only in the regime of water attack on treated adobe can this be discerned so clearly and so quickly.

The best result in this series was obtained with SSH in a mineral spirits solvent, rather than the more conventional cosolvent, (approximately 20% methyl ethyl ketone - 10% acetone). Mineral spirits is a petroleum distillate consisting of aliphatic and aromatic hydrocarbons. Wall 31, which was treated with the silane in this solvent, received a rating of 33 while wall 22, treated identically except for the use of the mixed ketone solvent, had a rating value of 25. We were able to smell residual aromatic hydrocarbons in the test walls after spraying was stopped. It is likely that the better performance observed in wall 31 resulted from the presence of heavier hydrocarbons, which provided additional water barrier and repellency properties.

TABLE 5
COMPARISON OF THE CONSOLIDATION OF ADOBE WALLS
USING DIFFERENT TYPES OF DIISOCYANATES AND DIFFERENT AMOUNTS OF CONSOLIDANT

WALL	CONSOLIDANT	POUNDS OF CONSOLIDANT USED IN HALF WALL[A]	PLACEMENT OF CONSOLIDANT[B] TOP & SIDES	BASE	RATINGS NORTH BRICK	NORTH PLASTER	SOUTH BRICK	SOUTH PLASTER	TOTAL[E]
33W	Diphenylmethane diisocyanate	3.8	3.4	0.4	7			5	24
33E	Dicyclohexylmethane diisocyanate and catalyst[C]	3.2	2.6	0.6		6	4		20
34E	DN 3390[D]	7.2	7.2	-	8			5	26
34W	DN 3390[D]	1.8	1.8	-		3	3		12
35W	Dicyclohexylmethane diisocyanate[D]	1.8	1.8	-		2	4		12
35E	Dicyclohexylmethane diisocyanate[C]	7.2	7.2	-	7			5	24

A. Each quantity of consolidant was dissolved in a mixture of 4.5 liters of methyl ethyl ketone and 4.5 liters of mixed xylenes.

B. Application was by brushing on of 2 to 6 coats.

C. Approximately 3.0 milliliters of dibutyl tin laurate was added to solution.

D. Approximately 0.5 milliliters of dibutyl tin laurate was added to solution.

E. Total is calculated on a full wall basis.

Wall 25 South

Results with Other Consolidants

Other isocyanates examined in this program were diphenylmethane diisocyanate and dicyclohexylmethane diisocyanate. Both are commercial products marketed by Mobay. Results outlined in Table 5 show that these worked about as well as DN3390. This table also demonstrates that the use of optimum amounts of impregnant is needed for good consolidation. In one set the east half of wall 34 was treated with 7.2 pounds of DN3390, while the west half received only a quarter of that amount or 1.8 pounds. Respective summary ratings of 26 and 12 illustrate the benefits of using a sufficient amount of consolidant. Almost comparable results were obtained when dicyclohexylmethane diisocyanate was used in a similar manner. These experiments are additional evidence of the criticality of the amount of isocyanate employed and the lesser importance of the type of polyfunctional isocyanate that is used.

Two additional treatments should be mentioned. Wall 32 was treated by brushing and bulk infiltration with 4.4 pounds of Acryloid A-21 dissolved in 50 liters of a mixed solvent consisting of methyl ethyl ketone, xylenes and butyl acetate. During the two months of water spraying this wall collapsed. Wall 36 was treated with 3 liters of DN 3390 in much the same way that treatment was carried out on wall 16 except that half of the methyl ethyl ketone in the cosolvent with xylene was replaced with butyl acetate, and 3 milliliters of dibutyltin laurate, catalyst, was added. A summary rating of 26 for this wall suggests that neither factor had a major impact on the quality of the treatment.

Reevaluations at Later Periods

Reevaluations of all of the walls was done three months and then fifteen months after the initial assessment. A sample of the reevaluation of 10 walls is shown in Table 6. Walls treated with both isocyanates and silane esters are included. These data show that during the year and a quarter after the water spraying there was no additional deterioration. An exception to this occurred with walls where the plaster coatings had pulled away. This behavior led to initial ratings of 3 or 4. In most of these cases this separated layer subsequently fell off to mandate a drop in rating to a value of one. The ratings, each time, were done without considering the treatment. The consistency of the ratings over time provides validation of the evaluation procedure.

TABLE 6

REEVALUATION OF WALLS THREE MONTHS AND FIFTEEN MONTHS AFTER THE END OF SPRAYING

WALL	AMOUNT OF CONSOLIDANT TO TOP & SIDES, LITERS			NORTH FACE						SOUTH FACE						SUMMARY RATING		
	[B]TYPE	SURFACE	BULK	BRICK			PLASTER			BRICK			PLASTER					
MONTHS --------->				0	3	15	0	3	15	0	3	15	0	3	15	0	3	15
16	DN3390	2.3B	0	5	6	6	5	6	6	7	8	8	5	5	6	22	25	26
17	DN3390	4.0B	0	7	7	8	4	4	4	8	7	7	4	1	1	23	19	20
18	DN3390	1.7B	2.8	10	10	10	9	9	9	9	10	10	9	9	9	37	38	38
19	DN3390	1.5B	0	5	7	7	4	3	1	4	6	6	2	1	1	15	17	15
20	DN3390	1.0B	0.6	9	9	9	4	5	5	7	8	9	8	8	8	28	30	31
23	SSH	18.5S	0	6	7	7	7	8	7	7	7	5	7	7	7	27	29	26
29	SSOH	11.5S	10	5	4	5	5	5	6	4	5	4	5	5	6	19	19	21
31	SSH[M]	8.8B	0	8	6	7	7	5	8	8	7	7	8	7	8	31	25	30
35W[D]	DCHM	1.5B	0				2	3	3	4	4	4				12	14	14
35E[D]	DCHM	6.0B	0	7	7	8							5	5	5	24	24	26

B. Applied by brushing

S. Applied by spraying

M. Dissolved in mineral spirits instead of ketone solvents.

D. On wall 35E and 35W, the amount of consolidant and the summary ratings were doubled to compare on a full wall basis.

More Recent Study of Brushing Procedures

A second set of five test walls was treated with the isocyanate DN 3390 in May 1989. The purpose of this test series was to determine if the high quality of consolidation that was achieved by bulk infiltration in the previous test wall program could be obtained simply by brushing. The strategy was to use more dilute solutions of DN 3390 in order to obtain deeper penetration. The use of lower concentrations meant that a larger number of brushings (more than the seven applications typically used in the earlier set) would be required to supply the quantity of isocyanate needed for a very good consolidation.

Table 7 summarizes the results obtained in this phase and shows the amount of DN 3390 as liters of isocyanate without solvent. These studies were done on quarter and half wall segments in order to examine more variables, but the quantities of consolidant are standardized to a full wall value to simplify comparison with earlier studies. The number of brushings was relatively low in the first two wall treatments (52 and 53) but rose to 11 on wall 54 and 18 on walls 55 and 56. Correspondingly the concentrations, which are not shown, range from 12.8% to 2%.

TABLE 7

CONSOLIDATION QUALITY RATINGS ON FIVE NEW TEST WALLS

Wall	DN3390 per full wall liters	Solvent	Number of Applications	Post Wetting Solvent	Catalyst	RATING Brick	Plaster	Summary Full Wall Basis
52W	3.0	M	6	M	No	6	9	30
52E	3.0	M	6	X	No	7	4	22
53W	1.5	M	4	M	Yes	0	0	0
53E	1.5	M	4	X	Yes	7	5	24
54W	2.3	M	11	none	No	5	2	14
54E	2.3	M	11	none	Yes	0	0	0
55WW	5.2	M+B	18	B	No	9	5	28
55WE	5.2	M+B	18	none	No	9	5	28
55EW	5.2	M	18	none	No	7	8	30
55EE	5.2	M	18	M	No	7	8	30
56WW	2.6	M+B	18	B	No	7	5	24
56WE	2.6	M+B	18	none	No	7	5	24
56EW	2.6	M	18	none	No	7	8	30
56EE	2.6	M	18	M	No	7	8	30

Catalyst was dibutyl tin laurate
M = methyl ethyl ketone
X = mixed xylenes
B = butyl acetate

The rating system applied to these walls after one month of being wrapped in plastic following treatment, two months of water spraying, and three months of natural exposure is also provided in Table 7. Before discussing the numerical ratings, it should be noted that these five walls were plagued with problems that did not seem to beset the original walls. The walls, as delivered by the contractor before treatment was applied, were of poor quality with much erosion and cracking. Apparently some patching was done, but it was not sufficient. The left half of wall 53 and the right half of wall 54 rather quickly collapsed when the water spray program was employed. These massive failures made no sense based on the nature of the treatment. They may have resulted from residual deep cracks that permitted spray water to penetrate through the consolidation to the core of the wall with the obvious disastrous results. These walls may also have suffered from an inadequate amount of consolidant around the base.

Nevertheless, this phase still provided information on the effectiveness of multiple low concentration applications. Failed walls were those using the smallest amount of consolidant, 1.5 and 2.3 liters. Walls treated with higher levels of consolidant, 2.6 to 5.2 liters, all remained intact. The use of a very large number of brushings, 18, gave treated wall ratings of 30, even with the application of only 2.6 liters of DN 3390, a relatively small amount. It does appear that multiple coatings with dilute systems will give better results than fewer brushings at higher concentration, but the consolidation is not as good as the optimum use of deep bulk treatment.

The Consolidation of Aged Adobe

The purpose of this research was to develop proceedings and formulations to consolidate aged, weathered adobe of structures of historic importance. In the course of time, adobe exposed to the atmosphere becomes weak and friable. Presumably the clay platelets, initially flocculated and aligned, become more dispersed. Void spaces are enlarged which leads to a weakening of the weathered surface. We tried several brushing experiments on small, nineteenth century adobe remnants at Fort Selden. Both DN 3390 and SSH were used. To our dismay, the aged adobe took up the consolidants but was not mechanically strengthened. Working with both Fort Selden adobe and a tan adobe from Tel Dan in Israel we have found that when the adobe is recast into mud bricks and dried, it can be consolidated under treatment conditions that fail with adobe structures that had been in existence for some time. We theorize that a slow dehydration takes place that takes the clay to a form that prevents the water-based curing mechanism from occurring. To test this hypothesis, a chunk of old Fort Selden adobe was soaked with 10% aqueous methyl ethyl ketone. This permitted a rehydration without physically altering the shape of the adobe. After the organic solvent evaporated, the piece was treated with 12% DN 3390 in methyl ethyl ketone and xylene. The product, after curing and drying, was mechanically strong and hard. Thus we have qualitatively demonstrated that historic adobe can be consolidated with isocyanates and silane esters, but the need for rehydration indicates that considerable research and development remains before on-site procedures can be recommended.

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The Preservation of Prehistoric Mud Plaster at Mesa Verde National Park

Allen S. Bohnert, Curator
Southeast Archeological Center
National Park Service
PO Box 2416
Tallahassee, Florida 32316
U.S.A.

ABSTRACT

Mud plaster is frequently found in prehistoric sites within the American Southwest. Mesa Verde National Park, a unit of the United States National Park Service, contains over 3,930 recorded archeological sites. Approximately 590 of these are cliff dwellings. More than 600 years after abandonment, many of the sandstone masonry walls in these buildings retain at least remnants of original mud plaster.

This paper discusses the multi-faceted plaster preservation program being formulated at the park. Initial steps included reviewing archival materials and thoroughly surveying extant plaster in eighteen cliff dwellings, containing over one thousand architectural spaces. Surveys of mud plaster on this scale are unprecidented in the United States. Survey methodology, results, recommended management actions, and future research needs are discussed. Additionally, the results of preliminary studies of the mineralogical characteristics of the mud plaster from Mesa Verde are presented.

KEYWORDS

Archeology, Anasazi, cliff dwellings, mud plaster, plaster conservation, Mesa Verde National Park

INTRODUCTION

Mesa Verde National Park, established in 1906, is the only National Park in the United States National Park Service created expressly to preserve cultural resources. Mesa Verde is noted for its wealth of archeological resources, particularly its cliff dwellings. The resources are of international significance, and in 1978 the park was selected as a World Heritage Site.

Of the 3,932 archeological sites recorded within the park, nearly 600 can be classified as cliff dwellings [1]. The majority are "sites of the Mesa Verde Branch of a Formative Culture known as Anasazi" [2]. The Anasazi resided throughout the four-corners region, an area where four state boundaries meet in the American Southwest. They lived in what is now Mesa Verde National Park from approximately A.D. 450 until the area was abandoned around A.D. 1300. Village locations shifted from the mesa tops to cliff alcoves toward the end of this period, and increased building activity in the alcoves began between A.D. 1230 and 1260. The resultant structures range in size from a single room to more than 200 rooms [3]. The alcoves sheltered Anasazi architecture from the elements, and the semiarid environment of southwestern Colorado further served to preserve this spectacular resource (see fig. 1).

Much Anasazi architecture is finished with mud plaster, especially the later sandstone and mud mortar cliff dwellings. It should be noted, however, that plaster was used to some extent by the Anasazi throughout their occupation of Mesa Verde. Nusbaum, for example, reported plaster in the earliest known Anasazi dwellings, pithouses, excavated in 1926 at Step House (Site # MV 1285) [4]. Until recently the focus of most plaster research has been on highly decorated plaster, rather than its systematic documentation or its potential relationship to cultural change and room function.

Nordenskiold, the first to scientifically document and record the archeological resources of Mesa Verde, recorded decorated plaster in several cliff dwellings during his 1891 exploration [5] (see fig. 2). Subsequent archeological work by Fewkes [6], Cattanach [7], Rohn [8] and others also provided some plaster data. In the Long House report (Site # MV 1200) Cattanach states:

> Some walls were "plastered" in places by smearing surplus mortar extruded between blocks and across the face of the surrounding wall. In most cases, however, the overall plaster was prepared and applied independently of the wall construction. The material was usually derived from the red and brown soils and was probably tinted more often than we realized with pigments made from hematite, kaolin and the like [9].

Rohn similarly describes Mug House plaster (Site # MV 1229), noting the consistent appearance of the pink plaster in the rooms. He hypothesizes that ". . . red loess from the mesa top continued in fashion for plastering after it had gone out of style as mortar . . .." [10]. While discussing kiva plaster, Rohn states that ". . . almost all the individual plaster consisted of a very thin brown or tan adobe body that had probably been acquired from Adobe Cave. Only in Kiva G was the reddish brown, mesa-top loess used instead. [11]"

Mud plaster is found in prehistoric sites throughout the American Southwest. It was not until Watson Smith's 1952 publication [12] that a relatively comprehensive survey of pueblo wall paintings became available. Smith's report included brief descriptions of plaster in notable sites throughout the Southwest, including Mesa Verde National Park. More importantly, the report includes an excellent description and analysis of decorative elements, materials comprising the mud plaster, and pigments used in prehistoric sites in the Jeddito Valley, Arizona.

It was not until the 1980s that there was a renewed interest in, and increased focus on, mud plaster. Reports by Chiari [13], Schwartzbaum [14], and others describing successful conservation treatments performed on decorated adobe surfaces became accessible to managers and resource specialists. Additionally, two reports by Constance Silver appeared, one in 1980 [15] and the other in 1982 [16]. Both publications used the extensive resources available through the International Center for the Restoration and Preservation of Cultural Property (ICCROM). These reports, more than any other publications, highlighted the lack of attention being given mud plaster and the need to pursue both the analysis and conservation of the prehistoric plasters in the American Southwest. Silver's reports graphically illustrated the need to develop comprehensive approaches to documenting and preserving both existing plaster and that being uncovered during current excavations. These two reports, combined with a certain amount of expanding professional interest in mud plaster, served to help increase general awareness that the plaster was indeed an integral component of Anasazi architecture and that its preservation was not ensured given present circumstances.

The pilot treatments described in the 1982 report involved the consolidation, reattachment, and cleaning of in situ plaster [17]. The report describes treatment methods and materials used in detail, and they will not be reiterated here. It should be noted, however, that this was the first time such treatments were tested on prehistoric mud plaster in the U.S. Mesa Verde National Park played an important role in the project since the treatments were performed in Kiva C and on the free-standing west exterior wall of room 28 in Mug House. The pilot treatment project also alerted park staff to the fragile nature of the plaster resource.

MESA VERDE PLASTER SURVEY

Park Management, becoming keenly aware of the lack of an integrated plaster data base and the continuing loss of this resource, obtained funding to begin a thorough plaster survey. Contracted survey work has been conducted during 1985 (Contract #-1490-4-0006) and 1987 (Contact #-1490-7-0002).

Major objectives, common to both survey projects, were:

1. to record the location and general condition of all extant plaster in selected archeological sites;

2. to compare generally, where documentation exists, the extant resource to that which was present historically; and

3. to provide recommendations for preservation treatment of the resource, keeping in mind the intimate relationships existing between the plaster and its masonry support.

A primary objective of the 1985 survey included a substantial archival work component. Mesa Verde National Park has accumulated a considerable amount of archival material since 1906. Most is located in distinct files in the Archeology Museum or at the Research Center. One major series of records pertains to ruin stabilization activities. The park's archeological ruins have undergone periodic stabilization since 1908. A second major archival data base is the archeological site record file. Other plaster data are located in historic photograph files and in the park's extensive archeological excavation records. All of these resources include substantial amounts of photographic and written plaster-related data.

These distinct data bases are not fully cross-referenced, nor are they automated. The idiosyncrasies of the records provided certain challenges to the contractor while integrating the plaster-related data. As mentioned previously, plaster has been addressed differently by past researchers. It may or may not have been specifically mentioned or reported in detail when archeological sites were surveyed and when excavation or stabilization work was documented. For example, older written stabilization records or completed archeological site forms may not have discussed the presence of plastered walls. However, photographs documenting the site or the work may clearly illustrate the presence of plaster. Also, when existing plaster was noted, the terminology describing or classifying it was not consistent. Decorated plaster may have been referenced using those terms or included under the grouping of "pictographs" as was done in the 1964 Wetherill Mesa survey report [18].

Nevertheless, the 1985 plaster survey contract successfully compiled and integrated much plaster data from the record groupings listed above. Eighty-five of the park's cliff dwellings [eighty-four are listed in the report] were reported as having documented prehistoric plaster [19] within as many as 1,861 architectural spaces. These data do not indicate the number of plastered walls, the extent of the plaster when documented, or the condition of the plaster. But, even when using these limited data, one can readily see that the cliff dwellings of Mesa Verde contain extensive and important mud plaster resources. How extensive, how important, and in what condition can only be determined through the examination of each architectural space in the eighty-five sites. Complete and systematic documentation of such an extensive resource is a time-consuming and expensive proposition. Obviously priorities must be established and a plan of action carefully formulated.

With the inception of the 1985 survey project, the contractor and park staff collaborated on the development of recording forms and formats. Each architectural space within certain cliff dwellings was to be fully documented, both in written and photographic form. It was decided to use a two-part, hierarchical survey form. One part generally documented individual architectural spaces. The second form was designed to document each wall containing plaster. Examples of these forms are available from the author. Data were recorded for each plaster's location, method of application, number of layers, presence of design elements, condition, color (Munsell), and extent. During the second survey minor revisions were made to this form, such as prompting for environmental and locational data pertinent to plaster preservation and for specific data concerning previous documentation and noted plaster deterioration [19]. However, data consistency was a primary objective of both surveys.

The plaster recording system used existing site maps and room numbering systems, and it was hierarchical by design. The system uniquely identifies each wall forming the plaster's immediate structural support, which is the basic recording unit. For example, MV 640-55-N denotes plaster on the north, interior wall of room 55, in site #MV 640. Similarly, MV 640-55-N-EXT identifies the same wall, but an exterior surface. The format and the system generally linked documented plaster walls to their spatial and functional contexts, served to systematize documentation while considering future automation of these data, and assisted in the analysis of structural concerns or ambient causes of deterioration [20].

Photographic documentation included at least one black-and-white photograph of each plastered surface. Additional photographs, black-and-white, color, or infrared were taken as needed to illustrate certain design elements and conditions. Each photograph was given a unique reference code on a photographer's log. Photographs also included the appropriate Kodak Scale and were referenced on plaster recordation forms. Drawings were made when needed to further illustrate complex or very poorly preserved motifs.

The 1985 survey established precedents for standardized plaster and condition terminology. Fully standardized masonry and architectural nomenclature has not been adopted by park staff. However, terms such as shaped or unshaped stone, single or double coursed walls, tower, kiva, and room were recorded during the plaster survey as they were used during previous archeological work in the park. The descriptive terminology for plaster and condition was kept to a useful minimum and was kept general. Further, each term was illustrated in final reports to facilitate their use and interpretation by future researchers. The glossary of terms used to document plaster, for example, included: aura incised design, painted design, incised and painted design, floor band, bichrome design, wainscot, colored wash, dado, de facto plaster, undecorated plaster, and absence of plaster [21].

The condition of the plaster was one factor evaluated when recommendations for further action were made by the surveyors. Terminology for specific examples of deterioration types and overall condition were established for both the surfaces and the plaster substrate. Surface deterioration caused by accretion (i.e., bird excrement, smoke blackening, nearby stabilization work, muddy runoff), and conditions such as powdering, flaking, separation from substrate and weathering losses were illustrated and defined. Along with the above surface condition nomenclature, several types of plaster deterioration were illustrated. These included lacuna, separation from walls, cracks, interlayer cleavage, and failing supports [22].

FIELD SURVEY RESULTS

The surveys documented plaster in eighteen sites containing just over one thousand architectural spaces. The cliff dwellings chosen for initial survey were the largest and best preserved. Preliminary data suggested that substantial amounts of plaster, both decorated and undecorated, were still present in all sites selected for documentation. Another factor influencing site selection was the interpretive importance of the site. Nearly all sites chosen for survey were open to public visitation or visible from public overlooks.

Over 1,900 square meters (20,500 sq. ft.) of plaster on 869 surfaces were documented during the surveys [23,24]. Approximately 75 percent of the plaster and the surface are in fair to poor condition. These figures certainly illustrate an extensive resource in need of attention. Numerous preservation-related recommendations resulted from the surveys. The more prevalent recommendations were:

1. to apply silicone beading to the ceiling of an alcove to form false driplines which divert water away from the buildings;
2. to stabilize architectural supports - often the base of a wall;
3. to closely monitor certain plasters;
4. and for a conservator to evaluate selected plaster for treatment.

It is not practical, nor is it feasible, to attempt to preserve all recorded plaster. A multicomponent action plan must be implemented if the plaster resource is to be documented and a significant sample preserved. A suggested action plan includes the following six major sections:

1. Active stabilization: Stabilize walls, control moisture to the extent possible, control rodents or birds, and eliminate insects - - continue developing a comprehensive approach to site preservation.

2. Monitoring: Develop a methodology and schedule to monitor systematically selected plaster based upon criteria such as overall condition, presence of design elements, uniqueness, representativeness of more mundane finishes (i.e., washes, monochrome or bichrome designs, auras, floor bands), interpretive importance, feasibility of preservation, and previous treatment.

3. Evaluation for conservation treatment: Backfill selected spaces, solicit conservation treatment proposals and contract for treatment, closely evaluate the effectiveness of the pilot treatments performed at Mug House.

4. Training: Further sensitize park staff (i.e. those responsible for management, interpretation, stabilization, and protection) to the importance and fragility of the plaster. Train the park's Stabilization Specialist and Ruins Stabilization Crew so that plaster monitoring, documentation, and preservation can be fully integrated into both the present stabilization program and future excavations, and ensure that newly recorded data are compatible with previous survey data.

5. Continue field surveys: Survey remaining cliff dwellings in priority order, again ensuring compatibility of new data with previous survey data, and improve survey methodology.

6. Expand research: Continue to support and formalize research projects related to plaster composition (pigments, binders, and minerals), material sources, plaster fabrication, determination of salts, and conservation treatment (cleaning, consolidation, and reattachment).

PLASTER ANALYSIS

Mud plaster from Anasazi sites has not undergone scientific analysis until relatively recently. Smith [25] reports the composition of kiva plaster from two sites in the Jeddito Valley as 90% sand and 10% clay. The report also lists thirteen colors and possible pigment sources, noting that it is unclear if pigments were added or if the clay and sandstone were previously stained. All pigments, except black, were apparently derived from inorganic materials. Smith also hypothesizes that an organic binding medium could have been mixed with pigments [26].

Recent studies by Silver [27] produced strikingly different and thought-provoking results. X-ray diffraction analysis shows that prehistoric plaster from Anasazi ruins in the four-corners area and a possible mud source in Mesa Verde National Park contain no mineralogical clays. Plaster from Lowry Ruin contains 75% quartz, 5-10% feldspar, 5-10% mica, and traces of additional material. The raw mud from Mesa Verde contains 50% quartz and 50% anorthite. The Lowry sample was also tested using stains specific to organic compounds. The plaster tested negatively, while a paint layer from Lowry tested positively for carbohydrates and proteins. The raw mud sample was not tested for organic materials. As suggested by Silver, the lack of mineralogical clay in her samples is remarkable, and the presence of organic binding media may partially account for the cohesiveness and durability of the paint layers and plaster.

Mesa Verde plaster samples were recently examined by Dr. Mary Griffitts [28,29]. X-ray diffraction of kiva and room plaster samples from Step House and Mug House demonstrate a departure from both Smith's and Silver's data. Table I illustrates comparative sample data from Silver's and Griffitts' reports. Of particular note is the relatively low percentage of quartz and high percentage of calcite in the white plaster from both Mesa Verde sites analyzed by Griffitts. Additionally, measurable percentages of mineralogical clay are present in the Mesa Verde samples.

Table I. Comparative Results of X-Ray Diffraction (After Silver 1987 and Griffitts 1989,1990) - - Note: Totals may not equal 100% due to sample variability.

Site/Sample	Quartz	Calcite	Feldspar	Kaolinite	Gypsum	Mica
Lowry Ruin	75%	-	5-10%			5-10%
River House Ruin	80%	Tr	15-20%			
MVNP - Raw Mud	50%		50%			
Mesa Verde National Park Plaster Sample Data Follows:						
Step House - Kiva A - dark	93-95%	0-10%	10-15%	2-3%	1-2%	1%
Step House - Kiva A - white	37%	15%	17%	2%		
Mug House - Rm 28, ext-white	43%	30%	8%	1%	2%	1%
Mug House - Rm 28, ext-pink	72%	4%	8	3%	2%	2%
Mug House - Kiva C	90%	15-20%		5%		

While examining thin sections from Mesa Verde plaster Griffitts identified serecite, a very finely divided mica resulting from the weathering of feldspar. Serecite is not found in any of the geologic formations studied by Griffitts. It is present, however, in the lower zones of the park's loess soils, just above an underlying layer of caliche. The X-ray diffraction data and occurrence of serecite suggests that loess soils may have been combined with caliche (calcite) to create certain plasters. Caliche evidently is a major component of the white plaster samples subjected to the above analytical tests. An empirical experiment by Griffitts produced a good plaster (50% caliche and 50% loess) of similar color and appearance to some original Cliff Palace plaster. The Mesa Verde plasters have not been analyzed for the presence of organic binders. This should be done in the future. With such tests one must be certain the samples have not been contaminated by previous conservation treatments or altered during burial. It would also be interesting to test hypothesized source material for the presence of organic material as a control, to ensure the raw materials do not contain substances which might skew the analysis.

CONCLUSION

Mud plaster in archeological sites of the American Southwest has not received the attention it warrants or needs. The plaster survey program at Mesa Verde National Park is unprecedented in scope, with over one thousand architectural spaces inventoried and over 1,900 square meters (20,500 sq. ft.) of plaster documented. Surveying, locating, and recording plaster and documenting its condition are necessarily the first steps in a comprehensive plaster resource preservation program. The Mesa Verde survey project illustrates the importance of such inventory data and the extent of the plaster resource in that park. It also illustrates the need to establish preservation priorities and a multi-faceted action plan since it is not feasible or practical to conserve all plaster. A suggested action plan includes stabilization, monitoring, evaluation of treatment needs, training, continued survey, and expanded research programs. Such programs are not only applicable to Mesa Verde, but also to all other areas with the potential for prehistoric plaster among their resources.

Silver's 1987 study discussing the presence of organic binding media and the absence of mineralogical clay in certain Anasazi plaster is intriguing. Similarly, the high calcite content, presence of mineralogical clays, and the presence of serecite in samples of Anasazi plaster from Mesa Verde is also interesting. Only a few samples comprise the present data base and more samples must be analyzed. Additional research in the areas of plaster composition, pigments, conservation treatments, and plaster replication is needed. This basic research must be performed if we are to reconcile apparently discordant data and to continue making progress with actual conservation treatments and ensure the long-term preservation of Anasazi plaster.

With further refinements in our ability to identify the composition of prehistoric plaster and material sources, plaster may prove to be a useful cultural and temporal indicator. Anasazi masonry styles have been used to illustrate certain attributes characterizing developmental phases by which sites are classified [30]. Regional variations in masonry style have also been used to identify sites attributed to different branches of the Anasazi [31,32]. The architectural finishes (i.e., plaster and paints) applied to the masonry potentially have similar capabilities.

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Figure 1. 1891 photograph of Square Tower House.

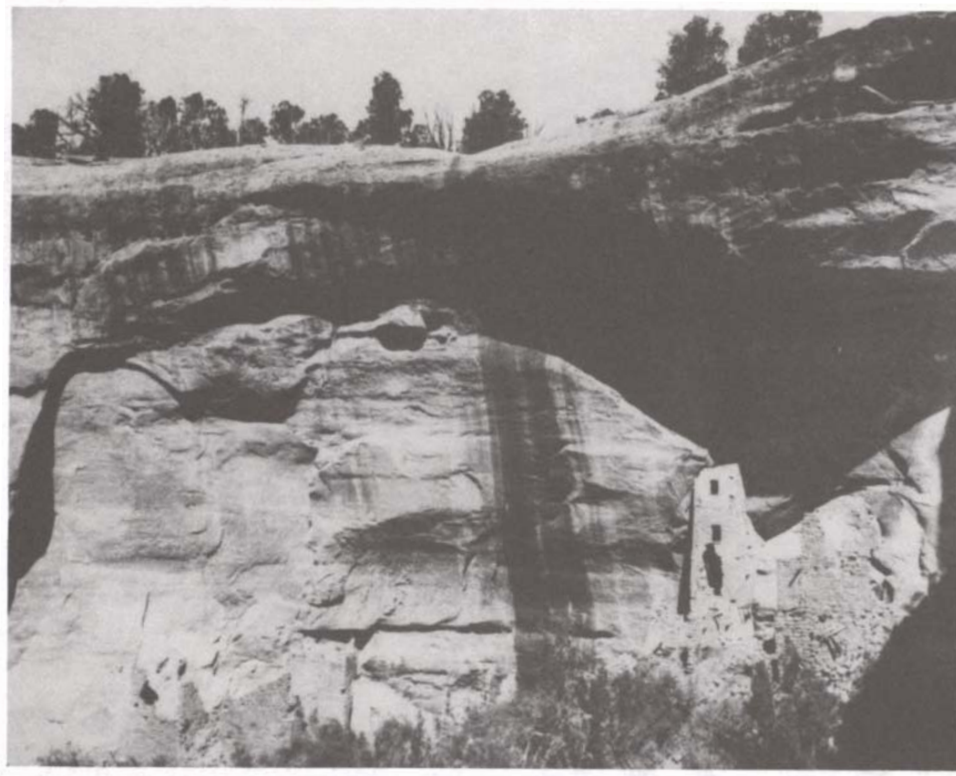


Figure 2. 1891 photograph of Square Tower House, by G. Nordenskiold.

ABSTRACT

Among the various techniques of earthen architecture preservation which have been applied in the past, the consolidation of vertical surfaces by chemical agents and the capping of the top part of walls play an important role. The ideal characteristics of a good consolidant are outlined. The consolidation mechanisms of synthetic resins and ethyl silicate are discussed, together with their advantages and disadvantages. The performance of field treatments with ethyl silicate and of capping techniques after twenty years of application are evaluated for a case study in Iraq. A way to regain good adhesion on deteriorated surfaces, based on the application of rice paper (moistened and pressured) is described.

KEYWORDS

Adobe, Earthen Architecture, Consolidation, Ethyl Silicate, Synthetic resins, Capping, Long-term evaluation.

CHEMICAL SURFACE TREATMENTS AND CAPPING TECHNIQUES OF EARTHEN STRUCTURES: A LONG-TERM EVALUATION.

Giacomo Chiari
Dipartimento di Scienze della Terra
Via Valperga Caluso 37. I-10125 Torino.
Italy

Introduction

The idea of solving the problem of adobe preservation by coating the surface with some perfect consolidant should be dismissed. Each preservative shows advantages and disadvantages; the perfect treatment has not yet been discovered and probably never will be. Adobe is a weak material that has always been used with the idea of constant maintenance and repair. In most cases the walls were originally protected by roofs, which in archaeological excavations are missing. One cannot expect to stop the natural evolution and modification of the material. All we can hope to do is to reduce the speed of deterioration.

Chemical surface treatments

An ideal consolidant for adobe should have the following characteristics: 1) confer water resistance but not water repellency in order to allow water migration both in liquid and vapour phase; 2) leave pores and capillaries open, and allow for other impregnations, even with different products; 3) confer mechanical strength and abrasive resistance both in dry and wet conditions; 4) have good penetration, i.e., low viscosity; 5) should not form films on the surface, nor show an abrupt planar boundary with respect to the untreated core; 6) have a thermal expansion coefficient similar to that of adobe; 7) should not change the colour, or cause gloss; 8) be resistant to stresses caused by salt crystallization, capillary rise of ground water, and freeze-thaw cycles; 9) be durable, i.e., resistant to water, and photo-oxidation; 10) be easily applicable, possibly also in damp conditions, and cheap; 11) should not be harmful to the operators; 12) should be reversible, if possible (see also [1]).

It is my opinion that a product fulfilling all these characteristics does not exist.

The consolidants most used on adobe are synthetic resins, usually thermoplastic, and ethoxysilanes. It is important to underline that general statements on the behaviour of whole classes of compounds have almost no meaning. Products that have the same nominal composition may vary greatly from one producer to another; also the application technique could influence the final results. Each individual product should, therefore, be tested on the specific material, possibly with accelerated aging tests, wet-dry cycles, and salts crystallization. Even this cannot assure that a consolidant which has given good results in the laboratory would behave equally well on the long-term field application. Large field comparative tests are presently carried out on specially built walls at Fort Selden (New Mexico State Monuments) and in Grenoble (CRATerre) for various products and cappings. The results of these tests will be extremely valuable to identify suitable consolidants. Keeping this in mind, one can try to describe the consolidation mechanism and to evaluate advantages and disadvantages of both types of consolidants.

Synthetic resins

Synthetic resins are long chains of organic polymers derived from a vast range of monomers. The most commonly used are the polyvinyl acetates, acrylics (among them Acriloid B72 and Primal AC33) and polyisocyanates [1]. They can be used in solution in organic solvents or in water emulsions, or the polymerization can be obtained in situ by the use of catalysts or by reaction with atmospheric moisture.

Solutions are best suited for surface consolidation, because the products are pure, and they show good aging properties and penetration.

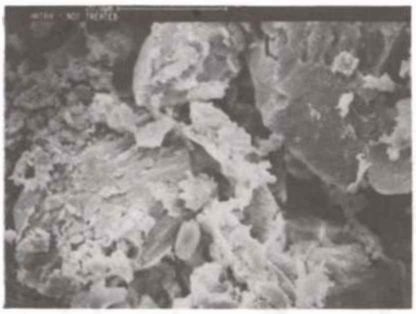


Figure 1. Scanning Electron Microscope (SEM) image of a nontreated sample from Hatra.

Water emulsions are obtained by addition of surfactants (usually soap-like substances). These additives may increase the speed of deterioration of the resin, by oxidation, breaking of the polymer chain, and cross-linking between chains. The results are change in colour, brittleness, and break down of mechanical properties. These mechanisms require the action of light (especially UV-radiation) and oxygen. In the case of emulsions the polymer globules suspended in water are relatively large, the liquid has a high viscosity, and penetration is low. Water is not a good carrier in the case of adobe, since it causes swelling of the clay particles and decreases the mechanical properties with the risk of material detachment during the treatment. Emulsions should therefore be applied as adhesives only, by injection inside the walls, and never on the surface.

Synthetic resins act as consolidants by penetrating inside the pores and coating the loose particles. Chemical reaction normally does not take place between the polymer and the material. The strengthening is obtained by the setting of the resin at the moment in which the solvent evaporates. In many cases, reverse migration of the polymer to the surface, as the solvent (especially if highly volatile) evaporates, causes the formation of a thin film. If the coating is not porous, which is the case for most synthetic resins, and does not allow for water transport, both in the liquid and vapour phase, the water that can gain access beneath the protective layer causes stress and detachment. Most synthetic resins have high thermal expansion coefficients, of one order of magnitude larger than adobe. Since the surface tends to be warmer than the inside during the day, and colder during the night, stress is developed at the interface, with possible detachment. Among the advantages of synthetic resins one can quote: good mechanical properties, a certain degree of reversibility with non-crosslinking types, and the fact that they may act as adhesives as well.

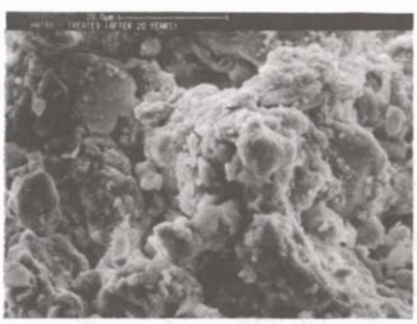


Figure 2. SEM image of a sample taken from the wall treated with ethyl silicate in Hatra. Although there is very little difference between the two "landscapes", the consolidated part is water resistant.

Technical description of the ethyl silicate reaction with earthen material

Ethyl silicate (tetraethoxysilane) is partly inorganic and partly organic, but after complete curing (which may take a long time) it leaves a purely inorganic residue. There are several kinds of commercial products (see the Materials section). The monomer consists of a silicon atom to which four ethoxy groups are bonded, $Si(OCH_2CH_3)_4$. When a water molecule reacts with an alcoholic residue, hydrolysis takes place: one ethyl alcohol molecule is formed (which evaporates) and an acidic residue remains attached to the silicon atom to form Si-OH.

The hydrolysis reaction is the following:

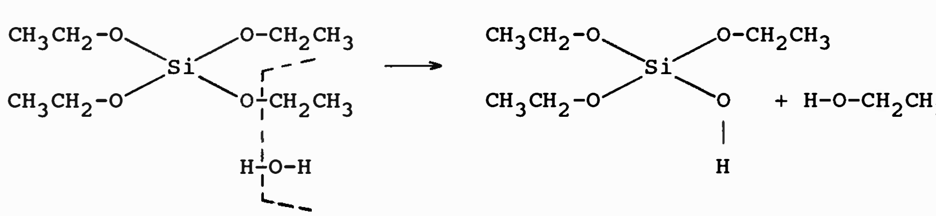


Figure 3. Application of moistened rice paper: the pressure allows adhesion to be reestablished.

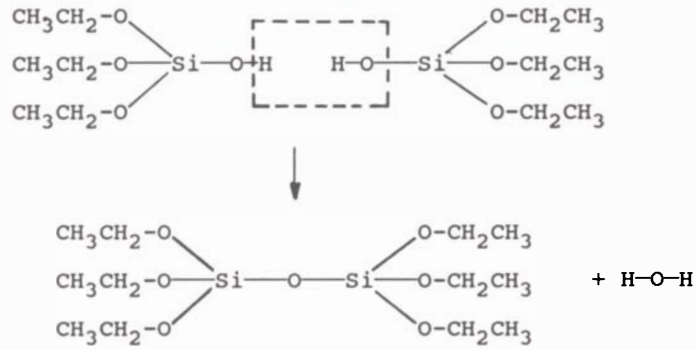
Figure 4. Detachment of the paper without any loss of surface material.

Figure 5. Overall view of the capping with one layer of strengthened bricks at Tell 'Umar, showing the plant overgrowth.

Figure 6. A section of the covering with one layer of strengthened bricks, still in perfect condition. (Tell 'Umar).

The hydrolysis of the four groups can take place at different times. If the four alcoholic residues are all hydrolyzed, silicic acid is formed: $Si(OH)_4$. When two acidic groups belonging to different molecules interact, condensation or polymerization takes place. One water molecule is released (and is again available for the hydrolysis reaction) and a strong Si-O-Si bond is formed.

The condensation reaction is the following:



A small amount of acid acts as a catalyst for hydrolysis. In the application to adobe, there is no need to increase the speed of the reaction, and better results are obtained without addition of acid [2-4]. With polymerization, a three-dimensional network of silica tetrahedra sharing one vertex is formed. Some of them usually still have ethoxy groups attached to the Si atom. The clay particles abundant in adobe have a large number of hydroxyl groups (-OH) located on their surface. Condensation may occur between the acidic group of the silica framework and the hydroxyls of clay particles. Of course, an extremely large number of such bonds are formed, and, if the clay particles are sufficiently close to one another, the silica framework helps to keep them together.

One of the major causes of deterioration of adobe is water, which separates the clay particles constituting the binding agent of the bricks. On excessive wetting eventually the clay is dispersed in a water suspension. The ethyl silicate treatment, by adding strong bonds between the clay, prevents clay platelets from being separated by water, and therefore gives the material the necessary water resistance. For the first period after treatment, silica gel is formed inside the pores and the total porosity is reduced. While the polymerization continues, the silica gel contracts and the pores reopen. With time, very little material remains inside the adobe, even the micro-pores are almost completely open, but the clay particles are still bonded together. The overall effect of the treatment is to confer water resistance to the material but not water repellency, neither at vapor nor liquid level [5].

Figure 1 shows a scanning electron microscope (SEM) picture of an untreated sample from Hatra, while Figure 2 shows a treated one. It can be seen that the changes due to the treatment are hardly detectable.

The treatment is completely irreversible, violating the principle that every intervention in conservation should be totally reversible. The fact that not only the surface and appearance of the material, but also its intimate structure, undergoes so little modification may in part justify the irreversibility. Other consolidants, even totally different in nature, can easily be applied, since the porosity and polarity of the material are practically unchanged.

The application by spraying makes its use very easy and has

Figure 7. On the north side, the unprotected wall has suffered an enormous loss of material, due to the rain. (Tell 'Umar).

Figure 8. The canalization of rain water over Tell 'Umar. In spite of some plant growth and some minor damage, this drainage system worked properly.

Figure 9. A natural canalization of water, left unprotected, to be compared to Fig. 8 (Tell 'Umar).

the advantage of obtaining a larger penetration in those parts which are more porous than others, thus leaving a very irregular separation between the treated and untreated parts. This strongly reduces the chance of detachment of the strengthened layer. Cleaning of the surface and extraction of soluble salts can be done after consolidation. This is not possible if synthetic resins are used.

Among the disadvantages, beside its irreversibility, one can recall that the treatment cannot be applied to wet surfaces. In this case, the excess of water causes the hydrolysis reaction to take place at much higher speed than polymerization. A glossy, fragile crust is formed, which crumbles without making the desired connections with the clay particles. Synthetic resins also present application problems to wet surfaces.

Another disadvantage is that ethyl silicate is not an adhesive, but only a consolidant. If a gap already exists between two blocks of adobe, they will be individually consolidated but not "glued" together. To achieve adhesion between already separated parts, one should make use of other strategies: the most obvious is to intervene as soon as possible, ideally during excavation, in order to have surfaces that are not yet damaged by weathering. If the surface is already damaged it is possible to regain adhesion by remodeling the surface using rice paper, water and pressure. The paper allows the crust to be sustained while it is carefully moistened. The material becomes slightly plastic, and, by exercising pressure with a hard sponge, one can reestablish an acceptable degree of adhesion. When almost dry, the paper can be detached without any loss of material, including pigments (See fig. 3,4). Both of these strategies were applied with success in the conservation of a painted frieze in Cardal, Peru, in 1987 (unpublished). If the detached crust is thicker than a few millimeters, the risk of it falling during the application of the rice paper is too high. Injections of synthetic resins (water emulsions) in the interior of the wall are recommended in this case.

Preservation of sites in Iraq: a case study

In 1968 a preliminary campaign for the conservation and preservation of archaeological finds in unbaked earth was carried out in Iraq, with the aim of documenting the problem of mud-brick deterioration [6,7]. Various laboratory tests of surface protection were performed, using most of the products widely used at the time. Ethyl silicate seemed to give the best preliminary results and was selected for major field tests, done in the Seleucia area and in Hatra in 1969. Synthetic resins (polyvinyl acetates and acrylics) were also used on a minor scale, by injection.

One liter of Silester ZNS, three liters of ethyl alcohol (96°), and 1 ml of hydrochloric acid as a catalyst was used to treat 1 m^2. The penetration was 2-3 cm in depth, and after a day or two the wall reassumed its previous colour. No changes in appearance were observed, but the water resistance was greatly enhanced. After a month of spraying water on selected spots three times a day, there was no evidence of erosion, while on a nearby untreated part a hole was formed after the first three sprayings.

Capping of the top part of walls

The yearly average rainfall in the area is about 300 mm, concentrated in a few torrential storms. Furthermore, in some sections people had to walk on top of the walls. For these reasons, it was decided that the chemical surface protection alone would not be sufficient, and two capping techniques were tried. The first one, used in the "Archives" of Seleucia, consisted of a layer of a few cm formed with a mix of earth and sand, with the addition of a minimum amount (5-8%) of portland cement, to avoid an excessive

Figure 10. A view of the "Archives" in Seleucia. The top of the walls was capped with soil-cement, which did not prove to be effective, since there was formation of water pools at the bases of the walls.

hardness. This capping was applied in two layers on the moistened surface. After good compression and drying of the first layer, the few unavoidable cracks were sealed by a second, thinner layer made with a mixture less rich in water. For a few days straw mats slightly sprinkled with water covered the capping to avoid an excessively quick drying process. With this procedure the cracking of the surface was practically avoided.

Trials of capping with addition of asphalt were also attempted, but immediately proved to be disastrous, perhaps because of the poor homogeneity of the slurry, which was mixed by hand.

A second type of capping was used to cover a large section of a wall, at Tell 'Umar. It consisted of a single layer of new stabilized bricks, made with the same soil-cement mix with the addition of straw. This allowed for a proper drainage system for the water that ran down from the artificial hill. A large quantity of bricks was manufactured using wooden molds. They were well dried in the sun for over a month, covered with wet straw mats for the first week and turned over every three days. The resulting bricks were perfectly solid, without any cracks.

Evaluation of the results

All the work in Iraq was done mainly in 1969. In the spring of 1971, the ethyl silicate treatments were still in perfect condition, and it was easy to notice the difference between the treated and untreated parts, which had already severely suffered from rain. The capping with soil cement showed some cracks, and in a few parts water infiltration had eroded preferential channels. The new layer of bricks was perfectly preserved with the exception of the vertical walls at the end of the drainage system which, being immersed in water, had collapsed. At that time, some repairs were made. After this, no maintenance work at all was done to the site, which was abandoned.

Figure 11. Another view of a small room in the "Archives".

The present situation, after twenty years

In May 1989 a critical evaluation of the work was done. The capping with one layer of straightened bricks gave the best results (see figs. 5,6). The canal that was devised to disperse the water proved to be effective (see figs. 7,8,9). At one point the water found a different path, and a lot of damage occurred. It would have been easily avoided if the site had been maintained.

The necessity of maintenance can never be stressed enough.

Some of the vertical walls were broken by the pressure of the roots and trunks of trees. On the north side, where the new bricks were not put in place, erosion due to water caused the loss of large mass of earth (see fig. 7).

Figure 12. Detail of the soil-cement capping, partially detached and cracked. Besides damage due to temperature changes and water infiltration, it should be remembered that people walked on the capping.

Overall, the technique of putting one layer of new bricks on top of the walls can be judged in a very positive way. Of course, the original material is no longer visible, but all archaeological and architectural information is still retrievable from direct inspection. This sacrificial layer can easily be removed in case more excavation is needed. This technique should not be confused, by any means, with large reconstruction of walls that are quite often carried out even using baked bricks set on top of small remains of adobe walls. This type of intervention should never be done.

The general condition of the Archives was disappointing (see figs. 10,11). Most of the small rooms were filled with earth, in part fallen from the walls, in part carried in by the wind. In some parts the capping had resisted, while in other parts it was cracked, allowing water infiltrations (See fig. 12). This confirms the opinion [8,9], that in the case of small rooms located below the field level, without drainage and with the possibility of water pool formation at the base of the walls, the only possible intervention is complete, immediate backfilling.

To check if the capping reduced in any way the speed of deterioration, a comparison was done with the nearby excavation of "Via Porticata", which had undergone the same abandonment for twenty years. Most of the walls completely disappeared, with the exception of two rooms, capped with soil cement (see figs. 13,14).

Figure 13. Rooms at "Via Porticata", in the Seleucia area, without any conservation work.

It can be concluded that the endurance of walls can be enhanced, to a certain extent, by soil-cement capping, provided that the bases of the walls are not in direct contact with water. It should be noted, however, that constant maintenance is needed, which seldom can be ensured. Furthermore, since the weakest point is the connection between the capping and the original vertical surface, capping the top part of a wall has some meaning only if the vertical surfaces are consolidated as well. In any other case, the capping is almost ineffective.

The ethyl silicate treatments done at the Archives were not visible, since most of the walls were covered with debris. After excavation the consolidated part was not relocated. The moisture and salt content were extremely high, and the very next day the entire surface of the excavation was covered with white salt efflorescences. The water table level was less than a meter deep. Unfortunately there is not enough documentation to establish when and why the treatment failed. What can be said is that under drastic conditions - e.g., when a wall is impregnated with salt water for twenty years - the consolidation with ethyl silicate is not effective enough to protect it.

Figure 14. Two rooms at "Via Porticata" which were protected with the soil-cement capping. In this case the capping performed better, probably because people did not walk over it.

In Hatra environmental conditions are different from Seleucia. The rainfall is more or less the same, but the water table is much lower. The treated wall had a stone base and did not collapse. The effect of rain alone on treated and untreated parts can be seen. One row of bricks at the top was left untreated for comparison. Figures 15 and 16 show that clay from the top row was washed down and covered the treated bricks. This clay encrustation was easily removed by the use of a rough brush, without effecting the consolidated surface. Even very fine details (see figs. 17,18) were perfectly preserved.

It can be concluded that in this case (as in many other similar ones, for example in Chan Chan, Peru) the ethyl silicate treatment did confer enough strength to the surface to counteract the effect of rain for twenty years.

General conclusions

Of the various conservation measures undertaken in Iraq twenty years ago, some endured this long period of abandonment remarkably well, and some did not.

Among the positive interventions one can note: a) the covering of the top of walls with a sacrificial layer of one row of new bricks; b) the repairs of already damaged walls by the use of the same kind of bricks, when well anchored to the original part; c) the water disposal obtained by the canalization of rainfall using ad hoc designed paths made with the strengthened bricks; d) the surface treatment of vertical walls with ethyl silicate, provided that the bases of the walls are not damaged by water.

Even small faults in the execution of this kind of work can

Figure 15. Wall treated with ethyl silicate in Hatra, as it appeared in 1969. The top layer of bricks was not consolidated.

Figure 16. View of the same wall in 1989. The bricks on the top are washed away from the rain, and the material ran over the lower, consolidated part.

Figure 17. Detail of the same wall in 1969.

Figure 18. Same detail after partial cleaning with a harsh brush (see especially the white gypsum mortar). Even small details are well preserved.

result in serious damage. It seems advisable, therefore, to re-evaluate the interventions after a period of time, correcting the possible mistakes. It should be stressed that a regular maintenance program is of paramount importance.

Among the failures is the capping done with a thin layer of strengthened soil directly on top of walls. Although it produced some results, it was not sufficient to preserve the walls for such a long period, especially under the very harsh conditions at Seleucia Archives. The formation of water pools at the bases of walls remains the biggest problem.

The ethyl silicate treatment on surfaces of walls severely affected by salt water also seems not to be a strong enough protection.

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Materials

SILESTER ZNS: ethyl silicate partially condensed (about 10 molecules of monomer), produced by MONSANTO (USA). Dealer: Pietro Carini, Via S. Marta 23, Milano (Italy) Tel. 06-874477.

TEOS: tetraethyl-ortho silicate, produced by Union Carbide Corporation. 270 Park Avenue. New York 10017 (USA).

Wacker Strengthener OH: Ethyl silicate mixed with solvent (toluene) and catalyst, produced by Wacker-Chemie GmbH, Prinzregentenstrasse 22, Munchen (FRG).

SYNTHETIC LATEX-SOIL SLURRY, A NEW ADOBE PRESERVATION TECHNIQUE

Richard L. Ferm
The International Foundation for Earth Construction
3282 Theresa Lane
Lafayette, CA 94549
U.S.A.

ABSTRACT

The problems of unnatural appearance and poor adhesion usually encountered when synthetic latexes or latex plasters are applied to adobe are overcome by use of a latex-soil slurry applied as a thin coating. The key property of these coatings is the ability tc prevent the passage of liquid water while allowing the escape of vapor water from the interior of the structure. Due to the high fluidity of the slurry, application can be made a simple brushing operation.

KEYWORDS

Adobe, latex, soil-slurry, stabilization, erosion protection.

Background

A wide variety of polymers and polymerizable monomers have been evaluated in the preservation and restoration of earthen or stone structures and artifacts [1]. Most of these are applied as penetrating solutions or sprays. Synthetic latexes (aqueous polymer emulsions or dispersions) have been used for such work only to a limited extent, mainly as binders for plasters or mortars. Typical examples are Fenn's work at Fort Bowie [2] and Bent's Old Fort [3].

The author has investigated the application of latexes to soils for a number of years in both laboratory and outdoor exposure tests that have clearly indicated the benefits and problems presented by these materials. Latexes, like most aqueous treatments, penetrate very slowly and darken the surface; moreover heavy applications give an unnatural glossy appearance. On the other hand, latexes are easy to work with and clean up, and some have excellent mechanical properties and resistance to degradation. These properties depend on the structure of the polymer and also on the type of emulsifier used in making the latex. The emulsifier greatly affects the degree of wetting and spreading of the polymer spheres in the latex on the soil particles. The relationship between the electrical charge of emulsion particles and that of mineral surfaces referred to by Clifton [4] has been found to be too simplistic to allow a narrow definition of the best emulsifiers. Many of the latex emulsifiers are nonionics.

The author has evaluated a large number of synthetic polymer latex commercial products and found only three or four so far that are suitable for adobe preservation/restoration work. These are Airflex (R) 500 and 510, an ethylene-vinyl acetate copolymer; UCAR (R) 365, a vinyl-acrylic copolymer; and possibly Rhoplex (R) E-330, an acrylic resin emulsion, which was promising in some initial testing. The field testing was all done with Airflex 510 or UCAR 365.

Latex used as a binder for plaster does not usually cause a color change problem if soil identical or very similar to the substrate is used. Sometimes soil eroded from the structure to be treated can be used. Latex-soil plasters tend to have a short useful life due to adhesion failure. This is because most plasters are fairly thick, 0.5 cm or more, and are usually mixed with latex contents of 5% or more based on the weight of dry soil used. Note that most latexes contain 45% to 55% by weight of active polymer. The combination of thickness and high polymer content can make a moisture barrier that will allow the accumulation of water at the interface between the wall and the plaster. Both additional damage to the interior and loss of the plaster will result in time. This problem has been described in detail by Clifton [5] who points out that restoration work on adobe by indiscriminate application of preservation materials can cause more damage than benefit.

A New Approach: Latex-Soil Slurry

In an attempt to balance the benefits of polymer-containing coatings and plasters against the problems they may create, the use of thin coats of latex-soil mixtures of slurry consistency was investigated. Field tests on adobe test walls did not develop any of the problems described above and were very effective in preventing erosion for four years of San Francisco Bay area weather. These coatings function by shutting out liquid water, but allowing vapor water to escape from the interior, and thus prevent interior condensation. Key features are the liquidity provided by adding sufficient water to the coating mixture to give a slurry and thus allow a thin application, and a reduced amount of latex, 0.5% to 3.0% (as supplied) based on the dry weight of the soil in the mix. The cured coatings were about 1.5 to 3 mm thick.

Application Technique

The consistency of the latex-soil slurry is regulated by the water content and does not appear to be critical. The amount of water to be used is determined by making trial mixes with the test soil and generally is about 17% to 20% of the weight of dry soil. The optimum amount of latex will probably be about 1.0% to 1.5% of the dry soil weight, but should be confirmed by making several small scale applications with slurries containing a range of latex concentrations. The test slurries are applied to a suitable substrate, allowed to cure for several days of dry weather, and then evaluated for erosion resistance. Rubbing the wet test surface with the finger should not result in a loss of soil after moistening with a water spray. The minimum amount of latex that gives satisfactory erosion resistance should be used. The latex should be first mixed with the total amount of water to be used to ensure a uniform coating. An ordinary paint brush works well as a slurry applicator. A gunite-type sprayer could probably be used for a large project. The slurry should be mixed occasionally, but settling does not appear to be a problem. The slurry can also be stored in a closed container and remixed again before use.

The substrate should be in sound condition prior to slurry application. Loose material should be removed by brushing if not too deep or extensive. Reinforcement of the surface prior to slurry application can be accomplished by a light treatment with a penetrating resin solution. The application rate must not be so heavy that it will form a water vapor barrier. Acryloid F-10 (R), a 40% solution of butyl acrylate in an aromatic naphtha, applied as a 10% solution in xylene works well. Acryloid F-10 has excellent weathering properties, but darkens the soil surface to an extent that it would probably not give an acceptable appearance without a latex-soil slurry overcoat.

The application of latex-soil slurry will not prevent the wicking up of ground moisture into the lower layers of the an adobe structure. In some cases the injection of a chemical grout or insertion of a metal barrier plate at ground level, as suggested by Clifton and Davis [6], may be considered.

Field Evaluations

All tests were made on walls constructed of unstabilized adobe bricks and plain soil mortar obtained from the Hans Sumpf Adobe Company of Madera, California. This adobe soil is considered an ideal soil for brick making. The composition is shown in Table I. These unstabilized bricks were made in a special plant run during which the usual asphalt emulsion stabilizer was withheld.

The test walls were constructed and coated in the fall of 1982 in the San Francisco Bay area. Four of the walls were about 1.5 m wide and 1 m high. The fifth wall was 3 m long and 1 m high. Soil slurry compositions ranged from 1.5% to 3% latex (as supplied) based on the dry soil weight. Only the Airflex 510 (R) and UCAR 365 (R) latexes were used. Application of the slurries was made with an ordinary paint brush. The coatings had a thickness of about 1.5 to 3 mm. Plaster of the same composition was troweled on one of the short walls and on the long wall. Some of the wall areas were given a light spray of a 10% solution of Acryloid F-10 (R) in xylene one day prior to the slurry appplication.

Inspections were made at intervals until January 1986 when shortly thereafter the four short walls were demolished to make room for another project. The fifth longer wall still stands today and continues to be used for new experimental work. At the last inspection in 1986 a heavy rain was falling making it possible to evaluate color and surface hardness under wet conditions. All applications, except the heavier plaster application, were in excellent condition. The thick plaster had serious adhesion failures. Otherwise no differences were observed between the two latexes or their concentrations. All surfaces when wet had the usual dark color of wet soil; they all returned to the normal soil color when dry. When the surfaces were pressed with a blunt rod, the areas sprayed with Acryloid F-10 (R) prior to slurry application had greater resistance to indentation than the corresponding untreated areas.

The longer wall which had been coated with a heavy latex-soil plaster developed serious adhesion problems and damage to the interior core. It has since been repaired and is being used to study other restoration methods.

Conclusions

Application of latex-soil coatings as a fluid slurry is a promising method for preserving and restoring adobe structures. However, since all field testing has been conducted with only a single soil type and outdoor exposures have been limited to only several years, the method should be regarded as experimental until tested more extensively. Thin application and use of minimum latex content in order to avoid formation of a water vapor barrier prevent wind and water erosion without damaging the core soil structure. The slurry is easy to apply and should be lower in cost than many preservation techniques. The method should also find application for earth housing improvement in developing countries as well as for the preservation of historical structures.

Table I

Composition of Hans Sumpf Company Adobe Soil

Particle Size Analysis

By wet sieve:

Grain size, mm	% Finer, by weight
2.30	99.9
1.00	95
0.59	83
0.30	64
0.20	56
0.15	52
0.08	45

By Coulter Counter (R):

On fraction below 0.08 mm grain size

Mean grain diameter: 7.3 μm

5% by volume is greater than 27 μm

95% by volume is greater than 2.0 μm

Clay Types

Kaolinite and clorite:	15%-20%
Bentonite:	Nil

Materials List

Airflex 510 (R), Aqueous emulsion of ethylene and vinyl acetate copolymer, 55% solids, Air Products & Chemicals, Inc., Box 535, Allentown, PA 18105. Telephone: (800) 345-3148.

UCAR 365 (R), Aqueous emulsion of vinyl-acrylic copolymer, 55% solids, Union Carbide Corporation, 39 Old Ridgebury Road, Danbury, CT 06817-0001. Telephone: (203) 794-6300.

Acryloid F-10, Butyl methacrylate polymer, 40% solution in VMP naphtha, Rohm and Hass Company, Independence Mall W., Philadelphia, PA 19105. Telephone: (215) 592-3000.

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DETERIORATION AND CONSERVATION OF SOME MUD BRICK IN EGYPT

FATMA M. HELMI
Cairo University, Faculty of Archaeology,
Conservation Department,
Giza, Egypt

ABSTRACT

Mud brick from two archaelogical sites at Abu-Sir and Mataria in Egypt was studied by X-ray diffraction, atomic absorption, thin section analysis, and scanning electron microscope. X-ray diffraction data showed that it consists of the following minerals : quartz, plagioclase and potash feldspars, mica, and variable amount of clay minerals. Deterioration phenomena are due to chemical weathering by water and effect of salt. Consolidation of mud brick was carried out by applying tetraethoxysilane, methyltrimethoxy silane, and methylmethacrylate-butylacrylate copolymer. Results were examined by scanning electron microscope.

KEYWORDS

MUD BRICK, DETERIORATION, CONSOLIDATION, WEATHERING, X-RAY DIFFRACTION, PETROGRAPHY.

1. INTRODUCTION

Mud brick has been widely used in ancient Egypt since the predynastic period in Naqqada, Upper Egypt. It was commonly used in constructing tombs in the 1st and 2nd Dynasties at Saqqara and Aby-dous. Clay was abundant all over Egypt, so houses were built from mud bricks which were suitable to the dry climate of Egypt. The size of the ancient Egyptian mud brick varied, some had the same dimensions as the recent ones, while others were very large size. In the Egyptian museum, there are two ancient mud brick with dimensions 96.5 x 53.3 x 30.5 cm. As stone became known, tombs and temples were constructed from it, whereas houses and pharaonic palaces were still built from mud brick both for poor people and for nobles. This is the reason that most of ancient Egyptian houses and palaces have vanished, because mud brick is less durable than stone used for tombs and temples [1].

Mud brick is composed of sand, silt, clay, and fibrous organic materials such as straw may also be added. Sand was added to increase compressive strength and minimize cracking when the adobe dried. Non-clay minerals act as internal binder. They reduce contraction and prevent cracking [2].

At excavation sites in Abu-Sir and Mataria, it was found that mud brick structures were very friable and extensively deteriorated. The aim of the present work is to study the deterioration factors of adobe. in these two sites and to find out the suitable consolidants for their conservation.

2. EXPERIMENTAL

2.1. Mud Brick Samples

Two mud brick samples from Abu-Sir (Old Kingdom 1st Dynasty) and Mataria (Roman Period) were studied. The samples were very friable and had pale grey colour.

2.2. X-Ray Diffraction Analysis

The samples were ground in an agate mortar to a fine powder, pressed in the specimen holder, and then mounted in a Philips X-ray diffractometer. The operating conditions were : Generator : Cu $K\alpha$ radiation (1.5418 A°) with Ni filter, 40 Kv, 20 mA current tube, speed : 0.1, chart : 5, Range : 1 x 10^3, time constant : 1, and silt : 0.1.

2.3. Chemical and Atomic Absorption Analyses

Complete chemical analysis of mud brick samples was carried out. Also the samples were immersed in deionized water for 24 hours, and the washing water was analysed for determination of the following ions and groups : Na, K, Ca, Mg, Cl, SO_4, CO_3.

2.4. Thin Section Analysis

Mud brick samples were sectioned, mounted on microscopic slides. Different minerals of each sample were identified using a Leitz polarizing microscope.

2.5. Consolidation

Three cubes 5 cm^3 were cut from each mud brick sample, then treated with tetraethoxysilane [TEOS], trimethylmethoxysilane (MTMOS), and methylmethacrylate-butylacrylate (MMABA) copolymer separately by penetration through capillary rise. The first two consolidants were used without dilution, but the last copolymer was diluted in 1:1 toluene and xylene. After one month the samples were treated once again, then allowed to stand for one month before examination with scanning electron microscope.

2.6. Scanning Electron Microscope (SEM) Examination

The treated samples were sputter-coated with gold (10 nm thickness) then were examined by SEM to compare the action of the consolidants and whether they filled pores, and the shape of the polymer links between grains after the polymerization process.

3. RESULTS

3.1. Abu-Sir Mud Brick

X-ray diffraction data of this sample Fig. 1 (a) indicated that it consists of α-quartz α SiO_2 (5-0490), Anorthoclase (Na, K) $AlSi_3O_8$ (9-478), albite Na $AlSi_3O_8$ (10-393), and trace amounts of biotite K(Fe, Mg)$_3$ $AlSi_3O_3O_{10}$ $(OH)_2$ (2-0045), kaolinite $Al_2Si_2O_5(OH)_4$ and montmorillonite $Na_{0.3}(Al, Mg)_2$ $Si_4O_{10}(OH)_2$. n H_2O (29-1498). Thin section examination Fig. 2 (a) showed quartz crystals (white), and large grains of orthoclase (simple twinning) in a matrix of fine grained silt and clay minerals, and organic materials. Most of the constituting grains were angular. Chemical analysis showed that it consists of 84.8% (by wt.) insoluble in HCl (silica and silicate minerals), 8.22% Al_2O_3, 1.30% Fe_2O_3, 0.67% Na_2O, 3.21% K_2O, 1.20% CaO, and 1.25% MgO. Atomic absorption analysis of the sample washing water showed that it contains 0.042 Na^+, 0.017 K^+, 0.015 Ca^{2+}, 0.003 Mg^{2+}, where volumetric chemical analysis confirmed the presence of 0.015 Cl^-, 0.004 SO_4^{2-} and 0.03 CO_3^{2-}.

SEM micrographs of this sample after treatment with TEOS, MTMOS, and MMABA are shown in Fig. 3 (a, b, c) respectively. In the case of TEOS the polymer network was formed on the grains and constitute links within pores. MTMOS forms less a continuous layer on the grains and also did not succeed in creating good links between grains. The copolymer shows a spongy form of the unhomogenous resin links.

3.2. Mataria Mud Brick

X-ray diffraction data of this adobe showed that it consists of the following minerals: α-quartz α-SiO_2 (5-0490), albite $NaAlSi_3O_8$ (10-393), anorthoclase (Na, K) $AlSi_3O_8$ (9-478), and trace amounts of biotite K(Fe, Mg)$_3$ $AlSi_3O_{10}(OH)_2$ (2-0045), and montmorillonite Na_n (Al, Mg)$_2$ $Si_4O_{10}(OH)_2$. n H_2O (12-219). Thin section analysis of the sample demonstrated quartz grains, some small and others large, plagioclase feldspar (Lamellar twinning) in a matrix of fine grained silt and clay minerals. Chemical and atomic absorption analyses of this sample showed that it contains 78.0% (by wt.) insoluble in HCl (Silica and silicate minerals), 9.58% Al_2O_3, 3.50% Fe_2O_3, 0.68% Na_2O, 5.04% K_2O, 1.40% CaO, and 2.48% MgO. Its washing water contains 0.038 Na^+, 0.017 K^+, 0.008 Ca^+, 0.002 Mg^{2+}, 0.012 Cl^-, 0.003 SO_4^{2-}, and 0.03 CO_3^{2-}.

SEM micrographs of the sample after treatment with TEOS, MTMOS, and MMABA are given in Fig. 3 (d, e, f) respectively. It is clear that TEOS was precipitated as nodules and penetrated through pores and around grains. MTMOS Fig. 3 e showed that links were formed also between grains but there are still large areas where little precipitation of the polymer occured. MMABA did not succeed in forming network links of the polymer.

4. DISCUSSION

The properties of mud brick and its durability to weathering depend to a great extent on their constituents and the interactions between them. Also, on the local environmental conditions. The amount of sand which is mostly the major component, silt or clay minerals which act as a binder, and the existence of organic matter, limestone, or fired brick, all play an important role in the deterioration process.

In the present work, results showed that ancient Egyptian mud brick samples consist essentially of quartz, plagioclase and potash feldspars in a loose packing matrix of silt and clay minerals, and organic materials. The author thinks that the main internal causes of deterioration of the examined mud brick were the loose packing and the angular ill-sorted constituting grains of different sizes. The cement material was not distributed regularly between quartz grains. There are large areas of fine silt and clay particles, where other areas have concentration of loose angular quartz grains as could be seen from thin section analysis and SEM micrographs (Figs. 2, 3). Also, the percentage of silt and clay is much more than in the ideal adobe stated by

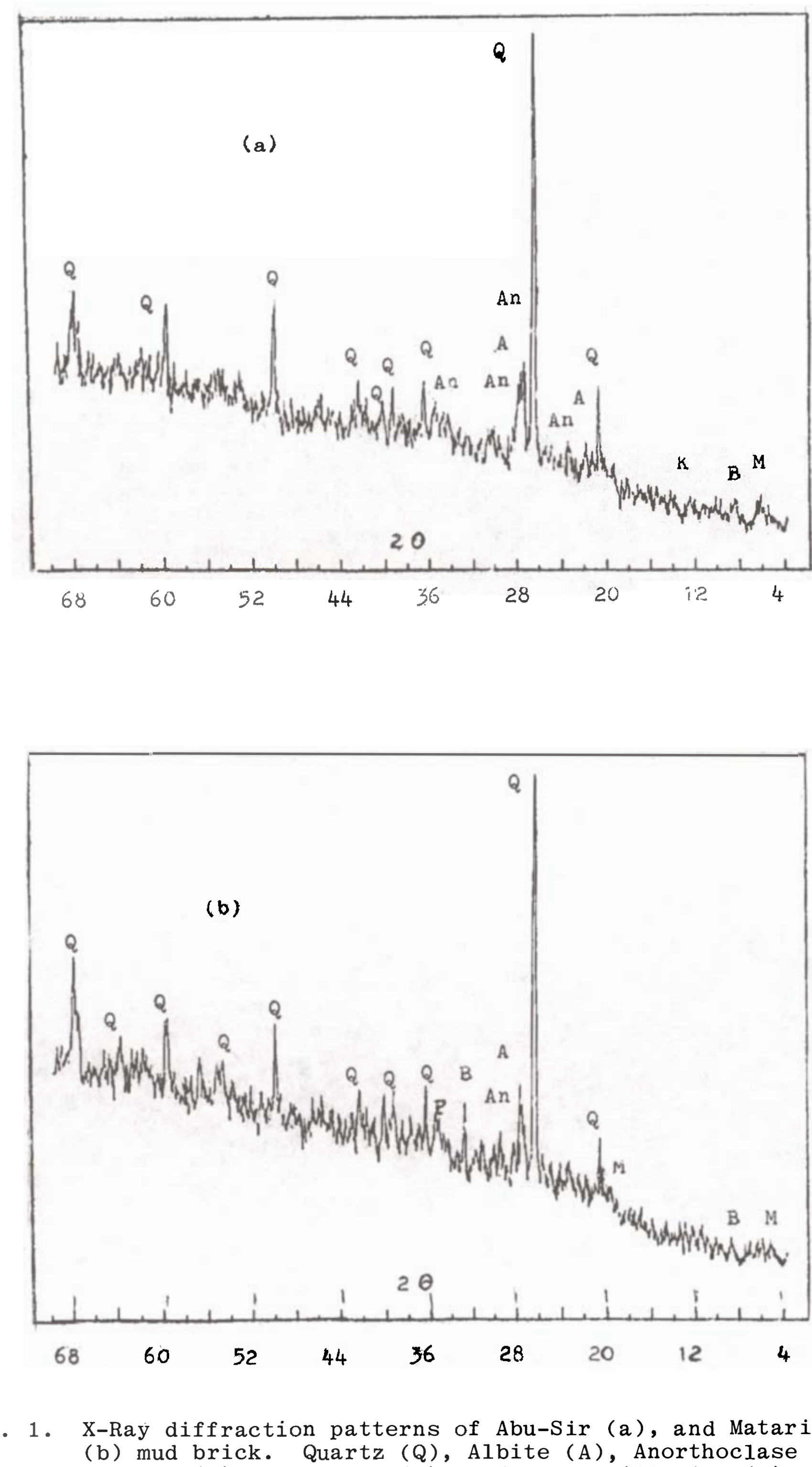

Fig. 1. X-Ray diffraction patterns of Abu-Sir (a), and Mataria (b) mud brick. Quartz (Q), Albite (A), Anorthoclase (An), biotite (B), Kaolinite (K), and Montmorillonite (M).

Clifton [3, 4]. The adobe based on different clay minerals may react to increasing water content. Montmorillonite adobe will be much more responsible to compressive deformation than a kaolinite one for the same amount of absorbed water [5].

Water is a serious factor for adobe deterioration. Absorption of water causes swelling of clay minerals and evaporation give rise to shrinkage, cracking, and breaking. The location of Abu-Sir excavation is near cultivated land; the adobe structure walls were found immersed in water due to the high water table level in this area. So, effect of water on adobe is erosion of surface along cracks and fissures, leaching of clay and silt matrix, and dissolution of soluble salt [6, 7]. Migration of soluble salt occurred towards the surface by evaporation, and recrystallization took place at the surface led to adobe deterioration.

Temperature fluctuation between day and night in both excavation sites is another possible factor for physical weathering of adobe in Egypt. Swelling by humidity in the early morning, and shrinkage at mid-day cycles likewise, may be implicated. Also, thermal stress and unequal expansion of the different constituents takes place giving rise to adobe disintegration.

Wind borne sand and detritus materials mechanically attacked adobe in both areas causing its abrasion. Riederer [8], has noted the intense mechanical attack of wind on stone in tropical countries.

The application of consolidants is very important for adobe conservation, which transform in situ into a polymer confer adobe new properties of durability and weather resistance. In the present work it is found from the obtained data that TEOS is the most suitable consolidant for the studied Egyptian adobe. It has low viscosity and penetrates well through adobe structure. Hydrolysis takes place by moisture in air and in adobe itself forms a network Si-O polymer in its structure and ethanol is evaporated. This agrees with the acceptance of Fielden [9], Gamarra [10], and Lewin [11] that TEOS with or without MTMOS and MEOS respectively as a surface treatment for adobe. The author's current research is the application of MTMOS as water repellent material after treatment of adobe with TEOS . MMABA is excluded because it may cause cracking by time and effect of U.V. radiation in situ, this in addition to the weak formed links in adobe structure.

5. CONCLUSIONS

Deterioration of mud brick in Egypt at Abu-Sir and Mataria excavations is due to the usual causes (ground water, thermal cycling, wind abrasion) but is accelerated by the adobe texture. Ill-sorted and loose packing of the different size constituent grains. TEOS was found to be the best consolidant for Egyptian adobe structure.

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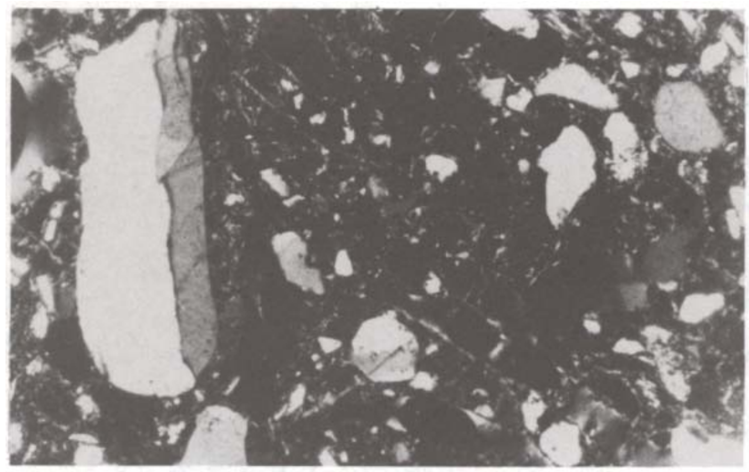
a



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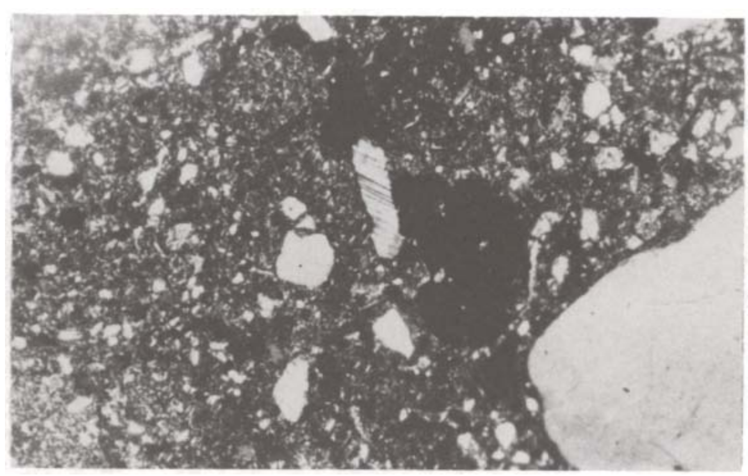


Fig. 2. Thin section photographs of Abu-Sir (a), and Mataria (b) mud-brick showed quartz, potash and plagioclase feldspars in a matrix of silt and clay minerals. x nicols, 6.3 x.

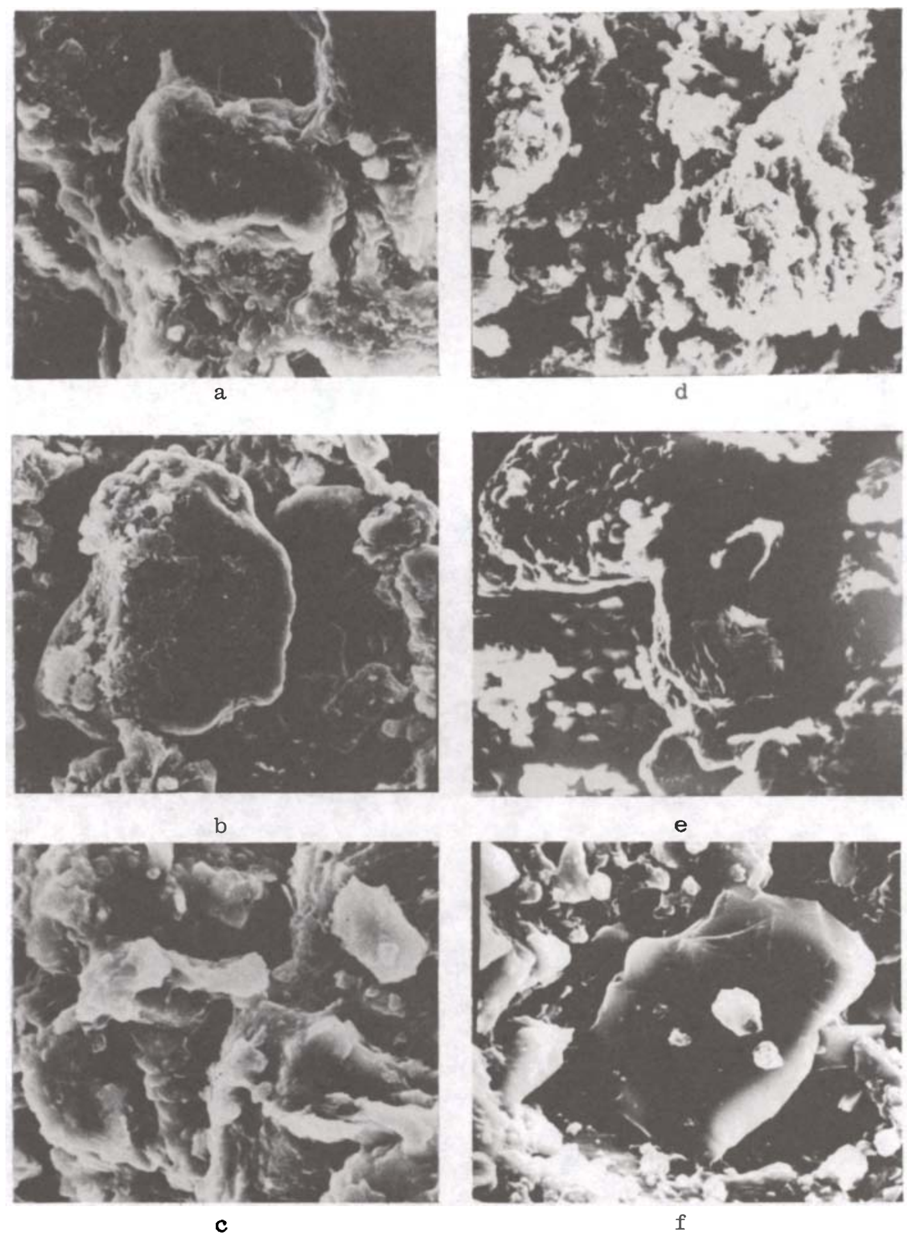


Fig. 3. SEM micrographs of Abu-Sir mud brick (a, b, c) and Mataria mud brick (d, e, f), after treatment with TEOS, MTMOS, and MMABA respectively, 400 X.

ABSTRACT

THE KEZIER GROTTOES, in the Xinjiang Autonomous Region of China, were carved in mudstones and sandstones. These natural sediments are poorly consolidated and behave like earth, disintegrating rapidly when immersed in water. Extensive research tests are reported on the use of potassium silicate of high molar ratio $SiO_2 : K_2O$ (typically 3.8) together with magnesium fluorosilicate and, in some instances, silanes such as methyltriethoxysilane as consolidants for the sediments. These yielded water-resistant products. Freeze-thaw, salt-resistance, accelerated aging, and water-absorption tests are reported. In field tests, walls were wrapped in gauze, wetted with glycerine and covered with plastic to prevent rapid drying and the formation of K_2CO_3.

KEYWORDS

Cave art, China, Consolidation of sediments, Grottoes, Magnesium fluorosilicate, Potassium silicate

THE WEATHERING CHARACTERISTICS OF THE ROCKS OF THE KEZIER GROTTOES AND RESEARCH INTO THEIR CONSERVATION

Huang Kezhong, Jiang Huaiying, Cai Run, Feng Lijuan
Scientific and Technical Institute for Conservation of Cultural Relics
People's Republic of China

Introduction

The Kezier Grottoes (Fig.1) are located in the Xinjiang Autonomous Region of northwestern China. They were carved in Tertiary mudstones and sandstones which are so poorly consolidated and cemented that they disintegrate immediately upon being wetted. In this respect they are similar to man-made earthen materials.

Fig.1 Kezier Grottoes; view near Cave 18 on the western side.

In 1986 the grottoes were surveyed, and it was noted that rapid deterioration was occurring despite the extremely sparse rainfall in the region. What little precipitation occurs is focussed into run-off channels that dissect surfaces and periodically cause collapse of large sections. Within the grottoes alkaline salts also cause flaking of the wall paintings.

In order to understand the characteristics of disintegration and develop strategies for consolidation and protection of the grottoes, a research program was undertaken. This addressed the mineralogy, chemical composition, soluble salts, and extensive laboratory and in-situ tests of consolidants. Accelerated aging tests are presently underway.

Rock Characteristics and Their Physical and Mechanical Properties

Lithological characteristics:

The geological strata of the grottoes region is the upper unit of the Tertiary period. The sediments are lacustrine in origin and are comprised of mudstone, sandstone, as well as lesser amounts of coarse sandstone, and gravel mudstone. The sandstone is grey to greyish-green, and its mineral components are mainly quartz, feldspar, as well as a lesser amount of a black mineral. Typically the thickness of single bed was 3-4 m. The cementing agents are calcareous or calcareous-mud, and the binding properties are poor, as shown by rapid disintegration of the rock in rainwater.

The rock walls in the grottoes have five to six layers of mudstone, the thickness of each being about 2 m. They are brown or grayish brown in color and contain soluble salts with locally fine gypsum layers, which weather easily.

Microscopy:

This work was carried out by the Geological Institute of the Academy of Sciences of China. Comprehensive chemical analysis, X-ray diffraction analysis, differential thermal analysis and scanning electron microscope examination has been done. The sandstone was poorly cemented and contained a great deal of carbonate (36.5% or so), and other soluble salts such as NaCl, $MgCl_2$, and $CaSO_4 \cdot 2H_2O$. After being fully submerged in water the rock lost its strength and completely disaggregated (Figs. 2, 3). The mudstone contained 5 -6 % montmorillonite.

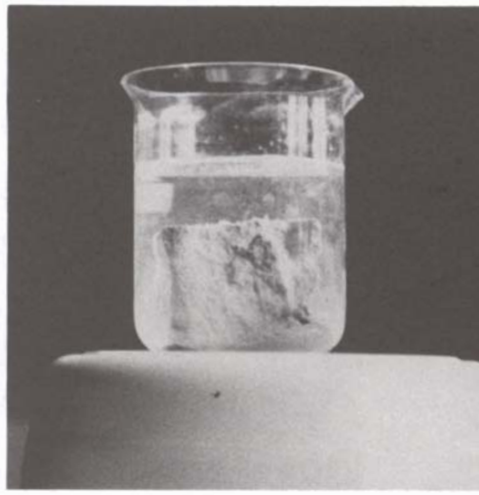


Fig.2 Photograph showing sample of the rock immediately after being placed in water.

Fig.3 Photograph showing the same sample (fig.2) 10 minutes later.

Physical properties and Mechanical strength:

The physical properties are presented in table I. In view of the fact that the sediments were so poorly compacted and fragile, a point loading instrument was used for tests of mechanical strength. The advantage of this method is that it avoids the problem of irregular samples, while allowing for the examination of seriously weathered sample surfaces. Typical averaged values of mechanical properties are presented in table II.

Table I Physical properties:

Sandstone:

bulk specific gravity	= 1.86g/cm^3
specific gravity	= 2.72
porosity	= 20.9%
pore volume	= 0.113 cm^3/g
mean pore radius	= 27.7 x 10^{-5} cm
water content	= 1.55 - 7.3%

Mudstone:

bulk specific gravity	= 2.01 g/cm^3
specific gravity	= 2.74
void ratio	= 0.267
water content	= 2.74%

Table II Mechanical properties:

Semi-weathered rock:
S_t = 0.86 kg/cm^2
S_c = 18.23 kg/cm^2

Weathered sandstone:
S_t = 0.66 kg/cm^2
S_c = 13.93 kg/cm^2

Semi-weathered mudstone:
S_t = 23.58 kg/cm^2
S_c = 497.8 kg/cm^2

where S_t = tensil strength,
and S_c = compressive strength

Consolidant Testing

Selection of materials:

Chemical consolidation should improve the physical and chemical properties of the rock and their water-resistance, thereby stopping their deterioration due to rain. The protective measures we considered using were treating the rock with weather-resisting chemicals.

According to the properties of the rocks and climate of the Kezier Grottoes, we decided first that the prerequisites for the selection of consolidants were improved water-resistance and compressive strength. In view of the fact that the rock is poorly compacted, the consolidants should have good penetration, show resistance to freezing and weathering. Because the chemical materials were not used directly on the mural paintings within the grottoes, a little difference in color was tolerable.

From the first, we intended to use potassium silicate for treating the rocks and invited our colleagues of the Administrative Unit of Binglingshi Grottoes, Gansu Province to join in the tests. Two preliminary in-situ test series, and many laboratory tests, were carried out in October 1986 and May 1987. Strength increased because of the use of potassium silicate, but initially depth of penetration and water-resistance were not sufficient. Thus potassium silicate was not used for large-scale treatment at that time. In order to further the project, our institute then researched and developed several new chemical weather-resisting materials based on particular grades of potassium silicate together with other additives.

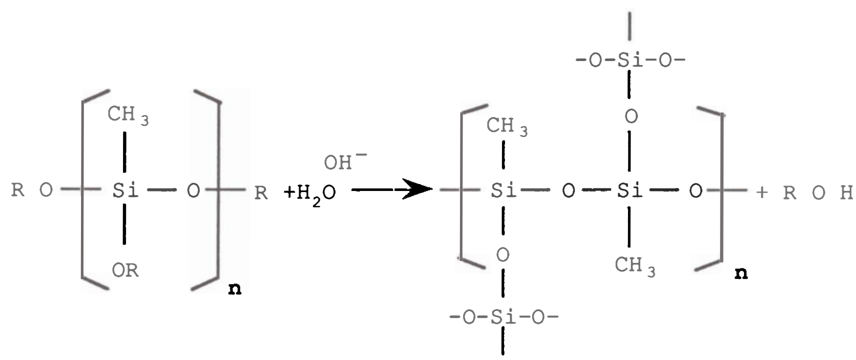
Test principles:

The rock of the Kezier Grottoes consists of quartz, feldspar and carbonates; it is fragile, flakes on rubbing, and disintegrates at once in water. Because the main component of the rock is silicon dioxide, a chemical consolidant which can form an inert silicon dioxide or similar compound was selected. Potassium silicate is weather-resistant but is strongly alkaline (pH 14), thus acidic magnesium fluorosilicate was added to neutralize the alkali and generate inert silicon dioxide and other compounds that would consolidate the rock and leave an inert substrate:

$$2K_2O \cdot nSiO_2 + MgSiF_6 \cdot 6H_2O + 2H_2O = 4KF \cdot 2H_2O + MgF_2 + 2(n+1)SiO_2,$$

where n is the molar ratio of $SiO_2 : K_2O$.

In addition, organic silicon compounds such as methyltrimethoxysiloxane or methyltriethoxysiloxane can form high-molecular silicone under the action of a weak basic catalytic agent:



where R is ethyl (C_2H_5) or methyl (CH_3)

This reaction is fast. In order to meet practical usage, it is necessary to regulate the amount of water and hardening agent as well as increase the amount of alcoholic solvent to slow the reaction. The alcohol serves also to slow the increase in viscosity as the polymerization proceeds and thus facilitates penetration into the rock.

Tests to determine the optimum formula:

A great deal of work on the selection of the best formulas suitable for consolidation of the Kezier Grottoes was necessary. Because of serious weathering of the rock, samples which could be used for tests were limited and it was impossible to obtain many samples for tests. Potassium silicate of molar ratio of $SiO_2 : K_2O$ over 3.4 has been used abroad; in our country potassium silicate of highest ratio 4.1 in liquid state can be produced. In brief, the formula developed was based on an aqueous solution of potassium silicate -- whose value was from 3.4 to 4.1 but mainly 3.8, diluted four-fold with water -- and was also reacted with magnesium flouorosilicate.

Adding magnesium fluorosilicate to potassium silicate solution precipitates catkin-like silicon dioxide immediately. The test called for brushing diluted potassium silicate solution onto the opposite two sides of the sample until it was permeated completely. After seven days of drying it was brushed with 3% magnesium fluorosilicate solution until completely permeated. After a further seven days of drying it was brushed with 5% magnesium fluorosilicate solution.

Samples for testing depth of penetration were brushed on one side only until permeated completely. The size of the sample was 5x5x5 cm. The main advantage of organic silicones such as methyltriethoxysilioxane was its superior water-resistance. However, the high cost of this material prevented its use in the Kezier Grottoes. In these experiments a group of tests of composite materials of inorganic materials and the organic silicones was involved.

In the course of the experiments it was found that if only simple brushing was done, without any wrapping of the samples, then poor penetration occurred on the second application, and the surface was suffused with white. The reason is that after brushing with potassium silicate solution the surfaces dried too quickly and crystals of potassium silicate aggregated on the surface. This converted into silicon dioxide and potassium carbonate after contact with the air. A thin impermeable layer often formed on the surface, preventing the second and third brushings from penetrating. However, if after brushing the samples were wrapped with gauze wetted with glycerine, the moisture evaporated slowly and the potassium silicate remained in the inner part of the samples, such that white potassium carbonate did not form on the surface. Subsequent brushing with 3% magnesium fluorosilicate solution, or 5% for third time, allowed easy penetration. After brushing with organic silanes the samples also were covered with gauze wetted with glycerine, which reduced the volatilization and prevented organic silicone resin from forming on the surface and creating a glossy, reflective layer.

Judging from indoor tests, potassium silicate of low molar ratio had a low strength and uneven penetration while the samples consolidated with potassium silicate of ratio 3.8 had a high strength and even penetration of about 5 cm. For samples treated with potassium silicate of ratio above 3.8 the strength did not increase.

Tests in-situ:

We selected seven rock walls of Kezier Grottoes (Fig.4), each with area of about 1 m^2. After physical tests in-situ to determine the rebound strength, samples were sent to Beijing for testing depth of penetration and water-resistance. Analysis of test results showed that the pure inorganic materials gave deep penetration and high strength, but water-resistance was poor. On the other hand, organic silicones gave good water-resistance, but the strength was poor and the penetration was uneven. We concluded that using composite inorganic and organic materials for consolidating the rocks of Kezier would, ideally, provide the best protection.

Fig.4 Site testing.

Systematic Tests:

In order to verify the test data further, we selected two of the better formulas and divided the test samples into two groups. Group A was the composite material and Group B the inorganic material.

Formula A:
potassium silicate of molar ratio 3.8
3% magnesium fluorosilicate
5% magnesium fluorosilicate
methyltriethoxysiloxane 100
ethanol 70
hardening agent SCP 0.8

Formula B:
potassium silicate of molar ratio 3.8
3% magnesium fluorosilicate
5% magnesium fluorosilicate

Examination of Consolidation Materials

Preparation of samples:

In order to make the data from laboratory tests and those from the in-situ tests comparable, we made it a rule that the preparation of the samples in the laboratory must be identical with the consolidation treatment in-situ. Thus, in the process of consolidation of the samples only spraying or brushing was used; submerging of the samples was not allowed, and that guaranteed the reliability of test data.

Density and porosity:

Mercury injection porosimetry was used to measure density and porosity. It was found that the density of Group A was somewhat higher than that of Group B: Both A and B were sprayed, and both A and B had much higher density than the original rocks.

The calculation of the porosity was by conversion between density and pore volume. The results showed that the porosity of group A samples was much lower than that of group B and original rocks.

Pore volume and mean pore radius:

The pore volume and the mean pore radius were measured for group A and group B. The pore volume of group A was 0.01664 cm^3/g, and was lower than that of 85% of the original rocks whose value was 0.11267 cm^3/g. At the same time it obviously was lower than that of group B. The mean pore radius of group A was higher than that of the original rocks but lower than that of group B.

Strength:

Two methods to measure strength in the laboratory and in-situ were used. In the laboratory, samples (5x5x5 cm) were sprayed on opposite sides. After drying, the sprayed sides were vertically measured by the method of point loading. The tensile strength of S_t = 2.26 kg/cm^2 and compressive strength of S_c = 47.51 kg/cm^2 were 3.4 times greater than those of the weathered rocks and 2.6 times greater than those of semi-weathered rocks. They were also higher than those of group B.

With regard to measurement in-situ, because the concentration of consolidant decreased with depth into the sample, the use of the point loading method for measurement was impossible, and we used the rebound method to measure the surface strength of rock. The surface strength of the original rock was too low to calculate its real strength; thus only the change in rebound value before and after treatment is used to describe their change of strength.

All the rebound values of the original rocks were less than 10, and indentations occurred on the rock surfaces after the measurement. The mean rebound value of Group A was about 15, while that of Group B was about 13. Only a trace of indentation occurred on the treated rock surfaces after the rebound measurement.

Tests for depth of penetration:

Measurement of penetration was based on the disintegration of the original rocks after submersion in water. In laboratory testing only one side of the sample of the 5 cm cube was sprayed which, after drying, was fully submerged in water. The unconsolidated part of the sample disintegrated, and this method showed that the depth of penetration of consolidation was more than 5 cm. Tests for penetration depth in-situ with the same basic method proved that the depth was 4-5 cm.

Tests for water-resistance:

Test samples for water-resistance were divided in two. One was submerged for a long time. The samples, 5 cm cube were sprayed on all sides and fully permeated and cured, then submerged in water. From 6th August 1987 to the present, none have disintegrated, whereas the original rocks disintegrated in less than 10 minutes. The other test was to dry and wet the samples alternately by submersion in water for 24 hours and then by placing them in an oven at 60°C for 72 hours to dry. Some 16 cycles have been completed so far without disintegration .

Water absorption tests:

These determined the amount of water moving through the sample surface per unit area with time. The purpose was to compare the change of capillarity and the water-resistance of surfaces of the rock before and after spraying. The samples were sprayed on one side then prepared into rectangular columns of 2x3x5 cm, dried and weighed and then the sprayed surface of 2x3 cm was brought into contact with water. Later it was weighed and the amount of water moving through the sample surface per unit area was calculated. A plot of water uptake with time was constructed. Both laboratory & in-situ results were determined. For group A the water-absorbing capacity was 0.008 g/cm^2 in 2 hours in-situ, and 0.34 g/cm^2 indoors, and the capillary rise of water was 2 cm in 2 hours. The water-absorbing capacity of the original rocks could reach 1.15 g/cm^2, and capillary height could reach 5 cm. in 10 minutes. For group B the water-absorbing capacity was 0.89 g/cm^2 in 90 minutes, and capillary height of 5 cm in 35 minutes. It was thus clear that the water-resistance of group A has greatly increased.

Freeze-thaw tests:

The 5 cm cube samples were fully sprayed, oven-dried and weighed, then submerged in a vacuum chamber for 1 hour, and placed in a freezer at -20°C ± 2°C for 4 hours before being taken out and thawed at room temperature. This process completed a cycle. From the results of nine cycles, the freezing-resistance of group A was better than that of group B, as well as the original rock.

Tests for salt resistance:

The preparation of the samples was the same as for the freeze-thaw tests. Samples were placed in saturated sodium sulfate solution for 20 hours, then dried at 60°C for 72 hours. After five cycles the stability of the samples of group A was clearly better than that of group B.

Tests for aging:

The protective materials were sprayed on thin samples 4x50x100 cm, and then put into aging apparatus of WE-SUN type, the temperature was controlled at 40°C, and sprayed with water every 3 hours. The apparatus has run for 1000 hours so far. Cracks occurred on the samples because of their thinness, and part of the samples of group A weakened at the corners; most of the samples of group B loosened and disintegrated. Tests are continuing.

Morphological observation:

The rock samples before and after treating were observed with the scanning electron microscope. It turned out that the composite materials either had sealed the sample surfaces of group A, or had filled the pores, but the pores had not been sealed completely. Flake-like inorganic materials also occurred on the rock surface (Fig. 5) and to a depth of 3 cm; flake-like or catkin-like inorganic material also covered the rock surfaces of samples of group B, but pores were filled in to a lesser extent, and some mineral grains were not covered with inorganic consolidant. Under the polarizing microscope we observed the composite materials partly filled in the pores to a depth of 1 cm in group A. On the surfaces of the samples the composite materials covered the minerals thicker than 1 cm. Tests in situ 2 were observed under crossed polarized light, it could be seen that the pores on the rocks' surfaces increased, and many minerals could be resolved. The composite materials showed small granular structure, and the inorganic materials showed catkin-like silicon dioxide.

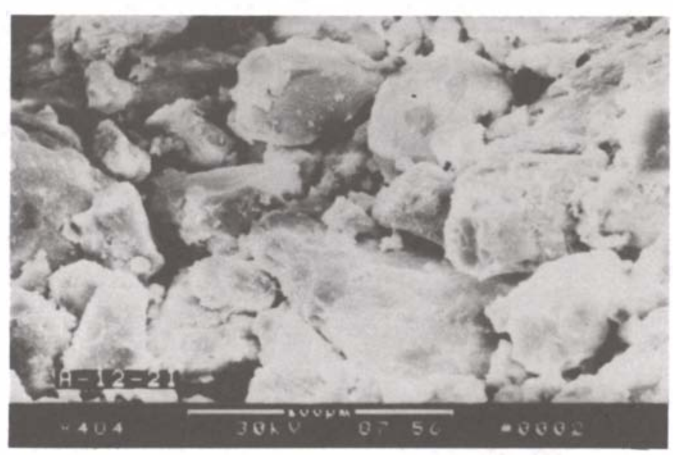


Fig.5 Scanning electron micrograph of the coating material covering the minerals in the rock sample.

Conclusion

Practicable methods of protecting the site against erosion by water were developed. These methods used spraying, or brushing of potassium silicate solutions of high molar ratio of SiO_2 : K_2O (typically 3.8), with other inorganic additives, on the surfaces of the rocks. In some tests these procedures were combined with alkylalkoxysilanes, but the high cost of these materials prevented extensive field use. The problems of K_2CO_3 efflorescence were largely eliminated through use of the appropriate ratio of silicate and by covering the surfaces with glycerine-impregnated gauze to retard drying.

PRESERVING THE EIGHTH CENTURY B.C. MUD BRICK ARCHITECTURE AT GORDION, TURKEY: APPROACHES TO CONSERVATION

Stephen P. Koob*, Mark H. Rogers, G. Kenneth Sams
Freer Gallery of Art and Arthur M. Sackler Gallery
Smithsonian Institution
Washington, D.C., 20560
U.S.A.

ABSTRACT

Conservation of the eighth century B.C. mud brick architecture at Gordion, Turkey, has been long overdue. Partial burning helped preserve some of the mud brick, but little has been done to protect it since excavation over thirty years ago. Two methods of intervention have been tested: consolidation with acrylic resins and protection with a coating of mud plaster. Both methods are viewed as temporary treatments that can be replaced when a more permanent protective treatment is found.

KEYWORDS

Conservation, architecture, mud brick, consolidation, acrylid, mud plaster.

Introduction

There are many individual factors that contribute to the decay of excavation sites, but by far the most destructive and frustrating is the combination of neglect and slow decomposition through time. It is inexcusable that the great relics of our past dissolve away unattended while new trenches are dug nearby. The primary concern at this time should not be the discovery of new civilizations, but the preservation of those already uncovered.

The ancient Phrygian city of Gordion serves as a perfect example of a site where such action is necessary. While this paper will concentrate only on the needs of the site's mud brick buildings, Megaron 1 and Megaron 4, it is by no means intended to obviate the attention needed by Gordion's other monuments.

A Brief Site History and Description

Megaron 1 and Megaron 4 belong to the Early Phrygian citadel that is the dominant feature of Gordion today. Excavations conducted by Rodney S. Young between 1950 and 1973 and by Mary Voigt in 1988-1989, under the auspices of the University of Pennsylvania, have uncovered numerous occupation levels within the 300 x 500 m "City Mound" situated on a flat plain along the Sakarya River about 100 km southwest of Ankara, Turkey (See fig. 1). Settlements run the gamut from Early Bronze Age strata in the tell's lowest layers to an early Roman Empire encampment in the topmost regions of the mound. The exposed sections of Early Phrygian Gordion lie in an enormous 150 x 200 m trench cleared from the eastern half of the City Mound during Young's excavations. Little was known of the Phrygians until Young's intensive search made it clear that by the end of the eighth century B.C. Phrygia, with Gordion serving as its capital, was a prominant civilization exerting considerable control over central Anatolia. It is also apparent that Gordion reached the height of its prosperity under the rule of the legendary King Midas and that Phrygia met its demise as a dominant power under his leadership when Gordion was burned and destroyed by the Kimmerians, a group of nomadic invaders, in ca. 700 B.C.

The Early Phrygian citadel, called the "Destruction Level" because of the significant fire damage and collapse of many of its structures, is divided into three main precincts: a palace area to the northwest, a high terrace to the southwest supporting two long service structures, and a multiroomed building that bordered the

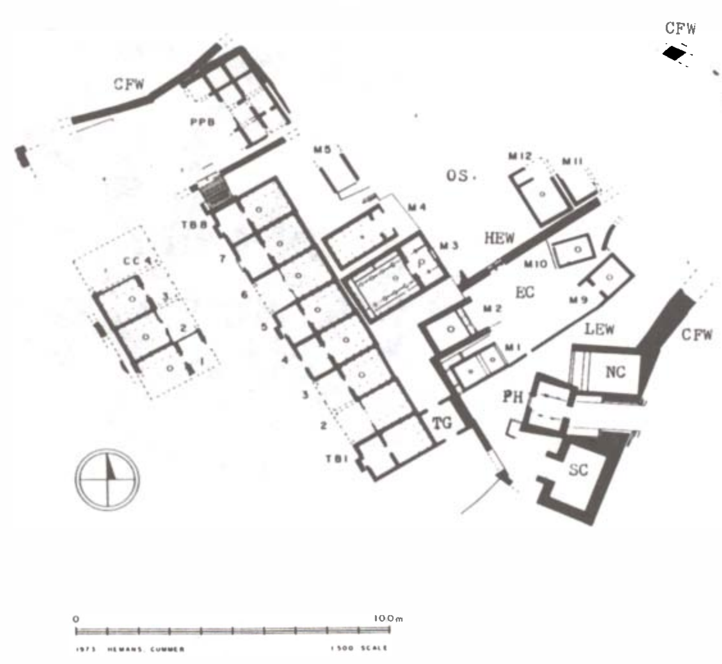


Figure 1. Gordion, overall plan of destruction level.

* Author to whom correspondence should be addressed

city's northwest fortification wall. To the southeast is a massive gate complex that served once as a monumental entrance to the city but was undergoing a rebuilding project at the time of the Kimmerian conflagration. The burned remains of the two mud brick megara stand in the palace area, which consists of two courtyards separated by a heavy enclosure wall running northeast-southwest and each containing groups of megara. Megaron 1 is located in the southwest corner of the "enclosed courtyard" nearest the gate complex (so called because of a light retaining wall that separates it from the gate structures), and Megaron 4 is situated on the northwest side of the "open square", the courtyard northwest of the heavy enclosure wall.

Megaron 1

Excavated in 1956 and dated to the ninth or eighth century B.C., Megaron 1 is one of the earliest buildings of the Destruction Level. The structure measures 9.5 x 17.5 m and consists of a porch and inner room, each with a central hearth (See fig. 2). Entry was gained through two central doorways placed symmetrically along the longitudinal axis, one leading from the enclosed courtyard to the front porch and the other piercing the cross wall between the porch and the inner room. Except for a stone socle the megaron's walls were built entirely of mud brick and wood and then covered with a thick coat of mud plaster. The existing walls are three bricks thick with alternating niches and piers on the inner and outer faces. The niches were left by wood posts set into the wall faces on the exterior and interior of the building and are wide enough to suggest pairs of posts. The remains of the wall faces stand to a uniform height of about 1 m, while the central row of bricks rises somewhat higher and is pierced at regular intervals by holes. A horizontal beam topped off the vertical posts and bricks of either wall face at this level. The voids through the inner brick core were for short crosspieces that tied the framework of each side together. The level above this first horizontal beam would have had its own posts and another wood leveling course above them.

During the fire, the roof--made of beams covered with a layer of reeds coated in turn by clay--collapsed along with all the walls above the first leveling course. The copious amounts of wood used in the timber framework and roof beams in conjunction with the highly flammable reeds must have made the blaze quite intense. This was made apparent by the vitrified state of in situ mud plaster that melted in the fire and began running down the walls. Many of the individual mud bricks, particularly those located in the niches left behind by burned out posts, were baked hard and blackened because of their proximity to the flaming timbers.

Megaron 4

Megaron 4 was completed at the end of the eighth century just before the Kimmerian fire. It rests about 2 m above the other buildings of the open square upon an extension of the citadel's

Figure 2. 1956- Megaron 1 just after excavation.

Figure 3. 1961- Megaron 4 just after excavation.

southwest terrace. The structure has exterior dimensions of 12.3 x 22 m (See fig. 3). The interior arrangement consists of a very shallow front porch and a deep inner room connected by a central doorway in the cross wall between the two rooms that is matched by a doorway of the same width between the facade's returns. Unlike Megaron 1, the walls were made of solid mud brick without a wood frame and range from 1.32-1.45 m in thickness. There are no vertical niches in the inner and outer faces and no bricks preserved at a uniform level to suggest horizontal string courses. Charred wood and reed found on the floors indicate that Megaron 4 had a roof similar to Megaron 1, and a pattern of post holes in the main room suggests that there was once a three-sided gallery level in the rear chamber along the back wall and flanks. As with other examples of this gallery system found in many buildings of the Destruction Level, Megaron 4's gallery provided its own support without piercing the actual wall fabric.

While Megaron 4 was razed almost to its foundations, it seems that the absence of a half-timbering system did not fuel as severe a fire as that encountered by Megaron 1. The roof and gallery no doubt burned and collapsed followed by the subsequent fall of most of the superstructure. However, the in situ sections of mud brick, which vary in height from 0.25 meters to 0.75 meters, do not exhibit the same degree of burning and discoloration as those in Megaron 1.

Decay of the Megarons

Climatic conditions in the Gordion region are inordinately harsh. The majority of the average annual 350 mm of precipitation falls during the winter months and is accompanied by freezing temperatures (-15°C). During the summer, when excavations are ongoing, the area is quite dry and windy with only limited rainfall, exceedingly high temperatures (40°C-45°C), and correspondingly low humidity (10%-20%). This is an ideal environment for the promotion of mechanical weathering on the excavation site, particularly for unprotected surfaces that are broken down by repeated frost-wedging and wet-dry cycles and washed or blown loose by rain and wind.

Of all the erosion at Gordion the most notable post-excavation deterioration has taken place on Megaron 1 and Megaron 4. Until the 1989 season, no intervention had been taken to circumvent the slumping of the earthen masonry that makes up the remaining walls of these monuments except for an application of acrylic resin to a small section of Megaron 1 in 1982 (see "Previous Treatment" below).

Megaron 1 seems to be better preserved than Megaron 4, although it was excavated five years earlier and has been exposed to the environment for a longer period of time. This is more than likely due to the more complete baking that the mud bricks of Megaron 1 underwent from the intense temperatures generated by the ignited timbers of the building's wood framework. Another factor

Figure 4. Overall deterioration of Megaron 1.

may be that Megaron 4 is in a more vulnerable position. It is elevated above the level of the other buildings in the palace area and does not benefit from any shade during the day or any sort of protection from wind and rain. Megaron 1, on the other hand, is bordered by terracing walls built at later stages of the citadel that extend along its southeast flank and rear wall. These offer at least some shade and certainly act as screens from some of the elements.

Despite the discrepancies in states of preservation both megarons are in terrible condition. For the first several years after it was unearthed, Megaron 1's individual bricks and their courses were clearly discernible and uninterrupted except for the niches left by timber posts. Now, after thirty-four years of continuous contact with snow, rain and wind, many sections of the walls have dissolved completely, while the outer surfaces of others have "melted" so that the walls' original forms are barely recognizable (See fig. 4). In megaron 4, the bulk of the walls have either disappeared or have been covered with slump that was once original brick surface. It is only at the returns of the cross wall and facade that one can still make out the seams that demarcate different bricks.

Previous Treatment

Prior to 1989, the only treatment undertaken on the mud brick architecture was the application in 1982 of an acrylic resin (Acryloid A-21) on a small section of Megaron 1 [1,2]. It is unclear whether the application has been effective in preventing further deterioration, particularly as the treatment was not carefully documented or photographed. Furthermore, it is doubtful that the high molecular weight (and corresponding viscosity) of the resin permitted deep penetration.

On-site Examination and Treatment Tests

In 1989, we made a detailed examination of the mud brick architecture of Megara 1 and 4 and discussed the deterioration of the mud brick, the previous treatment, the sampling of burned and unburned sections, proposals for treatment tests, and future research. We requested and received permission from the Turkish Archaeological Service to take samples of the mud brick. The analysis of samples will determine the condition and structural strength of the burned and unburned mud brick.

Megaron 1 was chosen as a site to test two treatment methods for the protection of the mud brick architecture. The first proposal was to cover a small mud brick section/pier with a modern mud plaster (or mud stucco) as a protective coating, which, although obscuring detail, was not unlike the protective mud plaster that had originally covered the surface. The second proposal was to consolidate another small section with an acrylic colloidal dispersion (Acrysol WS-24), both as a comparison to the mud plaster application and to the previous acrylic treatment (Acryloid A-21) applied in 1982.

Toward the end of the season we carried out both of these tests, after first photographing, cleaning, and sampling different sections of the mud brick. One of the local workmen, who had been replastering the mud brick in the Gordion excavation compound (house and walls), mixed up a thick mud plaster and carefully applied it directly over one of the mud brick sections/piers. This was allowed to dry and touch-up was done in any cracks that developed. Detailed photographs were taken to record the treatment so that any weathering and change over the winter can be compared in 1990 (see fig. 5).

Figure 5. Section/pier of Megaron 1 after mud plaster application.

Prior to the on-site consolidation test with Acrysol WS-24 we experimented on a large fragment of mud brick found lying in the middle of Megaron 1. This fragment was taken back to the excavation compound and consolidation tests were begun using different concentrations of WS-24 and using two different methods of application.

Acrysol WS-24 was chosen as the consolidant because of its excellent physical and chemical properties [3]. It is a very fine particle-size acrylic polymer of high molecular weight dispersed in a water medium, and its extremely low viscosity ensures deep penetration. The hardness and durability of the set resin (after water evaporation) should provide more than adequate strength and protection against adverse climatic conditions. After setting, the resin is removable with solvents (e.g., flushing with acetone), but in practical terms this would be very difficult.

The first method chosen was by simple wetting: dripping and pouring various concentrations of WS-24 directly onto the mud brick. This was done only to one end (the small end) and it was found that concentrations up to 20% resin were readily absorbed by the porous brick, except in the areas where the brick fabric had been sintered or fused by the destruction fire. A 4% solution of WS-24 was chosen for the complete consolidation, and after thorough wetting (at which point a build-up of consolidant occurred on the surface), the brick was left in the shade to dry.

In order to assess the penetration of the consolidant, the brick was broken in half after forty-eight hours when it felt dry to the touch. It was easy to see where the consolidant had penetrated because it had slightly darkened the substrate and, in fact, had not completely dried in the center. Complete penetration was achieved except on the one side where the brick was burned.

Figure 6. Consolidation test using 4% WS-24 on mud brick.

The second application test was carried out by placing the remaining brick fragment in a closed system and allowing a 4% solution of WS-24 to percolate or "wick" up from the bottom. The brick was placed in a double-lined plastic bag with enough solution at the bottom to cover one-quarter of the brick, and the plastic bag was then sealed. The percolation rise of the consolidant was monitored over the next several days, and once the solution had approached halfway up the brick (in thirty-six hours), more solution was added to replace that which had been absorbed (see fig. 6). After another forty-eight hours, the consolidant had reached about three-quarters of the way up the brick, but hardly moved after that. The brick was therefore removed the next day, and an unsuccessful attempt was made to break it (again to assess the penetration of the consolidant). The unconsolidated end was immersed in 4% WS-24, and when dry, the fragments were returned to the find spot on site to weather the winter. The brick was photographed and a careful examination will be done in 1990 to assess its condition and the effectiveness of the consolidation.

On site, one of the smallest and most deteriorated sections/piers in the SW corner of Megaron 1 was consolidated using WS-24. In this case, a 4% solution was both sprayed on with an atomizer and dripped from the top into one of the most exposed areas. The section, although only four courses high and two wide, literally drank up the consolidant, and over 2 liters of solution were applied. As the upper bricks became saturated, an excess of resin began to build up in one area, and it was decided that the end point had been reached. The excess was lightly brushed off using deionized water. Photographs were taken throughout all stages of the treatment in order to record and compare any changes the next summer (see fig. 7).

Figure 7. Section/pier of Megaron 1 after 4% WS-24 application.

Additional samples of mud brick were taken from Megaron 4. Analyses of the mud brick samples will be undertaken to determine their composition and cohesive strength, and, together with the analyses of the ancient mud plaster, will aid in selecting a future treatment.

Conclusions

The condition of the burned Gordion mud brick makes it an extremely interesting and problematic case study in the preservation of in situ earthen architecture. Two methods have recently been tested for the protection of the mud brick. The first treatment test involved the complete covering of a mud brick section with a mud plaster or stucco. The second method tested returned to the use of an acrylic consolidant, but in a finely dispersed aqueous medium. Both treatments have advantages and limitations, when one considers the nature of the intervention as "exterior" or "interior".

The mud plaster stucco approach is more in keeping with what the building had as an original facing, but now that the building is exposed to the elements, it will require regular maintenance. In addition, the effectiveness and protection has to be weighed against the somewhat disturbing aesthetic appearance. Even so, the covering preserves the general appearance, and the intervention is minimal as it does not introduce any new and unknown materials into the mud brick.

The introduction of the acrylic consolidant WS-24, though apparently penetrating deeply, presents many unknowns, regarding its cohesive strength, localized concentration, and interior penetration. As a temporary conservation measure, it allows the current condition of the structure to remain visible while protecting the mud brick from further decay.

Until a suitable and effective consolidant can be found to completely protect the exposed mud brick architecture at Gordion, the decision will have to be made as to what temporary measure is most acceptable. Further tests and research are needed to assess both the physical requirements of the mud brick and methods for complete impregnation. The exposed architecture at Gordion offers an important opportunity and site for future study and immediate attention.

NOTES

1. ________, Gordion Notebook 173, Gordion Archives at the University Museum, Philadelphia, 111.

2. M. H. Rogers, "Site Conservation at Phrygian Gordion" (Honors Essay, University of North Carolina at Chapel Hill, 1989).

3. S. P. Koob, "Consolidation with Acrylic Colloidal Dispersions", Preprints, AIC Annual Meeting, 1981, 86-94.

MATERIALS

Acryloid B-72, Acrysol WS-24: Acrylic resins, manufactured by Röhm & Haas, Philadelphia, PA; supplied by Conservation Materials Ltd, Sparks, NV, U.S.A.

CONSOLIDATION OF A NEOLITHIC EARTHEN SITE WITH POTASSIUM SILICATE

Li Zuixiong,
Preservation Research Institute,
Dunhuang Academy, Gansu Province,
The People's Republic of China

ABSTRACT

This paper presents the results of an experimental study of consolidation with potassium silicate of a neolothic earthen site at Dadiwan, Gansu Province, China. Details of the preparation of the potassium silicate solution, its properties, and the mechanism of its action with montmorillonite - containing clay are described. The physical and chemical properties of the potassium silicate-clay composite were determined by testing and instrumental analysis. Calcium flourosilicate and aluminium silicate were used with the potassium silicate solution. Of crucial importance is the molar ratio of SiO_2 to K_2O. The optimum ratio is 3.8 - 4.0. Higher concentrations of K_2O give poor results through eventual formation of K_2CO_3 by atmospheric carbonation.

KEYWORDS

Consolidation, Potassium silicate, Montmorillonite

Introduction

Weathering is the most serious cause of deterioration of earthen structures, and a solution to the problem is urgently required. By investigation and analyses of the ruins of a neolithic earthen site at Dadiwan, Qinan County, Gansu Province in northwestern China, it was concluded that montmorillonite contained in the clay is one of the main factors contributing to weathering. The purpose of the present research was to find ways to reinforce this type of earth by enhancing the degree of consolidation by chemical means and thus prevent weathering.

Ruins of house of Yangshao Period in Dadiwan, Qinan, Gansu [1]

At the beginning of the 1980s, two rare, large ruins of houses, designated F_{405} and F_{901}, built during the neolithic period of late Yangshao, were excavated at a site at Dadiwan. A unique aspect of the site is that the floors (in area about 300 and 131m^2 respectively) are made of burnt Liaojiang stone (the depositional calcium carbonte in loess), which is quite similar to contemporary man-made concrete type ceramics. These floor materials are believed to be the earliest known cement and man-made concrete filler.

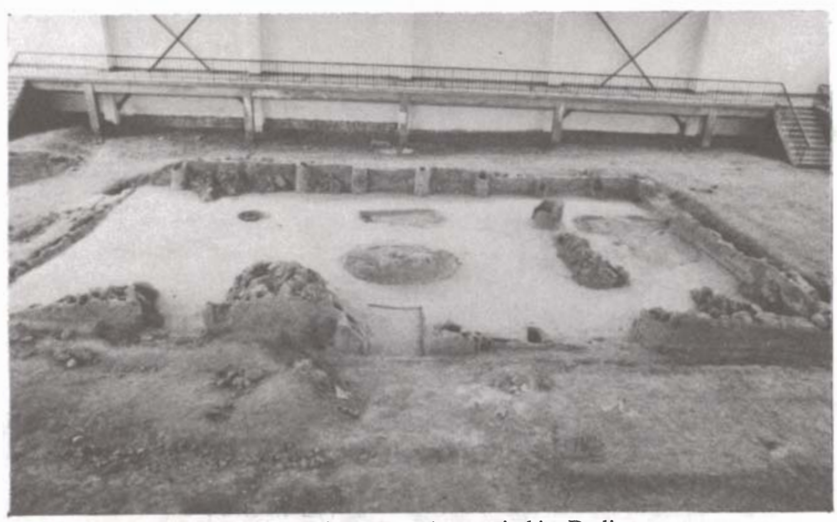


Fig. 1 - The F_{901} ruins of the house of the Yangshao period in Dadiwan.

Selection of Consolidants

The clay in the structures at Dadiwan contain some montmorillonite. As is well known, montmorillonite can absorb much water into its layered structure and swell considerably. Upon drying the clay contracts. Such an alternation of expansion and contraction accelerates weathering damage. It was the intent of the research to reinforce the earthen structures by permeating them with inorganic cementing materials which are similar to and can react with the clay, thereby improving the cementation and make the earth more weatherproof and stable. This, in theory, is an ideal way to reinforce and prevent earthen ruins from weathering.

Initially, tests on the material from Dadiwan were conducted with polyvinylalcohol, polyvinyl-acetate emulsions, and sodium and potassium silicate solutions of different molar ratios of metal oxide to silicon dioxide. Less than ideal results were obtained. Subsequently it was found that using potassium silicate with a high molar ratio of $SiO_2 : K_2O$, together with appropriate solidifying agent, cross-linker and surface active agent to reinforce the structure by permeation is an ideal method for consolidating.

At first, it is necessary to determine the optimum molar ratio of $SiO_2 : K_2O$ for the aqueous solution of potassium silicate. In the case of too low a ratio, after the potassium silicate and clay have reacted with each other, too much K_2O will remain which will form K_2CO_3 under the action of the atmospheric CO_2 and moisture:

$$K_2O + CO_2 \rightarrow K_2CO_3$$

If the potassium carbonate that results is not treated in time, or is removed, the stability of the cemented mass will be impaired. When the ratio is too high, it has a weakened cementation, which causes the strength of the solidified layer to decrease and, at the same time, tends to form a coagulated layer preventing the mass from being permeated to any depth. In such cases, spraying is difficult to carry out and does not produce good results. How to determine the optimum modulus for the potassium silicate? Through cementing an amount of clay (C) containing some montmorillonite [2] with an aqueous solution of potassium silicate (PS) at the same concentration, but with different molar ratios of SiO_2 to K_2O, a PS-C composite mass is made. Then test properties such as CO_2 - resistance, weatherability, water resistance and thermostability may be determined. By these tests the optimum ratio of the potassium silicate solution was determined to be 3.8 - 4.0.

Solidifying agents and cross-linkers are also important factors affecting the stability and applicability of the PS-C material. Tests have been carried out on more than 10 types of solidifying agents such as aluminium trichloride, iron trichloride, sodium fluorosilicate, calcium fluorosilicate and potassium aluminium sulphate. Judged by the solidifying speed and the stability of the PS-C-cemented mass, calcium fluorosilicate as the solidifying agent was found to be best. Through testing, powdery aluminium silicate was selected as the cross-linker.

Preparation of Potassium Silicate of Correct Molar Ratio

An industrial potassium silicate (molar ratio about 2.6) was diluted with water to a specific gravity of 1.3 and then caused to react in a 15 L stainless steel autoclave. It was heated by jacket-water bath to 100°C and stirred vigorously. At the same time, powdered silicon dioxide (80 mesh), mixed with warm water into a paste, was added gradually into the autoclave. The operating pressure rose to 21 kg/cm³. About two hours later, samples for determining the ratio were taken from the autoclave. If the required ratio was obtained, the PS preparation was considered complete. The PS obtained with an optimum ratio is a somewhat yellowish, thick colloid. It would be substantially colorless if purer starting material was used. The measured surface tension, density, viscosity and pH are given in Table 1.

Table 1. Surface tension, density, viscosity and PH values of potassium silicate (P.S.) solutions at given temperatures

P. S. solution	Temperature (°C)	Surface Tension (dyne / cm)	Density (g/cm³)	Viscosity (CP)	PH
Original	8.0 +/- 0.1	76.67	1.2529	118.89	
	25.0 +/- 0.1	75.17	1.2488	18.729	
	15				12
Diluted*	8.0 +/- 0.1	74.31	1.0478	1.7789	
	25.0 +/- 0.1	72.81	1.0449	1.1425	
	15				10 - 11

* - Potassium silicate solution diluted with water by 4X, + 1% $CaSiF_6$

The PS diluted four times with water is colorless and transparent. The procedure for preparation of the working solution is as follows:

Determine the dilution according to the requirements for application and measure the water required. Weight out respectively the $CaSiF_6$ and $Al_2(SiO_3)_3$ required and add them to the water. Stir the mixture and then pour it into the PS solution. Finally, add about 10ppm of NNO as diffusion agent and stir uniformly. It is then ready for spraying.

Preliminary Analysis of Mechanism of Action Between the Clay (C) and Aqueous Solution of High Molar Ratio of Potassium Silicate (PS).

X-ray Diffraction Analysis

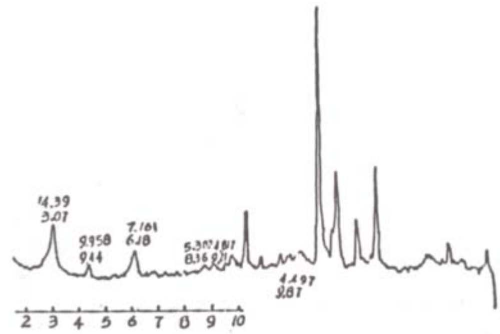


Fig.2 X-ray diffraction spectrum of clay containing montmorillonite.

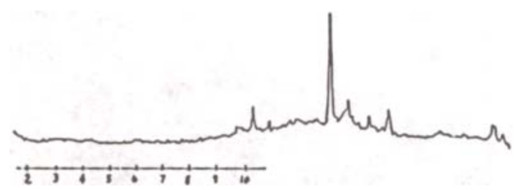


Fig.3 X-ray diffraction spectrum of PS-C.

Fig.2 is the spectrum of the clay containing montmorillonite; Fig.3 is the spectrum of PS-C. The spectra show that the clay minerals' crystallinity was destroyed by treatment with the PS. The clay minerals have turned substantially into an amorphous gel. Even if montmorillonite still exists in the clay, the clay treated with the PS solution, which is mainly potassium silicate, will have a reduced space between layers, i.e., the C-axial length will be reduced, thus resulting in reduced expansion by absorbed water due to exchangeability of the montmorillonite with the potassium ions.

Infrared Spectral Analysis

Fig.4 is the infrared spectrum of clay containing montmorillonite; Fig.5 is the infrared spectrum of PS-C. The infrared spectrum shows that the OH peak intensity near 3500 cm -1 of the mass has dropped considerably, and the OH shifted by 10 wave numbers. This is another reason why the PS-C cemented mass has higher water resistance.

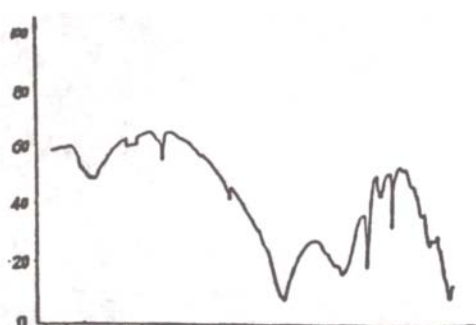


Fig.4 Infrared spectrum of clay contained montmorillonite.

Differential Thermal Analyis (DTA)

Fig.6 is the differential thermal curve of the clay containing montmorillonite; Fig.7 is the differential thermal curve of the PS-C. The differential thermal curves show that the clay has the first endothermic peak at 84°C, the second at 561°C and the third at 754°C, while the three endothermic sygnals of the PS-C are of 113°C, 684°C and 837°C respectively. That is to say, after the clay was treated with PS, its water-loss temperature rises. It is possible that part of the clay-absorbed water is converted into structural water on the clay resulting in an increase of the strength and water resistance.

Fig.6 Differential thermal curve of contained montmorillonite.

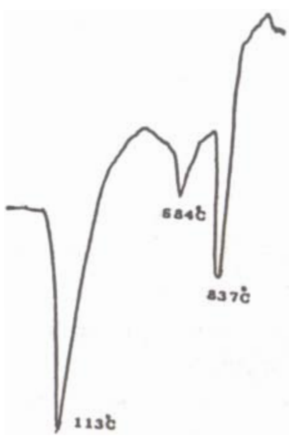


Fig.7 Differential thermal curve of PS-C.

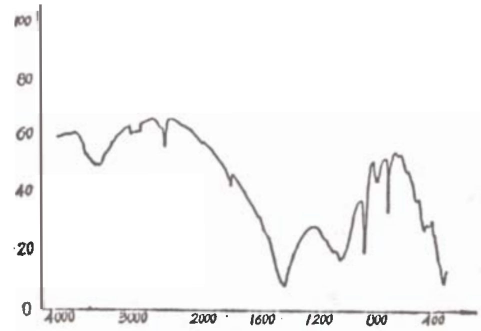


Fig.5 Infrared spectrum of PS-C.

Scanning Electron Microscope (SEM) Examination

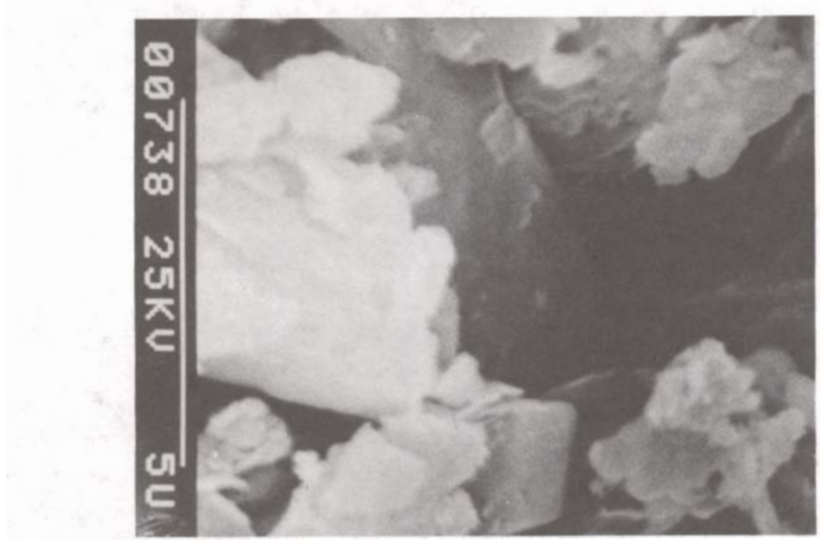


Fig.8. SEM photograph of clay containing montmorillnite, 9000 x.

Fig.8 is a SEM photograph of clay contained montmorillonite; Fig.9 is a SEM photograph of PS-C. The SEM photograph shows that an interwoven fibrous network of crystals, similar in structure to that found in hydrated gypsum, has formed. This is an important factor in imparting to the PS-C composite good water resistance and mechanical strength.

Fig 9 SEM photograph of PS-C, 9000 x.

Testing Main Physical and Chemical Properties of PS-C

Water Resistance

Test pieces of PS-C of different molar ratio were immersed in water until they disintegrated. Among test pieces which have been immersed for 16 months, the PS-C of high ratio (3.8-4.0) have not disintegrated, while those of lower ratio (below 3.5) disintegrated in a much shorter time.

CO_2 - Resistance

Resistance to CO_2 is one of the important indexes in examining the stability of the PS-C cemented mass. In the case of too low a ratio the potassium silicate will retain too much K_2O. This K_2O will gradually create K_2CO_3 under the action of CO_2 in air and cause the PS-C cemented mass to effloresce in moist air. This can be established by the following test: Small pieces of PS-C of different molar ratio are placed in a vacuum desiccator with water at the bottom and filled with CO_2. It is found that PS-C test pieces made with potassium silicate of low ratio went white and viscous on their surface within a few days. Samples of high ratio showed no change after months.

Weatherability

Small test pieces were placed outside and exposed to sunlight for six months, then tests were carried out for water and CO_2 resistance. It was found that test pieces of high molar ratio were stable and did not disintegrate when subsequently placed in water. Also no deterioration took place under CO_2 saturated with water vapour.

Basicity of the PS-C Cemented Mass

Because the PS solution is a strong-base, it might be considered that clay treated with the PS solution (that is the PS-C cemented mass) will be unstable and effloresce in air. This is not so: the silicon and aluminium in the expansible clay can cement with water and calcium only in a highly basic environment and increase the mechanical strength and stability of the PS-C cemented mass to a great extent. High basicity has become a simple and effective way to improve the engineering performance of expansible clay and has been widely used in civil engineering at home and abroad.

The original PS solution we used had a pH = 12 which dropped to about pH = 10 after being diluted. The PS-C cemented mass is quite stable which has been proven by the tests outlined above and in site applications.

CONSOLIDATION WITH PS OF THE F_{901} REMNANTS OF THE LATE YANGSHAO PERIOD HOUSE AT DADIWAN.

In August 1984 and in October 1985, site consolidation was undertaken on the weathered remains of the Yangshao house by spraying with PS solution. A 13-meter wall, one cooking stove and two post holes have been consolidated. Up to now, five years later, no abnormal changes have taken place on the surface of the structures. In our view an ideal effect was achieved (Figs. 10, 11).

In the site testing the weathered remnants of the house were sprayed once, twice and three times respectively for the purpose of comparison. From observations made over more than one year it is recommended to spray three times. Structures which have been sprayed three times still have good permeability, that is to say, it is possible to do fourth or fifth treatments if necessary.

CONCLUSION

Testing for consolidating the weathered archaeological earthen structures at Dadiwan, and on-site application, have shown that the PS solution reported here can achieve an ideal result in terms of strengthening the substrate while retaining good permeability. As seen by physical and chemical properties, testing, X-ray diffraction, infrared, scanning electron microscopy and differential thermal analyses, the PS-C is a kind of stable weatherproof inorganic composite which does not undergo marked changes in appearance. The tests have achieved the aim of changing the cemented state of clay containing montmorillonite through reinforcing by means of permeation with PS. There is, however, a problem to be solved through future research, that is, when applied to wet earth the PS shows poor permeability and a low rate of solidification. Furthermore, SiO_2

coagulates on the surface under such conditions and this results in a reduction in the consolidation and strengthening effect.

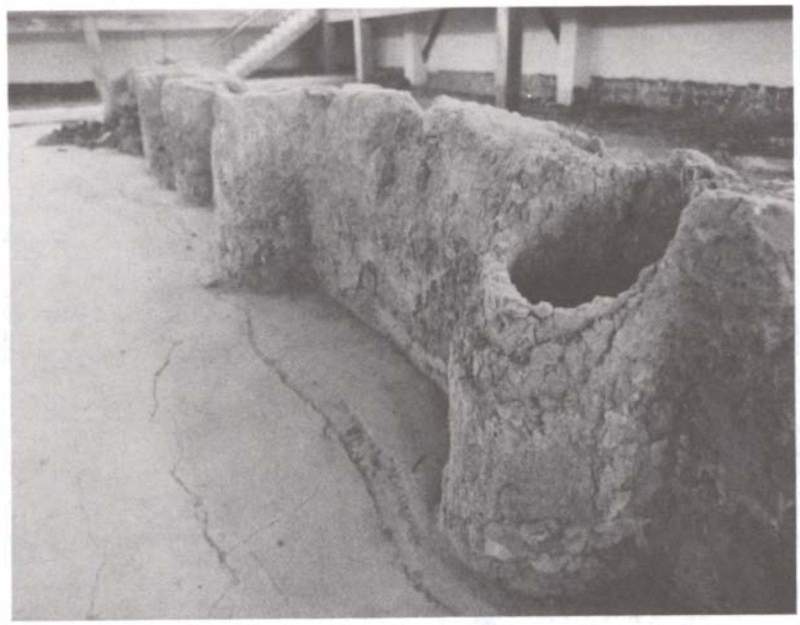


Fig. 10. The wall and skeleton pillar on adherent wall of F_{901} house-ruins after consolidation. (Photo, March 1990.)

Fig.11. The Pillar hole of propping beam wooden pillar of F_{901} house-ruins after consolidation. (Photo, March 1990.)

Acknowledgements:

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[1] The late Yangshao period of Dadiwan is 4,900-5,500 years before present.

[2] Clay (C) containing montmorillonite for testing was taken from the North Cave Temple, Qinyang, Gansu Province.

GENERAL CONSIDERATIONS ON THE PRESERVATION OF EARTHEN ARCHITECTURE IN MINAS GERAIS, BRAZIL; A PROPOSAL FOR REINFORCEMENT OF A BRAYED MUD WALL STRUCTURE

Sérgio José Fagundes de Sousa Lima, architect
SPHAN - Technical Office of São João del Rei
Rua Marechal Deodoro, 12 - Centro
36.300 - São João del Rei
Minas Gerais, Brazil

Sílvia Puccioni, engineer
SPHAN - Technical Consultory
Av. Rio Branco, 46, 5º andar - Centro
20.090 - Rio de Janeiro
Rio de Janeiro, Brazil

ABSTRACT

There is a considerable historical and artistic patrimony of earthen architecture in Brazil dating from the colonial period. A systematic study of the consolidation of this architecture is essential. This paper considers intervention methods for earthen structures as well as an analysis of their contents.

To illustrate the type of projects that have been undertaken in Brazil, a case study of the conservation of the Basilica of Our Lady of Pillar is discussed. This project involved the restoration of a severely deteriorated edifice, which required special analysis and structural reinforcement of the masonry of a brayed mud wall which had incurred static damage. The goal of the project was to maintain the old material while giving the masonry a new sustaining capacity, taking into account the original constructive system.

KEYWORDS

Conservation, restoration, brayed mud wall, pau-a-pique, adobe, moledo, reinforcement, consolidation.

Fig. 1: Wall with "moledo" base and adobe masonry. Tiradentes, Minas Gerais. Photo: Lima.

Brief Historical Overview of the Use of Earth in Architecture

The use of earth as a construction material dates to prehistoric times, to ancient Mesopotamia and Egypt. In Pre-Columbian America, its usage was widespread among the Aztecs and other North American peoples.

In South American countries such as Brazil, the Spanish and Portuguese introduced European techniques of earthen architecture during the early stages of colonization. As a result, the early urban architecture of these countries is characterized by features such as wide window sills, the predominance of walls over empty spaces, and specific wall thicknesses. Every type of architecture in the "mineira" (1) history of the eighteenth and nineteenth centuries--civil, official, or religious--was influenced. Earth became the most viable building material for structures and dividing walls of edifices because of the abundance of the material in the region and its environs and the mastery of the technique by artisans.

The construction systems that use this technique offer a variety of applications as seen in the edifices of our historical centers. Examples of earthen techniqeus are adobe and formigão (normally used for structural purposes, at least on the outside walls) and the pau-a-pique, taipa-de-sebe or taipa-de-mão for dividing walls and internal sealing.

Less frequently we find another material called moledo, equally characteristic of that region, made of decomposed clay, pebbles, and rocks. Because of its resistance (load-bearing capacity), it is also used in the structural masonry and dividing walls, in some cases exposed to open air. (See fig. 1.)

As an alternative to the use of earth, we find stone used as a material especially in edifices of monumental proportions. The use of stone inevitably increased the construction cost because of the difficulty of handling and transportation.
In a few cases rock is used for the entire structural system of the building, though in the majority of cases it forms only part of the structure, the foundations and corners, for example. Another advantage of stone is its decorative use.

General Considerations about the Preservation of Earthen Architecture

A. Systems conservation

Over the last six years, the National Artistic and Historical Patrimony Secretary (SPHAN) has exercised greater influence over the historical centers of the region Campos das Vertentes with the objective of repairing the damage occuring as a result of the social and economic decline in Minas Gerais. Some old edifices were in critical condition. Others required intervention at specific damaged points, which were easily repaired. In other cases the stability of the building was compromised, requiring more extensive intervention. In the case of structures whose inhabitants kept up comprehensive maintenance--from the roof to water and electrical installation and sewage system--the physical condition remained sound, reducing conservation costs.

B. Urgent work staff

In order for SPHAN to be effective in the historical centers, the Federal Government established an "urgent work staff" to restore

1. The style representative of Minas Gerais (a state in Brazil).

Description of the Constructive Systems

Brayed mud wall: This system is one in which the walls are of massive monolithic mud, which is formed in wood moulds held in position by traverses and wood sticks.

Adobe: This material consists of mud bricks with dimensions of 20 x 20 x 40 cm. It contains vegetable fibers or manure. It is put to dry in shadow and, after a few days, in the sun. It differs from conventional bricks in that adobe is not baked in an oven.

Formigão: This variation of the mud wall is made by not sifting the mud but rather mixing it with stony earth to make a conglomerate-like concrete.

Pau-a-pique: This is a kind of sealing which consists of pieces of wood set perpendicular between the "baldrames" (the lower support) and the "frechais" (the upper support), attached by holes or nails. Normally, other thinner pieces, sticks, are attached on both sides. After the texture is made the mud is thrown and pressed on by hand.

Moledo: This is a conglomerate made of clays, "saibro" (fine gravel) and decomposed rock, removed in blocks from the mines, in the shape of cobble stones of varying dimensions. Because this material is very resistant, it is applied "in natura."

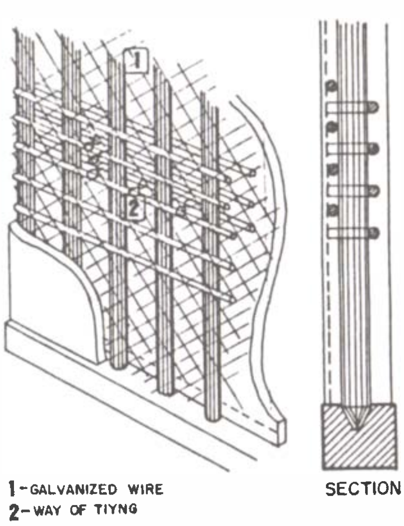

Fig. 2: Pau-a-pique wall. Illustration by Lima.

and maintain the architectural patrimony as well as furnishings. This staff is not sufficient to undertake all of the needed interventions and can only address the "most urgent" cases.

Through this staff the Brazilian Government is able to offer to the people of the historical centers, who are generally in need of financial resources, assistance in preserving their buildings. We offer, free of charge, the manual labor of specialized staff; private patrimony owners contribute the necessary materials when resources are available; SPHAN supplies the technical orientation.

C. Criteria and intervention methods

The first step in the restoration and conservation of a given damaged edifice is to examine the existing damage and to prepare a condition report. After verification of the financial condition of the resident, the subsidy is determined which the SPHAN will provide for the execution of the work.

If a decision is made to undertake the intervention, it is necessary to study the possible treatment approaches according to at least three criteria:

- The persistence in the use of the techniques, traditional or contemporary, which have been tested and which satisfy the purposes of the conservation project.

- The use of native material which is appropriate to the material being treated and which reduces costs.

- The historic authenticity of the object as well as its contemporaneity. Interventions should be indicated in distinct and transparent ways.

We can now delineate a chart of practical examples of solutions adopted for the treatment of certain materials.

D. Conservation of the wall

1. Pau-a-pique

We find the pau-a-pique system in several edifices, which show external deterioration due to contact with moisture caused by poor roofing or by soil saturation. In these cases, the solution is to eliminate the humidity or the surcharge and to investigate the rupture, disintegration, deformations, etc. that have occurred. From this point on we promote the repair of the masonry or, as an alternative, in situations of extreme disaggregation where repair is not possible, the option is reconstruction, using comtemporary techniques such as conventional fired brick, either solid or "emptied" ones or "sical" block (cellular concrete), etc.

1.1. Repair of the elements

-Paus-a-piques: those that present a useful section are maintained and conserved and rectified when necessary.

-Sticks: when completely deteriorated, new sticks are substituted.

-Mud wall: if losses are registered after the disaggregation of the plaster, the mud is often repaired using a mixture of mud-cement (~1:20), compatible with the old system in level of coefficient of dilatation. Eventually a layer of rough cast and two layers of final cast are applied.

In the most serious cases, when a considerable loss of mud is aggravated by the instability of the wood texture, a texture of galvanized wire is used on both sides to consolidate the whole system. (See fig. 2.)

2. Brayed mud wall

Monolithic (big block) masonry structure of large dimensions presents problems when it is directly exposed to open air. After the rough cast is dislocated, humidity (especially rain) disaggregates the structure. Also, structural problems arise due to fissures in the lower areas of the foundation, deterioration of the beams, etc. Usually, in the case of one- or two-story structures, the effects of the problem cease with the treatment of the problem--that is, if the roof is repaired or the foundation is reinforced, only the work of recomposing the damaged spaces remains. At most, it is possible to introduce an "atirantamento" (steel and wood wires to hold the walls together) on the masonry. In cases of excessive horizontal stress, this intervention consolidates the masonry with rigid structure.

3. Adobe and moledo (2)

Because of the peculiarities of these materials, they "behave" very well statically (rigidly), except in situations such as those that occurred with the brayed mud wall. Presently, there is no other method of intervention in these systems of construction.

The dimensions of these materials are considerable: adobe almost invariably measures 20 x 20 x 40 cm; moledo is quite variable, but its size is at least equal to the adobe brick. Usually they are used double in masonry, resulting in a minimum width of 40 cm, with the right enclosures.

4. General technical solutions

In any particular edifice there are different systems of earthen construction--structural masonry, both external and internal, and internal dividing walls. In certain situations there is a lack of cohesion in the junction of two systems which causes fissures on the corners. A galvanized iron texture can help to connect the masonry.

Every time we undertake an intervention on the roof of an edifice with structural systems of earthen construction, it is advisable to take advantage of the moment to execute a crowning belt, to connect the system by stabilizing the skeleton of the building. The effects of weather must be avoided, since the areas closest to the eaves suffer the greatest from accumulated rain water.

In order to alleviate the effects of ascending and lateral pressure of water on the masonry, it is advisable in certain cases to construct a ventilation ditch, a system whose purpose is to eliminate the direct contact between the masonry and the soil, by forming an intermediate "mattress of air."

A proposal for reinforcing a structure of a brayed mud wall. Specific case study: Basilica Cathedral of Our Lady of Pillar

A. The brayed mud wall

The brayed mud wall was largely used as a system of construction in the "Paulista Plateau" and in the state of Goiás. In the northeast, the use of this technique was not often utilized, but there is record of the use of this system of construction in 1660 in the city of Salvador, Bahia.
In Minas Gerais, the use of the mud wall was less frequently used. Other materials (wood, stone, etc.) were plentiful, and furthermore the region is quite uneven, a fact which favors the use of other techniques.

Reports of travelers from the nineteenth century (e.g., Richard Burton, 1868) have been found which prove the existence of civil and religious buildings constructed in "taipa" in several regions of the State; such is the case of the Basilica of Our Lady of Pillar in São João del Rei.

B. Basilica Cathedral of Our Lady of Pillar

This is an edifice made of brayed mud wall, dating from the early eighteenth century. The high altar contains the main chapel and altar piece, which was completed three decades later.

The construction includes an area of 1.056 m^2 with an average of 5.50 m height. The church square covers an area of 129 m^2, reached by a flight of stairs made of "cantaria" (carved stone). The construction consists of two parts, a posterior one which includes the high chapel and sacristry and another, anterior, which includes the main nave and the lateral corridors extending into the main façade, which was rebuilt during the middle of the nineteenth century in stone masonry. (See fig. 3.)

The main façade has a central door in the lower part, flanked by four smaller doors symmetrically set in relation to the central axis under five windows of the balcony finished by a triangular "frontão" topped by a stone cross. The façade is flanked by two towers provided with pyramid domes. All the details of the façade are made of carved stone. Inside, the temple is one of

Fig. 3: Façade of the Basilica Cathedral of Our Lady of Pillar. Photo by Lima.

2. Material made of decomposed clay, pebbles, and rock.

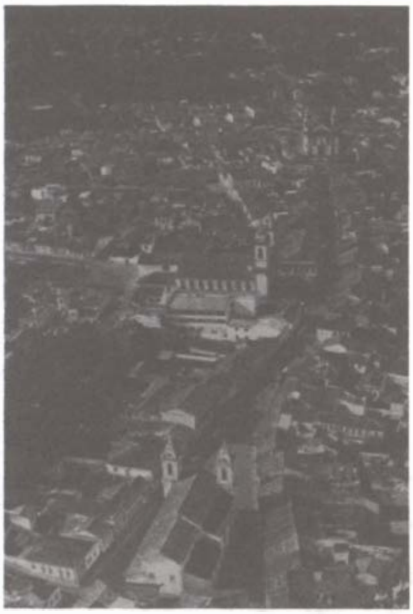

Fig. 4: Aerial view of part of the historical center of São João del Rei. In the center is the Basilica Cathedral. Photo by Lima.

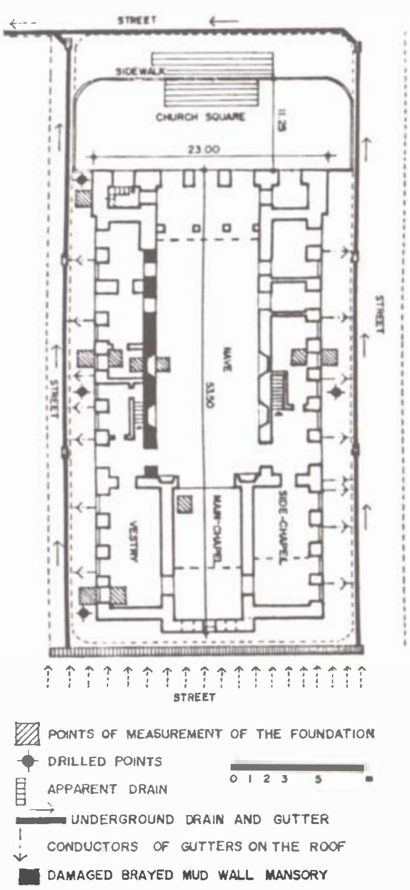

Fig. 5: Ground floor plan of Our Lady of Pillar. Illustration by Lima.

the most expressive of the "mineiro" baroque for its profusion of gold carving, mainly in the high chapel where proportion and harmony and grace predominate. The nave has seven lateral altars in the same style as the high chapel.

C. Reinforcement proposal

The building is settled in the southeast part of the town of São João del Rei, in the foothills of Rosario. (See fig. 4.)

In the time since the building's construction, the streets of the town have been paved, including those streets that begin behind the church and rise directly up the hill. This paving keeps the surface water from filtering down into the soil, as it did in former times. The resulting accumulation of water on the posterior part of the church causes erosion of the soil that holds the foundations at the right side of the building.

In addition, there is also the poor condition of the drainage system meant to collect rain water and conduct it to the sewage system.

These facts caused the "lisionamento" and the deformation of the right wall.

The deformation of the wall also caused the rupture of the eaves and dislocation of the tiles, allowing the infiltration of rain water on the mud walls over the course of many years. This caused the disaggregation of the earthen masonry, reducing its endurance, increasing the intrinsic tension of the material on the critical points of the structure, for instance in the "vazados" (empty spaces) of the doors, windows, niches, etc.

The altars at the right wall of the central nave, located at the openings that pass through the masonry, were in a severly damaged state. One could clearly see the lateral "flambagem" (as a result of pressure) of the carved wood columns that form the lateral altars.

As a first step, we removed the artistic elements, and we provided for the support of the "vão" (empty space).

The conservation of the roof had already been completed in 1986. An investigation into the stability of the building was elaborated, beginning with the investigation and geological study of the soil, in order to evaluate the support conditions, inspection and charting of the damage, with the setting of "testemunhos" (an instrument used to register the deformation) on the walls. These observations help to show the extent of the movement of the structure.

At the same time, we planned and implemented drainage on the posterior part of the building in order to conduct the surface water to the sewage system. Repair of the system for draining rain water from the roof was also proposed and implemented. (See fig. 5.)

After this work was completed, we began to observe the damage by periodic inspection, to verify the condition of the deformations.

These steps were necessary to reduce the financial costs of the intervention, by first eliminating the causes of damage and then intervening to repair the consequences.

At present, we are elaborating the structural reinforcement of the mud wall and intend to prevent the reinforcement of the damaged masonry and in this way avoid its substitution.

We know all the patterns of reinforcement are based on the behaviour of the supporting structure. In the case of the mud walls, the supporting structures have the following characteristics: They are considered cyclopean structures, for the height-section relation of their pieces is low and so is its capacity to absorb horizontal stresses. The spring coefficient and the ductility both have low values. Another element to be considered is the low capacity of deformation in plastic regime, which means a material has only a limited capacity to dissipate energy without articulating. As mud is a very fragile material, after being damaged it is difficult to analyze the static behaviour; each new element presents differentiated dimensions and conditions of support, producing secondary efforts on the critical points.

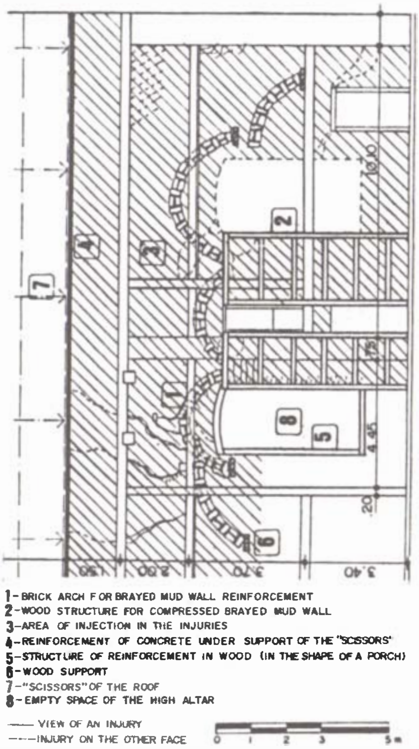

Fig. 6: Brayed mud wall reinforcement proposal. Illustration by Lima.

Thus, we consider that any proposal for reinforcement should take into consideration the original state of tensions, considering the elements working together. Also the fineness of the pieces should be considered. This is a basic fact for the qualification of the "portante" (load-bearing) capacity.

Some points of the proposed reinforcement are to be considered: The continuity of forms and volumes, the symmetrical distribution of the elements, improving resistance to tensions, the density and uniformity of the materials, the rigidness and ductility of the sections, the capacity of resistance compatible with the efforts and the limited capacity of deformation.

We then proposed reinforcing and consoliding the wall by filling the empty spaces and areas of loss with a mixture of soil-beton-ite-lime and reinforcing the empty spaces in order to support the surchages without modifying the original structural system of the walls.

The reinforcement involves installation of a parabolic arch of discharge over the empty space, in both sides of the wall and additional arches disposed upon the former in order to redistri-bute the strength lines near its original proceeding.

These arches will be made of baked mud bricks with mortar with a mixture of soil-cement.

The necessity of reinforcing the straps of the open space and improving the conditions of support of the "impostas" of the arch will be evaluated on site.

A moulding of the empty space will be executed in wood with a rectangular closed porch.

For the vertical sections that were crushed, a belt will be used with wood pieces on both sides, properly linked by transverse pieces. (See fig. 6.)

Conclusion

As one can observe from the text above, the task of preserving the earthen architecture in Brazil is still at a very rudimentary stage, without systematic studies showing the technical and financial difficulties found in this area where the Government is not totally aware of the need for a larger investment in research and labor. In recent times technical-scientific studies have begun to appear that support restoration work; this is developing slowly. Despite these problems, the work developed up to now has been rewarding. Quite satisfactory results can be obtained by using simple techniques, making it possible to save the majority of Brazilian patrimony from ruin.

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Seismic Mitigation

ABSTRACT

Quincha (or reed binding) is a type of construction used in Peru in colonial times and up to the first decades of this century. It is made of clay, reeds, and timber, materials with which high quality housing can be achieved and which have demonstrated good resistance to earthquakes. The present research, which comprises experimental and analytical studies, was directed at expanding basic knowledge on its structural behavior. The conclusions of this study have allowed for the proposal of simple rules of design. These rules can be used for the conservation of historical monuments.

KEYWORDS

Quincha (reed binding), structure materials, experiments, design, seismic behavior.

COMPORTAMIENTO ESTRUCTURAL DE LA QUINCHA

J. Bariola, M. Tinman, R. Ortiz, B. Alberca, J. Vargas
Pontificia Universidad Católica del Perú
APTO. 1761, Lima 100
Perú

Introducción

La quincha es un sistema constructivo empleado durante la colonia y hasta las primeras décadas de este siglo en el Perú. Los materiales usados en la quincha son tierra, madera y caña, con los cuales se logran estructuras livianas. En zonas urbanas, la quincha se usó mayoritariamente como segundo piso, sobre un primer piso de adobe. Este tipo de edificación brinda innumerables ventajas como hábitat en la costa del Perú, por el agradable ambiente que proporciona, por la seguridad que ofrece durante terremotos, y por su bajo costo. Luego del sismo de 1746, la construcción de quincha se adoptó masivamente por el buen comportamiento observado. La Universidad Católica del Perú y la Technical University of Nova Scotia, Canadá, con apoyo del International Development Research Centre of Canada, iniciaron en 1988 una investigación interdisciplinaria con el objetivo de promover el uso de edificaciones de quincha en zonas marginales de Lima. La investigación abarcó desde estudios experimentales hasta el diseño y construcción de diferentes obras. Este trabajo presenta mayormente los aspectos básicos de ingeniería estructural que sean de interés para un público amplio interesado en la construcción y conservación de edificaciones de quincha.

Características de la Quincha

Se describe a continuación el tipo de quincha usado en el proyecto de investigación de la Universidad Católica, haciendo alusión a otros tipos de quincha tradicional.

La cimentación, usada en diferentes obras construidas como parte del proyecto, consiste en una losa de concreto armada con caña (Fig. 1). En las construcciones tradicionales de quincha se encuentran cimentaciones de mampostería de ladrillo o de piedra asentada con cal.

Las paredes son formadas por paneles prefabricados de madera de dimensiones 0.80 m de ancho y alturas de 2 a 2.40 m, los que se clavan entre sí. Los paneles consisten en un marco de madera con travesaños como muestra la Figura 1. Una vez unidos los paneles se coloca la *estera,* tejido de cañas chancadas, que luego se tarrajea con barro. Los paneles tienen secciones de madera de 2.5 x 7.5 cm. El espesor terminado de los muros es 15 cm. Se usan paneles de dos tipos: paneles convencionales y paneles sísmicos (Figura 2).

El tipo de caña que se usa para las esteras y techo es el *carrizo* (Arundo Donax), el cual crece en los bordes de los ríos. Es muy común el uso de bambú partido y chancado (Guadua Augustifolia) y carrizo entero arqueado sobre travesaños de madera.

El techo es de vigas de madera, y cobertura de caña con mortero de cemento. Se usan vigas de madera de tornillo espaciadas a 0.8m. Las cañas proporcionan un aislamiento adecuado, a pesar de su reducido espesor. El mortero de cemento se aplica en espesores del orden de 2 cm, con lo cual se logra una cobertura liviana, durable y resistente a la lluvia. La quincha tradicional hace uso de la "torta de barro", una capa de barro de 5 a 10 cm de espesor. La Figura 3 muestra una perspectiva de la estructura.

Materiales

Como se ha mencionado, los materiales principales de la quincha son la tierra, madera y caña. Para la presente investigación se usó la madera denominada "Tornillo" (Cedrelinga Catenaeformis), proveniente del Oriente del Perú.

Se estudiaron diferentes especies de caña y bambú (1), obteniéndose los valores de la resistencia a la tracción. Por ejemplo para la caña brava (Ginerium Sagittatum) se observó una resistencia del orden de 2800 Kg/cm^2, semejante a la de algunos aceros.

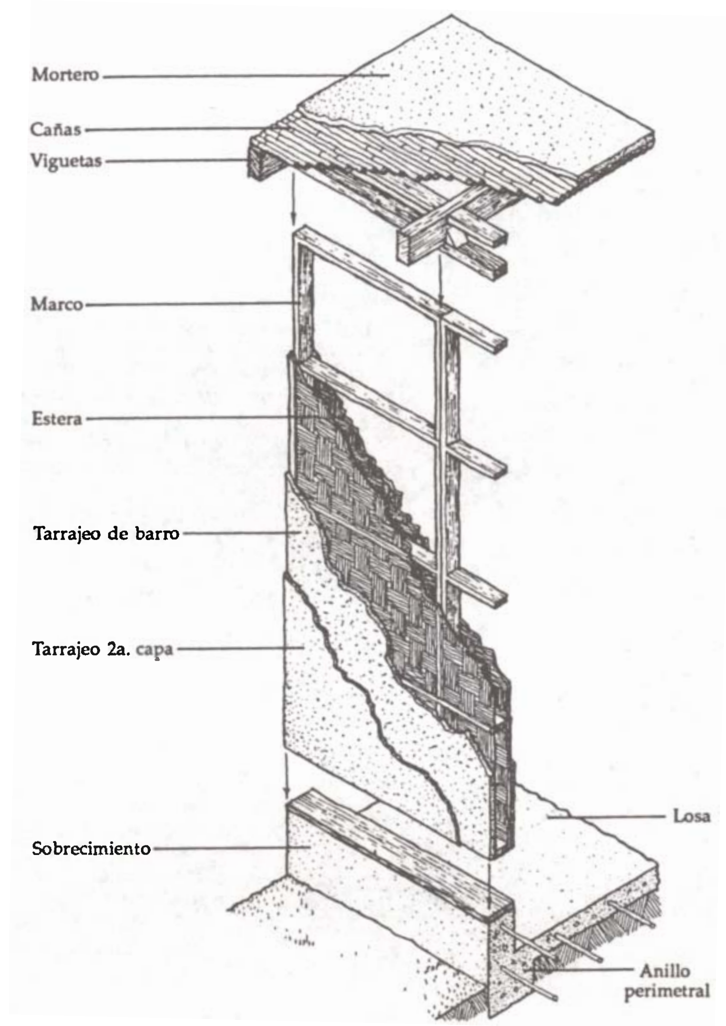

Figura 1 Detalle de Panel y Cimiento

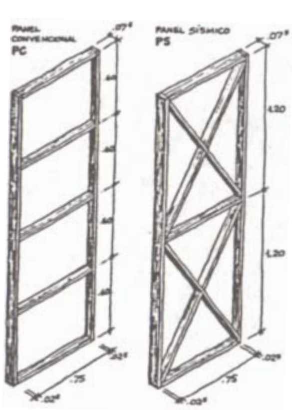

Figura 2 Tipos de Paneles

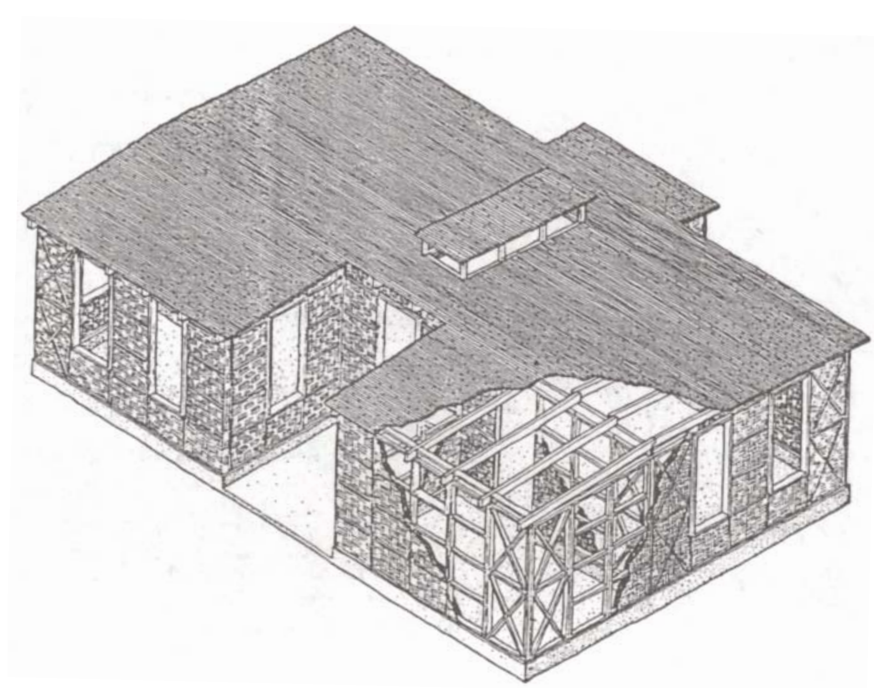

Figura 3 Estructura de Quincha

La "paja" puede ser cualquier fibra vegetal resistente y duradera, por ejemplo el ichu (Stipa Ichu que)crece en la sierra del Perú. También es posible usar césped, paja de arroz, etc. Es conveniente que la paja tenga fibras de aproximadamente 10 cm de largo.

La tierra es usada para el tarrajeo de las paredes en combinación con arena gruesa y paja. El tarrajeo se aplica en dos capas, cuyo espesor debe ser en lo posible 1.5 y 3/4 de cm. La capa delgada, la cual puede hacerse con arena gruesa o arena fina, permite cubrir las fisuras e irregularidades de la primera y darle un acabado final. Normalmente, la mezcla óptima (arena:tierra) está entre 1:1 y 1:2 por volumen para suelos de mediana plasticidad que son los más corrientes. Se añade una cantidad de paja equivalente al 1% del peso total seco. Cuando se observa excesiva fisuración, es necesario realizar pruebas para lograr una mezcla adecuada. El porcentaje que se añada dependerá de cuan arcillosa sea la tierra. La forma más práctica de determinar el porcentaje de arena gruesa adecuado es fabricar una serie de mezclas con proporciones en volumen, arena:tierra, de 1:3, 1:2.5, 1:2, 1:1.5, 1:1, con 1% del peso seco en paja, tarrajeandose paneles de prueba. Debe observarse la trabajabilidad de la mezcla y la fisuración al secar, escogiéndose la mezcla con adecuada trabajabilidad y que permita controlar la fisuración (entendida como solo la aparición de fisuras finas), con la menor cantidad de arena gruesa posible. El exceso de arena gruesa hace que la mezcla sea muy débil y fácilmente erosionable. Las Referencias 2-6, contienen diferentes estudios sobre las estructuras de tierra. La Referencia 4 trata el tema de la durabilidad de tarrajeos de barro.

Para el techo se usó (1) un recubrimiento de mortero cemento:arena gruesa en proporciones por volumen 1:6 y de 2.0 cm de espesor.

Ensayos de Laboratorio

Se realizaron diferentes ensayos para estudiar el comportamiento de las estructuras de quincha (1). A continuación se presenta un resumen en el que no se incluyen detalles y resultados técnicos.

La composición de los tarrajeos de los especímenes fue mantenida en proporciones aproximadas arena:tierra de 1:2. En algunos casos debido a la variabilidad de la plasticidad de la tierra, no fue posible mantener la misma proporción. La paja usada fue el ichu, en una cantidad igual al 1% del peso seco del material. La cantidad de agua fue definida de acuerdo a una trabajabilidad estándar medida con la aguja de Vicat (3). Las paredes de quincha fueron similares a las descritas anteriormente, excepto que el espesor fue de 5 cm en lugar de 7.5 cm.

Se realizaron diferentes ensayos de paneles para estudiar las propiedades mecánicas básicas, tales como su capacidad para resistir cargas verticales, las que son producidas por ejemplo por el peso del techo. Las resistencias obtenidas fueron bastante superiores a las que se dan en construcciones de 1 y 2 pisos, por lo cual esta solicitación no se considera crítica. Diferentes acciones, por ejemplo el viento, solicitan a los muros en dirección perpendicular a su plano. Con la finalidad de estudiar la respuesta de las paredes de quincha ante este tipo de cargas se realizaron experimentos observándose que el espécimen era capaz de sufrir deformaciones bastante altas, sin darse daños importantes y sin perder resistencia. Adicionalmente, se realizaron también ensayos dinámicos con la misma finalidad; verificándose nuevamente un buen comportamiento frente a cargas perpendiculares al plano de las paredes.

Ensayos de Paredes bajo Cargas Laterales

Este ensayo simula la acción de los sismos sobre las paredes mediante la aplicación lenta de cargas laterales. Se ensayaron 3 paredes de la forma mostrada en la Figura 4, a las cuales se les aplicó además de la carga lateral, una carga vertical de 2000 N por metro de ancho para simular el peso del techo. El objetivo del ensayo fue estudiar el comportamiento ante cargas laterales, y en particular determinar la influencia de la relación ancho/altura de las paredes. Los mecanismos de falla observados se indican en la Tabla 1. En todos los mecanismos de falla se pudo apreciar como parte del fenómeno la separación del tarrajeo y la estera. Como se aprecia, la resistencia por metro de ancho varía en menos de un 20% para los tres especímenes, por lo cual puede considerarse para fines prácticos que permanece constante.

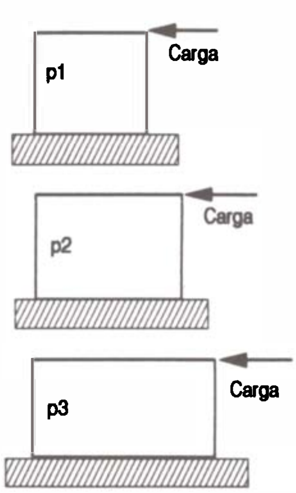

Figura 4 Ensayo de Paredes

Tabla 1 Resistencia de Paredes ante Cargas Laterales

Espécimen	Resistencia por m de ancho (N/m)	Mecanismo de Falla
P1	4,600	Volteo de la pared y separación estera-tarrajeo
P2	4,100	Fisura diagonal y separación estera-tarrajeo
P3	3,900	Fisura horizontal y separación estera-tarrajeo

Ensayo de un Módulo de Quincha

Se ensayó un módulo de quincha (Fig. 5) de 4 x 4 en planta y alturas de 2.40 y 2.80. Todos los paneles fueron de 2.40 m del altura, por lo que fue necesario un elemento reticular de madera para lograr la pendiente del techo. El techo del módulo tuvo un peso de aproximadamente 80 Kg/m^2. El espesor de todas las paredes fue de aproximadamente 0.10 m. Los objetivos del ensayo eran (1) desarrollar modelos que permitan estimar la respuesta, (2) investigar si el techo trabaja como un diafragma rígido y (3) estudiar el comportamiento global y de detalles de la construcción. El espécimen fue sometido a tres corridas con diferentes aceleraciones máximas del sismo. El sismo usado fue el registrado en Lima en 1970.

La falla ocurrió cuando el desplazamiento máximo (nivel del techo) alcanzó un valor equivalente al 0.5% de la altura del módulo. La falla se debió al desprendimiento del barro de la estera, lo cual constituye un punto crítico del sistema. La falla fue frágil, reduciéndose instantáneamente la resistencia a un 50% de la inicial. No hubieron daños de importancia en las paredes transversales al movimiento, en parte porque el techo constituyó una restricción efectiva al desplazamiento de las paredes transversales. El amortiguamiento medido del material fue de 8 %, valor alto en comparación con otros materiales, lo cual es una ventaja debido la disipación de energía que esto permite durante un sismo.

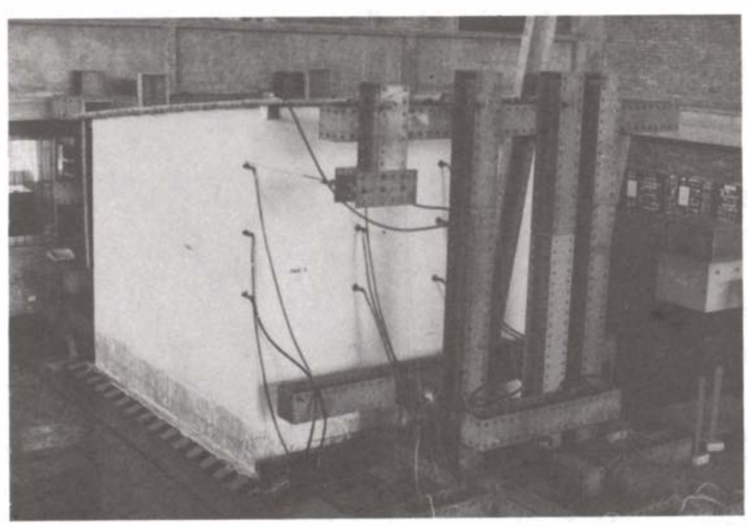

Figura 5 Ensayo del Módulo

Densidad de Paredes

Es deseable que los resultados experimentales se traduzcan en reglas simples de análisis. Dado que la resistencia de la estructura es proporcional al área de la sección transversal de las paredes (espesor x ancho), es posible expresar los requerimientos de resistencia en estos términos. El análisis sísmico se realiza corrientemente en direcciones horizontales. La Figura 6 muestra como ejemplo la planta del módulo ensayado y definiéndose dos direcciones, longitudinal y transversal.

Con el término *densidad de paredes* nos referiremos al área de paredes dividida por el área techada. Podemos calcular, entonces una densidad de paredes en la dirección longitudinal y otra en la dirección transversal.

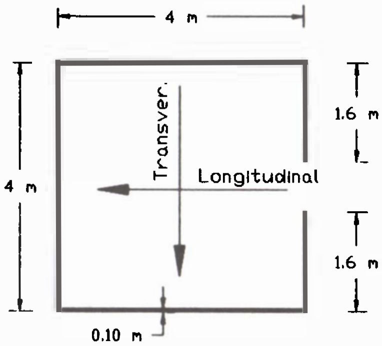

Figura 6 Direcciones para el Análisis

Por ejemplo, para el módulo ensayado (Fig. 6), considerando la dirección longitudinal, tenemos dos paredes de 4 m cada una. El área de paredes es 2 x 4m x 0.10m = 0.80 m² en esta dirección. Siendo el área techada 16 m,² la densidad de paredes es 0.80 m²/16 m²= 0.05 ó el 5%. Con esta densidad de paredes, el módulo resistió sismos muy severos cuya probabilidad de ocurrencia es muy remota.

En base a los resultados experimentales y análisis posteriores (1) se pudo concluir que una densidad del orden de solo un 2.5%, en cada dirección transversal y longitudinal, sería suficiente para resistir sismos con una aceleración pico del 20% de la gravedad, aceleración de diseño usada en el Perú. Se determinó (1) que de este valor, una cuarta parte debería consistir en paneles sísmicos, de manera de garantizar la seguridad en caso de un sismo muy severo. Estos valores son aplicables siempre y cuando los pesos unitarios de los componentes sean semejantes a los usados en este estudio, es decir, techos de 80 Kg/m² y paredes de 100 Kg/m².

Resumen y Conclusiones

El estudio resumido en este documento fue orientado a investigar experimental y analíticamente la respuesta sísmica de la construcción de quincha. Los ensayos incluyeron la simulación de diferentes fenómenos tales como la acción de las cargas de gravedad y los sismos. La estructura de la quincha permite el trabajo complementario de tierra y madera. El tarrajeo de tierra resiste las fuerzas laterales producidas por fenómenos tales como los terremotos, mientras la madera resiste el peso de la edificación. Desafortunadamente, la caña teniendo una gran resistencia no cumple una función estructural. Los resultados experimentales demostraron que para edificaciones de 1 y 2 pisos, las cargas de gravedad no son normalmente críticas. Los ensayos dinámicos del módulo y los ensayos de paredes con cargas laterales permitieron apreciar que el punto crítico del sistema es la adherencia barro-estera, produciéndose una falla frágil en la cual se reduce bruscamente la resistencia. Por este motivo se ha propuesto el uso de paneles sísmicos como una medida adicional de seguridad. La forma de verificar la seguridad sísmica de la construcción propuesta es en términos de la densidad de paredes, establecida como un 2.5% del área techada en cada dirección de análisis.

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LA ARQUITECTURA DE QUITO FRENTE A LOS SISMOS.

Inés del Pino*, Patrick De Sutter y Mario Morán P.
Instituto Nacional de Patrimonio Cultural
Cuenca 918 y Mejía
Quito - Ecuador

ABSTRACT

This paper synthesizes research on seismic interventions carried out on religious monuments in the historic center of Quito over the last two years. This study addresses structural diagnosis, analysis and evaluation of established methods for reinforcement and consolidation of structures. It briefly describes two case studies.

The structural intervention was aimed at restoring the rubble-work, which had deteriorated due to earthquakes, by using materials and technology that were consistent with the original construction.

KEYWORDS

"HISTORIC CENTER OF QUITO", "STRUCTURAL INTERVENTION", "EARTHQUAKE", "SEISMIC INTERVENTION", "ADOBE".

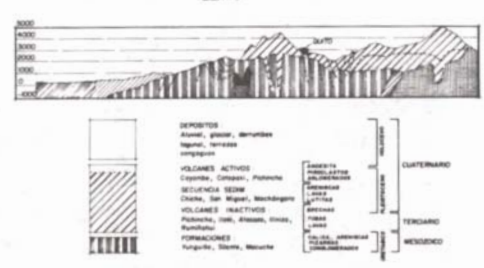
Objetivo

Sintetizar las experiencias obtenidas en el manejo de técnicas de conservación y reforzamiento en los monumentos coloniales religiosos de Quito afectados por sismos.

Marco referencial para el estudio

1. Aspectos geotectónicos referentes a la sismicidad regional: El Ecuador es un país andino ubicado en el continente Sud Americano (Quito, 0.180 S - 78.500 O) cuyo tectonismo está definido por los movimientos de las placas marítima de Nazca y continental Sud Americana que, al chocar, forman una zona de subducción interplaca (Ver graf. 1,2). La geomorfología andina y particularmente la de Quito, está caracterizada por un volcanismo activo y el tectonismo de las formaciones del Holoceno constituídas por depósitos aluvial, glacial, lagunal, cenizas volcánicas y secuencias sedimentarias del Pleistoceno (Ver graf. 3,4) [1].

La zona de subducción interplaca, el tectonismo andino y el volcanismo constituyen las principales áreas fuentes de los sismos (Ver graf. 5,6) [2][3].



2. Riesgo sísmico para monumentos históricos: El riesgo sísmico es medido en función de la máxima intensidad sísmica (Mercalli Modificada-MM) que el monumento ha resistido durante su vida útil sin llegar al colapso [4]; esta intensidad constituye el sismo de comprobación y solamente será aplicable para cada monumento cuyo período de observación sea mayor de 300 años.

FUENTES DE GRAFICOS

Graf. 1 y Graf. 2: compendio de varias publicaciones sobre Tectonismo Andino.

Graf. 3 y Graf. 4: Mapa geológico de la Provincia de Pichincha. Ministerio de Energía y Minas, 1985

Graf. 5: Elaboración en base al "Mapa sismotectónico del Ecuador", INECEL y al "Mapa Hidrogoelógico de la Provincia de Pichincha", Ministerio de Energía y Minas, 1985.

Graf. 6: Estudio microsísmico del valle internadino entre Latacunga y Guayllabamba. Minard Hall, Escuela Politécnica Nacional, 1978.

* Autor a quien debe ser dirigida la correspondencia.

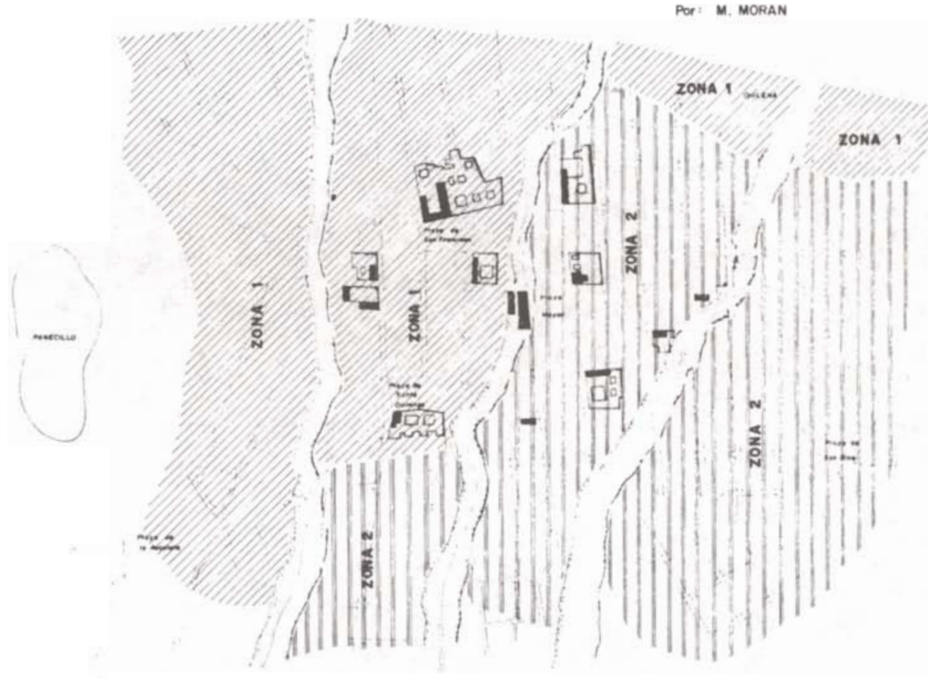
La definición del sismo de comparación en términos de la aceleración permite diseñar el reforzamiento límite adecuado para el monumento dañado por éste.

3. Microzonificación sísmica de Quito: Las condiciones dinámicas del suelo de fundación determinan otro parámetro, pues una respuesta inadecuada de la interacción suelo-estructura produce un riesgo que deberá ser moderado con una intervención estructural apropiada.

El proyecto de microzonificación sísmica para el Centro Histórico de Quito permite conocer parámetros dinámicos del suelo local (Ver graf. 7).

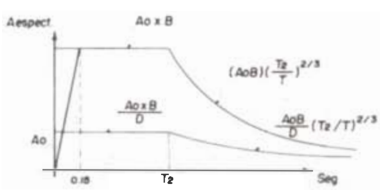
PROYECTO DE MICROZONIFICACION SISMICA
PARA EL CENTRO HISTORICO DE QUITO

Por: M. MORAN



ZONA	B	T_2
1	2.5	0.4
2	2.5	0.6

Para Construcciones Históricas D=2



ESPECTRO DE RESPUESTA

GRAF. 7

4. Valor arquitectónico del centro histórico de Quito: Existen dos razones que determinan el valor de Centro Histórico:

4.1 En el período colonial (1534-1810), Quito fue la ciudad de la región Norte del país menos afectada por el impacto sísmico ya que, en el mismo período, ciudades vecinas debieron ser reconstruidas o reubicadas.

4.2 La unidad espacial y formal del Centro Histórico de Quito se mantiene a lo largo de 400 años y constituye una de las pocas capitales de Latinoamérica que posee un centro de tal magnitud y características físicas.

5. Vulnerabilidad sísmica de los monumentos históricos construidos en tierra: En general, los conventos e iglesias de Quito se construyeron originalmente en adobe. Paulatinamente éstos monumentos se reconstruyeron en ladrillo. En monasterios de monjas se dieron los mismos cambios pero manteniendo el adobe en los claustros y cerramientos perimetrales.

Las construcciones históricas de adobe presentan alturas máximas de 10 metros, con muros cuyos espesores promedio son de 1.20 mt. en planta baja y 1.00 mt. en planta alta.

Las tipologías de las construcciones de adobe, que han demostrado su resistencia y estabilidad, se caracterizan por tener valores bajos, inferiores a 5 para la relación altura-espesor. Cuando esta relación tiene valores superiores a 5, su estabilidad frente a los sismos disminuye en ausencia de sistemas de arriostramiento lateral.

Lo expuesto demuestra que formas esbeltas como torres, muros sin arriostramiento y sistemas abovedados no han resistido los sismos de intensidades mayores que V (MM), lo que justifica la existencia de torres de ladrillo y reforzamiento de los muros con ladrillo, piedra y madera para mejorar su resistencia.

Reconocimiento de las tecnologías tradicionales de prevención sísmica

1. Tipologías arquitectónicas constructivas del centro histórico de Quito, procesos constructivos y materiales: El examen en muros de 17 monumentos históricos coloniales a lo largo de 22 sismos de importancia ha dado como resultado las siguientes conclusiones:

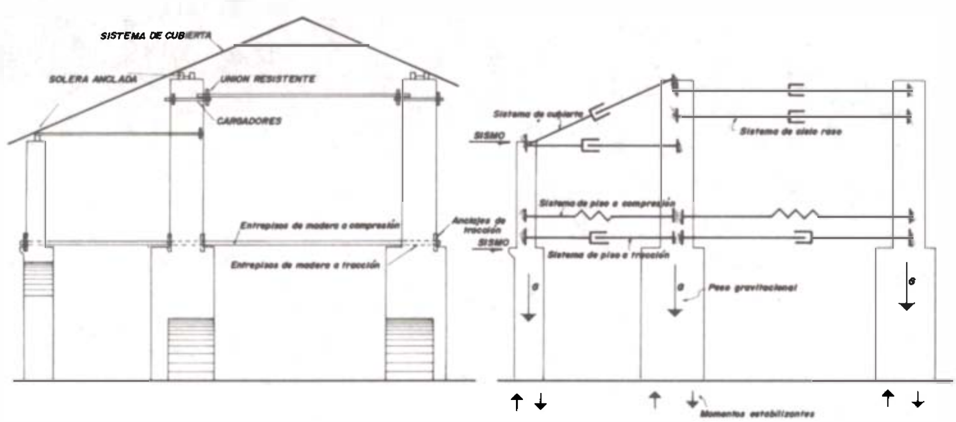
1.1 La totalidad de los monumentos religiosos conservan aún muros de adobe, muros mixtos adobe-ladrillo y solo en dos casos muros de bahareque localizados en planta alta.

1.2 En todos los casos, las cubiertas son de madera y teja con predominio de una estructura tipo rey y del tipo dos aguas adosadas.

1.3 La relación de los muros, en alto y ancho calculado por pisos, es la siguiente: en planta baja, la relación es de 3.35 y en planta alta es de 4.27, con excepción del monasterio de Santa Catalina que tiene una relación promedio de 6.0.

1.4 Las dimensiones más generalizadas para el adobe colonial van desde 44 a 46 cm. de largo por 22 y 23 cm de ancho y entre 12 y 13 cm de espesor. Los adobes producidos en el presente siglo tienen una dimensión generalizada de 40 x 20 x 10 cm. Mientras más antiguo es el adobe, mayores son las dimensiones. La pérdida de componentes orgánicos que son la paja y el estiércol es paulatina con el tiempo. Los adobes actuales producidos en la zona circundante a Quito eliminan los ingredientes orgánicos, reducen dimensiones y desmejoran su calidad.

1.5 Todos los muros estudiados son muros soportantes de adobe; se encontraron ejemplos de arcos de descarga y de bóvedas primitivas únicamente en el Hospital San Juan de Dios (Ver graf. 8,9).



SISTEMAS TRADICIONALES SISMORESISTENTES

MODELO ESTRUCTURAL PARA EL ANALISIS DE LA ESTABILIDAD.

GRAFICO No.8

Graf. 8: Propuesta de confinamiento para el Hospital "San Juan de Dios" de Quito, elaborada por Ing. Mario Morán.

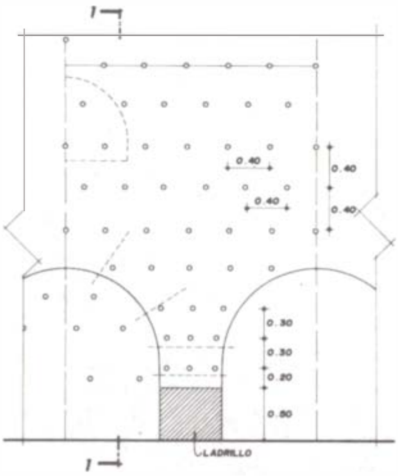
Patologías presentes en las tipologias constructivas y sistemas de comportamiento estructural en la arquitectura tradicional

Los sismos ocurridos en la colonia dieron paso a la ampliación de iglesias y conventos y a su reconstrucción parcial o total, razón por la que en la actualidad se encuentran muros mixtos con rellenos de ladrillo y piedra, que se unen con morteros de barro o de cal-arena, perdiendo su homogeneidad.

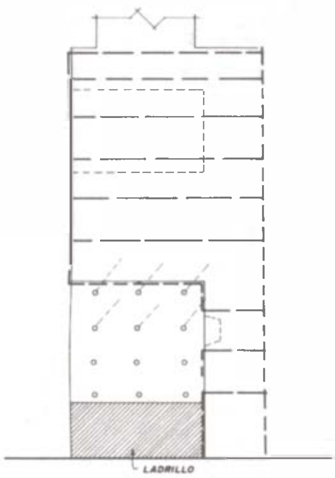
Los daños sísmicos, corresponden a una interacción entre las partes del muro y los sistemas de entrepiso y la estructura de cubierta.

Criterios de análisis estructural para construcciones en tierra solicitadas por sismos

1. Determinación del sismo de comprobación para el análisis de la edificación: Este tema constituye la principal preocupación para la determinación del nivel de intervención estructural.



E L E V A C I O N
ESCALA : 1:40



CORTE 2 – 2
ESCALA : 1:40

GRAFICO No. 9

Hospital "San Juan de Dios" de Quito. Intervención estructural en uno de los muros de adobe.

En los estudios realizados en Quito se ha utilizado la siguiente metodología.

a. Clasificación de las intensidades sísmicas registradas que han afectado al monumento.

b. Determinación del área fuente de los sismos que han causado daños a la edificación.

c. Cálculo de la intensidad sísmica en el monumento:

$$I = 8.1871 + 0.938\ M - 1.759\ Ln(R+40)$$ [5]

M = Magnitud (MSK)
R = Distancia hipocentral (Km)

d. Estudio crítico comparativo de las intensidades con los daños causados en el monumento, para establecer el sismo de comparación que servirá para los análisis de estabilidad.

2. Modelaje de los empujes sísmicos y cargas gravitacionales:

2.1. Empujes sísmicos: La aceleración se calcula mediante la siguiente ecuación de atenuación para Quito:

$$Ln\ a = 295.214 + 0.6479\ M - 1.2151\ Ln(R+40)$$ [6]

El período fundamental del monumento en tierra, por su gran volumen y baja altura, se lo podría considerar similar al período predominante del suelo, ya que conjuntamente con el muro constituirían un cuerpo continuo.

El empuje sísmico, como fuerza de inercia, se ha calculado utilizando las formas espectrales propuestas en el proyecto de microzonificación sísmica para el Centro Histórico [7], y la aceleración determinada para el sismo de comprobación.

2.2 Cargas gravitacionales: Constituyen el peso propio de los materiales que conforman el muro y las cargas de utilización como sistemas de entrepisos, tabiquería y cargas vivas, transmitidas como carga uniforme distribuída en toda la longitud del muro.

3. Determinación de los sistemas resistentes y definición del modelo estructural de análisis: Del análisis de las geometrías en planta y elevación del monumento y de los lineamientos de las fisuraciones producidas por los sismos, se determina en cada caso particular, los sistemas estabilizantes y sismorresistentes de la edificación los cuales son modelados estructuralmente para el análisis.

4. Métodos de análisis estructural y determinación de esfuerzos: Las características mecánicas particulares de los mampuestos y de los muros, conjuntamente con los problemas de comportamiento de la fisuración y microfisuración condicionan la necesidad de recurrir a métodos de análisis consistentes. Se ha utilizado generalmente métodos estáticos de cálculo, apoyados en la resistencia de materiales, aplicados sobre secciones unitarias de los elementos.

5. Diagnóstico y formulación de la teoría del comportamiento estructural del monumento: La comparación cuantitativa y cualitativa entre la resistencia disponible del muro y los esfuerzos mayorados, calculados por efecto de las cargas gravitacionales y sísmicas, permiten formular la teoría del comportamiento estructural sobre la cual se basa el proyecto de reforzamiento.

Desarrollo de técnicas de mejoramiento estructural

1. Técnicas de Reforzamiento: Las técnicas utilizadas son de dos tipos:

1.1. Reforzamiento de la mampostería mediante forramientos superficiales de malla metálica recubierta con mortero y anclada a la mampostería con micropilotes cortos.

1.2. Reutilización de las técnicas tradicionales de arriostramiento tales como entrepisos, llaves y soleras de madera, ayudados por tirantes de acero colocados a nivel de entrepiso y cubierta.

2. Técnicas de Consolidación: Las técnicas con finalidad de consolidación utilizadas en los monumentos consisten en la restitución de su continuidad perdida por los agrietamientos o inter-

venciones provocadas por el cambio de uso, mediante la colocación de micropilotes inyectados en la mampostería.

3. Técnicas de Mantenimiento: Los muros dañados por agentes tales como la humedad, erosión, sobreutilización o intervenciones inadecuadas fueron reparadas eliminando la causa de los daños y liberando los materiales incompatibles con la naturaleza del muro de tierra para luego recuperarlo mediante técnicas tradicionales de protección y reposición puntual de faltantes, en muchos casos aligerando las cargas muertas innecesarias y planificando un uso compatible con la resistencia y estabilidad disponibles en la obra muraria.

Casos de Intervención

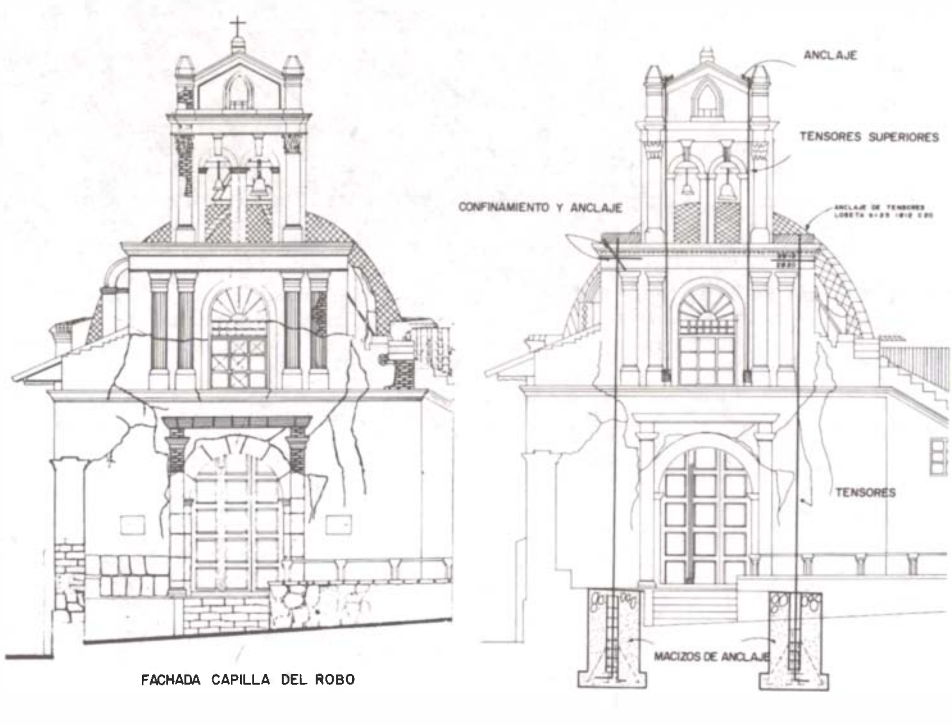
Hospital San Juan de Dios: Esta intervención se centra en el muro Sur del hospital (Ver graf. 9), destruido por efectos de envejecimiento, sobreutilización y pérdida de los mecanismos estabilizantes sismorresistentes.

Este muro de adobe data de 1564, es posiblemente el más antiguo de Quito y único en su forma, por los nichos abovedados en planta baja.

Las condiciones patológicas del muro determinaron el diseño de una intervención estructural cuyo objetivo es el "confinamiento armado" de las masas de adobe agrietadas y fisuradas para que por medio de inyecciones de morteros de terrocemento recuperen la continuidad y la resistencia adecuada para obtener una estabilidad con una seguridad consistente con la crujía de la cual el muro es parte.

El diseño de intervención se completó con propuestas de confinamiento del suelo de fundación y la reposición de los mecanismos de arriostramiento sismorresistentes originales.

Capilla del Robo: En este monumento, cobra importancia la conservación de la espadaña del frontispicio de la Capilla, por sus condiciones de gran esbeltez y la construcción mixta con dos materiales: ladrillo-adobe.(Ver graf. 10)



Graf. 10: estado actual y propuesta de reforzamiento y consolidación estructural de la Capilla del Robo.

Levantamiento realizado por el Instituto Nacional de Patrimonio Cultural.

La masa sobresaliente de la espadaña, por su esbeltez, es un elemento vulnerable al sismo; las vibraciones y desplazamientos laterales producidos afectaron al muro inferior de adobe, agrietándolo y fisurándolo con la consecuente pérdida de resistencia.

El estudio estructural demostró la necesidad de amortiguar y arriostrar la espadaña a fin de controlar la respuesta sísmica de este elemento. Para ello se diseñó un sistema de tensores verticales de arriostramiento anclados a dados de hormigón ubicados en el piso, que cumplen doble función: por una parte, controlar el volcamiento, y por otra, amortiguar las vibraciones.

La resistencia del muro de adobe fue mejorada mediante el uso de micropilotes de hierro, inyectados en la mampostería y el revestimiento de ésta con una armadura de malla metálica adherida a los micropilotes.

Conclusión

El objetivo de la intervención estructural en los edificios históricos de Quito es la de garantizar su estabilidad, sin pretender un reforzamiento más allá del resistido por el monumento a lo largo del tiempo.

La estabilidad sísmica de los monumentos coloniales construidos en tierra depende de los mecanismos de arriostramiento en madera proporcionados por los sistemas de entrepiso y cubierta.

Los testimonios actuales ponen en evidencia que formas estructurales complementarias a los muros, tales como arcos, bóvedas y cúpulas no fueron concebidas en tierra sino en otros materiales como ladrillo y pómez. Estas formas fueron importadas indistintamente desde zonas no sísmicas. Las torres han sido, a lo largo del tiempo, los elementos arquitectónicos más afectados por los movimientos sísmicos.

Los estudios de geofísica para el centro histórico de Quito han revelado parámetros dinámicos no compatibles con este tipo de edificaciones, lo que obliga a conservar los mecanismos tradicionales de protección sísmica.

La recuperación de la resistencia perdida por causas sísmicas, de envejecimiento, sobreutilización y falta de mantenimiento de los muros de adobe se ha practicado con la aplicación de técnicas de reforzamiento para otros materiales que se han adaptado para las obras de restauración en adobe.

El presente estudio posibilita el desarrollo de futuras investigaciones relacionadas con el riesgo sísmico y el comportamiento estructural de las edificaciones históricas.

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ABSTRACT

Research on antiseismic construction is increasing and finding concrete applications. It befits us to look with attention and modesty at the works bequeathed to us by architects of antiquity. They respected earthquake-resistant rules of construction. Since that time, we have invented little and forgotten much.

LE BATI ANCIEN DANS LES ZONES A RISQUES

Patrick de Maisonneuve
architecte-professeur
18 av.Saint Surin
87 000 Limoges
France

La leçon du passé

Avant d'avoir un certain regard sur le bâti ancien dans l'antiquité,il est important que nous distinguions les différents bâtis .Il existe des familles de bâti qui ont des caractéristiques particulières selon les matériaux qui composent les murs et par conséquent qui réagissent différemment.Pour cette raison ,il faut que nous appréhendions,les bâtis en fonctions de leur famille:le bâti en pans de bois et le bâti en pierre par exemple,réagissent différemment,vieillissent différemment,sont éventuellement sujets à des maladies différentes et l'on voit déjà là une raison pour spécifier les interventions sur un bâti selon sa nature.Il faut toujours avoir présent à l'esprit ces différentes familles de bâti.

bâti en pierres de taille
bâti en pans de bois
bâti en terre crue
bâti en terre cuite
bâti composite

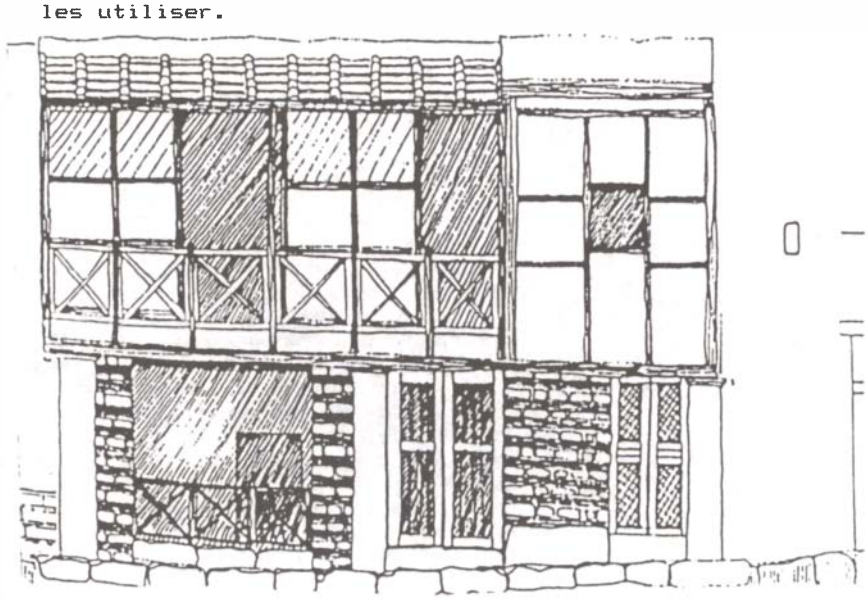
Chacune de ces familles selon qu'elle est constituée de maisons isolées ou en blocs aura des réactions qu'il nous faut essayer de comprendre.

Avoir un regard sur les techniques antiques de construction en étudiant leurs vestiges,pour un non archéologue,c'est lui permettre de mieux comprendre les techniques du bâti ancien sur lequel il travaille. Les différentes recherches nous permettent d'affirmer,peut-être avec présomption mais avec une évidente sincérité,que les témoignages du bâti simple traditionnel de l'antiquité étaient d'un niveau technologique aussi avancé que le nôtre parfois pensé de manière plus intelligente.Nous savons par la tradition écrite,le souci des anciens de construire en respectant les règles sismiques.Les travaux du professeur Bruno Helly disent maintes et maintes fois "Dieu les avaient puni car ils n'avaient pas respecté les règles."Mais quelles sont elles? Pour répondre à cette question ,il nous faut traverser les sites et les regarder avec un oeil différent.
A Pompei,nous découvrons grâce au travaux de Jean Pierre Adam les interventions de restaurations des Romains âpres le tremblement de terre de 51 ap J.C. et avant le recouvrement en 79 ap J.C.
Dans le site de Délos en Gréce ,les vestiges des soubassements nous étonnent.Par exemple,les maisons qui se trouvent à la proche périphérie de la "maison des masques"(remarquable pour ses mosaïques)nous montrent des compositions de murs fort étonnantes.Tel mur est composé de blocs de pierres importants avec ,entre eux ,de petites pierres qui par leur présence, leur nombre et leur polissage ont de toute évidence un rôle important.Ce système antisismique est comparable à celui des îles voisines comme l'île de Seriphos,les maisons du moyen-age de 1433,de même que les maisons plus récentes de 1885 sont composées avec ce même procédé,avec cependant une différence ,à savoir que les blocs sont souvent plus petits et moins soignés.Mais de toute évidence ,si une maison de 1433 nous est parvenue, cette maison a pu supporter bien des tremblements de terre.Si nous restons à Délos nous pouvons voir la encore des choses très intéressantes.Tel mur dans lequel les pierres s'imbriquent les unes dans les autres comme si elles se soudaient entre-elles.Cette composition de mur nous la retrouvons de la même maniéré dans le site ancien de la vieille théra,dans l'île de Santorin. Nous trouvons aussi dans le site de Délos des blocs de pierre de grandes longueurs .Ils liaisonnement deux murs ou angles de murs entre eux ou deux maisons entre elles. Cette technique , nous la retrouvons dans les sites des comptoirs venitiens ,mais aussi dans les maisons traditionnelles de l'île d'Andros en Grèce.Enfin au Théâtre de Délos ,les murs qui soutiennent les gradins sont pensés de manière très étonnante.Un site comme Délos est riche de remarques qu'il faudrait approfondir et rapprocher de bien d'autres sites.IL existe une foule de techniques,toutes ces techniques ne sont qu'une petite partie de ce que nous commençons à entrevoir

Les bâtis en pans de bois :c'est dans les sites archéologiques d'Herculanum ou de Pompei que nous trouvons des exemples.
Bien que Vitruve ,dans son livre ,n'accorde que peu d'intérêt aux maisons en pans de bois ,au regard des études qu'on peut mener sur les sites ,de nombreux éléments nous permettent d'affirmer que les pans de bois étaient beaucoup plus utilisé qu'on ne le pense.A Herculanum ,les pans de bois étaient très utilisés pour les étages.Notre regard se portera sur une maison que Maiuri Amadeo a fouillé la"Casa Graticio". Cette maison entièrement en pans de bois ne doit pas étonner dans un tel site antique dont les R.CH.sont en pierre.Nous allons essayer de comprendre cette maison dans sa présentation actuelle et dans les différentes réhabilitations par les archéologues .Malgré les techniques employées (le béton armé en plancher..) nous pouvons encore aujourd'hui très bien comprendre la technicité du pans de bois à l'époque romaine et la retrouver dans de nombreux bâtis anciens existants aujourd'hui.Ce qui nous permet de mieux comprendre les pièces du puzzles manquantes.Les pans de bois de cette maison étaient pensés et montés comme ceux que montaient les charpentiers du moyen-age et des époques suivantes.Ces charpentiers qui connaissaient la fabrication des navires ,savaient comment permettre à une maison en bois de se stabiliser entre deux maisons en pierres.En essayant de comprendre la maison avec Valerio Papaccio architecte du site antique nous pensons que la Casa Graticcio qui est construite entre deux maisons.samnites,utilise l'espace du jardin ou des dépendances d'une de ces deux maisons, et a été construite par un des deux propriétaires soit pour être louée soit ,comme on le pense à la suite d'un tremblement de terre .Cette maison ne comporte pas de murs pignons en pans de bois .Tous les éléments porteurs (planchers)reposent sur des piliers en briques..Ceux-ci sont désolidarisés des murs des maisons voisines.Nous verrons dans la troisième partie de ce document qu"à la suite d'un tremblement de terre il ne faut jamais laisser un espace vide entre deux maisons qui ont souffert .Très souvent lorsque une maison s'est effondrée,nous,les architectes, veillons à consolider les maisons voisines en soutenant les murs pignons par des poteaux et des poutres en bois.Ici ,dans le cas de la Casa Graticcio.la même technique a été employé.Simplement l'espace vide est devenu une construction.C'est le phénomène classique de l'utilisation par les propriétaires ,des espaces vides . En comparant cette maison avec des maisons en pans de bois de Limoges ou de Toulouse ....;nous comprenons que les Romains possédaient très bien la technique du bâti en pans de bois.

Les études,les observations et tous les enseignements que nous transmet confirment la connaissance des maisons en pans de bois que nous avons pu réaliser dans le cadre de la collection des 45 ouvrages de la connaissance du Bâti Ancien d'E.D.F. Cela nous aident à comprendre l'importance du pans de bois dans les sites à hauts risques sismiques comme Pompei et Herculanum.

Nous venons de voir à travers deux sites tellement connus de l'antiquité que les bâtisseurs antiques avaient une connaissance des techniques antisismiques et qu'il savaient les utiliser.



II partie

Nous disposons de techniques antisismiques

Dans le cadre des zones sismiques ces mêmes caractéristiques apparaissent sur le bâti ancien traditionnel que nous habitons aujourd'hui et que l'on peut situer du moyen âge à nos jours.Ce bâti traditionnel,selon sa nature (en pierre ou autres) a des constantes qu'il nous faut sans cesse retrouver et approfondir.Ces techniques ne sont pas hierachisées mais trés liées aux types de bâti.

1)Le bâti en pierre
Comme nous l'avons évoqué plus haut ,les maisons grécques ont leurs murs composés de mélanges de grosses pierres et de petites pierres avec un savant agencement,les cloisons sont en pans de bois et le plafond a la particularité d'être fait de rondins de bois sur lesquels peuvent bouger des pierres plates .Le tout est recouvert d'une importante épaisseur de terre .Lors d'un tremblement de terre ,le remplacement de ces techniques par une dalle béton fragilise le bâti.Nous pouvons voir 15 à 20 ans après un certain nombre de fissures,les dalles se relevant aux extrémités.Ceci nous montre qu'il ne faut pas appliquer n'importe quelle technique mais qu'il faut rester prés des techniques du bâti ancien et des connaissance des maçons locaux qui non seulement savent les mettre en oeuvre mais aussi savent les entretenir.
Tout le monde connaît les techniques présentes dans de nombreuses régions du monde,qui consistent à renforcer les soubassements des murs comme par exemple à Annecy ou en Corse...Il existe aussi des techniques plus subtiles et qui cache une permanence constante de réhabilitation:Celle d'un des premiers projets étudiés lors du tremblement de terre en Italie en nov.1980 dans la région de la Campanie.

Cette technique consiste en une superposition de contreforts et une utilisation de l'espace entre ceux-ci .Elle est employée dans sa plus grande exubérance dans certaines îles italiennes telle que l'île de Procidea ou l' on constate en examinant de près qu'il y a une succession de contreforts qui avancent sur la mer.Ces mêmes références se retrouvent en Gréce dans l'île de Santorin,employées de façon moins importante mais on trouve aussi d'immenses contreforts qui soutiennent encore des maisons du moyen âge.
Enfin de manière plus subtile ,c'est dans l'île de Paros que l'on utilise la technique de l'arc à l'intérieur de la maison.Lorsqu'on essaye de comprendre le positionnement de cet arc ,qui se situe souvent au centre de la pièce,on constate qu'il prend appui sur un autre arc extérieur à la maison qui sert de passage couvert.Celui-ci prenant appui lui-même sur l'arc d'une autre maison.C'est ainsi qu'il existe un immense maillage d'arcs à l'intérieur comme à l'extérieur des maisons.Le non entretien de ces arcs diminue toute leur efficacité.Ce que nous admirons avec beaucoup de plaisir lorsque nous nous promenons dans les îles grecques sous les passages couverts n'est que l'inlassable volonté des habitants de créer ce maillage afin de se protéger.Ces éléments que l'on croit comme des éléments de décor sont d'une importance antisismique capitale.

Enfin les maisons de Santorin ou les rares vestiges de la région Amalfitaine en Italie sont de véritables arcs en-elles-même.Toute la toiture constitue un arc.On trouve aussi de nombreuses petites techniques pour les ouvertures ou les fenêtres,en Yougoslavie ou en gréce.

Avant d'aborder les maisons en pans de bois et comme élément de transition regardons les maisons en pierres ou autres ,dont la partie haute est en pans de bois ,telles qu'on les trouve dans le nord de la Gréce ou en Yougoslavie.A chaque niveau,les murs comportent tous les mètres des sortes d'échelles en bois posées à plat sur le mur .Ainsi la maison est striée sur toute sa hauteur par du bois qui sert de chaînage ou de liaisonnement.Cette technique se retrouve en Turquie comme l'indique Haroun Tassief dans son ouvrage comme constituant un modèle de maison rurale préconisée et figurait à ce titre sur des affiches de propagande.

Pour le pans de bois c'est en Alsace (France)que l'on remarque l'emploi de la technique du bois long qui monte sur plusieurs niveaux.Il existe dans cette région une volonté de séparer chaque niveau ,une triangulation de la toiture,et une pièce de bois "le Man"qui équerre les sabliéres avec les poteaux corniéres.La particularité de cette pièce de bois est constituée par le fait qu'elle se cheville par l'extérieur .L'observation des maisons en pans de bois nous permet de constater exactement la même technique en Turquie et en Gréce.Dans l'île de Lefkas on remarque cette technique similaire,les restaurateurs du dernier tremblement de terre ont préféré positionner des escaliers bétons devant ce type de maison,ignorant complètement le fait que les escaliers étaient construits en bois.La propriété du bois est de pouvoir se déformer.

Enfin les maisons en terre,les études à ce jour ne nous permettent pas d'affirmer encore que nous disposons des des techniques appropriées.Par contre nous savons que la particularité de ces maisons est d'avoir comme on le dit en Dauphiné "De bonnes bottes et un bon Chapeau" c'est à dire que la charpente de la toiture avec son chaînage et son poids liaisonne l'ensemble de la maison sur des bases saines.Toute fragilité des Chaînages d'angles entraîne plus souvent la chute des murs.
L'étude des technique anciennes par type de bâti a pour but non seulement d'apporter les meilleurs réponses techniques en utilisant aussi bien les techniques anciennes que les techniques modernes.Mais surtout de comprendre le comportement de ce bâti et retrouver le savoir des génération d'utilisateurs.Mais il nous faut encore beaucoup chercher et surtout analyser.

III partie
Le bâti antisismique:des réglés ,une implication...

Parmi les problèmes que nous constatons avant et après un tremblement de terre on relève un certain nombre de constantes cause de danger.
1)le problème du non entretien et des constructions abusives
2)le problème de la méconnaissance des fissures ,de l'interprétation de la lecture de celles-ci pour en évaluer le danger

En zones à risques ,le danger vient souvent du non entretien des habitations.Le non-entretien de la toiture et des murs,quelque soit le type de bâti,rend vulnérable aux secousses non seulement l'habitation mais aussi les maisons voisines.Lors des tremblements de terre ,on a pu observer des bâtis ayant souffert à cause d'un élément défectueux,une poutre mal ancrée...par exemple.Parmi les premières observations c'est telle cheminée qui peut être en danger ,telle tuile mal positionnée ,tel linteau non conforté qui peut constituer un danger.
De même la construction sauvage est un problème très grave et qui cependant s'amplifie.Un propriétaire de dernier étage qui construit une surélévation sans tenir compte de son voisinage est un réel danger.Dans le cas de Polla en Italie c'est une construction abusive qui a déstabilisé un îlot entier,alors que celui-ci avait fort bien tenu jusqu'à présent grâce à ses contreforts.
Un autre problème apparaît ,c'est le changement de nature des matériaux.Lorsque un propriétaire d'un bâti en pierre pense consolider sa maison en remplaçant une poutre bois par une poutre métallique ,ou un plancher bois par un plancher béton,les matériaux réagiront de manière différente et peuvent créer des désordres.Une des premières maisons que j'ai abordée après un tremblement de terre avait un rez-de-chaussée en pierre de taille ,le premier étage en béton ,le deuxième étage en brique.Le fils avait construit sur la maison de son père et avait réalisé une habitation pour son propre fils en brique au deuxième étage.Lors du tremblement de terre ,l'étage en béton s'est déplacé de 10 à 15cm ,quant à l'étage en brique,il fut totalement effondré.
De la même manière ,on a vu sur maisons ou la toiture avait été remplacée par une toiture en béton : des dalles (toiture) avaient bougé de plusieurs centimètres sur les murs de pierre

La lecture du bâti à travers ses fissures
Au niveau d'un îlot, la lecture des fissures nous permet de comprendre ce qui s'est passé sur le bâti. Nous devons aussi savoir si les fissures sont dangereuses ou non.

Dans le cadre des réflexions que nous pouvons faire sur le bâti ancien, le premier problème est la connaissance de ce bâti. Fort longtemps ignorée, cette connaissance n'est pas encore diffusée dans le cadre des écoles d'architecture.
C'est un réel problème car on peut en voulant réhabiliter faire plus de mal que de bien. On l'a souvent constaté dans les sites archéologiques ou les restaurations ont contribué à accroître la destruction des sites. Mais la connaissance du bâti est importante car c'est dans ces zones que vivent les familles les plus pauvres, les hommes travaillant dans d'autres régions ou pays. Apporter des techniques citadines peut être totalement contradictoire pour le bâti mais aussi les vieux maçons qui sont sur place ne les connaissent pas. Il est donc important d'aider ceux qui sont sur place à mettre en oeuvre leurs propres techniques qui respectent le bâti. Il est étonnant de constater qu'une technique que l'on trouve en Yougoslavie se retrouve en grèce et dans d'autres pays. Nous devons donc avant de faire toute conclusion approfondir nos connaissances par des recherches et des échanges.
Un des principaux problèmes du bâti réside dans l'entretien de celui-ci. Tout bâti entretenu a de meilleurs chances de bien réagir.

Comme nous l'avons vu précédemment, c'est la recherche de techniques spécifiques dans les zones sismiques qu'il nous faut approfondir souvent en étudiant les techniques de nos pères de l'antiquité à nos jours.

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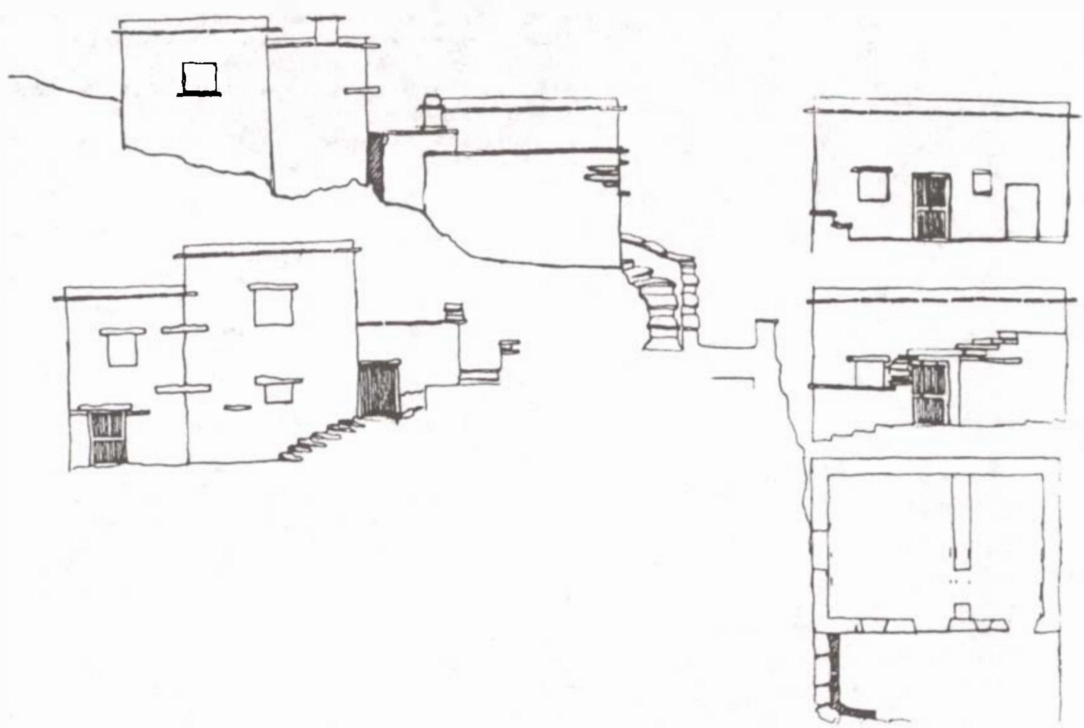

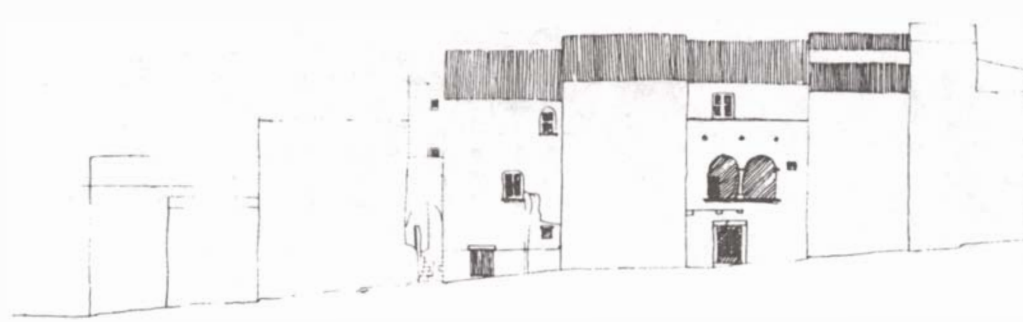

ABSTRACT:
On October 17 1983 an earthquake measuring 7.1 on the Richter scale with an epicenter in Santa Cruz County shook northern California causing massive property damage and some loss of life. Among the structures affected were the last four Hispanic Era historic adobe buildings in Santa Cruz County. Two of the four had previously been strengthened to varying extents to withstand seismic events. the Santa Cruz Mission Adobe and the two story Castro Adobe. The damage to each of the four structures is described, evaluated and major factors contributing to the damage are identified.

KEYWORDS:
Adobe, earthen architecture, seismic, earthquake, seismic mitigation

DAMAGE TO HISTORIC ADOBE BUILDINGS NEAR THE EPICENTER OF THE 1989 LOMA PRIETA EARTHQUAKE SANTA CRUZ COUNTY CA

Edna E. Kimbro
Historical: Architectural: Conservation Research

At 5:04 P.M. on October 17, 1989, an earthquake measuring 7.1 on the Richter scale occurred centered in Nisene Marks State Park in Santa Cruz County. For 15 seconds it shook Northern California causing massive property damage and some loss of life. Over the ensuing months thousands of aftershocks followed, 90 measuring over 3 on the Richter scale, 20 above 4, and 3 over 5. Santa Cruz County lies for the most part on the Pacific plate, west of the San Andreas Fault dividing the Pacific and North American plates. The Pacific plate is gradually moving north.

Only four Hispanic era historic adobe structures remain in Santa Cruz County where the twelfth Franciscan Mission was founded by Spain in 1791: the Branciforte Adobe (Ca. 1806-1818, the Bolcoff Adobe (Ca. 1839-1844), the Santa Cruz Mission Adobe (1822-1824), and the Castro Adobe (Ca. 1846-1850). Although these structures are the oldest historic buildings located in this part of zone 4, only two of the four had previously been strengthened to help withstand seismic events. All four were presumably affected by the 1906 San Francisco earthquake judging from old photographs and physical evidence of damage.

Figure 1. The Branciforte Adobe, 1987

Figure 2. North end wall, Branciforte Adobe. 1990

Figure 3. The Bolcoff Adobe, 1990

The Branciforte Adobe

A one-story, two-room building, the Branciforte Adobe (Ca. 1806-1818), fared relatively well in the Loma Prieta earthquake of 1989. Originally it was constructed as a one-and one-half story, tile roofed one-room structure with adobe gable ends and a *tapanco* or loft above. Currently the Branciforte Adobe has woodframed additions to the west and south, a woodframed replacement south end short wall, and woodframed replacement gable over the north end adobe wall. The west long adobe wall is no longer loadbearing as the shingled roof now rests on the woodframed west wall of an addition and on the east adobe wall.

The Branciforte Adobe is oriented with the long walls running north-south and faces east as was typical of early California adobe construction. The walls are 60 cm thick, with a height to thickness ratio of 4.5 for the long walls. The adobes measure 30 cm in width by 7.5 in depth by 60 cm in length and are laid in Flemish bond. A 30 cm interior partition wall added to the structure a 1848 features vertical wood members with specially cast adobe infill between, representing a seismically superior building technique. A similar adobe partition wall was added to the Santa Cruz Mission Adobe circa 1848 as well.

Besides the usual diagonal cracking about the door and window openings, through the wall vertical cracks occurred at the previously undamaged northeast and northwest corners of the adobe. A vertical crack widened near the northwest corner where an opening had been cut and partially filled by a cupboard.

Previous to the seismic event of October 17, 1989 the Branciforte Adobe had been rehabilitated between 1976-1986, was well maintained and in a good state of preservation. Moisture problems had been alleviated by the installation of a French drain at the north gable end and restoration of the *corredor* sheltering the east long adobe wall. These factors, together with the low height to thickness ratio and prior loss of the adobe gable, apparently contributed to the structure's performance under earthquake loads despite its proximity to the epicenter and lack of seismic strengthening.

The Bolcoff Adobe

Bolcoff Adobe, a one-story, two-room structure dating from ca 1839 to 1844, was the least obviously damaged by the earthquake although it is ill-maintained and in a poor state of repair.

The long walls of the Bolcoff adobe are oriented north-south with the facade facing east like the Branciforte Adobe. The walls are constructed of adobes measuring 20 cm in width, 7.5 cm in height, and 35 cm in length laid in English bond. They are 70 cm thick and the ratio of height to thickness is 3.6, well within the current code requirement of 5 in seismic zone 4.

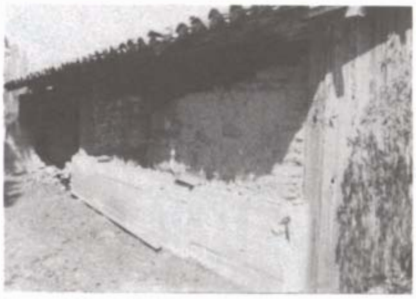

Figure 4. West elevation, The Bolcoff Adobe, 1990

The north portion of the west long wall has been replaced with formed concrete and reinforced concrete encapsulates the base of the southern wall segment extending about a meter up the wall. The south end short wall has been replaced with woodframing which supports the heavy barrel tiled roof at that end. The roof plate rests on concrete corner buttresses at the north end and at the midpoint of the east long wall; the adobe walls do not carry the load.

Mudstone foundations extend over a meter deep into the alluvial soil of the former stream bed of Wilder Creek. Ground level inside and out of the structure has been lowered over time about 30 cm exposing portions of the footings. Above the stone foundations excessive moisture has resulted in considerable erosion of the wall face, undermining the east wall near its base.

Effects of the October 17, 1989 earthquake on the Bolcoff Adobe were not devastating as might have been expected given the building's condition. A pre-existing vertical crack widened in the east wall and diagonal cracking was observed in the north end wall. There, high in the gable portion of the wall, an unframed opening suffered the loss of some adobes near the apex and the opening itself was displaced to the west. The most dramatic effects occurred in places where portions of the deteriorated adobe wall surfaces fell away exposing the darker interior of the mud bricks.

The moderate nature of the damage to the Bolcoff Adobe is attributed to stability resulting from the low height to thickness ratio of the walls, the small number of openings and the fact that the weight of the roof is not borne by the walls. The location of the Bolcoff Adobe farthest from the epicenter may have been a factor in favor of its continued survival.

Figure 5. The Santa Cruz Mission Adobe, 1990

The Santa Cruz Mission Adobe

The Santa Cruz Mission Adobe, a one-and one-half story seven-room structure was completed in 1824 for Indian neophyte quarters at the mission. On October 17, 1989 the building was undergoing restoration and had recently been retrofitted with a horizontal concrete bond or ring beam connecting the historical outer walls with the newly reconstructed adobe cross walls. Also, a new plywood sheathed roof well anchored to the bond beam had been constructed awaiting installation of roof tiles.

The Santa Cruz Mission Adobe is atypically oriented with its long walls running east-west and the reconstructed short walls aligned north-south. The walls are constructed of adobes 20 cm wide by 7.5 cm and 42.50 cm in length laid in English bond. They are 82.5 cm thick with a height to thickness ratio of 2.66 for the long walls. The reconstructed short walls suffered the greater damage, cracking diagonally with cracks forming "X" configurations in the wall expanses and cracking diagonally at the top of openings. What initially appeared to be out-of-plane displacement turned out to be poor workmanship in the construction of the walls, the product of failure to align the courses vertically.

Figure 6. Southwest corner, the Santa Cruz Mission Adobe, 1990

At the west end or short wall, a pre-existing vertical crack which had been repaired with Portland cement stucco in 1966 widened and deepened, extending through the wall at the corner. At the same corner a wide vertical crack opened in the south long wall, leaving an essentially freestanding column of adobe which toppled in an aftershock, cracking the bond beam on the west side. The upper portion of the west short end wall moved outward horizontally to the west beneath the bond beam leaning more than 10 cm from vertical. The lower portion of the wall suffered some out-of-plane damage with loss of stones from the foundation.

Factors contributing to the instability of the west end include: 1) failure to properly repair the existing vertical crack at the corner; 2) a later door cut into the west wall west face close to the corner; 3) unstable foundation conditions not completely remedied; 4) recent archaeological excavations very near the wall; and 5) lack of vertical anchorage of the bond beam to the wall.

The gables confined between the ring beam and roof framing suffered little damage. Some original mission period mud plaster with Native American Graffiti located high on a short gable wall survived more or less intact. Also intact is a mud plastered surface decorated by Indian neophytes on the interior of the long south adobe wall. This surface was painstakingly re-adhered to the adobe wall by Constance Silver and Nan Rosenthal in 1987.

The long walls aligned perpendicular to the primary north-south direction of the earthquake motion were comparatively little affected by the earthquake. Predictably, they suffered narrow diagonal shear cracks at both existing and recently filled in door and window openings. Narrow, near vertical cracks appeared on the exterior of the walls marking the intersections with newly reconstructed interior crosswalls. The original perimeter walls exhibit noticeably better workmanship in their construction with deep footings extending well over a meter below grade and mudstone rubble masonry reaching high above grade as well. They have been kept dry and roofed, and have been little affected by basal erosion.

The response of the Santa Cruz Mission Adobe to the earthquake may have been improved by the recent removal of a unoriginal second story. That factor together with the installation of a ring beam, the low height to thickness ratio of the walls, the reconstruction of multiple cross walls and the rigid roof diaphragm, contributed to the building's survival with only moderate damage.

Figure 7. The Castro Adobe, 1990

Figure 8. Damage from cocina ridge beam, the Castro Adobe, 1990

The Castro Adobe

The Castro Adobe, ca 1846-1850, the only two-story historic adobe structure in the county, is located less than 5 miles from the epicenter of the Loma Prieta earthquake. The walls of both stories are a uniform 70 cm thick and the height-to-thickness ratio of the long walls is just over 3, calculating each story separately. The adobes, 35 cm wide by 7.5 in height by 70 cm in length, are laid in heading bond on shallow mud-mortared cobble foundations about a third of a meter deep. They are made of dark subsoil with straw, while the mortar is light topsoil with considerable straw admixed.

The building is oriented typically with long walls running north-south penetrated by numerous openings. The doors and windows are symmetrically disposed and aligned one above the other. The large columns of masonry between openings cracked diagonally forming large "X" shapes. There are but two adobe cross walls on the lower floor and none above. The second story is essentially one large room 9 by 24 m.

North of the two story block, a one-story adobe *cocina*, or kitchen, was constructed against the north wall with an oversized opening in the east long wall. Within the last 30 years the roof of the *cocina* was altered in seismically unsound ways. That is, the roof rested directly on the east long wall but was raised about 10 cm above the west long wall bearing on narrow adobe infill between short studs and was not anchored to either side wall. During the earthquake, the roof's massive laminated ridge beam rammed a hole into the midpoint of the two-story north wall and cracked it vertically through the wall. The roof moved as a unit about 15 cm north thrusting out the west long wall and producing a vertical crack at the northwest corner over 10 cm wide. The north gable end wall of the *cocina* suffered major out-of-plane damage about a meter from the base. Finally, a tiny pre-existing vertical crack through the north gable end wall, where a corbel was inserted in the 1950s, widened about 10 cm. With aftershocks, the northwest corner and part of the north end wall became a freestanding column of adobe leaning outward.

Following the 1906 earthquake, the Castro Adobe had been fitted with wall anchors at the first floor plate level; these performed well in 1989 preventing the collapse of the second floor. Also, a wooden tie beam had been embedded in the north wall penetrating the east and west long walls at the midpoint of the second floor. In the 1950s, the historic roofing system was replaced by trusses and the spongy second floor suspended from the bottom chords by steel rods through the floor joists.

In 1987, evidence of settlement of the south end of the building prompted installation of a concrete grade beam to stabilize the south gable end wall *in situ*, leaning more than 10 cm from vertical at the apex. Wide welded steel straps were added extending about half way around the structure at the top of the first and second stories just below the plate, to anchor long walls. On October 17, 1989, the upper portion of the south gable end wall collapsed outward, taking the steel strap down with it. A wide vertical crack opened in the south wall at the southwest corner and a hairline crack opened at the southeast corner. A diagonal crack (which had been repaired with expanded metal lath on the exterior) widened in the west long wall at a doorway; other cracks, similarly repaired on the interior, re-opened and widened.

At the north end of the two-story block, the long walls cracked at the corners to beyond the wooden tie beam, which proved of dubious value. Both the long and short walls cracked diagonally around doors and windows. A vent, which had been opened through the wall without a header, exacerbated severe through-the-wall diagonal cracks.

Much of the damage to the Castro Adobe was predictable and partially the result of misguided interventions: "new" openings without headers, a poorly designed roof over the *cocina*, an ill-conceived tie beam, and an end wall "stabilized" out of vertical. A significant role was played by flaws inherent in the building's initial construction: shallow foundations built on fill, a paucity of cross walls, the use of heading bond, incompatible mortar, one- and two-story adjoining sections, large number of openings, their alignment, inserted load bearing corbels, etc., etc. Contributing to the building's continued existence are the uniform wall thickness of both stories, the low height-to-thickness ratio, the tying of the roof trusses to the first floor joists, the wall anchors, the north-south orientation of the long walls, the absence of any problems associated with moisture, and the overall high level of maintenance.

Conclusions

The Loma Prieta earthquake of 1989 represents only the latest demonstration of the destructiveness of seismic events to California's Spanish Colonial and Mexican earthen architectural heritage. In recent years several of the state's rare adobe monuments have been devastated by earthquakes. San Fernando Mission church was wholly destroyed in 1971; Mission San Gabriel and the Pio Pico Adobe (a State Historic Park) were severely damaged in 1987 necessitating their closure; and in 1989, the Castro Adobe joined their ranks.

None of these historic adobe structures had been effectively strengthened to withstand seismic events of appreciable magnitude, largely because of the high cost to retrofit an otherwise sound building to the standards of California's Historic Building Code. The costs are great enough that those responsible for stewardship of historical adobe resources gamble with geology. They pray the cost of earthquake repairs and necessary strengthening after a seismic event will not exceed that of pre-earthquake retrofitting. This is a gamble impossible to win in the long run and one that places California's irreplaceable historical heritage at risk.

Peru, Mexico and other Latin American nations similarly affected by "mother" earth's movements, and even more richly endowed with Spanish Colonial earthen architectural masterpieces, have assumed the leadership role in developing seismic strengthening techniques for adobe structures. These techniques have not been widely tested or accepted, much less well understood, in California. Engineers unfamiliar with them risk potential losses of historic resources in their misapplication. Clearly, existing seismic improvement techniques suitable for historic adobe buildings must be introduced in California and further research commenced to explore new methodologies.

If the status quo continues and alternative effective and affordable means to achieve seismic stabilization are not identified, tested, and adopted for use in the state, California's proud mission past will continue to be lost one piece at a time: an end wall today, a gable tomorrow, a dome, belltower or vault the next day.

ABSTRACT

This study focuses on the different applied building systems used by engineers, architects, and builders of adobe structures built immediately after the earthquakes that affected Guatemala in December 1917 and January 1918. These systems show the effort in improving the resistance and safety of these structures, considering the constant threat of further seismic activity.

Many trips were made to Guatemala City to explore the city, having selected five representative cases, describing each one's characteristics as well as the consequent effects that the structures suffered due to the 1976 earthquakes. The conclusion is that it has not been adobe, as material, that failed but the lack of adequate technology and maintenance.

Based on this conclusion, our purpose is to promote interest and knowledge of the experience of this study and that it will be useful in our work as preservationists of old buildings and planners of new housing.

KEYWORDS

ADOBE STRUCTURES, SEISMIC DAMAGE, GUATEMALA, 1917-1918

PREVENCION SISMICA EN LAS CONSTRUCCIONES DE ADOBE, EN LA CIUDAD DE GUATEMALA DESPUES DE LOS TERREMOTOS DE 1917-1918

María Elena Molina
1a. Calle Oriente No. 8
Antigua Guatemala

Introducción

Guatemala es un país que es constantemente afectado por diversos terremotos. Estos han devastado su territorio causando grandes pérdidas humanas y materiales. Entre éstas últimas, las construcciones en adobe, han sufrido severos daños.

Sin embargo, actualmente encontramos numerosos ejemplos de edificaciones en adobe que han logrado resistir satisfactoriamente esta intensa actividad sísmica. Por lo tanto, se hace necesario investigar y conocer sus características constructivas y tomarlas como experiencia para aprovecharla en la búsqueda de alternativas de restauración, consolidación y reestructuración de edificaciones antiguas, o bien, para programas de vivienda nueva de bajo costo. Además, evaluar esta experiencia constructiva, nos permitirá argumentar en relación a la idea errónea y generalizada que el adobe es un material que debe ser desechado en áreas de riesgo sísmico.

El presente es un trabajo preliminar que nos inicia en el conocimiento y comprensión de los sistemas constructivos utilizados en la arquitectura de adobe realizada en la Ciudad de Guatemala después de los terremotos de 1,917 y 1,918. (1)

Estos sistemas constructivos constituyen un testimonio histórico del avance tecnológico alcanzado en esa época, en las construcciones que preveen el riesgo sísmico, cuya eficacia, actualmente puede ser evaluada mediante las respuestas de comportamiento estructural observadas en estas edificaciones, después del terremoto de 1976. (2)

No existe investigación previa que haya tratado este tema. Por lo tanto este estudio ha sido elaborado con limitada información histórica y a través de observación de campo por la ciudad de Guatemala. En ésta se identificaron y observaron aquellas construcciones que muestran un sistema constructivo a base de adobe, escogiendo cinco de los casos más representativos y registrando, mediante fotografías, sus principales características constructivas.

La época de construcción de éstas edificaciones, así como los daños sufridos a causa del terremoto de 1976, fueron establecidos a través de entrevistas con los propietarios o usuarios de estos inmuebles.

Casos observados:

Caso 1

En este caso se pudieron observar las siguientes características:

Muros de adobe de 0.47 m. de espesor, que funcionan como muros portantes de carga, definiendo las crujías principales de la vivienda (3).

Los muros entre ambientes son tabiques construídos con adobe colocado de canto, de 0.15 m. de espesor, reforzados con reglas de madera y alambre espigado de hierro galvanizado, colocado en forma de retícula diagonal al muro, con intervalos de 0.30 X 0.30 m. en ambas caras del mismo.

Se utilizan varillas de acero de 1" de diámetro, uniendo los muros de carga, ancladas por medio de pernos sobre placas de metal (ver fotografía No. 1). Estos tirantes coinciden con los tabiques, quedando empotrados en el repello de una de sus paredes.

Con respecto a la volumetría, las crujías principales se encuentran conformadas por ambientes cúbicos de 4.5 X 4.5 X 4.5 m.

La cubierta a dos aguas, con pendientes de 45% aproximadamente, con estructura de madera cubierta con lámina de zinc.

La tipología es característica de las casas señoriales de la época histórica en estudio, con una planta en forma de E con dos patios interiores, uno inmediato al área de zaguán (área de vestíbulo inmediata al ingreso principal), y el otro patio, ubicado en la parte posterior de la vivienda inmediato al área del comedor (espacio que sirve de división entre ambos patios), donde se encuentra ubicada el área de servicio, conformada por los cuartos de servidumbre, la cocina y la pila o lavadero. Como área de transición entre los patios y los ambientes interiores, se encuentra el pórtico o peristilo que sirve de área de circulación y vestíbulo entre tales espacios.

Condición de la estructura después del terremoto de 1976

Se puede observar que la vivienda resistió aceptablemente el terremoto de 1976. Los daños sufridos, tales como grietas y desprendimientos de material en las cabezas de los muros y en los acabados, fueron reparados inmediatamente. Actualmente, sufre deterioro por falta de adecuado mantenimiento.

Caso 2:

En este caso se pudieron observar las siguientes características:

Muros de adobe en el exterior de la vivienda, reforzados con alambre de hierro galvanizado, colocados en forma de retícula diagonal al muro, a intervalos de 0.25 X 0.25 m. Estos muros de adobe, se encuentran apoyados sobre un muro de ladrillos de mayor espesor, que se levanta a una altura aproximada de 0.70 m. sobre el nivel exterior del suelo (ver fotografía No. 2).

Los tabiques interiores, son muros livianos, construídos con un sistema especial, consistente en una estructura de parales de madera colocados cada 0.30 m. Estos se encuentran cubiertos utilizando dos sistemas: a) machiembre de madera; b) malla metálica cubierta con mezcla, repello y blanqueado, dejando vacío el interior del muro.

La volumetría se encuentra conformada a base de espacios cúbicos de 4 X 4 X 4 m., con una cubierta de dos aguas con pendientes de 45%, y lámina de zinc sobre estructura de madera.

La tipología en este caso, varía con respecto a la acostumbrada en este período post-terremotos 1917-18, ya que presenta asimetría en la volumetría. Además, cuenta con los dos patios interiores circundados por el pórtico o peristilo y posee un jardín exterior, que sirve de transición entre la vivienda y la banqueta y calle pública.

Condición de la estructura después del terremoto de 1976

Se pudo apreciar que los muros no presentan grietas, sino únicamente desprendimientos de material de acabados. El problema actual es una absoluta falta de mantenimiento.

Caso 3

La construcción de este caso, es una vivienda popular ubicada en una zona periférica de la ciudad y presenta las siguientes características:

Muros exteriores de adobe, reforzados con reglas de madera en sentido horizontal y vertical. En sentido horizontal presentan una separación de 0.30 m. aproximadamente, en sentido vertical se encuentran colocadas a cada 0.90 m. aproximadamente.

La cubierta de lámina de zinc sobre estructura de madera con una pendiente de 30% a una sola agua.

La altura es relativamente baja, 2.75 m., con una volumetría en forma rectangular exteriormente. No fue posible observar su conformación interna.

El sistema constructivo utilizado en este caso es similar al utilizado en la arquitectura vernácular de las poblaciones rurales del territorio guatemalteco. Este consiste en tabiques que se construyen de palos entretejidos y barro (4).

Condición que presenta la estructura después del terremoto de 1976

Carecemos de datos exactos pero, en base a la observación de campo, pudimos apreciar la ausencia de grietas. Los daños que presenta son en la cubierta, la cual pareciera que se ha colocado provisionalmente. Además se observaron la pérdida de los acabados en la parte inferior de los muros, así como el deterioro de las piezas de madera debido a la acción de los insectos (termitas), (ver fotografía No. 3).

Caso 4

El sistema empleado en este caso corresponde a inmuebles modestos, propiedad de personas de pocos recursos económicos, localizados en zonas periféricas de la ciudad de Guatemala.

Entre sus principales características podemos mencionar las siguientes:

Los muros exteriores son de adobe colocado de canto, repellados rústicamente, reforzados con madera y alambre espigado, dispuesto sobre el muro en forma horizontal a cada 0.30 m. Este muro de adobe se asienta sobre un pequeño muro de ladrillo que se levanta aproximadamente 0.40 m. sobre el nivel de piso exterior, (ver fotografía No. 4).

Una variedad de este tipo de muro la podemos apreciar en la fotografía No. 5.

Estas viviendas tienen una volumetría exterior, en forma rectangular o cuadrada, con ambientes interiores de pequeñas dimensiones. La altura es de aproximadamente 2.75 m. y se encuentra cubierta con lámina de zinc sobre estructura de madera, a una agua, con una pendiente de 25% aproximadamente.

Condición después del terremoto de 1976

En éstos casos no se observaron grietas, sino únicamente deterioro en acabados exteriores y en las piezas de madera de refuerzo.

Caso 5

Durante el recorrido exploratorio, se pudieron observar varios ejemplos de viviendas que utilizan en sus muros el ladrillo y el adobe alternativamente, por ejemplo:

-- tres hiladas de adobe y una hilada de ladrillo,
-- una hilada de adobe y dos hiladas de ladrillo.

Los muros son gruesos de aproximadamente 0.45 m.

La cubierta es de lámina de zinc sobre estructura de madera, a dos aguas, con pendientes de 45%.

Su volumetría es típica de las construcciones post-terremotos 1917-1918, donde predominan las plantas arquitectónicas en forma de E y de F, con sus dos patios interiores, el pórtico o peristilo, el zaguán, etc.

Condición de estas estructuras después del terremoto de 1976

En realidad carecemos de datos suficientes que nos permitan establecer con precisión los daños que sufrieron estos inmuebles a causa de dicho terremoto. Sin embargo, los casos observados en el centro de la ciudad de Guatemala, mostraban sus muros en buena condición, con excepción del deterioro en la parte interior de sus muros, debido a la humedad.

CONCLUSIONES:

Las construcciones que después de 1917-1918 utilizaron el adobe redujeron la masividad de las edificaciones anteriores mediante la sustitución de las cubiertas de teja por cubiertas de lámina de zinc, así como los muros interiores gruesos que fueron sustituídos por tabiques delgados y livianos.

Para construir estas viviendas, se utilizaron los adelantos tecnológicos de la época (mallas, placas, pernos, alambres galvanizados y tirantes de metal) que fueron aplicados para crear nuevos sistemas constructivos que permitieran mejorar la resistencia del adobe a los esfuerzos de tensión a causa de los sismos.

La experiencia constructiva, que a grandes rasgos se encuentra contenida en este primer estudio, nos muestra que las construcciones de adobe que fueron reforzadas utilizando estos sistemas antisísmicos, resistieron aceptablemente el terremoto de 1976, y, que las edificaciones de adobe que fallaron, en su mayoría, carecían de técnicas constructivas antisísmicas complementarias o estuvieron sujetas a un deterioro previo por falta de mantenimiento.

En los casos estudiados, se puede apreciar el uso frecuente de materiales como la madera, el adobe, el ladrillo, y el metal. Estos, en diferentes combinaciones, conformaron los sistemas constructivos antisísmicos de la época.

Es necesario continuar la investigación de este tema de la tecnología constructiva antisísmica utilizada en el pasado, la cual, ignorada, constituye una valiosa fuente del conocimiento para el uso y la conservación del adobe en zonas de riesgo sísmico.

Fotografia No. 1

Fotografía No. 2

Fotografía No. 3

Fotografía No. 4

Fotografía No. 5

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NOTAS

(1) La información histórica existente sobre estos terremotos es escasa, desconociendo el grado de la magnitud que tuvieron y estimando la intensidad en 10 grados de la escala Mercalli.

(2) Se calcula que este terremoto alcanzó en la ciudad de Guatemala, una intensidad de 10 grados en la escala de Mercalli y una magnitud de 7.5 grados en la escala de Richter, calificado como devastador y provocando la muerte de 25,000 personas.
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(Ponencia presentada en el Seminario sobre Protección de Monumentos en áreas sísmicas, Antigua Guatemala, UNESCO, ICOMOS, OEA, CNPAG, Nov. 1979).

(3) La palabra crujía, significa: Espacio comprendido entre dos muros de carga. Cada una de las partes principales o naves en que se divide la planta del edificio. Tomado de J.R. Paniagua, Vocabularios Básico de la Arquitectura, Ed. Cátedra, 2a. Ed., Madrid 1980, 112.

(4) J.R. Tórtola, "la Vivienda de Bajareque en....." (Tesis, Fac. Arquitectura, USAC, 1986, 3).

REPAIR OF CRACKED ADOBE WALLS BY INJECTION OF MODIFIED MUD

Nels Roselund
Kariotis & Associates
711 Mission Street, Suite D
South Pasadena, CA 91030

ABSTRACT

This paper presents the conclusions from a demonstration project designed to develop a procedure for stabilizing the walls of the Pio Pico Mansion Adobe of Whittier California damaged by earthquake.

Adobe walls of the building were cracked by the Whittier Narrows earthquake of 1987, which left portions of the walls loose and likely to become unstable in further earthquake shaking. The procedure calls for filling the cracks with mud that has been modified with lime and fly ash for strength and hardness. The mud is mixed to a fluid consistency and pumped into the cracks under pressure. The mud hardens to produce a material that has hardness, strength, and permeability characteristics similar to the adobe and that bonds to the adobe. The material, tightly filling the cracks, keys together the irregular surfaces on each side of the crack. This restores the interlocked effect of the original assembly of adobe bricks, stabilizing the wall.

KEYWORDS

Repair, cracks, seismic, stabilization, restoration, injection, earthen architecture.

Location and History of the Pio Pico Mansion Adobe

The Pio Pico Adobe is in the City of Whittier, California, about 6.4 km (four miles) from the epicenter of the Whittier Narrows Earthquake of October 1, 1987. It was originally constructed in about 1850 by Pio Pico, Governor of California, as headquarters for his "El Ranchito." It is near the San Gabriel river, and was apparently damaged by flooding in 1867-68 and again in 1884-85. In 1905, the building was intended for demolition for materials for land fill for construction of a nearby bridge. A historical society was formed to save it; the society then went on to conduct a restoration, 1907 to 1909. The State of California took ownership in 1917.

It was poorly maintained until 1944 when a second restoration was started during which walls were repaired, floors and walls were replaced, and steel beams and tie rods were embedded in walls. This work continued until 1948. A third restoration was begun in 1967 during which walls and foundations were strengthened.

The 1987 earthquake left the walls standing but extensively cracked. The Department of Parks and Recreation of the State of California is preparing for stabilization and restoration of the adobe.

Description of the Building

It is a U-shaped building divided by adobe partitions into thirteen rooms. It has a partial second story constructed of boards on sawn lumber joists supported in pockets in the wall and a lumber-framed roof supported on the tops of the walls. The walls and partitions are generally about 60 cm (two feet) thick; there is one 30 cm (one foot) thick partition. The walls are about 300 cm (ten feet) high in the first story. The gable end at the second story rises to about 240 cm (eight feet) above the second floor.

The 1987 earthquake damage consisted principally of cracks in the adobe walls. Walls in which steel beams and tie rods were found (probably from the 1944-48 restoration) were cracked, but the most seriously cracked walls appeared not to have been reinforced. There are signs of uneven settlement of the building probably related to floodings. The cracking patterns are generally vertical, indicated that, in general, the walls responded to earthquake shaking by rocking on horizontal planes, causing approximately vertical shear-related cracks near wall intersections where adjacent walls tended to restrain rocking, and approximately vertical flexural cracks at some distance from the intersections. Cracks extend through the walls and outline blocks of loose assemblies of adobe bricks and mud mortar. The rocking caused material to be eroded from the shear-related cracks as parts of the walls moved relative to one another. The cracks with horizontal orientation (on which the walls rocked) are generally closed by gravity. The generally vertical cracks vary in width from fine to as much as 2.5 cm (one inch) or more. There are many cracks in the 0.6 cm to 2.0 cm (one-quarter to three-quarter inch) width range. Some vertical cracks are at old repairs containing brick, packed soil pieces of adobe occurred, and other materials. Some vertical cracks are partly the result of separation due to failure of walls to return to their original position after rocking, but most appear to be due to loss of material eroded by the relative movement each side of the crack.

Anticipated Response to Earthquake Shaking

The response of the walls to earthquake shaking of the intensity of past earthquakes is basically stable. The walls rock safely at their base, lightly restrained by the roof and floor diaphragms. Assemblies of adobe blocks and mortar, loosened by past shaking could be further loosened and shaken from the walls by future earthquake. If the loose assemblies were stabilized into the walls, reoccurrence of the shear-related cracks and flexural cracks could be expected during future earthquakes, but overall stability of the walls is anticipated.

The Demonstration Project

The California Department of Parks and Recreation sponsored a project to develop a means of stabilization of the walls. The demonstration project was conducted by Kariotis and Associates of South Pasadena, California. It was proposed to stabilize the cracked walls by injection of a fluid material into the cracks that would harden to a soil-like fill. The material would have to have properties of hardness, strength, and permeability similar to adobe to be compatible. It should have insignificant shrinkage after placement, and it should bond to adobe.

Samples of mud grout with various additional ingredients were mixed in small batches of about 9 kg (twenty pounds). Molds for casting mud samples were made by hand-compacting moist soil around a piece of 5 cm (two-inch) diameter pipe held at the center of an approximately 15 cm (six-inch) diameter cylindrical metal can from which the top and bottom had been removed. When the pipe was removed, a cylindrical mold of soil was formed measuring 5.7 cm (two-one-quarter-inch) diameter by approximately 15 cm (six-inch-long). The cylindrical samples were cast by pouring the fluid mud into the molds. Accompanying puddle samples were also made by pouring mud onto a moist soil or visqueen sheet base. The samples were allowed to cure about four weeks. Then the cylindrical samples were sawn in cross section through the can, mud sample, and mold.

In order to have a means of controlling water content and evaluate consistency of fluid grout a simple flow-diameter test was used: grout is poured from a 5 cm (two inch) diameter by 10 cm (four inch) cylinder onto a flat, smooth, imperious surface to make a roughly circular puddle. The puddle diameter is measured; the average of two puddle widths measured perpendicular to each other, one of which is the maximum width, is called the flow diameter.

The sawn samples were observed for shrinkage, hardness, abrasion resistance, and permeability. The puddle samples were observed for breaking strength. Shrinkage was evaluated visually by noting whether a crack formed at the perimeter between the sample and the mold. Hardness, breaking strength, and abrasion resistance were evaluated qualitatively by hand, comparing the samples with the soil mold material and with adobe in the walls of the building. Permeability was observed by setting samples in a pan with shallow water, and the time required for saturation of the sample was compared with time for saturation of the adjacent soil mold.

After the small samples were evaluated, and a mix for further testing was selected, larger samples were prepared for a test of the injection procedure. To be able to evaluate the flow of the fluid mud against adobe in a crack in the wall, a test frame was constructed to mount a panel of clear acrylic plastic against the surface of an adobe wall. Because of the irregular surface of the adobe wall, the space between the plastic panel and the adobe surface varied from zero to about 5 cm (two inches). The edges of the panel were sealed with wet newspaper, and mud was injected into the space between the plastic panel and the wall. The flow of the mud into the void was observed through the plastic.

After the sample between the plastic panel and the wall had cured, the panel was removed and the sample observed for hardness, breaking strength, abrasion resistance, thickness of the leading edge of flow into thin zones of the void, and bond to the adobe.

The Injection Process

Mixed mud was transferred by buckets from a drum mixer to a holding tank with an agitator. The holding tank fed a Moino pump that forced the mud into a hose that delivered the mud to a 1.3 cm (one-half-inch) diameter nozzle that was used to inject the mud into holes in the plastic panel. The pump was capable of developing 207 kPa (30 psi) pressure.

Results of the Demonstration Project

In general the samples modified with various amounts of Portland cement and/or fly ash and lime had improved characteristics compared with the unmodified soil samples. Samples containing Portland cement tended to be harder, stronger, and less abradable than the adobe of the building. Samples modified with fly ash and lime were made that had strength and hardness comparable to adobe, but were somewhat more easily abraded than the adobe, especially at surfaces exposed to the air during curing. Twenty grit silica sand was added to some of the samples to try to improve abrasion resistance; significant improvement was not noted.

The unmodified soil samples had excessive shrinkage: cracks formed around the perimeter of the samples, and they became loose in their molds. The modified mud samples in general showed no shrinkage; except one sample developed a crack of about .005 cm (.002-inch) width. A crack in the cross section of one sample seemed to be due to the effects of sawing.

Initial shrinkage of samples in the molds was observed within the first hour after placement. In most cases the shrinkage produced a depression of about 1.3 cm (one-half inch) in the center of the top surface of the sample over the 15 cm (six-inch) depth of sample below. However, initial shrinkage of about 3.8 to 5 cm (one-an-one-half to two inches) occurred in three samples. Most of the samples were mixed in small batches in a slowly rotating drum, but the samples exhibiting a large amount of shrinkage were mixed at high speed. Since excessive initial shrinkage could be detrimental to filling cracks, slow mixing seems to be important, perhaps to avoid incorporation of excessive air into the mix. Too much water in the mix could also contribute to excessive shrinkage.

Mud injected into the void between a plastic panel and the adobe wall flowed into spaces as thin as about 0.16 cm (one-sixteenth inch). There seemed to be little resistance to horizontal flow of the grout into spaces wider than about 0.32 cm (one-eighth inch). A head of about 25 cm (ten inches) was developed above the injection nozzle.

After curing for about four weeks, the injected mud had a hardness comparable to the adjacent adobe and bonded to the adobe well enough that when peeled from the wall, a thin layer of adobe came off with the sample. The injected adobe samples had shrinkage patterns. Mixes that, indicated by excessive initial shrinkage, improper mixing procedures and water content, displayed shrinkage patterns that were judged to be excessive. The mixes that had low initial shrinkage in the cylindrical sample had a pattern of cracks on the wall of about .01 cm (.004-inch) width between uncracked pieces about 2.5 cm (one inch) in size; shrinkage indicated by this type of crack pattern was judged to be acceptable.

Permeability of the modified mud was compared with the adjacent compacted soil by placing the sample cross section in shallow water. Saturation times for soil and cured modified mud were virtually the same.

The hardened grout has a smooth texture and is a very light grayish tan, in color. The lightness of color is largely due to lime in the mix. It is not comparable in appearance to adobes or mud mortars we have encountered.

Conclusions

The mud injection procedure appears to be a good alternative to conventional crack repair methods such as rebuilding damaged walls, removing and resetting adobe blocks, or filling cracks by hand. Such methods are labor intensive and require skills that are no longer common, especially in urban areas like Southern California.

The use of lime and fly ash as mud modifiers contribute beneficially to both the fluid mud and to the hardened fill in the cracks. In the fluid state, lime gives the mud good water retention qualities that will help maintain fluidity as it flows across adobe surfaces. Fly ash, consisting principally of minute balls of glass, contributes lubrication properties to the fluid mud. Fly ash, a pozzolonic material, reacts chemically with lime to form a cementicious component that improves the strength and hardness of the crack filling material and reduces shrinkage. The resulting material, being basically a soil material, has properties compatible with the adobe it is repairing.
Since the mud was observed to flow into approximately 0.16 cm (one-sixteenth-inch-wide) voids behind the plastic panel, it should be expected that the procedure may be used to repair

cracks as small as approximately 0.32 cm (one-eighth inch) in thickness. Shrinkage was observed to be insignificant in the 5.7 cm (two-one-quarter-inch) diameter samples, indicating that repair of cracks of up to 5 cm (two inches) in width may be appropriate. The crack patterns noted in the plastic panel samples indicate that water content and mixing procedures need to be strictly controlled to minimize shrinkage of the injected material, especially when wide cracks are being repaired.

Improved abrasion resistance may be attainable if coarser sand or natural sand is used. However, use of coarse sand will greatly reduce the life of a Moino pump.

Proposed Application

It is now proposed to use the injection of modified mud to stabilize the walls of the Pio Pico Mansion. The stabilization project will be conducted using a silty sand soil. The selected soil will be tested for suitability for the project by making modified mud samples to be evaluated for shrinkage and hardness. The test program for the selected soil will be conducted by making samples using packed soil molds as was done for the demonstration project. Proposed proportions by weight for the samples are as follows:

- 60 parts soil
- 20 parts silica sand (20 grit)
- 18 parts fly ash (type F)
- 2 parts lime (type S)
- water as required for proper consistency.

Proportions by weight instead of volume are required because of the tendency of soil to bulk.

The wall cracks have been mapped and injection locations have been designated on project drawings.

To augment the resistance of the walls to shear-related cracks adjacent to wall intersections, 1.9 cm (three-quarter inch) diameter threaded fiber-glass rods, rod will be embedded to cross the intersections. The rods will be installed 5 cm (two inch) diameter holes drilled that will be pumped full of the modified mud.

Project specification are as follows:

1. The specifications for the test procedure are:

   a) Prepare packed soil molds on the ground inside a 15 cm (six-inch-diameter) by 30 cm (twelve inch) high metal cylinder of the type used for concrete compressive strength testing. The metal cylinder shall have top and bottom removed. Form the mold with a 5 cm (two-inch) diameter standard pipe at the center of the cylinder. Place moistened soil in approximately 2.5 cm (one inch) lifts around the pipe. Tamp each lift of the soil firmly with a rod of about 2.5 cm (one inch) diameter. Build mold to a depth of 30 cm (six inches). Finish the top of the mold to a level surface. Rotate and lift the pipe often to keep it free from the compacted soil surface.

   b) Mix grout in proportions and flow diameter to be tested.

   c) Pour grout into the molds in three lifts, puddling each lift with a wooden stick. Top the sample with a 12.5 cm (five-inch) diameter puddle about 2 cm (three-quarter inch) over the top of the compacted soil mold.

   d) The following day, note whether settlement of grout has occurred. If the top surface of the puddle drops below the top surface of the mold, there is excessive initial shrinkage requiring correction of mix or mixing procedure before proceeding.

   e) After twenty-eight days, saw the mold in sections without disturbing the sample and observe the packed soil-grout interface. A crack or separation between the sample and the packed soil is an indication of excessive shrinkage after set, which shall be corrected before proceeding. (Be sure that an observed crack is not caused by the sawing operation.)

f) Store sawn samples in a dry place at room temperature.

g) Fourteen days after sawing compare the hardness of the sample with the hardness of the adobe at the building by scraping with a metal tool. Acceptable hardness is equal to or slightly harder than the adobe. Adjustment of the proportion of cementitious material (fly ash and lime) to soil and sand may be required to achieve acceptable hardness. The proportion of lime to fly ash shall be kept constant.

h) An acceptable grout mix shall have the following characteristics as determined above:

- acceptable initial shrinkage
- no shrinkage after set
- acceptable hardness
- materials and procedures for making grout for the project shall be identical to those that produced the acceptable samples

2. Specifications for the injection work are:

a) Mixing
Combine the dry ingredients in a slowly rotating drum mix. Add fly ash and lime to the soil-sand mixture. Mix until uniformly blended. Add water gradually. Test flow diameter when mixture reaches a uniform consistency.

b) Mixing time
Grout not used within one hour after adding water shall be discarded.

c) Pumping
Pump grout from a mortar pump with agitating hopper that is capable of developing a pressure of 30 psi. Pump through a flexible hose to a 1.3 cm (one-half-inch) diameter thin-wall metal tube nozzle.

d) Consistency
Cracks less than 1.3 cm (one-half inch) in width: 14.6 cm (five-an-three-quarter inch) flow diameter.
Cracks 3.8 cm (one-half to one inch) width: 13.3 cm (five-an-one-quarter-inch) flow diameter.
Cracks 2.5 cm (one inch) and greater in width: repointing consistency; shall maintain its shape and not flow when deposited by the nozzle.

Flow diameter
The measure of fluid grout consistency shall be measured as follows:

Fill a 5 cm (two-inch) diameter by 10 cm (four-inch) high cylinder with grout. Pour the grout from the cylinder from a height of 15 cm (six inches) onto a smooth plastic sheet on a flat surface to form an approximately circular sample. Measure the width of the sample on two perpendicular axes, one of which shall be the maximum width of the sample. The flow diameter should be taken as the average of the two widths.

e) Preparation of cracks

1. Expose the full length of the crack to be injected. Remove plaster and other obstructing materials, being careful not to disturb framing members.

2. Remove accessible loose pieces of adobe and mortar from the crack.

3. Blow dust and small particles from the cracks with compressed air.

4. Caulk cracks on both sides of wall with wet newspapers. Caulk in lengths of about 15 cm (six inches) between 1.3 cm (one-half-inch) diameter openings. Press the wet newspaper into the cracks at a depth about equal to the cracks width. Alternatively, caulk with stiff grout to which two parts Portland cement have been added. When caulk is hard, drill 1.3 cm (one-half-inch) diameter holes into the crack at 15 cm (six inches) on center. Use non-impact drilling equipment.

f) Injection
Inject each crack from one side of the wall only. Start from the bottom and inject into 1.3 cm (one-half-inch) diameter openings in sequence working up. Plug injected holes with wet newspapers. Flow of grout shall be observed from 1.3 cm (one-half-inch) diameter opening on the opposite side of the wall. If grout does not appear on the opposite side of the wall, the reason will be determined and corrected before proceeding. As grout flows from a hole on the opposite side of the wall, the hole shall be plugged with wet newspaper. Proceed with injection until the crack is filled with grout.

g) Newspaper caulking shall be left in placed until grout has set (approximately two or three days). Remove newspaper caulking before the grout hardens (approximately seven to ten days.)

h) Clean-up
Remove all hardened spills and unused grout from the site and dispose of it legally. Leave floors broom clean.

3. Specification for the threaded fiberglass rods are:

a) Fiberglass rods shall by 3/4" diameter threaded rods of glass fiber in vinylester resin; Fibrebolt as manufactured by Morrison Molded Fiber Glass Company. Nuts shall be fiberglass. Washers shall be galvanized standard cut steel washers.

b) Drill holes for 2" diameter fiberglass anchors with non-impact tools.

c) Holes for fiberglass anchors shall be drilled after cracks in the vicinity have been injected and the grout has set.

d) Injection holes for fiberglass anchors shall be 1/2" diameter and shall intercept the bottom of the hole into which the anchor is inserted.

e) Injection grout into the injection hole, filling the anchor hole and embedding the fiberglass rod in one operation. Plug the injection hole with wet newspaper. Remove the plug after grout has set and before it hardens.

<u>Further Research</u>

Walls repaired by the proposed injection process have not been subjected to in-situ testing, nor to actual earthquake shaking. A test program to evaluate how well the method actually restores the integrity of repaired walls would be an important next step. Future testing should focus on the effect the grouting process has on resistance to formation of shear-related cracks adjacent to wall intersections as well as the effectiveness on restoring the bond of loose assemblies into the wall.

"CRITERIOS Y TECNICAS DE RESTAURACION APLICADAS EN LOS MONUMENTOS DE ADOBE EN EL PERU"

Roberto Samanez Argumedo
M.S. Arquitecto
Apartado Postal 289 Cusco-Perú

ABSTRACT

The author outlines geographic features of the Peruvian landscape previously occupied by ancient civilizations that left behind a substantial legacy of structures made of earth. The 300 years of Spanish colonization added to this legacy.

This paper presents an analysis of social and economic factors bearing on the survival of these structures over the last 150 years. Five specific interventions are described and documented, with discussion of the theoretical orientation and results. Finally, the experience of restoring archeological and colonial monuments made with adobe is summarized, with the recommendation that more research is needed on the preservation of the Andean mural paintings that adorn the walls of adobe houses and churches built during the colonial period.

KEYWORDS

Earthquake damage, reconstruction, restoration, improved adobe blocks, mural paintings. history.

Introducción :

El Perú está situado en la parte central y occidental de América del Sur, en un territorio en el que la Cordillera Andina presenta distintos planos altitudinales, con marcadas diferencias de clima, topografía y vegetación que determinan la existencia de un litoral desértico, de valles interandinos, altiplanos y de selva tropical. Gracias a su cercanía a la línea ecuatorial, las partes altas de los Andes tienen climas benignos que han permitido su ocupación desde épocas muy antiguas.

Los grupos humanos que ocuparon ese territorio desde hace dieciocho mil años se adaptaron a sus condiciones geográficas, obteniendo el mejor provecho de sus variados ecosistemas y alcanzaron un alto grado de organización y desarrollo tecnológico.

El empleo de bloques de tierra secados al sol o tierra confinada y apisonada, constituyó el procedimiento constructivo más utilizado en el Perú antiguo y lo encontramos en la costa árida y sin lluvias, donde se combinaba la tierra con cañas y fibras o en las zonas lluviosas de la cordillera, donde existe abundante piedra que se empleaba en la cimentación de las edificaciones.

Desde 2000 años antes de Cristo se levantaron complejas edificaciones de tierra creando una arquitectura monumental expresada en pirámides truncadas, templos y conjuntos urbanos de gran calidad . Al producirse la conquista española en el siglo XVI se introdujeron cambios fundamentales en los aspectos tecnológicos y culturales, pero se continuó construyendo con adobes, por ser éste un material al que también estaban habituados los europeos, que lo seguirían utilizando durante los casi trescientos años que duró el Virreynato del Perú.

En el período que siguió a la independencia del dominio español ocurrida en la primera mitad del siglo pasado y casi hasta la década de los años cuarenta del presente siglo, el adobe continuó siendo el material básico para las edificaciones y en la actualidad todavía representa la única alternativa de bajo costo para que gran parte de la población pueda construir sus viviendas.

Fortaleza de Paramonga construida con tierra, en la costa peruana, antes de la llegada de los españoles.

Las primeras intervenciones de restauración:

Como en pocos lugares del mundo en el territorio descrito florecieron numerosas civilizaciones y culturas que a través de los siglos dejaron un cuantioso legado monumental, que debería haberse conservado celosamente para convertirse en un ejemplo de la capacidad técnica y artística de las generaciones pasadas y constituir un hito de identidad para los peruanos. Sin embargo, por mucho tiempo, esa herencia del pasado fue olvidada e incomprendida sin merecer ninguna acción de protección.

En la década de 1930 a 1940 se efectúan los primeros trabajos para conservar los monumentos coloniales mediante intervenciones que denotan empirismo y falta de criterios adecuados. Por lo general se respetó poco la originalidad de los materiales y se prefirió la reconstrucción antes que la restauración. A raíz del terremoto que afectó a la capital del Perú en 1940, causando cuantiosos daños en los monumentos religiosos y en la arquitectura civil, se restauró un número importante de iglesias coloniales construídas con adobe y estructuras ligeras de caña y barro, que en su mayor parte habían sido modificadas y remodeladas en el siglo XIX. En esos trabajos la preocupación se encaminó a la recuperación de la fisonomía original de las fachadas e interiores, sacrificando la autenticidad de los testimonios en aras de reconstrucciones historicistas.

Construcciones de adobe de época Inca en el sitio de Tambo Colorado, con restos de pintura de vivos colores.

A partir de la década de los años sesenta se llevaron a cabo las primeras labores en los monumentos arqueológicos de la costa peruana encaminadas a su reconstrucción, con el objetivo de conservarlos y sobre todo de permitir que los visitantes perciban como fueron esos testimonios antes de su abandono y ruina. Los resultados fueron muy discutibles y objetados por los arqueólogos porque se efectuaron completando los materiales originales de los edificios, sin contar con las evidencias que justifiquen la reproducción de formas hipotéticas.

Iglesia Jesuíta de los Desamparados edificada en 1670, demolida en 1937.

Iglesia de La Merced en Lima, mostrando su aspecto neo clásico antes de la reconstrucción de 1939.

Aspectos de la misma Iglesia reconstruida tomando como referencia grabados y fotografías del siglo XIX.

Situación actual y tareas futuras de conservación:

Por lo general los planes y acciones estatales para conservar y recuperar el patrimonio monumental peruano, han surgido a raíz de catástrofes como los terremotos que periódicamente dejan sentir sus efectos. Así como el sismo que afectó Lima en 1940 determinó las primeras obras de restauración en las iglesias coloniales, fue a raíz del terremoto que se produjo en Cusco en 1950 que se contó con la primera misión que efectuaba la UNESCO fuera de su sede, para orientar la recuperación del conjunto monumental.

En 1970 la ciudad de Trujillo ubicada en el norte del país, fue dañada por un nuevo terremoto y para contribuir a la recuperación de sus monumentos se organizó otra misión de la UNESCO que preparó un conjunto importante de proyectos, recogiendo los criterios contemporáneos de restauración e introduciendo la modalidad del trabajo interdisciplinario. Con la creación del Instituto Nacional de Cultura en 1973 se organizaron las áreas encargadas de la conservación del patrimonio histórico y se encaminaron adecuadamente los criterios para la restauración.

En ese período se recibió una importante participación de la UNESCO para desarrollar un plan en la zona de Cusco por un período de siete años. Más adelante en el marco de un plan de desarrollo turístico que contó con fondos de un préstamo del Banco Interamericano de Desarrollo se empezaron los trabajos directos en los monumentos arqueológicos y coloniales incluyendo una amplia labor de conservación de bienes muebles.

La mayor parte de los monumentos intervenidos en esa época eran de adobe y planteaban problemas nuevos que motivaron trabajos de investigación para encontrar la tecnología apropiada, desarrollando criterios para interpretar las lesiones y establecer los procedimientos metodológicos para trabajar correctamente en ese tipo de estructuras. Los resultados fueron muy alentadores y determinaron la creación de cursos semestrales de capacitación que, a su vez, permitieron la presencia en Cusco de destacados especialistas en la materia.

Ese proceso tuvo el mérito de permitir una evolución de los conocimientos y lograr que un considerable número de técnicos y profesionales compartan conceptos comúnes con respecto a las teorías y criterios de restauración, dejando definitivamente las controvertidas ideas aceptadas hasta la década de los años sesenta.

En lo relativo a la restauración de los monumentos históricos construídos con adobe, la experiencia que se obtuvo en esos años, con los trabajos realizados en Cusco, permite resumir los siguientes principios básicos:

- En los monumentos históricos edificados con adobes, estos elementos constructivos también son testimonios de la tecnología original y son parte de la documentación histórica que debe conservarse en lo posible, por lo que la sustitución del material en forma indiscriminada o la reconstrucción son prácticas que no se pueden aceptar.

- Al reemplazar los adobes deteriorados como parte del proceso de restauración, necesariamente se debe mantener la homogeneidad, lo cual excluye el uso de adobes estabilizados.

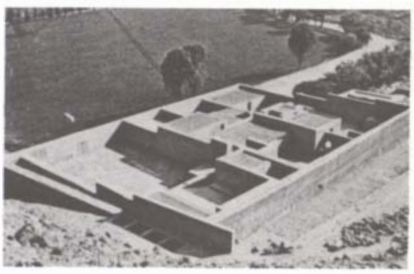
- Es recomendable que para la restauración de edificaciones de adobe que aún están en uso, como los inmuebles coloniales y republicanos, que demandan mayores requerimientos de estabilidad estructural, se utilicen adobes nuevos de dimensiones iguales a las de los originales pero fabricados con tecnología mejorada en sus características mecánicas y físicas.

- La preparación de adobes mejorados para ser utilizados en reemplazo de aquellos cuya sustitución es imprescindible, se hará mediante la selección cuidadosa de los componentes y un adecuado proceso de control de la elaboración y secado.

- Antes de emprender un trabajo de restauración es imprescindible establecer un diagnóstico para conocer los síntomas, la naturaleza y las características de las estructuras afectadas. Es por eso que además de la investigación de las lesiones y signos externos de deterioro se debe intuir cuál es la relación entre causa y efecto, vislumbrando los remedios más eficaces para anular la causa.

- Es recomendable que las soluciones de consolidación y refuerzo estructural se busquen incorporando alternativas locales y pro-

Huaca del Dragón en la costa norte, reconstruida en 1963 completando muros y relieves.



Palacio pre-Inca de Puruchuco cerca de Lima reconstruido completando arbitrariamente muros y techos.

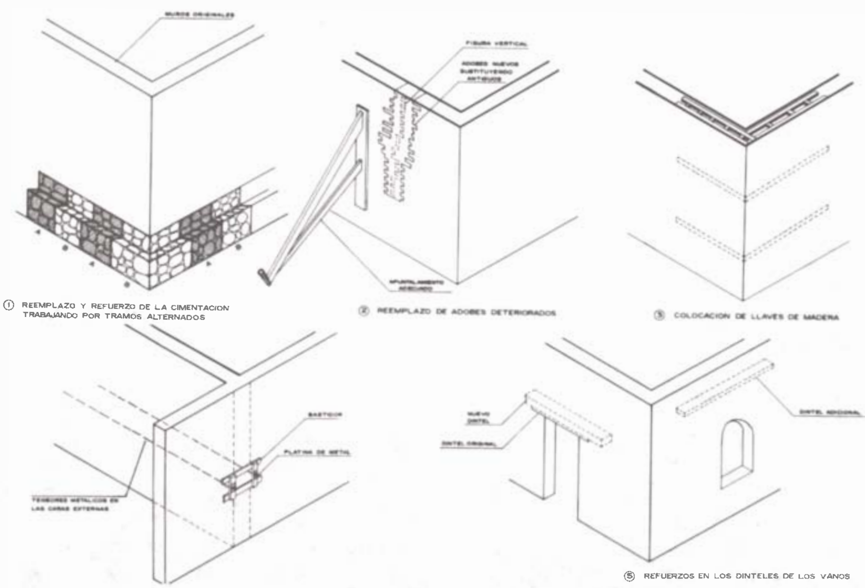
Palacio de época Inca existente en Yucay cerca de Cusco, restaurado con criterios adecuados en 1976.

Interior del mismo palacio mostrando la diferencia entre lo original y lo repuesto esquemáticamente, en base a las evidencias arqueológicas (a la derecha).

pias, prefiriendo la mano de obra y los materiales tradicionales existentes en el lugar. Excepcionalmente y cuando las condiciones lo justifiquen se podrá recurrir a técnicas y materiales industrializados.

- Aún conociendo las causas que originan los daños en los monumentos de adobe, existen casos en que el diagnóstico es complejo y no hasta el análisis matemático de los principios estructurales, sino la intuición del especialista experimentado. Como esos especialistas son escasos y se deben formar en la práctica, es conveniente el trabajo de equipo con la participación del arquitecto restaurador.

- Por último es fundamental tener en cuenta que no se puede participar en un proyecto y menos en una obra de restauración, sino se conoce a fondo qué son y por qué tienen valor las edificaciones antiguas. La formación y capacitación especializada en lo conceptual y práctico, es indispensable.



Por lo general en los monumentos que se intervinieron en la zona de Cusco y otros lugares del país desde 1975, se adoptaron las recomendaciones antes mencionadas, consiguiendo resultados satisfactorios, ejecutando los trabajos a partir del refuerzo de la cimentación, la consolidación de los muros sustituyendo puntualmente los elementos dañados, la colocación de "llaves" de madera para reforzar el encuentro de muros y la adición de dinteles mejorados en los vanos.

Sin embargo, la restauración de edificaciones antiguas construídas con adobes puede presentar casos de mayor complejidad, que no siempre pueden ser resueltos a base de los elementos citados, que son parte de la tecnología tradicional mejorada. En muchos casos los requerimientos para la nueva función de los inmuebles antiguos, la seguridad de los usuarios o de las colecciones museográficas, obligan a tener en cuenta soluciones que sean más seguras ante el riesgo sísmico.

Deben aceptarse, por lo tanto, alternativas que incorporen estructuras adicionales de refuerzo, de diseño especial para que sean compatibles con las normas y principios de la restauración y que permitan garantizar las construcciones con adobe en áreas sísmicas.

Se han experimentado con éxito estructuras de concreto armado o madera incorporadas a los muros de adobe mediante diseños especiales para evitar el daño del material de refuerzo sobre los adobes que en caso de sismo, tienen comportamientos diferentes.

En el caso de los monumentos pre-hispánicos construídos con adobes, que por su condición de testimonios arqueológicos no se restituyen a una función actual, los requerimientos de conservación han estado encaminados a proteger los edificios en forma decidida, aunque esto implica poner cubiertas temporales que nada tienen que ver con las originales.

Para mejorar la resistencia de los adobes, se han introducido importantes avances técnicos, aplicando emulsiones acrílicas con lo cual se logró endurecer e impermeabilizar el material antiguo.

Friso con figuras en relieve en la ciudad pre-hispánica de Chanchán, tratados con silicato de etilo.

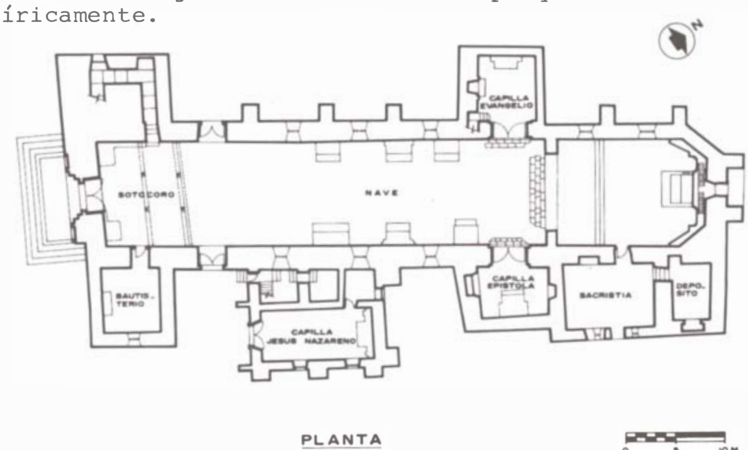
Un especialista de la Universidad de Turín enviado al Perú por la UNESCO probó la aplicación de un producto remineralizante, el éter de ácido silícico para reforzar los silicatos que se encuentran en la composición del barro, haciéndolo impermeable. El silicato de etilo se disuelve en alcohol y se caracteriza por tener gran capacidad reticular y por lo tanto se obtiene buena penetración en frisos y muros.

Ese producto se utilizó con éxito para preservar los adobes y morteros de barro de revestimiento de monumentos arqueológicos en la zona de Cusco y en varios sitios de la costa peruana.

Otro aspecto que empezó a cobrar importancia en la década de los años setenta, fue el de la conservación de la pintura mural asociada a las estructuras de adobe, tanto del período pre-hispánico como de la época colonial. Gracias al clima seco y árido de la costa peruana se han conservado importantes testimonios de pintura mural, en los sitios arqueológicos de Pañamarca, Garagay, Paramonga y Sechín. Lamentablemente muchas de ellas se deterioraron por haberlas dejado al descubierto o porque fueron restauradas empíricamente.

CORTE TRANSVERSAL

ELEVACION FRONTAL



PLANTA

Relevamiento de la iglesia de Oropesa, cerca de Cusco, construida al final del siglo XVI. Conserva importantes pinturas murales de varios períodos.

Más abundante es la pintura mural existente en las iglesias coloniales, en especial en las numerosas parroquias y capillas rurales situadas entre Cusco y el lago Titicaca. Encontramos allí pinturas renacentistas ejecutadas entre 1570 a 1630, con interesantes temas mitológicos, también pinturas barrocas del Siglo XVII y murales de fuerte influencia indígena pintados desde el Siglo XVIII hasta el inicio del siglo pasado.

La profusión de pinturas murales se explica por su utilización como instrumento de catequesis y por su valor didáctico para inculcar la religión cristiana a los indígenas. La existencia de esas pinturas también en casas coloniales demuestra que se trata de una expresión artística de gran aceptación y difusión.

Bautisterio de la iglesia de Oropesa durante el proceso de recuperación de la pintura mural del siglo XVII, cubierta con estuco.

Los estudios sobre la pintura mural son relativamente recientes, en particular, los referidos a las pinturas al temple, policromadas, que se aplican directamente sobre una base de preparación encima de los enlucidos de barro que revisten los adobes. Las restauraciones que se emprendieron en Cusco a mediados de los años setenta, introdujeron técnicas de exploración que permitieron descubrir gran cantidad de pinturas cubiertas por capas posteriores y recuperarlas tras paciente trabajo.

Si bien se lograron buenos avances en el conocimiento de las técnicas y componentes de la pintura mural, habiéndose experimentado y probado diversos materiales y productos químicos para su consolidación, será necesario hacer un gran esfuerzo para emprender acciones dirigidas a conservar las pinturas murales, que de otro modo desaparecerán en pocos años.

La estructura social que permitía a las iglesias rurales contar con tierras de cultivo para sufragar los gastos de su cuidado y mantenimiento desapareció con la reforma agraria, quedando éstas en el más grave abandono, que está produciendo su ruina acelerada.

Dramático estado de conservación de la mayor parte de las iglesias decoradas con pintura mural.

Lamentablemente, por ahora, solamente se está procediendo a inventariar las iglesias, capillas y casas con pintura mural, pero no existen recursos para su conservación.

Adecuada restauración y reintegración de la pintura mural en Andahuaylillas y consolidación preventiva en el Molino de los Incas, de Acomayo.

Las técnicas que pueden ser correctas para la consolidación de los muros de adobe, pueden afectar la pintura mural.

Por otro lado, los trabajos que en escaso número se vienen llevando a cabo por organismos estatales, para conservar algunas de esas iglesias, están a cargo de técnicos y personal que no tiene una idea cabal del altísimo valor de estos testimonios. Obreros de restauración que conocen el trabajo de consolidación en los muros de adobe, a falta de adecuada orientación, intervienen en muros pintados de la misma forma como lo hacen en paramentos sin pintura, ocasionando daños irreparables.

Constituye pues, un reto para el futuro inmediato estudiar medidas de protección para las pinturas murales y métodos de intervención que se adapten a las circunstancias y no causen daños a ese tipo de expresiones pictóricas.

Lamentable intervención reciente para reparar fisuras en el muro de adobe sin respetar la pintura. A la derecha se ven los daños en la pintura al reparar la cubierta.

Es imprescindible preservar la edificación antigua para salvar la pintura mural que es parte de ella.

CONCLUSIONES:

Hemos señalado brevemente, al iniciar la ponencia, las especiales circunstancias geográficas que hicieron posible que en el Perú antiguo se den grupos humanos de "alta cultura" convirtiéndose en uno de los lugares del mundo donde se desarrollaron grandes civilizaciones. En el difícil territorio del Perú existen alrededor de 50,000 sitios arqueológicos y un número menor, pero no menos importante, de testimonios históricos de época colonial y republicana. Gran parte de ese patrimonio está en peligro de destrucción a falta de una política adecuada de difusión y conocimiento de los valores propios y a la falta de acciones de defensa y conservación.

A lo largo de los últimos 150 años de vida republicana, parte de ese importante patrimonio cultural, por lo general construído con adobe, ha sido depredado y destruido.

Salón con friso y arteso-nado pintados, en la casa del siglo XVII de Don Fernando de Vera, en Cusco.

Detalle de la pintura mural restaurada cuidadosamente diferenciando las partes reintegradas de las originales. La restauración, con asistencia de la UNESCO, concluyó en 1978.

Sin embargo, la experiencia reciente en el campo de la restauración de monumentos de adobe en el Perú es importante y puede ser muy util no sólo para futuras intervenciones locales, sino para quienes busquen información para emprender tareas similares, pero a su vez los restauradores de monumentos y obras de arte de este país requieren todo el apoyo y colaboración de la comunidad internacional, para preservar su patrimonio histórico.

Uno de los rubros más necesitados de acción inmediata, por su carácter singular y su gran valor histórico, es la pintura mural andina del período colonial que amerita el apoyo y el esfuerzo de instituciones y técnicos empeñados en labores similares, para evitar que prosiga su deterioro y para sentar las bases científicas de su correcta conservación.

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SEISMIC STRENGTHENING OF HISTORIC ADOBE BUILDINGS IN CALIFORNIA: AN OVERVIEW

Gil Sánchez, FAIA, and Daryl Allen
Gilbert Arnold Sanchez Architect Inc.
3022 Glen Canyon Road
Santa Cruz, California 95060

ABSTRACT

This paper provides an overview of modifications by the earliest adobe builders and describes present-day, more sophisticated, seismic strengthening systems. After the 1960s seismic strengthening systems were employed using a combination of grade beams, columns, and bond beams. But when the State Historical Building Code was adopted in 1976, it allowed systems that are far less destructive to historic fabric. Three examples of structural strengthening systems in historic adobes since 1975 are described. The first example documents a high-impact system (now out-moded and possibly unneccessary). The other two examples utilize systems that rely primarily on the concrete bond beam. The Santa Cruz Mission Adobe restoration (a bond beam system) was put to the test during the 1989 earthquake and performed well. The evidence in this project supports the hypothesis that a structural system consisting of a bond beam is sufficient to withstand moderate to severe earthquakes.

KEYWORDS

Seismic strengthening, retrofit, adobe preservation, historic architecture, earthquakes, California missions

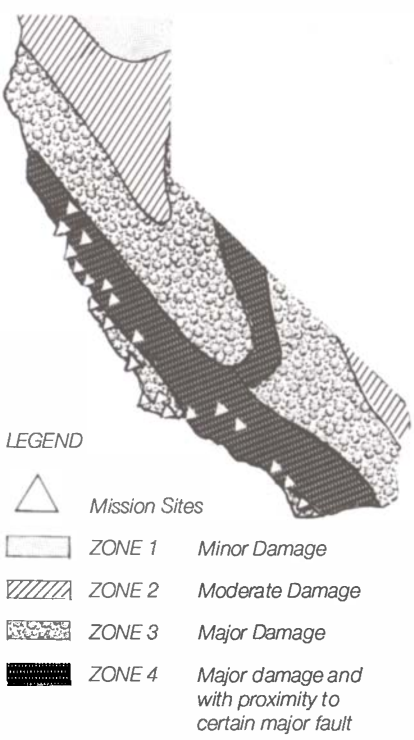

Figure 1. Spanish mission locations superimposed on seismic risk map (Seismic information from BOCA National Building Code, 1987).

Running parallel with the development of adobe building in California is a history of periodic destruction by earthquakes. The use of adobe as a building material was introduced into Alta (upper) California by the Spanish Crown. The chain of Franciscan mission settlements that extend northward from Baja California are located in an area which coincides with what is today designated on the seismic risk map as Zone 4—the area of greatest damage and area closest to major earthquake faults (see fig. 1) [1]. Destruction by seismic forces was a tremendous threat to the early builders of adobe mission and ranch buildings, as the results of years of painstaking labor could be destroyed in seconds.

A great earthquake which struck in 1812 in southern California affected missions from as far south as San Diego to as far north as Mission La Purísima in central California. Fr. Luis Gil and Fr. Marcos Amestoy of Mission Santa Bárbara wrote in their annual report, "In the terrible earthquakes of December 21st and the days following, the mission was considerably damaged, necessitating a careful inspection and somewhat extensive repairs." [2] Distressed reports similar to the above are repeated over and over in the annual reports of the Franciscan fathers.

As a result of the 1812 earthquake a belfry and a roof of the stone church at Mission San Gabriel (known as San Gabriel de los Temblores) collapsed [3] and the Great Stone Church with vaulted ceilings at San Juan Capistrano was in ruins after only six years of use [4]. The adobe church at Mission San Buenaventura was damaged by earthquakes in 1800, 1808, and a new church under construction was damaged by the 1812 temblor requiring repair work and modifications to the building design [5].

In central California in 1825, an earthquake with many aftershocks battered the mission church at Mission Santa Cruz. Due to a lack of workers, it was never adequately repaired and when a major earthquake struck in 1857, the church, by then described as "in ruins," was destroyed [6]. To the north at Mission San José, a new adobe church was under construction in 1808 when an earthquake struck the San Francisco Bay Area. Because of this quake and its aftershocks, it was decided to construct a low bell tower instead of the taller one originally planned. This mission church had adobe side walls 9 m (30 ft.) high and 1.5 to 2.7 m (5 to 9 ft.) in thickness with massive buttresses. An enthusiastic French priest "improved" the simple church building by removing the buttresses and cutting tall, Gothic-influence windows. This modification no doubt contributed to the inability of the church walls to resist lateral motion when a major quake rolled through the area in 1868. The church was destroyed [7]. In the Los Angeles area, the church at Mission San Gabriel is presently closed due to damage from an earthquake in 1987.

Adaptations Developed to Withstand Earthquake Forces

The earliest adobe builders on the California coast, educated through trial and error, understood their material well enough to make the following adaptations to improve resistance to seismic forces:

- A ratio of wall thickness to wall height of 1 to 5 was typically maintained. For example, a 9 m high wall would be built 1.5 m in thickness [8].
- Openings in walls such as doors and windows were kept small and to a minimum.
- Bell towers and bell walls were often built low, not extending above the roof.
- Large stone or adobe buttresses were built to brace long walls or corners, such as at Mission La Purísima and at Mission San José church.

Figure 2. Mission San Juan Bautista, Convento Wing. View of damage after the 1906 earthquake. (Photograph from San Juan Bautista Historical Society)

After the demise of the mission system in the 1830s, many of the mission structures fell into disuse or were relegated for utilitarian purposes such as storage rooms or stables. Little interest was shown in these aging relics until after 1900 when activity which was primarily reconstruction occurred at 5 or 6 mission sites in the state [9].

On the crest of renewed interest in the restoration of historic adobes after the 1960s, architects working with structural engineers devised seismic strengthening methods to satisfy building officials and owners of the buildings. A serious drawback to the early types of structural systems which employed grade beams, vertical columns, and bond beams was their great impact upon historic fabric. However, at the time, both public officials and design professionals were understandably cautious about the safety of the public in buildings constructed of archaic materials. Case studies follow later in the article which describe early seismic strengthening systems designed by the authors' firm.

The Development of the State Historical Building Code in California

Work on formulating a code to establish acceptable safety standards, while recognizing the unique qualities of historical structures, had begun in 1963 with recommendations from the California Landmarks Advisory Committee. The Committee expressed a need to protect public health and safety with a new building code that also offered "enough flexibility to allow restoration of a historic feature while still retaining its historic integrity." The Department of Parks and Recreation working together with the Office of the State Architect developed statewide input into a draft bill which passed the legislature in 1975. The bill (SB 927, Mills) became effective January 1, 1976 [10].

When Clarence Cullimore, Jr. of the Office of the State Architect was called upon to prepare the Adobe section of the State Historical Building Code, he drew upon the experience of his father, Clarence Cullimore, Sr. The senior Cullimore, an architect practicing in Bakersfield, California, in the 1920s and 1930s, had designed and built some two hundred new adobe buildings which employed the use of the concrete bond beam (or tie or collar beam) to encircle the walls at the top. A concrete bond beam reinforced with steel reinforcing bars acts as a band to stabilize walls as it receives the weight of the roof (and seismic forces when they occur) and distributes the load evenly, passing it down through the walls. The roof structure is attached to the bond beam so that it will not be displaced during wall movement from seismic forces [11].

In addition, Cullimore, Jr. had first-hand knowledge of an early bond beam retrofit to an historical adobe in Long Beach, California—Rancho Los Cerritos—which had undergone a strong earthquake. L. T. Evans, structural engineer, had designed a bond beam retrofit for both the two-story residence and the one-story, 140 feet long wings in a remodel of the 1844 ranch house in 1931 [12]. In 1933, two years later, an earthquake measuring 6.3 on the Richter Scale spread destruction throughout the Long Beach area. The walls of many unreinforced brick buildings fell into the streets. When Clarence Cullimore, Sr. inspected the adobe structure after the quake, he was pleased to find the adobe ranch house practically unscathed. A few cracks were observed where the one-story wings had racked against the two-story section, and there was a crack over the front door. But there were virtually no cracks at all in the one-story wings and the two-story main section [13]. This "field testing" verified that walls strengthened with bond beams could indeed withstand moderate earthquakes.

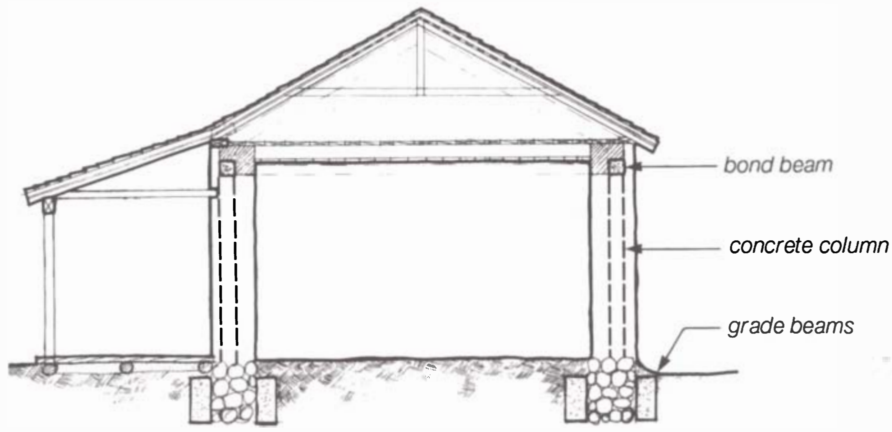

Figure 3. The Peralta Adobe, ca. 1800. Restoration and seismic strengthening completed in 1975. At this time, both vertical and horizontal concrete supports were required. Gil Sánchez, FAIA, architect.

Case Studies of Seismic Strengthening Techniques

This article will not attempt to document every strengthening method employed in the state, but will outline those techniques which are most familiar—those designed and constructed by the authors of this article.

In 1973, one of the present authors was retained by the City of San Jose to restore the Peralta Adobe, a simple one-story residence built before 1800 which is the only extant structure from the Pueblo de San José [14]. Because this was prior to the adoption of the Historical Building Code and since the Uniform Building Code of 1970 gave little or no mention of construction using unfired masonry units, structural engineers at the time could assign no value at all to the load-bearing ability of unstabilized adobe walls. Therefore, it was considered necessary to design a structural system which by itself could support the roof, with adobe walls being treated simply as infill.

For the Peralta Adobe project, Ken Yuen, structural engineer, designed a system of steel reinforced concrete grade beams, columns, and a bond beam at the roof line (see fig. 3). Adobe bricks were removed at all four corners of the building to allow for pouring the vertical concrete columns. At the base of interior and exterior walls, continuous steel-reinforced concrete footings (grade beams) were placed. At the top of the walls, a recess was excavated into the adobe material for pouring the continuous bond beam around the perimeter of the building. Vertical columns were tied into the grade beam and bond beam so that, in theory, the concrete structural elements would continue to support the roof and provide for human safety even if all the adobe walls were to collapse during an earthquake. All new structural work was concealed behind adobe and mud plaster, so that it could not be detected visually.

The disadvantage of this type of structural system, particularly for such a small building (12.8 m x 6 m), is the disturbance to the historic adobe walls. This stabilization is what Randolph Langenbach would describe as a "Vietnam approach," in which the building is practically destroyed in the name of "saving" it [15].

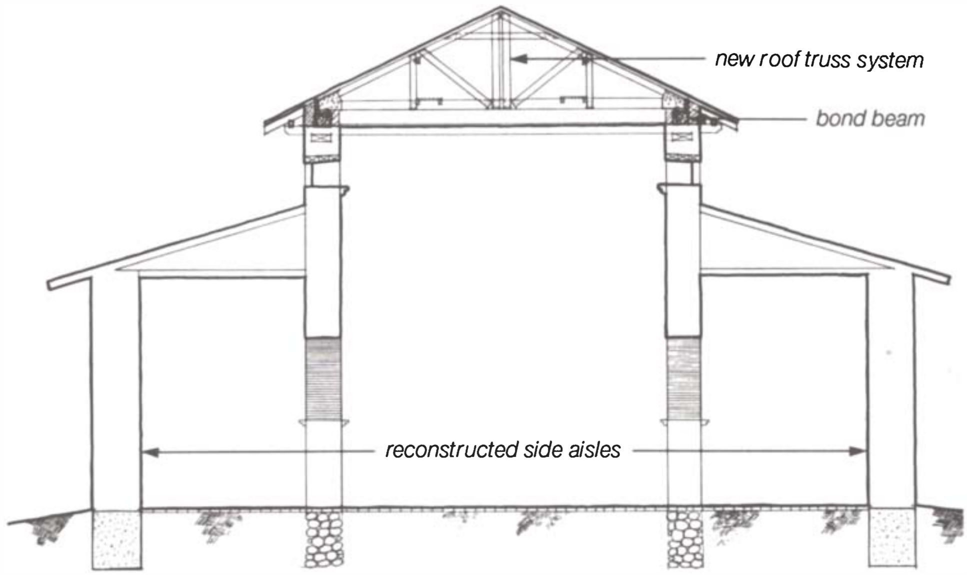

Figure 4. Mission San Juan Bautista Church, 1803-12. Restoration (supervised by Harry Downie 1975-78) included side aisle reconstruction by Michael Taylor, general contractor, and main roof reconstruction by Gil Sánchez, FAIA, architect.

Seismic Strengthening and Roof Reconstruction at Mission San Juan Bautista

This project was begun under the direction of Harry Downie and the Catholic Diocese of Monterey and consisted of reconstructing exterior church walls which had been lost due to damage in the 1906 earthquake. In the original construction the walls between the nave and side aisles were pierced with an arcade of arches, but they were soon filled in with adobe to become solid walls [16].

The first portion of the work was carried out in 1975 (by Michael Taylor, general contractor) which included installing a reinforced bond beam at the top of the newly constructed exterior walls. After the Historical Building Code came into use, unstabilized adobe walls could now be considered as load bearing walls and less structural work was deemed necessary. In addition to removing thick concrete buttresses (built after the loss of the exterior walls) and early adobes placed to fill the arched openings, epoxy was injected into each mortar joint of the arches for extra fortification [17].

The present author (G.S.) was called in to solve the problem of a sagging ceiling framing system in the church (see fig. 4). The original system designed with beams and a king post was exhibiting excessive deflection. The historic system was documented and removed and a new system was designed which was connected to the new bond beam. A new roof was installed over the church nave and side aisles and the historic roof tiles were reinstalled. The mission buildings sustained no damage during the October 17, 1989 earthquake, but for some reason which is as yet unexplained, the earthquake shocks also bypassed the little town of San Juan Bautista.

Seismic Strengthening and Restoration of Mission Santa Cruz Adobe

This adobe building owned by the State of California is the only structure remaining from the original Santa Cruz mission complex. It was built in 1822-24 to house native American families. After several years of historical research and archaeological investigation to document historic fabric and determine construction details, the present author was retained by the State to prepare construction documents for a restoration back to its mission period appearance [18].

For seismic strengthening, it was decided to install a concrete bond beam at the top of all perimeter walls and all cross walls at the plateline. The bond beam was deliberately not keyed in to the wall so that the adobe walls could flex if needed beneath the rigid beam. Cross walls that had been removed through the years were reconstructed in their historic locations and keyed in at the corners. The adobe cross walls extended upwards to the ridge of the roof and the ridge and roof beams rested on these adobe walls. To better distribute the weight of the roof beams, reinforced concrete seats were installed at the location where the beams rest on the adobe cross walls. These were not connected to the bond beam beneath them but were left "floating," supported only by adobe (see fig. 5).

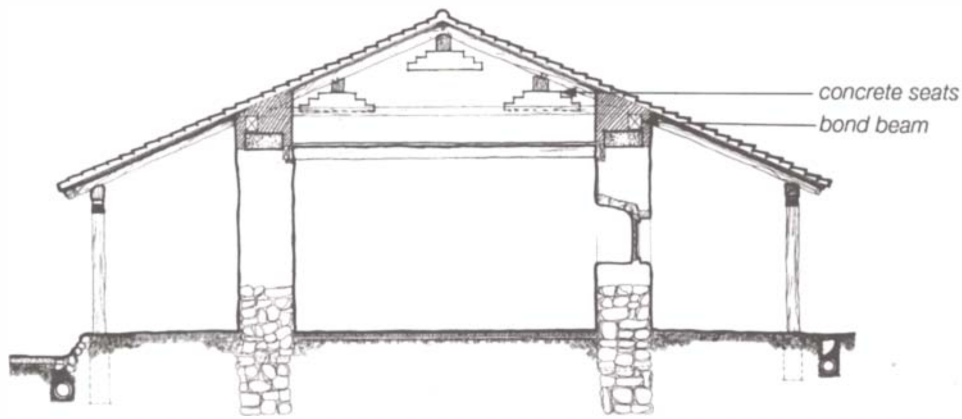

Figure 5. Mission Adobe at Santa Cruz Mission State Historic Park, 1822-24. Restoration and seismic strengthening with bond beam. Project included reconstructing four crosswalls which had been removed. Gil Sánchez, FAIA, architect.

The structural work at Mission Santa Cruz represents a system in which the adobe walls are allowed to take the full stresses of the roof load; it also recognizes the ability of the thick adobe walls to absorb energy from seismic shock. Randolph Langenbach suggests, in his descriptions of vernacular construction in Kashmir, India, that a lack of rigidity may be a positive factor to withstand earthquake forces. Speaking of historic buildings in Kashmir that have survived numerous earthquakes he states, "Because of the primitive materials and means of construction in Kashmir (masonry and timber runners combined), strength was not possible, so flexibility was necessary" [19].

The seismic strengthening work at Mission Santa Cruz was tested on October 17, 1989 when an earthquake measuring 7.1 rocked the area. Although the restoration had not been fully completed at that time, all structural reinforcing was in place including structural plywood at the roof. This adobe—the oldest building in Santa Cruz—survived the event extremely well, in contrast to many unreinforced brick buildings in the downtown area which were damaged beyond repair. As could be expected, the shorter cross walls, less flexible than the long side walls, exhibited tension cracks in the "X" pattern [20] and cross walls which were pierced with door openings were cracked more severely than solid ones. The long side walls of the mission were virtually uncracked. One end wall of the mission building was slightly displaced, moving a few inches outward from under the bond beam at the plate line, but it was determined that it could be jacked back into plumb position. Subsequent repair work consisted of injecting cracks with a mix of mud mortar and fly ash, in addition to jacking one end wall. Fiberglas rods were inserted at an angle at damaged building corners and wall intersections. Compared with the heavy losses to historic buildings in Santa Cruz from the 1989 quake, this repair work can be considered minimal.

Conclusions

Seismic activity has threatened adobe buildings since the introduction of the building type into California. In the 1970s highly rigid seismic strengthening systems with columns supporting the roof were thought to be necessary for public safety. After the Historical Building Code was adopted, seismic strengthening systems utilizing only a bond beam were encouraged. In terms of preservation, this system is much more favorable because it destroys less historic fabric. The Santa Cruz Mission Adobe, a one-story structure strengthened only by bond beams at perimeter and cross walls, was "field tested" in the October 17, 1989 earthquake and performed exceedingly well. The evidence in this example supports the hypothesis that a structural system consisting primarily of a bond beam (which allows for some wall movement) is sufficient to withstand moderate to severe earthquake shocks.

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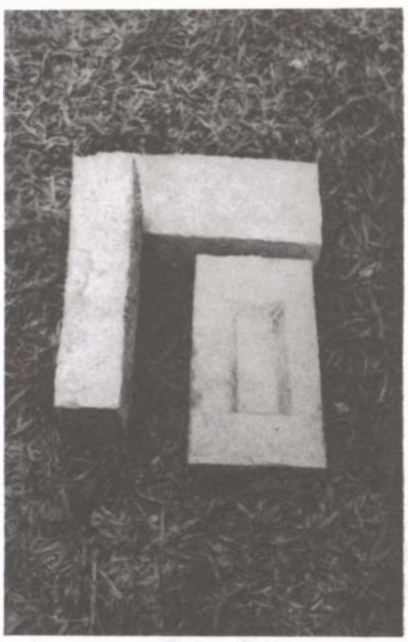
Current Field Research

ABSTRACT

This study consisted of identifying the constructive methods using adobe and a hand operated block press. The thermic characteristics of adobe were analyzed and show that using adobe walls with high thermal inertia it is possible to provide comfortable internal temperature.

KEYWORDS

Adobe, earthen architecture, Brazil.



ADOBE
Mud brick dried in the sun.

ADOBE: CONSTRUCTIVE METHOD AND THERMIC CHARACTERISTICS

Maria Auxiliadora Afonso Alvarenga
111, Praça Governador Valadares
Araxá, Minas Gerais, 38.180
Brazil

Introduction

The technologies that use earth as building material for domestic architecture have been used in Brazil from the time of their discovery until the present. The Portuguese and Africans brought their constructive methods, called adobe and pisé. By integrating them with those used by natives of Brazil, they developed another method called "taipa" or "pau-a-pique" (wattle).

Whole cities in Brazil--Ouro Preto, Diamantina, São João del Rei and others--were constructed using earth technologies. The preserved buildings of these cities indicate that with sound construction methods, careful selection of earth, together with proper protection of the walls from erosion by storms, this type of construction is capable of lasting for centuries.

These technologies were used intensively in Brazil until the coming of D. João VI, and the royal family to Rio de Janeiro. At that time, with the opening of the ports to "friendly nations," English materials such as Portland cement and glass came to be used indiscriminately.

With the advent of modern architecture and the international style, materials such as glass, steel, and concrete became symbols of "status" and modernity.

The oil and energy crisis of 1973 brought about a reevaluation of these modern materials, which are produced at a high cost of energy and resources. Engineers and architects who were interested in building comfortable houses at low cost had to look in other directions.

As a result, research began into the use of those older technologies that adapted so well to local climate and culture.

Still, the biggest problem in a country like Brazil is that people prefer imports from foreign countries because they have more "status." Earthen architectural systems are considered to be the lot of the poor who have no other choice. People do not see that building with earth is a good alternative in a country like Brazil because it is well adapted to the local climate and social conditions. Because of these misconceptions, it becomes more and more difficult to find builders who know how to select the soil and are knowledgable about the constructive method.

Adobe is one of the technologies that continues to be used because of its simplicity. The first part of this study provides an overview of the whole process, based on data obtained from many cities in northern Minas Gerais where these technologies are still used. Through personal contacts, photographs, and by participating in construction, it was possible to identify the principal elements in the adobe constructive method.

Adobe or mud brick

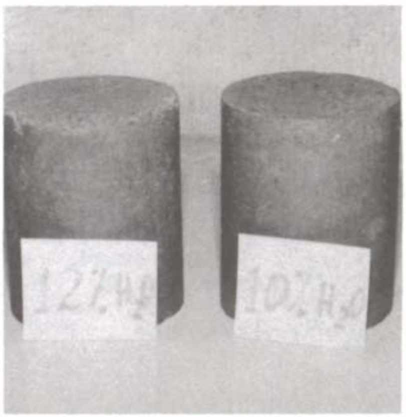
Adobe comes from the Arabic word "Adob," which means mud brick dried in the sun. It is a constructive method that uses a mud brick molded in a wooden or steel form.

It is probably the most popular earth building method used in Brazil at this present time. Its relative simplicity, which allows for "autoconstruction," and its low cost explain why it is so widely used.

Another factor is that adobe is an ecological building material. It uses natural elements and does not interfere with the environment, which is a great concern to people today. With walls of the right weakness, adobe can provide internal comfort with stabilized temperatures independent of external conditions.

Description

QUANTITY OF WATER
The best mud consistency for moulding contains 15% and 20% of water.

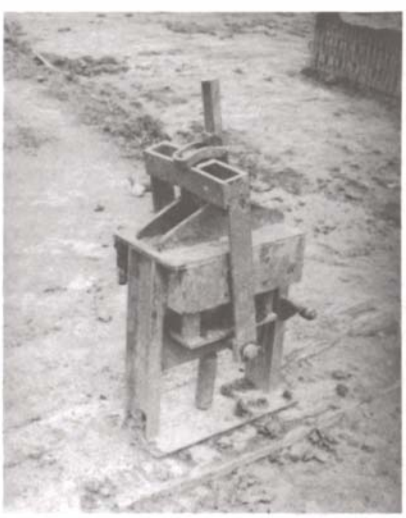


The process involves using a proper soil, with some kind of stabilizer, puddled with water. This mud can be mixed using bare feet or a mechanical process. It is necessary to test the soil in order to identify what kind of stabilizer will be used. The mud mixture is left undisturbed for 24 hours in order to attain the proper consistency. In northern Minas Gerais, the builders believe it is necessary to make adobes in "becrease moon," in order to have some cracks. It is necessary to pay attention to the quantity of water used; for adobe, the ideal consistency is 15% to 20% water by weight in its dry state. When it has attained its proper consistency, the mud is put into a wooden form, which may be dusted with a fine sand in order to facilitate removal of the finished adobes. After each adobe is finished, it is necessary to wash the form to make sure that no mud remains in the corners.

A man using a single mould can make between 200 and 500 adobes in a day. For a small house of about 60 square meters, about 3,000 adobes are required. When they come out of the moulds, the adobes must remain undisturbed for three days; then they must be left face upwards for another day in order to dry out. The adobes need to be completely dry before being used for construction. Thirty days seems to be sufficient in a normal climate without storms. It is important to cure them in the shade, not in the sun, without protection, which can cause shrinkage and consequently cracks.

Moulds

MOULDS
The adobes can be manufactured using a cinva-ram press or a wooden mould.



It is possible to use a two-brick, four-brick, or single mould. The simplest and most practical method is the single, bottomless wooden mould. It can be lined with sheet metal to allow the mould to slip easily away from the adobe when lifted. The adobe size depends on the mould; the most common has dimensions of 10 x 20 x 35 cm. The single mould has been used in a quick way that produces the same quantity of mud bricks as the multiple moulds. Special closer brick will be required for bonding, for this kind of adobes it is necessary to fix suitably shaped pieces of wood inside the mould.

Soil Selection

The proper selection of the soil is essential for a good earth building. It is necessary to investigate the kinds of soil that are available in the region. If the soil is unsuitable for the kind of construction desired, it can be mixed with others in certain proportions and used to make adobes. Simple identification of the texture and specific tests can be used to make a proper analysis and select the suitable soil. Observation of the soil texture helps to determine the soil composition. When one rubs dry soil between the fingers, the sand particles are gritty to the touch, the silt and fine particles adhere closely to the skin and have a silky feel when the sand particles are discarded. Lateritic soil, normally red and reddish-brown indicating the presence of iron (hematite) or yellow and yellowish-brown indicating the presence of limonite, often do not shrink or swell much upon wetting. They have high stabilizing qualities which are apparently connected in some way with their iron compounds and colloids. This kind of soil is desirable for earth construction. In order to manufacture adobes, it is necessary to select a soil without organic substances. Soils are usually graded into divisions according to the size of the soil particles. According to the International System of soil-texture classification:

|——CLAY——|——SILT——|——FINE SAND——|——COARSE SAND——|
0.0020(mm) 0.020(mm) 0.20(mm) 2.0(mm)

Generally, soils containing less than 20% clay are classed as sand and gravel, loamy sands, sandy loams, and loams, depending on the clay content. Soils containing from 20% to 30% clay are called clay loams and those over 30% clay are classed as clays. The silt loam and clay loam are considered suitable for adobe. But it is necessary to have the right proportion of clay to sand. Adobes made of soil with too great a proportion of clay are vulnerable to shrinkage and consequent cracking. The presence of sand in the selected soil is important because of its compression resistance and because sand is an inertial material in the presence of water.

TESTS
Before selecting the soil, it is necessary to know the percentage of clay and sand.

Analysis

A simple test can identify the percentage of clay and sand in a given soil sample. A small quantity of the selected earth is placed in a glass filling it to one third. Then measure the height that corresponds to the earth sample. Put water into the other two-thirds of the glass. Turn it over with a tampion and wash it repeatedly until the water runs clear because the clay and silt have floated off. Now measure again. Suppose the first measure was 5 cm, and the last was 3 cm. The following formula expresses the relationship:

$$\begin{matrix} 5 - 100\% \\ 3 - x \end{matrix} \quad \therefore \quad x = \frac{300}{5} = 60\%$$

The test shows that the percentage of sand is approximately 60%. In this way the correct percentage of sand and clay can be checked. The samples selected are triturated, put in a dish, then heated. The dried soil is weighed. Using a no. 200 U.S. sieve, the sample is washed, eliminating the clay and silt. The residue is dried again and then weighed. By comparing the measures the exact percentage of sand and clay can be determined. Generally the difference is 5% to 10% between the tests.

Soil preparation

After analysis and correct selection of the soil, it is time to prepare the mud. The soil should be reasonably free from humus or any quantity of organic material. A steel sieve can be used to make the soil homogenous and eliminate the larger stones. A shallow pit can be prepared in which the material is mixed. Based on the results of the tests described above, it may be necessary to add sand or to mix the selected soil with another kind in order to obtain the effective moisture. Other admixtures can also be used in order the stabilize the material.

Earth stabilization

The clay contained in the soil is susceptible to present differences and volume changes when mixed with water. Alternating cycles of wetting and drying causes gradual disintegration at the surface, especially at the point of contact with the water. The sand is inert and the particles do not absorb moisture, and it limits the volume changes of adobes because of the shrinkage of clay. It is possible to use admixture to stabilize the soil. Attaining the correct proportion of clay and sand is the first step. If the soil has too much sand, it is necessary to mix clay in as a binder or cementing agent, and if there is too much clay, it is necessary to add sand in order to limit the volume changes which cause shrinkage and cracks.

There are other kinds of stabilization:

1. Cementing: Using an agent such as Portland cement to reduce the volume changes of the clay.

2. The addition of fibers: straw, hair, sisal, and other similar materials can be used in order to reinforce the mud and reduce the volume changes.

3. Water-resistant stabilization: use of certain materials such as asphalt, mixing oil, to give permanent water-resistant stabilization.

4. Compaction: This increases weather resistance in machine-made blocks.

5. Lignin and tropical plants; Euphorbia lactea, with a hard elastic white film and the film of banana can be used mixed with the water that puddles the soil in order to give protection from tropical storms. It can be used in wall paints, when the plants are cut and chopped up in containers. This produces a sticky liquid which can be mixed with lime before using.

To select the proper stabilization and the quantity that is necessary it is better to make tests with different substances and different quantities before starting construction.

The quality of stabilized adobe bricks can be established recognizing testing methods:

1. General conditions: Cured mud bricks shall be reasonably true to size with parallel sides and free from excessive cracks and other defects.

STABILIZATION
The adobe bricks can be stabilized using a press.

BUILDING THE WALLS
When the adobes are completely cured, they can be used in building walls.

2. Moisture: Content of mud brick when dried and ready for use shall not be more than 4%.

3. Shrinkage cracks: Shall not be more than 1/8 inch in width and 3 inches in length.

4. Compression strength: Shall average 300 pounds or more under recognized test methods, per square inch with tolerance to 250 pounds for one brick in a test series of five.

5. Absorption: Shall average less than 2 1/2 percent of dry weight in 7 days.

6. Erosion: Bricks shall not be appreciably pited or eroded in two hours under a fine spray of water under 20 pounds of pressure.

7. Modulus of rupture: Shall average not less than from 40 to 50 pounds per square inch with tolerance to 30 pounds for one brick in a test series of five.

Mortar

Mud mortar is most commonly used for adobe wall. It is more appropriate and gives a more homogenous final result. Earth found in ant and termite houses can be used to guarantee its quality. Using some kind of stabilization, the same mix should be used as in the mud bricks. In the state of Minas Gerais, the most common mortar is 4 parts sand, one of ant or termite earth, and half of cow dung (4: 1: 1/2).

Building the Walls

Since the adobes are completely cured, they can be used in building walls. Side preparations, foundations, and provisions against dampness are requirements that must be completed before beginning the adobe walls. It is necessary to provide a special protection against moisture between the foundation and the adobe wall. Stone, brick, or wood can be used to prevent infiltration of water on the walls. The height of the foundation can be about 15 cm above the ground to protect the wall against rain and consequent erosion. When the construction is finished, protective wall coverings can be applied, mud plaster or mud mixed with a small quantity of cement and lime. If cement and lime is used, it is essential to test the quantity because a mortar that is too strong can diminish adhesion between the adobe walls and the covering.

Considerations about Earthen Homes

Certain considerations must be kept in mind when building a home of earth: views, protection against inclement weather, a suitable slope to assist drainage and provide for sewage lines. If the site is sloping, it will be an advantage, if the fall is in a direction suitable for drainage. In selecting the site it is necessary to consider the kind of soil that is available and the constructive method that best suits the particular site and building lay-out. Other local materials such as wood, stone, kiln-fired brick can be incorporated into the house design if they are available. The orientation of the house must consider the best view, the solar and wind directions as passive means of obtaining comfortable internal temperatures. In the case of a tropical country like Brazil, the orientation must, in some cases, be chosen with a preference for the dominant winds. In Araxá, with a tropical climate but high altitude (900 m), there is a thermic amplitude, which makes the solar orientation most important.

To protect the walls from weather, verandas can be used to keep out the water during rainstorms and to protect from hot sunshine during summer. The roof should be extended considerably from the walls giving complete protection from rain. Impervious masonry is desirable to a height above the finish grade which will prevent erosion from the splash of rain water. Wood or stone can be used before starting the adobe walls to reduce capillary action. A substantial foundation and footing, designed for the unit compressive soil bearing capacity is essential. Other considerations depend on the special requirements of the climate or the builder's desires.


INTERNAL TEMPERATURES
Using adobe you can provide comfortable internal temperatures.

Thermic Characteristics

Since the 1973 oil crisis, the home as energy consumer has come under consideration. Bardou (1979) states that approximately 1/3 of the total energy consumed is used by houses. Using solar energy and bioclimatic architecture, it is possible to heat or cool houses using passive methods without any further costs and providing comfortable internal temperatures. Using climate data, the designer can understand better the local meteorological parameters and orient the house adequately. Knowing the simultaneous action of temperature, sun, and wind, it is possible to have a bioclimatic conception of the project. There are two fundamental aspects to the thermal action of a building. First, it can be assumed that the external conditions are permanent and the internal temperature is constant; the thermal conductivity of the material, its resistance and conductance are considered. But, in fact, the temperature regimen is variable, and it is necessary to consider radiation and convection. In this case, the thermal characteristics that better explain the reality are heat capacity (C) and thermal inertia ( ). The heat capacity can be obtained by the specific heat of the building material c - (J/Kg C).

Calculation

For adobe the characteristic time constants found for the different wall thicknesses was: 3.47, 6.17, 18.9, and 38.59 days respectively; using brick, the characteristic time found was 2.2, 3.91, 11.98, and 24.46 days respectively.

Conclusion

Using adobe as a building material, it is important to know the constructive method, its special requirements in order to inform the design considerations, selection of the better kind of soil, simple tests to certify it, and each step of the construction. Knowing its thermal capacity, using local materials, and considering the climate, an adobe house can be constructed at low cost and comfortable internal temperatures using passive and natural means.

"Man has always had a creative instinct, which reveals itself in one way or another," and a house can express the builder himself, his personality, his dreams and determination to resolve the problem of building a shelter for himself and his family. Earth, with its universal availability, its thermal properties, low cost and ecological considerations, seems to be one of the best materials for home construction. Nonetheless, people are neglecting this method because of misconceptions. Millions of people today do not have homes. Using earth as a building material could help to solve this housing problem while revitalizing these building techniques.

Autoconstruction experience

Practical experience in using the above principals was offered in the construction of an adobe house outside of Araxá, an area of a small city in Brazil. In every aspect, from the design to construction, the architect worked with the community to take advantage of its knowledge of ambient comfort and adobe building techniques. Using CINVA RAM, a hand-made brick press was obtained. The community used the press to manufacture the adobes, but they preferred to use the single wooden form because of its simplicity.

The first difficulty in the construction was the builders' dissatisfaction with the adobe. They considered it synonymous with poverty and the lack of any other choice. After many discussions, they were convinced that they could construct a comfortable house using adobe. The steps of the construction were detailed in photographs.

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INFLUENCE DE L'HUMIDITE SUR LES PROPRIETES THERMIQUES DU MATERIAU TERRE : PROBLEMATIQUE, METROLOGIE, RESULTATS EXPERIMENTAUX.

Jean-Paul Laurent
Institut de Mécanique de Grenoble
BP 53 X, 38041, Grenoble-Cedex, France

ABSTRACT

Considering the example of some earths used to realize "Pisé" (rammed earth), we present here experimental results concerning the influence of temperature and water-content on thermal properties of earth building material. After an introduction on the structure characterization methods of this particular granular porous material, the main mecanisms of adsorption and migration of water in earth walls are reviewed. The experimental device, a "thermal shocks probe", we use to determine the thermal parameters, heat-conductivity and heat-capacity is also described. The main conclusion we have drawn from this study is that, if the water content is not too important, the influence of temperature on heat-conductivity can be neglected and the influence of water-content on thermal parameters modelized by linear relationships. Figures and numerical values are given to estimate practically the thermal parameters of an earth buiding material in normal conditions.

KEYWORDS

EARTH BUILDING MATERIAL, POROUS MEDIUM, HEAT & MASS TRANSFER, EXPERIMENTAL METHODS, HEAT CONDUCTIVITY, STRUCTURE, CLAY, HUMIDITY.

MOTS CLES

MATERIAU TERRE, MILIEU POREUX, TRANSFERTS DE MASSE ET DE CHALEUR, METHODES EXPERIMENTALES, CONDUCTIVITE THERMIQUE, STRUCTURE, ARGILE, HUMIDITE.

Introduction

Les terres utilisables en tant que matériau de construction sont des milieux poreux granulaires dont la cohésion est assurée naturellement par une certaine proportion de phase argileuse. Quelle que soit sa composition minéralogique, celle-ci possède une structure microporeuse qui confère au matériau terre un caractère hygroscopique. Pratiquement, cela signifie que, même après la période de séchage qui suit la mise en œuvre et en l'absence de toute arrivée d'eau "parasite", une paroi en terre contient toujours une certaine quantité d'eau adsorbée par l'argile en présence de l'humidité de l'air. Sous l'effet de sollicitations climatiques, notamment thermiques, cette eau est susceptible de changer d'état (vaporisation/condensation) et/ou de migrer dans l'espace des pores, ce qui modifie évidemment le bilan thermique final. Il est indispensable d'étudier, de modéliser et de quantifier ce couplage entre transfert d'eau et transfert de chaleur dans une paroi en terre car il est clair qu'il conditionne essentiellement le confort thermique propre à ce type d'habitat. Le travail que nous présentons ici s'inscrit dans cette perspective.

Après un rappel sur la caractérisation de la structure poreuse du matériau terre et ses propriétés thermiques à l'état sec, nous passons en revue les divers phénomènes physiques qui sont à l'origine de la fixation et du transfert de l'eau dans ce matériau. Nous introduisons ensuite la notion de "paramètres thermiques apparents" d'un milieu poreux humide et nous décrivons la méthodologie de mesure de la conductivité thermique et de la capacité calorifique par "sondes à chocs thermiques" que nous utilisons. Enfin, nous présentons et nous discutons les principaux résultats expérimentaux que nous avons obtenus concernant l'influence de la température et de la teneur en eau sur les propriétés thermiques du matériau terre.

Pour cet exposé, nous avons choisi d'illustrer notre propos en considérant le cas de terres "à pisé" d'une région de France : le Dauphiné (Voir Fig. 1 et Tab. I), que nous avons plus particulièrement étudié [1,2]. Toutefois, il est clair que l'approche méthodologique que nous avons adoptée est transposable à d'autres classes de matériaux . Nous avons d'ailleurs, nous-mêmes, également travaillé sur des "torchis" ou sur des terres africaines utilisées en " façonnage direct " [1,2].

Structure et caractérisation du matériau terre, propriétés thermiques à l'état sec

Une terre crue peut être employée comme matériau de structure si, par un procédé quelconque, on peut atteindre un niveau de densité qui lui confère une résistance mécanique suffisante. Par ailleurs, un certain nombre d'identifications préliminaires (granulométrie, teneur en argile, essai "Proctor", etc…) doivent être effectuées pour savoir si une terre donnée peut effectivement être utilisée pour construire [3,4]. Quelle que soit la technique constructive finalement utilisée, la structure physique du matériau terre, en situation normale de fonctionnement, s'apparente plus à celle d'une roche poreuse qu'à celle d'un sol bien que celui-ci soit, en l'occurence, la matière première constitutive. Globalement, on pourra donc le caractériser au niveau macroscopique par des paramètres comme la densité sèche ou la porosité (Voir Tab. II). L'expérience montre que la connaissance de ces seuls paramètres suffit souvent pour prévoir correctement certaines caractéristiques fonctionnelles. Par exemple, concernant les propriétés thermiques en particulier, nous avons pu montrer que la densité sèche détermine essentiellement la conductivité thermique "à sec" (Voir Fig. 2) ce dont on peut rendre compte physiquement [1,2]. Par contre, lorsque l'on s'intéresse aux propriétés hydriques, ou à l'influence des conditions hygrothermiques sur le comportement mécanique ou thermique d'une paroi en terre, il devient absolument nécessaire de considérer d'autres facteurs structuraux.

En premier lieu, il importe de caractériser, qualitativement et quantitativement, la phase argileuse qui conditionne essentiellement les propriétés hygroscopiques (Voir § suivant). Or, la minéralogie de ce type de roches sédimentaires est singulièrement complexe [5]. Chimiquement, les argiles sont des silico-aluminates hydratés dont la structure cristalline possède la particularité d'être organisée en feuillets. Ces feuillets sont eux-mêmes constitués de couches d'atomes dont l'empilement forme deux types de motifs : octaédriques autour des atomes d'aluminium ou tétraédriques autour des atomes de silicium. Il est possible de différencier les différents groupes d'argiles suivant la séquence d'empilement des couches d'atomes dans le feuillet à laquelle correspond une distance interfoliaire caractéristique (Voir Tab. III). L'identification de ces minéraux s'effectue par cristallographie aux rayons X mais, dans les terres naturelles, de nombreux types de minéraux argileux peuvent être présents simultanément (Voir exemple Tab. I) et leur différenciation peut s'avérer difficile d'autant plus qu'ils sont susceptibles de former des composés interstratifiés (illite/montmorillonite ou montmorillonite/chlorite par exemple) et que leurs distances interfoliaires ne sont pas toujours très stables (cas des smectites). De plus, il est souvent impossible de déterminer pratiquement le pourcentage en masse que représente la phase argileuse. On peut alors se contenter d'un critère granulométrique en assimilant phase argileuse et fraction massique de diamètre de grain inférieur à 2µm.

Parallèlement à l'identification des argiles, il est également important de caractériser la structure du réseau de pores intergranulaires. En effet, c'est dans cet espace que s'opèrent les phénomènes de transfert hydrique et sa morphologie influe donc sur les valeurs des coefficients de transfert correspondants. Plusieurs techniques complémentaires peuvent être utilisées pour caractériser ce réseau poreux: voir Tableau II.

L'eau dans le matériau terre, notion de paramètres thermiques apparents

Comme nous l'avons dit en introduction, les matériaux auxquels nous nous intéressons ici contiennent toujours de l'eau. Celle-ci pourra être caractérisée par sa proportion en masse (w) ou en volume (θ) avec :

$$w = \frac{\text{Masse d'eau}}{\text{Masse totale}} \quad \text{ou} \quad \theta = \frac{\text{Volume d'eau}}{\text{Volume total}} \qquad (1)$$

$$\theta = w.d_s \quad (d_s : \text{densité sèche})$$

En fonctionnement normal, l'eau adsorbée par le matériau terre provient de la vapeur d'eau contenue dans l'air et elle est localisée essentiellement dans la phase argileuse qui possède une très grande surface spécifique et les pores les plus petits. Pour caractériser cette tendance à fixer l'eau ("hygroscopicité"), on réalise en laboratoire des "isothermes d'adsorption" : relation teneur en eau à l'équilibre en fonction de l'humidité relative de l'air (H.R.). La Figure 3 en présente des exemples qui montrent bien qu'en l'occurence ce n'est pas la densité sèche le paramètre important mais bien le type de terre. A l'équilibre à une teneur en eau donnée, on aura "condensation capillaire" (apparition d'eau liquide) dans les pores de rayons inférieurs à un seuil r(q) que l'on peut estimer, connaissant l'isotherme d'adsorption, par la relation de Laplace-Kelvin :

$$-\frac{2\,\sigma(T)}{r(\theta)} = \frac{\rho_l RT}{M} \text{Log H.R.}(\theta) \qquad (1)$$

Avec :

σ : coefficient de tension superficielle air/eau (0,073 N/m à 20°C)
T : la température du milieu (°K).
ρ_1 : masse volumique de l'eau (998,3 kg/m³ à 20°C).
R : constante des gaz parfaits (8,3143 J/mole.°K)
M : masse molaire de l'eau (18,01534 10^{-3} kg/mole).

Sous l'effet d'un gradient thermique, notamment, le potentiel de l'eau dans le matériau terre peut être modifié de manière différentielle et divers mécanismes de transferts et/ou changement d'état apparaissent alors. Philip et De Vries ont, les premiers, formulé les équations générales traduisant ces transferts couplés de masse et de chaleur dans un milieu poreux humide [6]. Depuis, de très nombreux travaux ont porté sur ce thème (Voir par exemple : [7], [8] ou [9]). Nous nous contenterons, ici, de rappeler quelques résultats en relation avec la notion de paramètres thermiques apparents .

Si l'on suppose vérifiées un certain nombre d'hypothèses dont les plus importantes sont : milieu homogène, matrice solide indéformable et phase liquide incompressible, fluides parfaits (vapeur d'eau et air), pas d'hystérésis, pas d'effet de gravité, pas d'échanges radiatifs, équilibre thermique instantané, etc..., le premier principe de la thermodynamique (conservation de l'énergie) permet d'écrire l'équation de la chaleur, pour un milieu poreux humide, sous la forme :

$$C\frac{\partial T}{\partial t} + \rho_l L\frac{\partial \theta_v}{\partial t} - \rho_l W\frac{\partial \theta_l}{\partial t} = \mathrm{div}\left(\lambda\, \mathrm{grad}\, T\right) - \mathrm{div}\,(Lq_v) - C_m q\, \mathrm{grad}\, T \quad (2)$$

Variation d'enthalpie (a) (b) (c)

Où (a) représente le transfert de chaleur purement conductif, (b) le terme de transport par chaleur latente et (c) celui par chaleur sensible avec :

t : le temps (s).
C : capacité calorifique (J/m^3°K).
L : enthalpie de vaporisation (2454,3 J/kg à 20°C).
W : "chaleur de mouillage" (J/kg).
λ : conductivité thermique (W/m°K).
θ_v ,θ_l : teneurs en eau volumiques liquide et vapeur (m^3/m^3).
q_v, q : densités de flux de vapeur et de flux total (Kg/s.m^2).
C_m : capacité calorifique du mélange air + vapeur d'eau (J/m^3°K).

S'il n'existe dans le milieu que des forces motrices d'origine thermique, une analyse d'ordres de grandeur permet de négliger le terme (c) devant les deux autres. En développant le terme (b) l'équation (2) prend alors la forme suivante :

$$C\frac{\partial T}{\partial t} + \rho_l L\frac{\partial \theta_v}{\partial t} - \rho_l W\frac{\partial \theta_l}{\partial t} = \mathrm{div}\left[\left(\lambda + \rho_l L\, D_{tv}\right)\mathrm{grad}\, T\right] + \mathrm{div}\left[\left(\lambda + \rho_l L\, D_{\theta v}\right)\mathrm{grad}\, \theta\right] \quad (3)$$

Où D_{tv} est le coefficient de diffusion de la vapeur sous l'effet d'un gradient thermique et $D_{\theta v}$ le coefficient de diffusion de la vapeur sous l'effet d'un gradient de teneur en eau. Si, de plus, on retient l'hypothèse d'une humidité répartie de manière uniforme, (3) peut se ramener à une expression "classique" de la loi de Fourier :

$$C^*\frac{\partial T}{\partial t} = \mathrm{div}(\lambda^* \mathrm{grad}\, T) \text{ avec } \lambda^* = \lambda + \rho_l L D_{tv} \text{ et } C^* = C + \rho_l L\frac{\partial \theta_v}{\partial T} - \rho_l LW\frac{\partial \theta_l}{\partial T} \quad (4)$$

λ^* et C^* seront considérés comme étant les paramètres thermiques apparents du milieu poreux auxquels on a accès par la mesure.

Dispositif de mesure des paramètres thermiques

Pour mesurer la conductivité thermique et la capacité calorifique, nous utilisons des méthodes de mesure en régime transitoire imposé par "sondes à chocs thermiques".

Rappelons que le principe de ce type de méthode consiste à créer un choc thermique dans le matériau, dont on veut mesurer les propriétés thermiques, par l'intermédiaire d'un élément chauffant alimenté électriquement. Une réponse à cette excitation est mesurée en transitoire par l'intermédiaire d'un capteur placé dans le matériau ou dans l'élément chauffant. La connaissance de la forme analytique de la "fonction de transfert" entrée/sortie correspondant à une géométrie donnée permet d'identifier les paramètres thermiques à partir des courbes expérimentales [10].

Ces méthodes existent depuis plus d'un demi-siècle et sont largement utilisées dans différents domaines car elles présentent de nombreux avantages : simplicité de l'appareillage, rapidité de la mesure, automatisation possible et, surtout, possibilité d'opérer in-situ dans des conditions hygrothermiques quelconques en respectant l'état physique du milieu. Pour notre part, nous avons cherché à optimiser des sondes en fonction de l'usage que nous souhaitions en faire. En particulier, nous avons conçu une sonde "monotige", pour la mesure de la conductivité thermique, et une sonde "bitige" permettant également la détermination de la capacité calorifique [1, 10, 11]. Ces sondes (Voir Fig. 4) sont mises en place par perçage préalable. Les performances atteintes, grâce à un corps de chauffe breveté de très faible inertie thermique, nous ont permis d'atteindre une précision de l'ordre de ±5% quelle que soit la résistance thermique de contact sonde/matériau.

Mesures de l'évolution des paramètres thermiques du matériau terre en fonction de la teneur en eau et de la température

1. Méthodologie : Pour mener à bien cette étude, nous avons intégré nos sondes au sein d'un dispositif automatisé associant les fonctions de commande, d'acquisition et de traitement, pour la mesure des paramètres thermiques, au pilotage en température d'une étuve.

Pour des raisons d'ordre pratique, nous avons choisi d'étudier l'évolution des paramètres thermiques en fonction de la température à des teneurs en eau données. Nous avons donc réalisé successivement des teneurs en eau que nous avons choisies intermédiaires entre l'état sec et la teneur en eau à la fabrication : (w=0, 1, 2, 4 et 8%) ce qui couvre plus que la gamme des teneurs en eau qui peuvent être atteintes "naturellement" par le matériau terre en fonctionnement normal comme le montre la Figure 3. La gamme de température explorée allait de 0° à 60°C. Ces choix ont été motivés par le souci de se placer dans des conditions proches de celles du matériau réel en œuvre.

Pour obtenir ces teneurs en eau avec une répartition aussi homogène que possible, nous avons utilisé la méthode suivante : après injection dans les échantillons (cubes de 10 cm d'arête enveloppés dans des housses en matière plastique), de la masse d'eau liquide correspondant à la teneur en eau souhaitée, on opère une redistribution par vaporisation sous l'effet d'un chauffage micro-ondes. L'efficacité de cette méthode a été contrôlée en effectuant un certain nombre de mesures au banc gammamétrique de la répartition de l'eau dans le matériau. Les teneurs en eau finales étaient déterminées par pesée, par référence au poids sec, avec une précision de l'ordre de 0,1%.

2. Résultats : Dix échantillons de terre crue non-stabilisée réalisés à partir de sept terres différentes ont été sélectionnés. Pour ne pas alourdir notre présentation, nous ne reportons pas, ici, l'intégralité des résultats obtenus que l'on pourra retrouver dans [1]. Nous présentons, à titre d'exemples, les différents types de comportements observés en ce qui concerne l'évolution de la conductivité thermique (Voir Fig. 5) ou de la capacité calorifique (Voir Fig. 6). La Figure 7 effectue une synthèse, pour tous les échantillons de terres du Dauphiné, de la variation relative de conductivité thermique par rapport à l'état sec en fonction de la teneur en eau pondérale.

Terre	c (J/kg°K)
Morestel	891
Isle d'Abeau	815
CD300 N°2	813
CD300 N°1	818
Marchand	807
La Verpillière	820

Tab. IV : Chaleurs spécifiques à sec mesurées au calorimètre

3. Interprétation des résultats obtenus : Toutes les mesures réalisées en fonction de la teneur en eau ont montré que l'on pouvait admettre une variation linéaire de la capacité calorifique en fonction de la teneur en eau avec une pente égale à la capacité calorifique de l'eau (Voir exemple Fig. 6). On peut donc estimer la capacité calorifique d'un matériau terre humide à partir de la valeur obtenue à sec (Voir Tab. IV) par :

$$C_{humide} = C_{sec} + \theta . C_{eau} = 1000.d_s.c_{sec} + 4{,}18\ 10^6\ d_s\ w \quad (5)$$
$$(J/m^{3\circ}K) \qquad\qquad (J/kg^\circ K)$$

Si l'on considère maintenant l'évolution de la conductivité thermique en fonction de la teneur en eau pondérale (Voir exemple Fig. 5), on constate également une variation pratiquement linéaire aux faibles teneurs en eau. De plus, ce comportement est indépendant de la densité sèche du matériau considéré. On pourra donc estimer simplement la conductivité thermique d'un matériau terre humide, quelle que soit sa densité, par :

$$\lambda(w) = \lambda_{sec}\,(1 + K_{\lambda w}.w)\ \text{pour}\ 0\% \le w \le 4\% \quad (6)$$

Où $K_{\lambda w}$ est une constante dépendant uniquement du type de terre. Nous avons relevé, pour les terres du Dauphiné, des valeurs de $K_{\lambda w}$ comprises entre 0,085 et 0,14 indépendantes de la densité sèche. Compte tenu de la diversité des comportements hydriques que l'on peut attribuer à des teneurs variables en argiles de nature différentes, un coefficient de + 20% par rapport à la valeur à sec, à défaut d'autres renseignements, donnera une estimation plausible de la conductivité thermique du matériau terre en œuvre dans une atmosphère d'humidité relative moyenne.

A sec et pour les teneurs en eau faibles, la conductivité thermique est toujours légèrement décroissante en fonction de la température. Ceci est dû à la variation de la conductivité thermique de la phase solide, en particulier du quartz. Aux teneurs en eau plus élevées, par contre, la conductivité thermique peut croître faiblement en fonction de la température. Il faut voir là l'influence de la phase fluide contenue dans l'espace poral (air + vapeur d'eau et, éventuellement, eau condensée), dont la conductivité thermique augmente en fonction de la température. Toutefois, ces variations restent faibles, ce qui montre que l'eau est fortement liée dans la phase argileuse d'un matériau terre, et, pratiquement, on pourra négliger l'influence de la température sur les propriétés thermiques utiles.

Conclusion

Le travail que nous venons de présenter peut être considéré comme le premier volet d'un programme plus ambitieux visant à la modélisation complète du comportement hygrothermique réel du matériau terre. Pour pouvoir résoudre les équations couplées de transfert de chaleur et de masse dans ce matériau, il faudra également disposer de valeurs des coefficients de transferts hydriques et de modèles de leur évolution en fonction du type de terre et des conditions de température et de teneur en eau. Ceci constitue actuellement un de nos axes de recherche.

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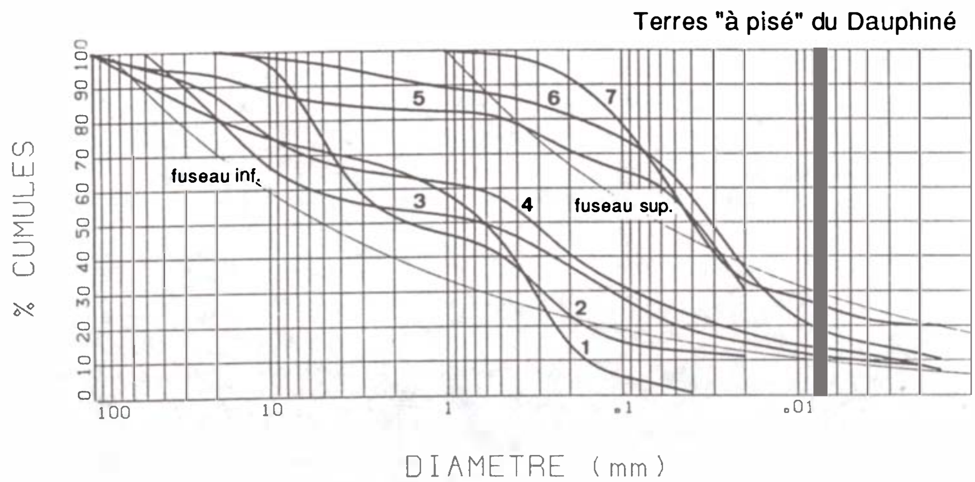


Fig. 1 : Courbes granulométriques de 7 terres "à pisé" du Dauphiné.

TERRE		PHASE SOLIDE GRANULAIRE							PHASE ARGILEUSE							
N°	Désignation	Quartz	Calcite	Feldpaths	Plagioclase	Hématite	Micas	% < 2 microns	Kaolinite	Illite	Illite/Mont.	Montmo.	Mont./Chlor.	Chlorite	Smectite	Vermiculite
1	Morestel	88	2	4	6	0	0	≈ 0	50	0	0	0	0	50	0	0
2	Marquis	100	0	0	0	0	0	6	tr	20	30	15	0	15	0	15
3	Isle d'Abeau	61	26	13	0	0	0	9	25	50	0	25	0	0	0	0
4	CD300 n°2	64	19	5	5	0	7	9	0	100	0	0	0	0	tr	0
5	CD300 n°1	88	2	5	5	0	tr	15	0	57	0	0	0	0	43	0
6	Marchand	80	0	0	20	0	0	13	10	40	20	0	20	10	0	tr
7	Verpillière	49	0	51	0	0	0	20	20	40	0	0	0	0	40	0

Tab.I : Caractéristiques des terres du Dauphiné étudiées.

	CARACTERISTIQUE	DEFINITION	OBTENTION	REMARQUE
GLOBALES	Porosité totale	$n = \frac{\text{Volume des pores}}{\text{Volume total}} = 1 - \frac{d_s}{d_g}$	pycnométrie porosimétrie mercure	eau, hélium... limitée au + petit pore accessible
	Densité sèche	$d_s = \frac{\text{Masse sèche}}{1000.\text{Volume total}}$	pycnométrie pesée	- état sec de référence
	Densité de grain	$d_g = \frac{\text{Masse sèche}}{1000.\text{Volume solide}}$	pycnométrie	généralement : 2,65
MATRICE SOLIDE	Distribution de diamètres de grain	Fraction massique de grains de diamètre d<do en fonction de do	tamisage + sédimentométrie	grains supposés sphériques
	Composition minéralogique	% relatifs et nature des minéraux	analyse X	diagramme de poudre microscopie électronique
	Composition chimique	% relatifs et nature chimique des minéraux	analyse X	généralement exprimée en oxydes élémentaires
RESEAU POREUX	Distribution de diamètres de pores	Fraction volumique de pores de diamètre d<do en fonction de do	porosimétrie mercure adsorption moléculaire analyse d'image	pores cylindriques par calcul (BJH) -
	Surface spécifique	Surface développée des pores ramenée à l'unité de masse	porosimétrie mercure adsorption moléculaire analyse d'image	par calcul direct (BET) -
	Géométrie du réseau poreux	Morphologie du réseau contiguïté entre phases coordinence des grains	analyse d'image	performances liées aux algorithmes d'analyse utilisés

Tab.II : Principales méthodes de caractérisation d'un milieu poreux granulaire.

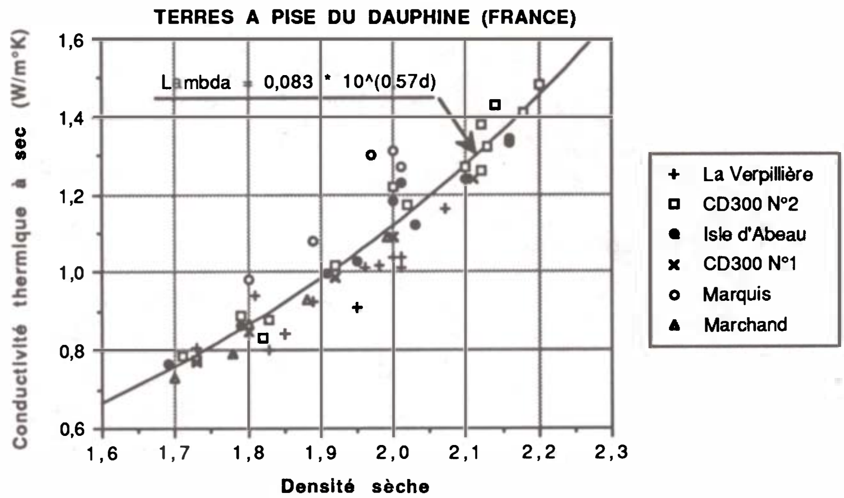


Fig. 2 : Influence de la densité sèche sur la conductivité thermique "à sec" [1, 2].

Distance interfoliaire	FAMILLE	FORMULE CHIMIQUE
7 Å	Kaolinite	$Si_2O_5Al_2(OH)_4$
10 Å	Montmorillonite	$Si_4O_{10}(Al_{2-x}Radical_x^{2+})(OH)_2Cation_x\,nH_2O$
	Illite (Micas)	$(Si_{4-x}Al_x)O_{10}(Al_2)(OH)_2K_x$
	Vermiculite	$(Si_{4-x}Al_x)O_{10}(R_{3-y}^{2+}R_y^{3+})(OH)_2CE_{x-y}$
≈ 14 Å	Chlorite	$(Si_{4-x}Al_x)O_{10}(R_3^{2+})(OH)_2(R_x^{3+}R_{3-x}^{2+})(OH)_6$

Tab III. : Les différentes familles d'argiles rencontrées dans le matériau terre [5].

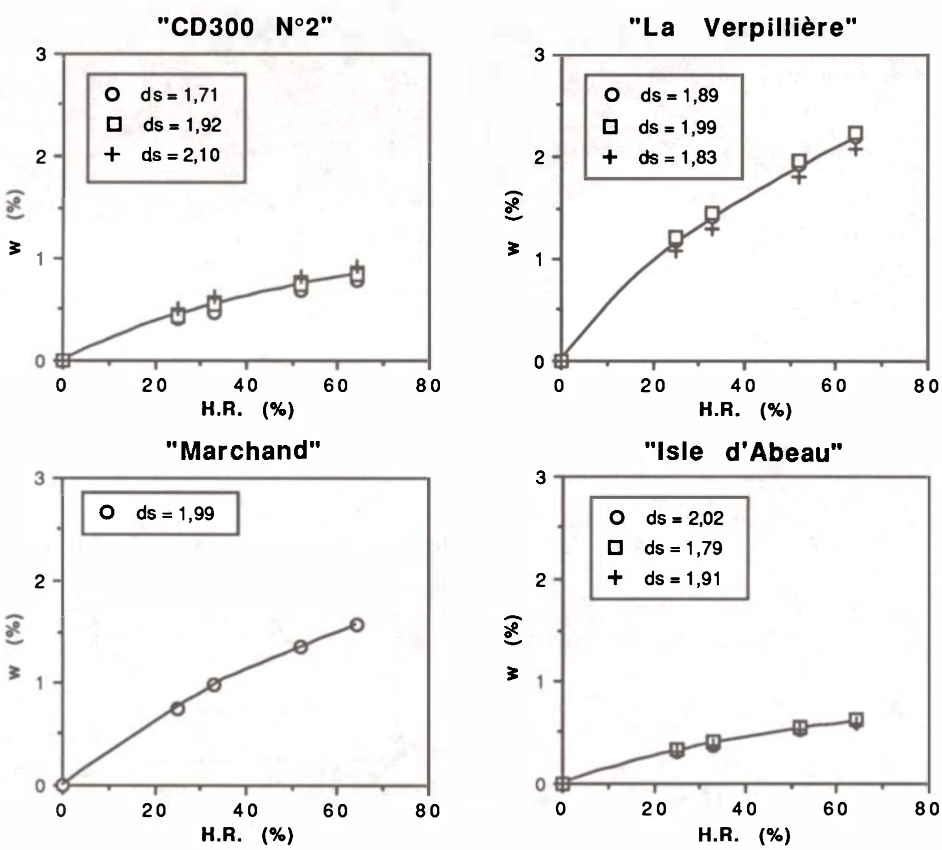


Fig. 3 : Isothermes d'adsorption pour 4 terres "à pisé" du Dauphiné.

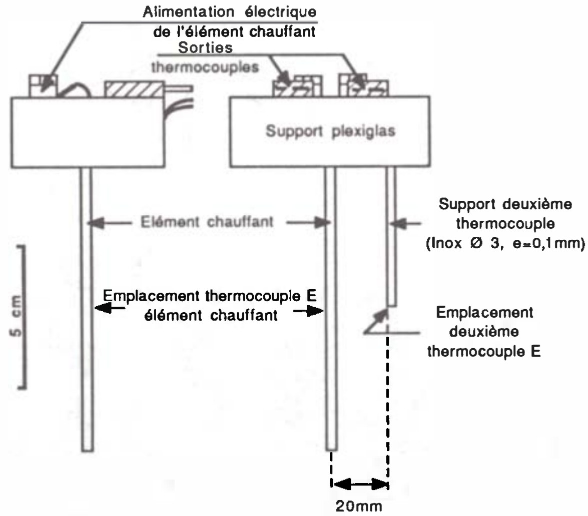


Fig. 4 : Sondes utilisées pour la mesure des paramètres thermiques

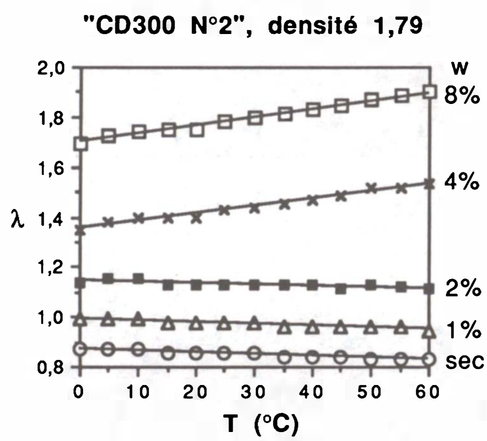


Fig. 5 : λ = f (T,w)

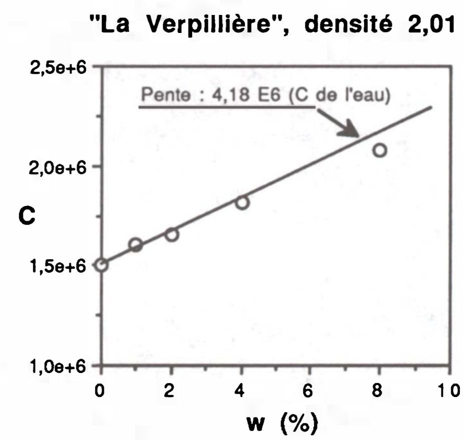


Fig. 6 : C = f (w) à 20°C

Fig. 5 & 6 : Exemples d'évolutions mesurées des paramètres thermiques en fonction de la température et de la teneur en eau

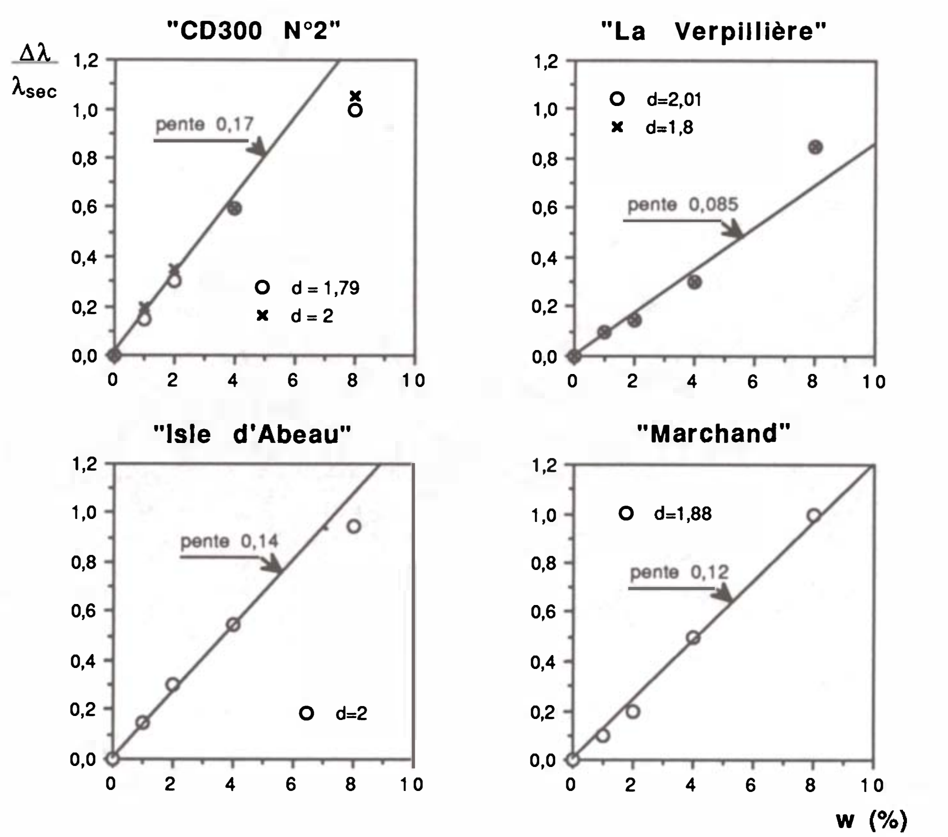


Fig. 7 : Variation relative de la conductivité thermique en fonction de la teneur en eau. Synthèse des résultats obtenus pour 4 types de terres "à pisé" du Dauphiné

ABSTRACT

Site Tulor 1 has become one of the most outstanding archaeological discoveries in recent years in the north of Chile being the oldest example of earth technology used for building a village in this country.
Efforts to preserve this site's ruins have generated joint research work which will combine the following studies:
Assessment of its present condition.
Identification of degrading agents threatening its extinction.
The construction of an experimental polygon.
Characterization of earth based materials.
Experiments will be oarried out using various techniques aimed at stabilizing the earthen village's wall.
At present, research work being conducted on these earthen head walls involves among other techniques the use of chemical surface treatments (consolidants), ethyl silicate based.

KEYWORDS

Conservation, Consolidation, Experimental Polygon

CONSERVACION DE UN SITIO ARQUEOLOGICO CONSTRUIDO EN TIERRA

* Eduardo Muñoz G.
Universidad de Antofagasta
Casilla 170 Antofagasta
Chile

Mónica Bahamóndez P.
Centro Nacional de Conservación y Restauración. Av. Kennedy 9350
Santiago, Chile

I. Sitio Arqueológico Tulor 1

El Sitio Arqueológico Tulor 1, denominado también Aldea de Tulor, está ubicado en el Salar de Atacama, a unos 10 kms. en dirección S.O. del Pueblo San Pedro de Atacama, Región de Antofagasta, Norte de Chile.

Según las investigaciones arqueológicas que se han efectuado, la cronología del Sitio se extiende desde los 400 años A.C. hasta los 100 años D.C., y correspondería al período intermedio temprano en la secuencia cultural de las regiones atacameñas. Se trataría de uno de los asentamientos permanentes de los inicios del período agropecuario de esta compleja cultura local con actividades de caza, recolección e incipiente agricultura (A. Llagostera et al., 1984; A.M. Barón, 1986)

La Aldea de Tulor consiste en 23 estructuras de planta circular, de las que se generan pasadizos y construcciones anexas de formas mixtas hasta un total de 106 estructuras dispuestas en compleja trama de crecimiento celular. Se accede a los recintos por vanos de puerta de dos tipos: los originales con dintel y los horadados en las paredes de tierra en distintas épocas, evidenciando una gran dinámica en su ocupación.

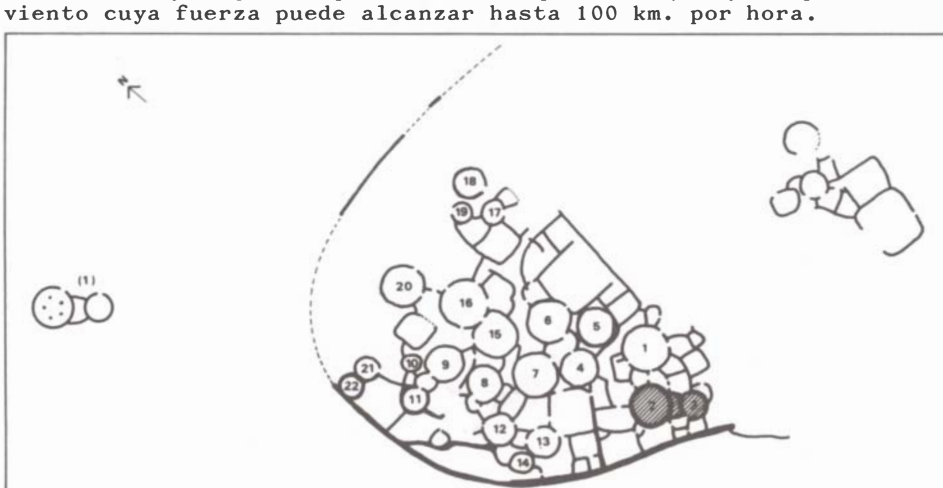
El conjunto está defendido por un muro de mayor volumen que el de las estructuras, dispuesto en semicírculo en dirección de sur a noroeste.

La construcción fue realizada con bloques de tierra modelados in situ, diferenciándose hiladas superpuestas. De los restos, que aún se conservan, se elevan muros hasta una altura de 1,85 m. La superficie total del Sitio que se conoce en la actualidad alcanza a 2.800 m^2

Aunque este Sitio ya era conocido desde la década de 1950 (G. Le Paige, 1957-58), la comunidad científica chilena puso en relieve su gran importancia sólo después que fuera redescubierto en el año 1981. Los trabajos arqueológicos se iniciaron en el año 1982 (Ver graf. 1, foto 1)

II. Problemas de Conservación

Este yacimiento se ubica en un medio ambiente deteriorado por el avance de la desertificación, la que, a su vez, ha sido causada por los cambios fluviales ocurridos en los últimos siglos en esa zona. La región del Salar de Atacama corresponde a un desierto de altura (2500 m. sobre el nivel del mar). El clima está influido por las condiciones que rigen en Los Andes Meridionales, con un comportamiento pluvioso cíclico en los meses de diciembre, enero y febrero. Los meses de invierno se caracterizan por la ausencia de lluvias y bajas temperaturas. En primavera, hay temporales de viento cuya fuerza puede alcanzar hasta 100 km. por hora.



Graf. N° 1 Sitio Tulor 1 Planta de Conjunto Escala: 0 10 m

(1) Polígono de Ensayos
▨ Estructuras en cuya forma se basó la reconstrucción

El medio ambiente es el mayor agente de degradación del Sitio de Tulor. En sus comienzos la desertificación sepultó la Aldea con arena arrastrada por el viento. La formación y avance de dunas han hecho evolucionar el deterioro de los restos de las construcciones de acuerdo a sus propios cambios. El material que desplaza el viento es arena con gran cantidad de sales solubles, las que se depositan principalmente en las cabezas de muro. Las precipitaciones disuelven las sales. Luego los muros absorben la solución que contamina el material de tierra provocando efectos degenerativos irreversibles, tales como cristalización, subflorescencia y exfoliación. Este estado favorece ampliamente el efecto abrasivo del viento y arena sobre las cabezas de muro afectadas. A lo anterior se suma una enorme gradiente de temperatura entre el día y la noche, y una humedad relativa baja, factores que propician la formación de grietas y fracturas, así como la meteorización del material, los cuales, a su vez, actúan como agentes multiplicadores del deterioro.

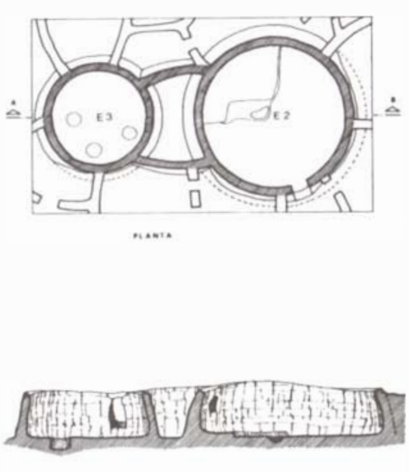
Las excavaciones arqueológicas, practicadas en temporadas sucesivas entre los años 1982 y 1985 (10% de la superficie descubierta del Sitio), expusieron al intemperismo estructuras que durante siglos estuvieron cubiertas por la arena, lo que, indudablemente, ha provocado un incremento de su degradación en los últimos años.

Otro factor importante de destrucción lo constituye la actividad turística que, desde hace algunos años, se ha intensificado en la zona.

III. Criterios de Intervención

Las investigaciones han determinado que debido a los elementos climáticos adversos, en la actualidad resulta improbable crear las condiciones de conservación del Sitio excavado para ser exhibido. No obstante, la preocupación va más lejos al tener que enfrentar el hecho de que las estructuras que no han sido excavadas y que se encuentran enterradas en forma natural también sufren el efecto del desgaste progresivo de las cabezas de muro, ya que la arena que las cubre no es suficiente barrera para que los vientos abrasivos cumplan su efecto devastador. Prueba de lo anterior es la diferencia de altura de muros entre estructuras localizadas en el sector norte y sur, 0,20 y 1,85 m. respectivamente. Considerando lo anterior se preve próxima la extinción del Sitio en su estado actual.

La importancia de este yacimiento para la investigación arqueológica y de otras disciplinas científicas exige agotar los esfuerzos para su conservación. De este modo, los criterios de intervención se han hecho sobre la alternativa de conservar el Sitio bajo tierra, conscientes además de otras experiencias que recomiendan esta alternativa como la más óptima en sitios con problemas insolubles para la tecnología actual (A. Alva *et al.*, 1984; N. Stanley, 1984)



Graf. Nº 2 Plano de las estructuras Nºs 2 y 3 utilizadas como modelo en la reconstrucción ideal usada como polígono de ensayos.

Escala: 0 2 m

IV. Conservación del Sitio

IV.1. Polígono de Ensayo: Reconstrucción ideal de estructuras típicas

La necesidad de comenzar las investigaciones para la conservación del Sitio motivó la construcción de una estación experimental de campo que, a su vez, se pudiese utilizar como Polígono de Ensayos. Además, de acuerdo con las investigaciones arqueológicas, se podrían reconstruir hipotéticamente las condiciones ideales de funcionalidad de las estructuras circulares agregando el elemento techumbre (inexistente) y el acceso a nivel del suelo a diferencia de la posición semienterradas en que se encuentran en la actualidad.

Se escogió la forma de las estructuras (E) circulares típicas Nº 2 y 3 (Ver graf. 1 y 2) que son las mejor conservadas del conjunto, para hacer las réplicas. La reconstrucción incluiría, además, el espacio que se interpone entre ambos círculos unidos por muros de enlace semicirculares.

A poco más de 30 m. desde las últimas construcciones de la Aldea, en dirección oeste, se allanó un espacio de 300 m^2 para construir las réplicas y se replantearon las dos circunferencias. La base se estabilizó picando la capa de tierra que luego se humedeció y apisonó lográndose una base de fundación compacta.

El Sitio de Tulor, está construido sobre un depósito aluvial de tierra arcillosa, el material empleado en la construcción de la Aldea procede del mismo lugar. De igual modo para el Polígono de Ensayo, se escogió el material de un sector inmediato al terreno a construir. Debido a la baja granulometría y excesiva plasticidad del material de tierra fue necesario hacer una mezcla agregando un 30% de arena.

Para aproximarse a la técnica de bloques modelados in situ de los muros originales, se optó por la técnica de tapialera con un molde sobredimensionado de 0,40 x 0,45 x 0,60, dando lugar al desbaste posterior a fin de dar la apariencia de los muros originales. Fue necesario superar algunas dificultades para esta técnica de tapial con material de baja granulometría. Esto obligó a hidratar la mezcla sobre los niveles requeridos, lo que se manifestó en el agrietamiento de los bloques durante el proceso de secado. Este inconveniente se superó ajustando la cantidad de agua en la mezcla y con la colocación de cobertizos de hule para impedir la rápida evaporación en este ambiente de sequedad extrema. Al concluir la albañilería a la altura de 1,75 en la E2 y 1,60 en la E3, se desbastaron los muros dejando una leve inclinación hacia el interior. Además, se cortó un vano de ventana que se comunica con el espacio intermedio. En la E3 se cortó en el muro un vano de puerta, imitando este rasgo original de la dinámica de ocupación.

La reconstrucción hipotética de la techumbre se hizo en base a evidencias arqueológicas que mostraron indicadores débiles de una armadura de techumbre en posición radial. Esto fue rápidamente aceptado, ya que resulta la solución más lógica a la forma circular de las estructuras y permite su construcción de forma cónica aprovechando la menor longitud de las vigas. El uso de pies derechos en el interior se pudo advertir por huellas dejadas en la E16 que es la de mayor diámetro del conjunto (7 m.)

Se hicieron las armaduras de techumbre radiadas y en forma cónica con maderos de chañar (gourliaea cortican). En la E2 se colocaron cinco pies derechos a media luz de las vigas radiales para aminorar la flexión. En la E3 no fue necesario el uso de pies derechos por su menor tamaño. Las vigas se unieron con varillas costaneras de 2,5 a 5 cm. de diámetro formando círculos concéntricos. Todas las piezas de madera se amarraron con cuero de camélido, según la técnica vernacular andina.

Las cubiertas se hicieron con una capa de 0,10 m. de ramas de la especie arbustiva brea (atriplex), colectadas en los alrededores del Sitio. El relleno se hizo con ramas verdes y secas que fueron colocadas en paquetes en posición radial. Sobre las ramas se colocó una capa de barro de 0,05 m. de espesor, cuya dosis fue de un 70% de arcilla, un 30% de arena y un tercio de volumen con paja de trigo. Finalmente se colocó una cubierta de terminación que consistió en una mezcla de un 25% de arcilla más un 75% de arena. Esta última capa sellante de grietas y fisuras deberá ser mantenida constantemente (E. Muñoz., 1987, describe en detalle la construcción de la estación de campo y polígono de ensayo)

En uso como Estación de campo, las casas reconstruidas ofrecen una excelente adaptación al clima del desierto, tanto por la inercia térmica de sus materiales, el espesor de sus muros, el tipo de techumbre y quizá, también, por su forma circular. En el ambiente de Tulor de grandes oscilaciones de temperatura, las estructuras se mantienen frescas de día y cálidas de noche.

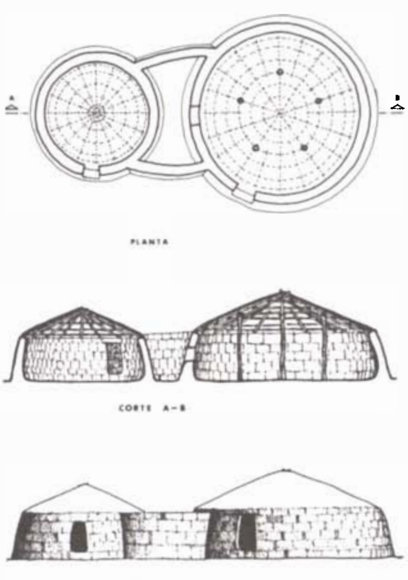
El uso como Polígono de Ensayo se ha diversificado entre mediciones térmicas, mediciones del desgaste de los muros expuestos a los vientos abrasivos y al intemperismo en general. También se han ensayado soluciones "capping" (1) previamente a su aplicación en los muros originales. De mayor interés han sido los tratamientos superficiales y pruebas con sustancias químicas a base de silicato de etilo (2), gracias a lo cual podrían ser aplicadas sin riesgo en los muros originales (Ver graf. 3, foto 4)

IV.2. Investigación: caracterización de materiales y ensayos específicos

Las investigaciones preliminares consistieron en la caracterización físico-química del material de tierra usado en la construcción de las estructuras. Este material de procedencia aluvial se compone de un mayor porcentaje de arcilla, limo y arenas finas, por lo que su granulometría es baja y su plasticidad exagerada. La manifestación física es un alto índice de retracción y consiguiente agrietamiento durante el proceso de fraguado. Los análisis determinaron altas concentraciones de sales solubles, que varían en los distintos lugares del yacimiento y también en los muros de las estructuras. Otras investigaciones se han orientado a la estabilización de las cabezas de muro, las que, como se ha mencionado, sufren un constante proceso deteriorante.

(1) Morales G., Ricardo (1983) define la técnica "capping" para la estabilización y recomposición de las cabezas de muro expuestas al intemperismo.

(2) Chiari, Giacomo (1983); Schwartzbaum M., Paul et al. (1983) y Morales G., Ricardo (1983) comunicaron interesantes experiencias sobre el uso de consolidantes en base a silicato de etilo.



Graf. N° 3 Plano del polígono de ensayos y estación de campo.

Escala: 0 2 m

IV.2.1. Estratigrafía de muros

Los trabajos de investigación y sondeo permitieron comprobar la existencia de una estratigrafía claramente definida, con distintas propiedades mecánicas dentro de un mismo muro, situación que se encuentra directamente relacionada con los mecanismos de deterioro que éste sufre.

Para el estudio de dicha estratigrafía se hizo un pequeño corte en el muro norte de la estructura N° 57 y se extrajeron las siguientes muestras:

Tabla I. Estratigrafía del muro:

Muestra	Ubicación	Espesor	Características
1	superficial	2-4 cm.	costra dura
2	2° estrato	2-4 cm.	polvo muy fino, sin cohesión
3	3° estrato	6-10 cm.	muy duro y compacto
4	muro no alterado	no determ.	material homogéneo

Tabla II. Análisis de muestras por espectrometría de rayos X: Este análisis permite identificar cuantitativamente los componentes más importantes de la muestra.

Muestra	Elementos analizados % en peso									
	Fe_2O_3	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	Na_2O	SO_3	Cl	$NaNO_3$
1	3,8	0,5	3,3	1,9	39	9,1	1,5	15	0,4	10,6	0,14
2	3,8	0,4	4,6	2,0	41	9,6	2,0	13,5	0,2	10,0	0,19
3	3,3	0,4	3,2	1,6	34,5	7,5	1,4	17,6	0,5	13,6	0,12
4	4,5	0,6	4,1	2,8	59,4	14,8	2,4	4,4	0,5	2,0	0,005

Tabla III. Determinación granulométrica (% en peso que pasa por las mallas, Norma ASTM) pH de muestras.

Tamiz N°	Muestra 1	Muestra 2	Muestra 3	Muestra 4
4	100	100	100	100
10	98	99	100	100
20	96	98	99	98
40	94	96	97	92
60	92	94	94	86
200	67	64	69	51
pH	6,5	6,7	6,6	6,3

Foto N° 1: Detalle de estructuras excavadas en pleno proceso de deterioro.

IV.2.2. Caracterización del material de arrastre

Se realizó una serie de análisis que permitieran, mediante una aproximación volumétrica, conocer la fuerza del impacto del material de superficie causado por el viento sobre los muros de la Aldea.

Tabla IV. Determinación de granulometría del material superficial de arrastre.

Tamiz :	4	10	20	40	60	200
% peso que pasa	100	68	35	32	28	8

Tabla V. Constantes físicas del material superficial de arrastre.

Densidad (Kg/m3)	Material retenido en malla # 10	Material bajo malla # 10
- Real saturada	2.509,0	2.606,0
- Real seca	2.406,0	2.593,0
- Neta	2.608,0	2.737,0
Absorción %	2.51	2.04

- Coeficiente volumétrico medio C = 0,30 (partículas retenidas en malla # 10)

IV.2.3. Soluciones capping experimentales

Se experimentaron soluciones capping con materiales tradicionales como tierra-arena-cemento y cal. Los mejores resultados se consiguieron con una mezcla de la siguiente dosis: tierra 20,0% + arena 75,0% + cemento 2,5% + cal 2,5% = 100,0 % más un tercio del volumen en fibra vegetal.

Foto N° 2: Estructuras sin excavar casi extinguidas por los agentes degradantes.

Este capping se degradó casi totalmente 26 meses después de su colocación debido al desgaste del viento abrasivo. Sin embargo, tiene la ventaja de un desgaste parejo y no se produjo horadación eólica bajo la capa, efecto colateral muy frecuente cuando se aplica esta técnica debido a la diferencia de dureza con los materiales de la cabeza de muro y la mezcla capping. Esta mezcla se probó

Materiales

1. Cemento Portland
2. Cal hidráulica
3. - Agente consolidante OH (Wacker Strengthener OH)
   - Hidrorrepelente 090L y 090S (Silicona Wacker 090L y 090S) Wacker Chemie:GMBH Werk Burghausen 8263. Burgnausen/OBB West Germany. Teléfono (08677) 832222, Télex 56944.

en altura de 1,75 m. (en el Polígono de Ensayo) con resultados óptimos comprobados 4 años después de su colocación.

IV.2.4. Ensayo de consolidación e hidrorrepelencia en muros del polígono de ensayos

De acuerdo a los objetivos para cuales fue creado el polígono de ensayo, se han realizado sobre sus muros numerosas pruebas de tratamiento superficial con productos a base de silicato de etilo fundamentalmente. Dichas pruebas, cuya finalidad ha sido la de verificar el adecuado comportamiento de los productos en el clima desértico del norte de Chile, ha permitido a la vez, optimizar el método de aplicación y determinar, previo estudio de las condiciones ambientales, las horas del día adecuadas para realizarlo.

Como un primer acercamiento al problema, el uso del polígono de ensayo ha sido altamente provechoso, pudiendo comprobarse en primera instancia que la protección de las zonas tratadas en los muros ha sido efectiva contra los agentes deteriorantes.

IV.2.5. Ensayos de consolidación e hidrorrepelencia de soluciones capping con técnica de apisonado

En vista de los resultados obtenidos en el polígono de ensayo, se profundizó en la investigación, aplicando el tratamiento superficial a muestras realizadas con técnica de apisonado (solución capping en proceso de investigación) Para tal efecto se fabricaron 30 cubos de tierra de Tulor de 64 cm3 (4 x 4 x 4)
10 cubos : muestras testigo
10 cubos : consolidante (Wacker Strengthener OH)
10 cubos : consolidante + hidrorrepelente (Wacker S. OH + Silicona Wacker 090L)

Estos ensayos, actualmente en desarrollo, tienen como objetivo comparar el comportamiento del material al ser sometido a procesos de erosión y comprensión, así como impregnación con niebla salina.

De los resultados que se obtengan de estos ensayos dependerá la aplicación de los productos mencionados a la solución capping definitiva.

V. Conclusiones

El Sitio Tulor 1 proyecta su importancia a diversas áreas de interés científico. Además de contribuir con importantes indicadores para la arqueología como asentamiento sedentario temprano; para la historia de las tecnologías representa el Sitio conocido más antiguo construido de tierra hasta ahora en Chile.

Las investigaciones realizadas sobre las condiciones y problemas de conservación que afectan al yacimiento, conllevan a presumir que es poco probable crear las condiciones necesarias para que permanezca como sitio excavado para ser exhibido. No obstante, la degradación de las estructuras, aun estando enterradas, hace necesaria la investigación de técnicas específicas para estabilizar las cabezas de muro en constante deterioro por los agentes mencionados. Estas soluciones se deberán complementar con la colocación de barreras de control eólico y la elaboración de un plan permanente de preservación del Sitio post intervención.

Los avances que se han logrado hasta ahora y que aún se investigan se relacionan con la técnica para la estabilización de las cabezas de muro mediante el reemplazo del material de tierra, contaminado y degradado irreversiblemente, por una mezcla de arcilla y arena de granulometría controlada. Esta es aplicada en los muros mediante el apisonado, lográndose una efectiva integración entre el material del muro y el de reemplazo. Las cabezas de muro estabilizadas serían sometidas a tratamiento a base de silicato de etilo, en caso de obtener buenos resultados con este producto.

Por tratarse de un proyecto actualmente en desarrollo, los resultados se encuentran en proceso de elaboración, por lo cual, serán dados a conocer posteriormente.

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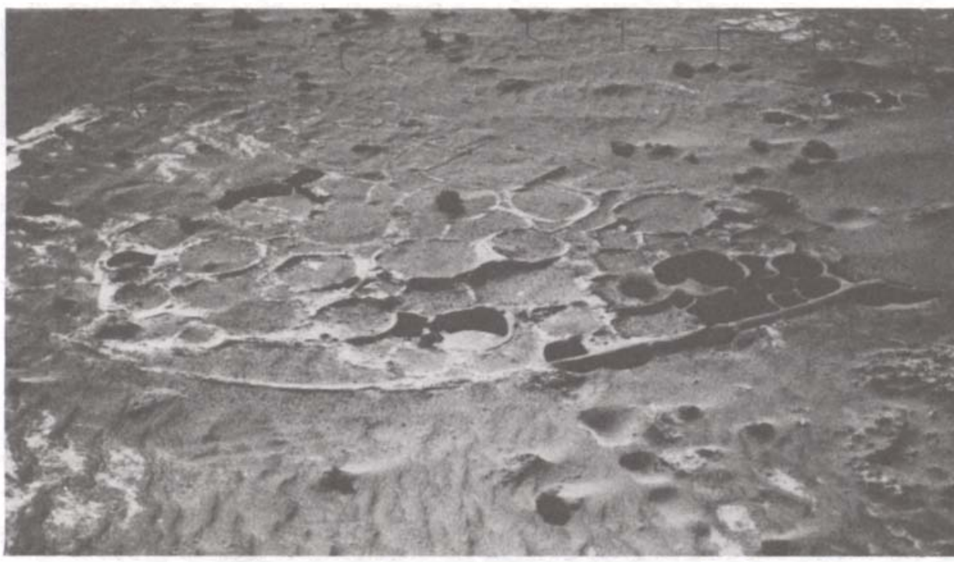


Foto N° 3: Vista aérea del Sitio Tulor 1, en donde se aprecian las estructuras excavadas entre los años 1982-85. Foto: Ana M. Barón.

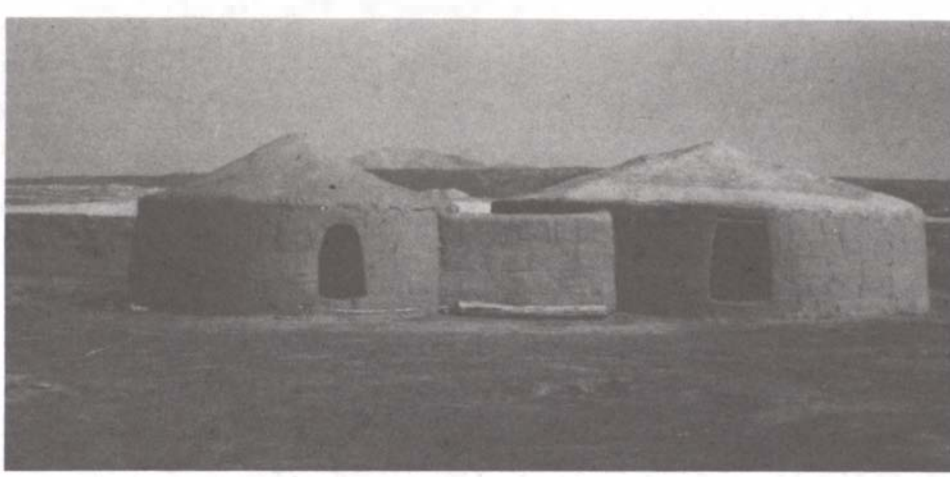


Foto N° 4 : Polígono de Ensayos construido a semejanza de las estructuras originales N°s 2 y 3.

Fotografía y fotomecánica
Ottorino Ovalle O.

AN INVESTIGATION INTO THE PATTERN OF DETERIORATION OF *DAGA* (EARTH) STRUCTURES AT ZIMBABWE TYPE MONUMENTS

Webber Ndoro
National Museums and Monuments
Great Zimbabwe Ruins
P. Bag 9158
Masvingo
Zimbabwe

ABSTRACT

The majority of prehistoric structures in southern Africa were constructed of *daga*, a local clayey soil which is still being used for building houses in the rural areas. Although the material does not normally survive for long periods, at some archaeological sites the structures remain as evidence of the Iron Age communities. If these ruined structures are to be presented to the public as site museums, there is a need to preserve them. In southern Africa, conservation of archaeological sites has placed emphasis on dry stone walls and neglected the *daga* structures. The goal of the current research programme is to redress this situation. The project seeks to understand the material and the causes of deterioration of the prehistoric structures by documenting the symptoms of distress and nature of decay assocciation with them. This approach is already yielding results which are helping to understand the behaviour of the material and structures built of *daga*.

KEYWORDS

Conservation, Prehistoric structures, Excavated structures, Patterns of decay, Wattle and daub, Southern African vernacular architecture, Physical and chemical composition of *daga*.

INTRODUCTION

The Zimbabwe-type monuments scattered all over Southern Africa are well-known by both academic researchers and tourists for their prehistoric dry stone wall structures. The ruined monuments, whose settlement patterns reflect the socioeconomic arrangement and cultural ethos of the African Iron Age communities, are dated AD 1100 - 1500. More than 150 of these dry stone or Zimbabwe-type monuments have been recorded in southern Africa. The most famous and largest of these Iron Age monuments are the Great Zimbabwe ruins, which comprise the dry stone walls and numerous *daga* (earth) structures of varying sizes, constructed over an area of approximately 720 hectares. This ancient settlement, which provided most of the data in this paper, is located 29 km south-east of Masvingo, a modern town in south-central Zimbabwe.

The dry stone walls to which the academic researcher and the visitors have been attracted can only be described as the skeleton of the prehistoric monuments. The flesh is the dwelling structures, built with Africa's most common indigenous building material, *daga*, a puddled clayey soil, binding together naturally weathered granite gravel aggregate. When dry, the mixture forms a durable material, which is described as "*daga* cement" or "granite cement" because of its characteristics. In prehistoric times, the builders utilized the plastic properties of the material which was wet, to construct substantial round houses and moulded fittings on the walls and floors. The fittings were mainly benches, kerbs and basins. At times, decorative motifs were placed on the walls or floors [1]. Some of the *daga* features are less easily identifiable today. Different *daga* surface textures and colour changes were achieved by exploiting the varied clay mineral deposits which were derived from the local parent geology. The most carefully selected and worked *daga* produced a hard, smooth surface which was able to survive considerable wear and exposure. The material was also used for constructing smelting furnaces and grain bins. Some of the *daga* structures have partially survived in various forms for 500-600 years. In prehistoric times, the domestic *daga* structures were enclosed by the dry stone walls, in order to divide space into areas and form courtyards and enclosures. In some sections of the settlement, the stone walls were also plastered with *daga* so that the enclosure presented a homogenous appearance with the dwellings.

BACKGROUND TO INVESTIGATIONS

Although some attempts have been made over the past decade to conserve the structures at Zimbabwe-type monuments, most conservation efforts have focused on the dry stone walls to the exclusion of the *daga* features [2,3]. However, it should be recognised that the *daga* structures are part of the monuments, and it is difficult to visualise the sites in their proper historical perspective without them. Overemphasis on the dry stone walls gives visitors and researchers a slightly distorted interpretation of the Zimbabwe-type monuments.

Unlike the dry stone walls, very few *daga* structures remain above ground. Most of the structures are concealed by vegetation, soil and rubble deposits. Of those above ground, only partial structures survive as evidence of the proto-historic features. The evidence of the underground structures are the numerous mounds scattered inside and outside the dry stone enclosures. The mounds are the results of the deterioration of the once complete *daga* structures. Archaeological excavation of these reveal the remains of the prehistoric *daga* features. In some cases, these will be floor fittings, dividing walls and, at times, artistically moulded and decorative features of houses expressing something of the symbolic and figurative ethos of the proto-historic communities. If these structures are to be made the subject of presentation or research work, there is a need to retard the process of disintegration and deterioration. This is even more critical for the ruined structures above ground. If left to the ravages of nature, they will become meaningless mounds of soil dotted in and around the dry stone monuments.

At the Great Zimbabwe ruins some attempts were made two decades ago to preserve the *daga* structures using chemical water-repellents. These preliminary attempts failed, partly due to inadequate understanding of the deterioration mechanisms, and to the high costs of the treatment. The primary aim of the project reported in this paper is to document and quantify the nature of decay associated with *daga* structures. It is hoped that this will give an insight into the failure mechanism and provide practical guidelines for the conservation of prehistoric remains.

FIELD STUDY

Generally, physical weathering, atmospheric conditions, movement of soluable salts and biodeterioration account for most of the decay associated with *daga* structures. However, the rate of deterioration is a function of the *daga* composition, texture, construction methods and subsequent use of the structures. Prehistoric *daga* structures represent an end-product of the sequence of events ranging from construction and occupation to abandonment and transformation to a partially eroding archaeological feature. In the case of excavated structures, a new process of transformation and decay will begin again as soon as they are exposed to the "new environment" above ground. In order to understand the pattern of decay it was necessary to begin investigations by analysing the designs and methods of construction employed by communities still using the material.

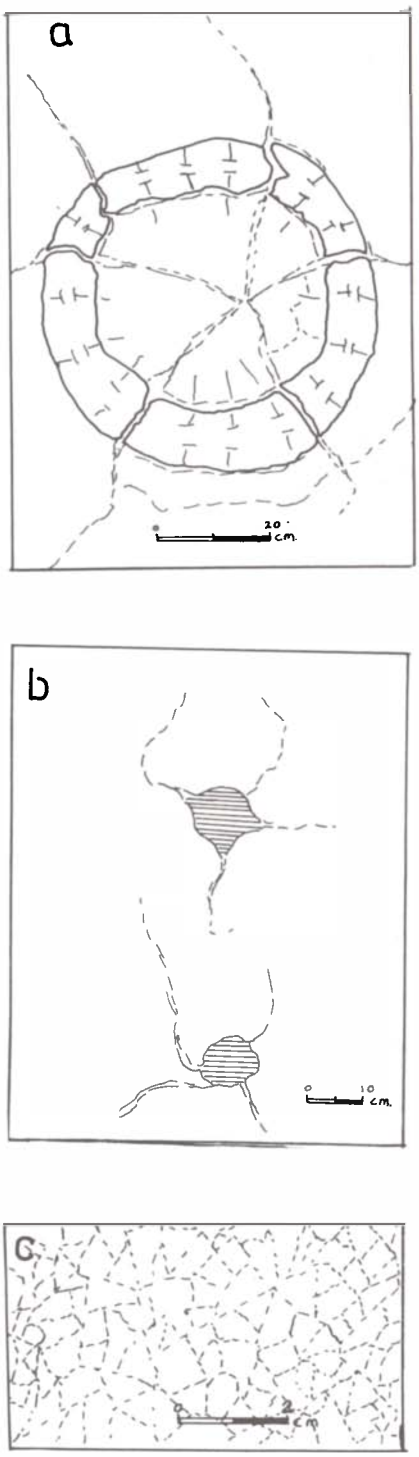


Figure 1: Patterns of Distress

Investigations on contemporary daga constructions

In southern Africa *daga* houses are still being constructed, albeit with some modification of the proto-historic methods. However, study of the contemporary construction methods can give insight into the failure mechanisms associated with such structures and an indication of the nature of structural problems encountered when using *daga* as the primary building material. Such study provides an overview of the inherent weakness in the construction methods and also indicates likely patterns of use-wear before abandonment. However, there is a weakness in using such a method of analysis: that of assuming that no changes in construction and use-wear occurred from prehistoric times to the present. Today we know that a large percentage of *daga* structures are on a temporary basis until the owner can afford to build in brick. Thus, the temporary nature affects the design and construction procedures.

Contemporary *daga* house construction begins by building a timber framework which is then packed and plastered with *daga* both internally and externally. The building method is similar to wattle and daub construction. Only the floors and internal fittings are made exclusively of *daga* material. The surface finish and hence the *daga* mixture used on the floor is different from that used on the walls. The floor material contains a higher ratio of clay to gravel. This gives the material greater plasticity for moulding such fittings as the fireplace, the bench and wall shelves. At times, cow dung is added to the material to act as a binder and for colour variations. For the walls, the gravel ratio is increased to give the surface a rougher but strong finish. During occupation the house is regularly plastered using a weaker *daga* mixture at least once every two to three years. However, the floor receives a more regular maintenance by having a cow dung coating at least once every three months. This gives a hard protection to the surface. During occupation, the rest of the structure receives adequate protection from the elements through proper maintenance of the thatched roof. Most people prefer building on bed rock in order to avoid waterlogging and termite attack.

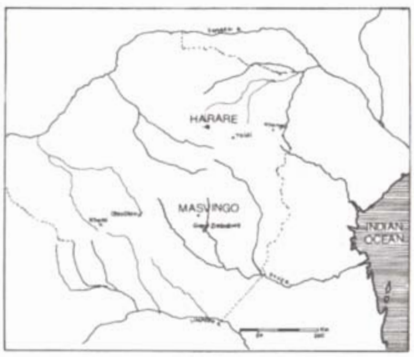
Besides the expected shrinkage fractures, cracks appear on the structure just after construction. These tend to follow the joints between the floor, fittings and wall. These cracks are normally covered up during routine maintenance by plastering. Despite regular maintenance, two areas of floor usually show signs of distress due to use wear. These are:

(a) The fireplace, which generally exhibits multiple microfractures superimposed on large deep radial cracks (Fig. 1a). This is largely due to the continuous heating and use of this area. Apart from cooking, this space is the most utilized area in the house.

(b) The doorways and step platforms which show multiple micro-fractures and flaking of the *daga* surface. This area is subjected to differential moisture and sunlight changes (Fig. 1c).

The permutation of cracks on all these areas varies with the general use of the structure.

The walls, which generally have a rough surface finish both internally and externally, do not usually suffer from surface flaking or microcracking. The most common symptoms of distress on walls are vertical cracks, which tend to correspond with the alignment of the internal timber framework. In serious cases of failure, blocks of *daga* collapse and expose the timber framework. Repair is normally done by replastering; the success of this depends on finding a suitable quarry with compatible material. In some cases, random deep cracks occur due to termite attack on the timber frame. If the cracks are threatening the stability of the structure, rebuilding is normally carried out. When the structure is abandoned, the thatched roof is usually the first to decay and collapse due to lack of maintenance. This exposes the underlying *daga* structure to the natural elements. The result is a ruin and, with time, the decaying *daga* will appear like a mound.



MAP I. South-central Africa showing sites and areas mentioned in the text.

Investigations on archaeological remains

After analysing the pattern of *daga* deterioration in contemporary vernacular architecture, the project then documented the decay in prehistoric structures. The purpose was to identify factors of decay caused by abandonment and those problems which could be attributed to constructional weakness and use-wear. All the surviving structures which were still above ground were located in regions with low precipitation and with soil formation of reddish granite clays (Table I, Map 1).

No	Site	Soil Type	Climate	Condition	Structure Type
1	Khami	red-brown clayey sands	hot/dry	above ground	plastered stone walls
2	"	"	"	"	floor and wall
3	"	"	"	"	floor and features
4	Dhlodlo	red-brown clayey sands	"	"	floors, walls and features
5		"	"	"	floors and walls
6	"	"	"	"	floor and features
7	Great Zimbabwe	grey clayey sands	hot/wet	above ground (badly eroded)	floors and wall
8	"	red sandy clay	"	excavated	floor and features
9	"	"	"	"	floors, walls and eroding features
10	Tsindi	brown-red clayey sands	"	"	floors and features
11	Nyanga	red sandy clay	cool/wet	reconstructed	complete houses with fittings

*Hot= above 18 C, Cool= below 18 C; Wet= above 800mm, dry= below 800mm

Table I: Distribution of prehistoric *daga* structures and their conditions

Although the prehistoric structures show some genealogical relationships with present-day structures, archaeological evidence indicates some subtle differences in their design and construction. The prehistoric structures were designed to last, and were more complex than the more recent single-compartment hut-dwelling synonymous with *daga* material.

The prehistoric houses were often divided into two or three compartments, with vernadahs, complex interior platforms and fittings. Some walls seem not to have incorporated a timber framework within the *daga* matrix and were non-load bearing. The roof was supported by the outside verandah posts. The non-load bearing walls were used to protect and divide interior space. The verandah sometimes had a low *daga* wall around it. The surface finishes for the wall and floor were similar, and at times decorated [4]. There is evidence of firing the *daga* structure in order to give it colour and durability.

The post-collapse appearance of prehistoric structures is characterised by a random heap of *daga* blocks, deep vertical and horizontal cracks, and a general loss of shape. In some cases, roots of plants have penetrated the cracked and eroding structures. The top section of the walls shows signs of weathering, with most of the edges eroding away. The interior surface of most of these curvilinear walls show signs of serious erosion, and the exterior surfaces exhibit a peculiar flaking towards the base of the wall (Figs. 2,3)

The failure patterns on the floors and internal fittings are similar to those in the pre-deposition structures except that the ravages of time make them appear worse. In areas where timber posts had been dug into the floor, undulating cracks have tended to develop radially (Fig. 1b). Besides these, randomly distributed cracks were noticed in most floors. Data obtained when monitoring these floor cracks by using levels and strain gauges suggested that they were not active, although they provide potential areas through which weathering and erosion agents could start the process of decay. The edges of the floors also showed signs of continuous decay due to micro-erosion and abrasion. With the newly excavated structures, microfracturing and flaking was a general phenomenon. These gave a rough and undesirable appearance to the fabric of the structure. The fired floors show no signs of this type of deterioration but are weak in compression (Fig. 4).

CURRENT RESEARCH INVESTIGATIONS

Pre-deposition cracks and patterns of failure in most cases seem not to exhibit movement. However, they tend to form zones of weakness which facilitate the development of subsequent processes of decay. These emanate from environmental fluctuations and lack of maintenance after abandonment. Current research has focused on experimental work and on the investigation of the chemical and mineralogical properties of the material in order to explore further the failures observed. Tentative results on the *daga* structures are beginning to give an insight into their failure mechanism.

The initial investigation into the chemical and mineralogical nature of the *daga* was carried out on samples from the Great Zimbabwe ruins. The aim was to investigate those physical and chemical properties which might contribute to the deterioration of the material. Samples from two structures which were representative of the possible types observed at Great Zimbabwe were analysed. The selection was based on colour differences of the grey and red/brown *daga*. Results of the mineralogical analysis indicate that the materials are from decomposing local granite (See Table II). Chemically the material has a high content of silica and alumina and also contains moderate amounts of iron and potassium. Chemical tests also confirm archaeological data which indicate two sources of quarrying for the *daga*. Firing of *daga* structures in order to achieve durability is also indicated by the deficiency in kaolin.

Experimental work shows that given a good quality of *daga* from historically known quarries, walls are primarily affected by construction design and climatic factors. The use of timber uprights introduces two problems: differential thermal coefficient of expansion of the materials and potential attack by termites. There are also difficulties when *daga* is used to plaster stone walls. Problems such as bulging associated with stone walls tend to lead to the detachment of the *daga* plaster. The *daga* walls which do not incorporate timber in their matrix are most seriously affected by the climate (See Fig. 5). Experiments with walls of different composition have shown that rainfall erodes the top surface area thereby forming gullies on the wall, which in turn leads to the creation of vertical channels. This decreases the tensile and compressive strength of the wall. The wetting and drying due to seasonal differences exacerbates the situation.

Minerals	grey *daga* samples	red/brown *daga* samples
quartz	51.3	40.0
kaolin	41.2	11.2
mica	0.8	30.0
felspar	4.3	3.5
iron/potassium oxides	2.8	2.5

Physical properties of all samples				
mean density	1.8g/ml.	mean porosity		33%
Size range of pores-microns	500		Approx.	40%
	500	106		11%
	106			49%
*pH Approx. 6.6 and soluble salts	.23%			

Table II. Approx. mineralogical/physical properties of *daga* samples from the Great Zimbabwe ruins [5].

The *daga* floor experiments were designed to explore different parameters since their deterioration patterns are different from those noticed on the walls. Different floor foundations with varying *daga* compositions were analysed in order to investigate the genesis of the random cracks noticed on prehistoric structures (Table III). Current data shows that floors on rock foundations manifest cracks which tend to align with the layout of the stones. When subjected to natural elements these cracks widen rapidly. Foundations with sandy soils tend to perform better than most and exhibit fewer cracks. A possible explanation for the occurrence of random cracks could be the collapse impact of the superstructure on to the floor, but this hypothesis needs more exploration

Foundation	Cracks Mean/m	Mean Width/mm	Mean Depth/mm	Ave Floor Movement/mm	Comment
Clay	25	2	3	-5	multiple cracks
sand	11	3	3	-3	few deep cracks
ash	15	1	-	-6	microcracks edges eroding
stones	22	4	5	0	wide cracks edges eroding

Table III. Behaviour of reddish sandy clayey *daga* with different foundations.

On excavated *daga* structures it has been shown that the development of microcracks and flaking takes place within the first ten hours of exposure to direct sunlight. It seems that it is not the temperature which affects the *daga* surface but rather the rate of drying. Attempts to repolish with cow dung have met with partial success. If applied regularly, it creates a membrane which in turn protects the *daga* surface from direct sunlight and some biological attack. The polish gives an authentic and aesthetically acceptable appearance. However, if the cow dung is not applied properly, it can encourage termite attack.

CONCLUSION

The aim of the present investigation of *daga* structures is to document the failure mechanisms and patterns of associated deterioration. The primary assumption is that in order to find a solution which can retard the deterioration, we must understand the genesis of the problem. Since we are dealing with the end-product of a protracted and complex process, a study of the symptoms of the problem may help to identify the causes of distress. Deterioration may manifest itself in particular forms and patterns. It is realised that the problems are not monocausal but, by trying to isolate the various factors which contribute to the decay of *daga* remains, we can begin to have an insight into possible remedies.

ACKNOWLEDGEMENTS

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Fig. 2: Prehistoric structure-interior decay.

5. Analyses undertaken by Dower-Datech Ltd., using X-ray flourescence and X-ray diffraction techniques.

Fig. 3: Prehistoric structure-exterior decay. Note flaking towards base of wall

Fig. 4: House floor with features- a month after excavation. Note random cracking and weathering.

Fig. 5: Experimental wall- after a year of exposure to elements of nature.

ABSTRACT

Adobe brick test walls were constructed in 1985 near the historic adobe ruins of Fort Selden in southern New Mexico to assess the performance of various preservation methods that could be used to protect the walls of the historic fort. The methods include: (1). use of chemical sprays and amended mud plasters to retard erosional rates of the vertical wall surfaces; (2). implementation of assorted treatments to the bases of walls to determine the rate in which the capillary rise of moisture can be affected; (3). and testing different types of wall caps to determine their effectiveness in protecting the tops of walls.

After five years of exposure, many of the tests implemented provided valuable results. Regular monitoring of this project will continue until 1995, at which time a comprehensive report on the test wall experiment will be compiled.

Key Words

TEST WALLS, AMENDMENTS, WALL CAPS, FOUNDATIONS, SPRAYS, EARTHEN ARCHITECTURE

Fig. 1 Test walls, looking west, southwest. The historic ruins and the visitor center are in the background.

Fig. 2 Test walls, looking east.

AN EVALUATION OF THE NEW MEXICO STATE MONUMENTS ADOBE TEST WALLS AT FORT SELDEN

Michael Romero Taylor
National Park Service
P.O. Box 728
Santa Fe, N. Mex. 87504
USA

INTRODUCTION

In 1985, a series of adobe brick test walls were constructed 200 meters east of the historic adobe ruins of Fort Selden State Monument in southern New Mexico (figs. 1 & 2). These test walls were built to assess various preservation methods that could be used to protect the historic adobe walls at the Fort. A secondary purpose was to provide information to the public on how to better preserve historic walls made of earth. Three general research parameters were investigated: (1) the viability of using chemically amended mud plaster mixes and chemical sprays to protect vertical surfaces of earthern walls, (2) installation of various systems at the bases of walls to monitor capillary rise of moisture, and (3) the use of various capping techniques to protect the tops of walls.

The historic ruins of Fort Selden have been exposed to the elements without roof protection since 1891. When the military post was acquired by the State of New Mexico in 1972, it was developed for display and interpretation to the public. At that time a decision was made to leave the walls essentially as they existed without any reconstruction or erection of shelters. The site managers elected to maintain the historic walls through a process of regular maintenance of patching and recapping using mud. (For a description of the stabilization methods used on the fort and for more information regarding its history, refer to the paper by Thomas Caperton in this publication). Cyclical maintenance using unamended (that is, without chemicals or stabilizers) materials is an admirable approach and is the preferred preservation methodology for historic ruins. This approach to wall preservation would have worked at the site if sufficient staff were available to stay apace with the maintenance program. However, over the last ten years the cyclical maintenance program clearly could not keep up with the preservation needs, as significant loss of wall fabric was taking place. This motivated the test wall project in order that options other than frequent maintenance might be found.

TEST WALL DESIGN

The Museum of New Mexico State Monuments initiated the research effort with a literature search aimed at learning which methods had already been tested and reported. Consultation was then conducted with personnel from the preservation and adobe construction professions throughout the southwestern part of the United States. Some of the techniques that had provided positive results in other testing regimes were incorporated into this test wall project [1]. A few techniques that had failed in past preservation attempts were implemented in order to demonstrate the deleterious effects of such treatments. Since funds were limited, only a fraction of the innumerable methods and chemicals available to test were implemented in this experiment.

Detailed descriptions of the test wall plot that are not contained in this paper can be found in previous reports [2, 3]. Architectural specifications and drawings were produced by P.G. McHenry, AIA [4]. The adobe bricks and the soil used for the mortar and plaster in the construction of the test walls were all from the same source. The soil particle size of the adobe bricks is 63% sand, 19% silt, 18% clay (nonexpandable). The mortar used in the laying of the brick and for the plaster was tempered with washed sand to make a workable mix. What follows is a brief description of the New Mexico State Monuments adobe test wall design.

Amended Panels

Unamended mud plaster is the most compatible rendering material for earthen walls. The only problem with this type of wall protection is that, if left unsheltered, it requires frequent maintenance. Methods to retard the erosional rate of plasters have been tested and implemented for thousands of years. Preservationists today many times face a shortage of funds and time to maintain a structure properly using unamended mortar. For this reason they continue to seek a suitable amended rendering for earthen walls which retards the cyclical maintenance without compromising the wall by the effects of coatings that are too rigid, impermeable, or visually obtrusive.

Another ongoing endeavor has been the search for a compatible preservation material that can be sprayed or brushed onto an earthen wall without the use of a plaster coating.

In an attempt to identify certain naturally occurring amendments and manufactured chemicals that could be compatible with historic earthen walls, the following research design was implemented.

Two walls were constructed of adobe brick and mortar. Each wall is 19.8 meters long (65 feet), 1.52 meters high (5 feet), and 24.4 cm wide (10 inches). One wall was set on a north/south axis and the other on an east/west axis. Each wall face is divided into thirteen panels, 1.52 meters (5 feet wide). There are twelve amended panels on each wall face with one panel of unamended mud which serves as a control (fig. 3). The four wall faces are the same. The amendments are applied to both sides of the wall, opposite each other, including the wall top. Each amendment and control panel has a north, south, east, and west exposure. Thus the effect of climatological conditions, including storm patterns and solar orientation, can be assessed for each panel.

Fig. 3 Amended wall, south face, looking west/northwest. Panel with straw is on the right.

The treatments used include amended mud mixes applied as plasters and sprays and roll-ons, which were applied directly to the wall surface.

The amended mud plaster was applied in three coats to a total thickness of 2.54 cm (one inch). Each of the amended panels was divided in half on a vertical axis. One half of the panel was treated with a 5 percent solution and the other with a 10 percent solution of the chemical amendments. The different solutions of the same amendment will be used to determine the minimal amount needed to be cost effective when used for retarding the erosional rates of plaster. Refer to Table I for a description of each amendment, its history of use, and its present performance in this project.

Like the amended mud plaster panels, the panels used for the spray and roll-on experiments were divided in half on a vertical axis. One half of each panel was plastered with three coats of unamended mud and the other half was left unplastered. These panels are being used to assess the effectiveness of spray and roll-on applications on mud plastered and unplastered earthen ruins, such as the ones at the adjacent fort. Chemical amendments were either rolled or sprayed on both halves of the panel at equal strength. Refer to Table II for a description of each amendment, its history of use, and its performance to date in this project.

Fig. 4 Example of test wall constructed with concrete wainscot installed along the base.

Wall Base Experiments

Various methods have been used throughout history to retard the capillary rise of moisture into earthen walls. Some have proven beneficial and some detrimental to the preservation of wall bases.

Twelve walls, each with a different type base, were constructed as part of this project to assess the effects of capillary rise (fig. 4). Each wall is 1.52 meters high (5 feet), and 25.4 cm wide (10 inches). The various types of wall treatments were selected upon the basis of modern and historic practices. Some of the techniques used are known to be detrimental to the preservation of earthen walls but were used in this experiment to show graphically through time their effects on the wall bases. Refer to Table III for a description of each wall base design.

Each wall contains eight electrical resistance sensors, which provide data on relative moisture contents within the wall. The readings are taken with a resistance meter (Soiltest Moisture Temperature Meter (R), model - 300B).

Wall Cap Descriptions

In many parts of the world, a wide variety of ways have been used to protect the tops of exposed earthen walls [5]. Many of the methods used are ones that protect yard or corral walls that were never built to be covered by a roof overhang. Other methods have been developed to protect the tops of archaeological ruin walls built of earth. Some have been successful and some have not. One of the goals of this test wall project is to assess the performance of various techniques used to cap walls.

Four different wall caps, each 1.52 meters long (5 feet), were applied to an unamended adobe wall 6.1 meters long (20 feet), (fig. 5). The types of capping materials used are commonly found in New Mexico. The four wall caps are: (1) A course of adobe bricks stabilized with asphalt emulsion placed on top of and flush with the wall, (2) a course of adobe bricks stabilized with asphalt emulsion placed on top of and perpendicular to the wall face, thus creating a 5.1 cm overhang on each side of the wall sloping to the north, (3) a rounded cement cap troweled on to the top of the wall, and (4) three courses of fired brick applied to the top of the wall to form a denticulated cap.

Fig. 5 Wall cap experiment, looking northwest.

MONITORING PROGRAM

A comprehensive photographic monitoring program is being conducted for each test wall panel. Black and white photographs and color slides have been taken from established datum points every two months since testing began in 1985.

Relative moisture readings from the wall base experiment were taken after

Table 1
Amended Mud-Plaster Mixes

Amendment	Composition	Previous Uses	Test Condition
El Rey Superior 200 (basically Rhoplex E-330 with a debubbling agent addded)	methyl methacrylate/acrylate resin at 47% solids in water	Rhoplex MC-76 and Rhoplex E-330, almost identical to El Rey Superior 200, have been used at Chaco Canyon, Aztec, and Wuptaki National Monuments to repoint masonry walls for up to 15 years	little erosion, with the 5% solutions showing slightly more than 10% solutions; slightly darker than unamended plaster
Soil Seal Concentrate	latex acrylic balanced with copolymers prepared in emulsion form; consists of 40% polyethoxylated ethanol and 3.5% silicates; it is 46% solids in water	used commercially for soil surface erosion control, it had been used as a soil stabilizer in adobe bricks, mortar, and repointing of masonry walls at Pecos National Monument in the 1970's	moderate erosion, with 5% solutions showing slightly more erosion than 10% solutions; slightly darker than unamended plaster
Daraweld-C	high polymer resin emulsion at 51% solids in water	used commercially as a bonding agent for concrete; used by National Park Service in adobe preservation but use has ceased due to its relative impermeability	little erosion, with 5% solutions showing slightly more than 10% solutions; the 10% solution is slightly darker than unamended plaster; the 5% solution shows no color change
Asphalt Emulsion	petroleum-based product	since the early 1940's a popular amendment for stabilized brick in construction; also used somewhat in the southwest as a mud-plaster amendment although its relative impermeability over unamended mud-brick walls inhibits evaporation	little to moderate erosion, with similar rate for 5 and 10% solutions; much darker than unamended plaster
Agave juice	extracted from boiled agave leaves, the pulp is pounded and the extract steeped for 2-3 weeks	has been used by some desert cultures as an adobe plaster amendment	moderate to serious erosion; no color difference from unamended plaster
Straw	4 1-lb. coffee cans of straw cut into 2-inch lengths were mixed with 1 wheelbarrow of mud	used universally as a mud-plaster amendment; promoters claim that it acts as a binder to reduce cracking on wall surfaces, critics claim that it encourages moisture penetration and is a food source for insects which then enter wall	moderate to serious erosion; termites have created "tunnels" through the mud plaster on the north face accelerating its erosion

Table 2
Amended Spray and Roll-On Applications

Amendment	Composition	Previous Uses	Test Condition
Acryl 60 base coat and Super Quickseal finish coat, used in this sequence because of manufacturer's recommendation (roll-on application)	Acryl 60: acrylic polymers and modifiers, designed as an additive to Portland cement to improve adhesion and mechanical properties Super Quickseal: cement-base coating, a commercial finish coat for masonry and concrete	Acryl 60 had performed well in 3 years of use at Bent's Old Fort	the Acryl 60/Super Quickseal combination has experienced moderate erosion; color can be matched by manufacturer
K & E Penetrating and Hardening Mineral Sealer	Inorganic mineral salts at 30% solids in water	at Bent's Old Fort experienced little erosion after 3 years exposure	moderate to serious erosion; no color change from unamended plaster
Linseed oil	1 part linseed oil: 5 parts mineral spirits	used somewhat in adobe-plaster preservation and in mud-floor consolidation; used at Bent's Old Fort in a 1:2 solution and showed very little erosion	moderate to serious erosion; darkened the wall surface
Silicote	modified silicone resin spray at 9.9% solids in xylene	not known if it has been used in adobe preservation	moderate to serious erosion; no color change from unamended plaster
Seal-Krete	a commercially manufactured acrylic for waterproofing stucco, masonry, cement and mud brick	not known if it has been used as a spray on adobe or mud plaster	moderate to serious erosion; no color change from unamended plaster
Thorocoat (roll-on application)	a ready-mixed non-cementitious 100% acrylic-textured coating for protecting and decorating a variety of exterior and interior surfaces	mud-brick preservation uses not known but manufacturer claims that its thickness allows cracks and pores to be water resistant and to release moisture	moderate erosion although most is located where settlement cracks have occurred; color can be matched by manufacturer

Table 3

Types of Wall Bases

1.	Standard concrete foundation with stem wall, and a cement stucco over wall surface
2.	Rock foundation with mud mortar and exposed adobe wall surface
3.	Base course (a varied grade of rock and soil used for highway underlayment) foundation with exposed adobe wall surface
4.	Unamended adobe foundation with exposed adobe wall surface
5.	Unamended adobe foundation surrounded with sub-surface polyethylene sheeting sloping away from the wall to provide a drainage gradient; the wall has an exposed adobe surface
6.	Unamended adobe foundation surrounded with a sub-surface layer of mud amended with Union Carbide R-274 (a silicon base water repellent) sloping away from the wall to provide a drainage gradient; the wall has an exposed adobe surface
7.	Unamended adobe foundation with perforated plastic pipes set on each side of it in gravel which drain into a rock filled sump; the wall has an exposed adobe wall surface
8.	Unamended adobe foundation with cement stucco over the wall surface
9.	Unstabilized adobe foundation with a poured and formed concrete wainscot, exposed adobe wall surface
10.	Rock foundation with mud mortar and a poured and formed concrete wainscot, and exposed adobe wall surface
11.	Unamended adobe foundation with unamended mud plaster on the wall surface
12.	Unamended adobe foundation coated with parge plaster and asphalt vapor barrier, exposed adobe wall surface

Table 4

Erosion Ratings – Amended Panel Test Walls

After 4 years and 4 months exposure:

Very little erosion = 5
Little erosion = 4
Moderate erosion = 3
Serious erosion = 2
Very serious erosion= 1

#	Treatment	Wall Direction				
		N	S	E	W	Avg.
1.	Control Panel	2	2.5	2.5	1	2
2.	El Rey Superior 200	4	4	4	4	4
3.	Daraweld – C	3.5	4.5	4	3.5	3.9
4.	Asphalt emulsion	4	3.5	4	3.5	3.7
5.	Super Quickseal/Acryl 60	3	3.5	3	3	3.1
6.	K & E Mineral Sealer	2	2.5	3	1.5	2.2
7.	Linseed Oil	2	2.5	2.5	2.5	2.4
8.	Thorocoat	3.5	4	2	3	3.1
9.	Agave juice extract	2.5	2.5	2.5	5	3.1
10.	Soil Seal Concentrate	3	3.5	3.5	2.5	3.1
11.	Silicote	3.5	2.5	2	2.5	2.6
12.	Seal-Krete	2.5	2.5	3	1	2.2
13.	Mud w/straw	3	3	2.5	1	2.3
	Severity of exposure direction	38.5	41	38.5	34	
	Averages	3	3.2	3	2.7	

Very little erosion.

Little erosion.

Moderate erosion.

Serious erosion.

Very serious erosion.

Fig. 6 Examples of Erosion rates.

every measurable precipitation for the first two years of the project.

Munsell Soil Color analysis of amended walls is conducted on an annual basis.

Erosional profiles of the chemically amended panels will be recorded in 1995. During wall construction in 1985, small aluminum pins were inserted perpendicular to and flush with the panel surfaces. The pin ends serve as reference points for the recordation of erosional profiles.

Temperature and precipitation records have been maintained to provide the environmental information necessary to evaluate the performance of the test wall experiments.

OBSERVATIONS

It should be stressed that the results of this experiment to date are specific to the particular conditions of the site. These include soil particle size and mineralogical content of the soil used in the manufacture of the adobes and mortar, application technique, and climatic conditions that existed when the treatments were applied and that have existed since. What is reported to have favorable or nonfavorable results in this test wall experiment may provide different results under other conditions. Recommendations, however, can be made for further testing based on the positive results reported in this paper. The test walls have provided interesting results since they were constructed five years ago. Refer to Table IV for each panel's condition and to (Fig. 6) for examples of erosional rates.

Rainfall at the site has been above normal since 1985, averaging approximately 30 cm (12 inches) of rain per year. The greatest amount of precipitation occurred in August 1988 when 13 cm (5.2 inches) of rain fell, 5.1 cm of which fell within two hours. There have been some fairly significant accumulations of snow on the walls. One storm deposited .61 meters (2 feet) of snow. The subsequent freeze/thaw action from this moisture contributed greatly to the deterioration of the walls. Storm patterns seem to be predominately from the west, southwest, and northwest.

Amended Panels

The west faces of the amended panels are generally eroding faster than the other faces (fig. 7). The south faces of the panels are generally eroding slightly less than the north and the east faces (fig. 3). This can be attributed to the prevalent storm patterns which exist at the site. In addition, the north faced wall panels exhibit more deterioration at their bases than the other three exposures, due most likely to the lack of sun which slows the melting of accumulated snow and the evaporation of accumulated rain. During periods of freeze/thaw, this type of lingering moisture will cause accelerated failure of the wall and plaster fabric.

The amended wall tops have generally cracked and begun to fail at various rates, much more so than the treated vertical faces. This pattern is expected to some extent because of the exposure of the horizontal wall top to falling rains and accumulating snows.

The 5 percent solutions of amended mixes have generally eroded slightly more than the 10 percent solutions, with the exception of the agave juice and asphalt panels which seem to be failing at approximately the same rate.

Of the amended plaster mixes tested, El Rey Superior 200 (Rhoplex E-330) and Daraweld-C have proven so far to be the most favorable in providing a rendered protection. It should be pointed out that in many circumstances, especially when dealing with an archaeological site, plastering an earthen wall to provide a sacrificial coating may not be aesthetically pleasing and will obscure certain attributes of a wall such as the earthen brick coursing or pise levels. In cases such as these, other preservation methods may be deemed more appropriate, such as capping the walls using sufficient drip edges or construction of shelters.

It is recommended that further tests be conducted using Rhoplex E-330 and Daraweld-C as amended mixes for plaster. Rhoplex E-330 should be used instead of Rey Superior 200 because the straight Rhoplex will not darken the mortar as does the El Rey Superior 200, which has been amended by the manufacturer with a de-bubbling agent. The 10 percent solutions (1 part amendment to 5 parts water ratio) are providing sufficient protection to the unamended wall for the first five years of exposure. It is estimated that a wall plastered with these percentages of amendment would have to be replastered every ten years. Caution should be taken in using these types of amendments on historic resources without further testing, however.

It is also recommended to test many more of natural occurring amendments that were evaluated only briefly in this project. If proven effective, and in many parts of the world they have, naturally occurring amendments are most often

Fig. 7 Amended wall west face. Control panel is on the right.

easily obtainable and much less costly. The agave juice extract should be researched more as to how long the juice is left to steep, what the ideal concentrations would be, etc. Amendments such as prickly pear cactus juice, lime sprays, and charcoal should be investigated further [6].

Both the straw-amended panels and the control panels are eroding faster than the amended mix panels. The panels amended with straw have eroded slightly less than the control panels. The erosional patterns for these panels are even throughout the vertical face without developing large voids or cracks, which are evident on most of the amended spray and mix panels. This even, sheet-type of erosion is visually much more pleasing than the amended panels.

The sprayed and rolled-on applications are generally eroding more than the amended mud mix applications. In fact, most of the sprayed panels have eroded faster and created more damage to the adobe substrate than the control panel. The erosional patterns of the sprays can be characterized by large gouged areas that have developed in the vertical face where runoff moisture is directed into weaker areas. The water-based sprays have penetrated only about 1 millimeter. None of the spray applications have performed well.

The Super Quickseal roll-on exhibits considerable checkered cracking (see fig. 8). Thorocoat has begun to crack, allowing moisture to enter (fig. 9).

It is not recommended to experiment with or use any of these sprays on earthen ruins. However, there do exist solvent-based, monomer and low polymer type sprays that have proven effective in preserving earthen architecture. For more information on these type of sprays, refer to the article by Agnew et al., in this publication.

Wall Base Experiments

The twelve walls that were built with various types of wall base treatments are providing less information than hoped. The readings from the sensors were taken for a period of two years, then stopped because the data obtained was minimal. However, the data did indicate that the two walls with concrete wainscots and the two walls with the cement stucco renderings are retaining more moisture above grade than the other wall-base treatments.

The failure of the moisture sensors to provide more data may be attributed to (1) lack of sufficient levels of moisture to be monitored, and/or (2) improper instrumentation used to obtain the relative moisture readings. The instrumentation used for this experiment does not provide quantitative data on percentage moisture content. Other nondestructive means to obtain measurable moisture readings should be investigated.

Fig. 8 Detail of the erosional pattern on the Super Quickseal panel.

The wall-base experiment is, however, beginning to exhibit differential rates of erosion at the bases of the walls. Even though these erosional rates are presently very subtle, it is anticipated that within a few years definite correlations can be made between basal erosion and the various techniques used at the bases of the walls.

Wall Caps

The four different types of caps installed on the 6.1 meter-long test wall are providing some interesting results. All four wall caps, including the one with an overhang, are experiencing accelerated erosional patterns at the interface between the cap and the top of the unamended wall. This is anticipated to some extent since rain quickly runs off the fairly impervious caps and is directed into the top of the unamended wall where the moisture can penetrate.

Fig. 9 Thorocoat panel. Note cracks and deteriorating coating.

The cap with the overhang is failing in part because the south overhanging portion which slopes to the north has no drip edge, causing water to run back under the overhang and penetrate the unamended wall top. On the north side of this same cap, moisture is eroding the unamended wall top, probably because the overhang does not extend out sufficiently away from the wall. The important question here is how much do impervious caps, similar to the ones used here, protect the wall tops, as compared to leaving the wall tops exposed with no protection. When comparing the loss of the top of the walls between this wall cap experiment and the top of the uncapped walls in the wall base experiment, some useful conclusions can be drawn. First, the caps have indeed protected the tops of the walls. Approximately 3 cm of wall top has been lost from the uncapped walls, whereas no loss in height of the wall has occurred on the capped walls. What is interesting, however, is that the wall that has been capped has lost considerably more vertical wall surface on the upper portion of the wall, just below the interface between the cap and the unamended wall, than the uncapped walls. Comparisons in upper wall thickness between uncapped walls and this capped wall indicate that as much as 3 cm of vertical wall fabric has been lost.

Thus it seems that the installation of fairly impermeable caps without proper drip edges on unrendered walls may not be sufficiently beneficial. In this experiment, the caps have protected the tops of the wall but have accelerated vertical wall deterioration. Uncapped walls have lost material from the top but seem to exhibit less fabric loss on the upper vertical surfaces. Long-term monitoring of this wall cap experiment needs to be conducted in order to determine how much, if any, the wall caps will protect the walls as compared to those that do not have caps.

It is recommended that more experimentation be done utilizing caps that have sufficient overhangs extending out away from the wall. These overhangs should provide drip edges that will prohibit moisture from flowing back into the structure. Monitoring the splash effects at the base of such treated walls should also be conducted.

CONCLUSIONS

To date, the test wall experiment has yielded results that can justify further testing of some of the techniques used in this program. The project has also graphically shown which technique should not be considered to be used on historic earthen walls.

Since the construction of these walls in 1985, the Getty Conservation Institute has entered into a major testing program with new walls built adjacent to Fort Selden State Monument test plot. The Getty's program includes testing chemical consolidation of walls, shelter designs, drainage techniques, and structural reinforcement designs. The research of these two institutions is expected to yield important insight into how to better preserve historic earthen architecture.

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Problems of Moisture

ABSTRACT

Predicting the durability of structures made of rammed earth is still a difficult matter. We have studied ways of increasing its life span by combining sound building methods with the use of impregnation materials to protect the exposed surfaces.

The research results relate static load of compaction and water content to mechanical properties and resistance to a water drop test.

KEYWORDS

Rammed earth, static compaction, aging, durability.

METHODOLOGIE D'ETUDE AU LABORATOIRE DE LA TENUE A L'EAU DU MATERIAU TERRE

Gérard Didier et Fouad Ghomari
I.N.S.A. Département Génie Civil - Laboratoire Géotechnique - Bâtiment 304 - 20 avenue Albert Einstein - 69621 Villeurbanne CEDEX - FRANCE.

I - INTRODUCTION

Les constructions en terre crue sont sujettes à l'érosion lorsqu'elles sont soumises à des conditions climatiques sévères.

L'importance de ces agents météorologiques varie largement avec le type de climat, la localisation géographique, l'exposition et l'architecture de la construction. Le matériau terre est essentiellement sensible à l'insolation, au vent, aux précipitations, à l'humidité et à la température.

Ces divers facteurs responsables de la dégradation des constructions en terre, sont difficiles à quantifier et à reproduire. Il faut considérer ceux d'entre eux qui sont à l'origine de la destruction, afin de mettre au point des méthodes de mesure caractérisant la durabilité du système.

Dans cet article, la battance est notre modèle, celui-ci traduit l'érosion de la terre sous l'action de chocs répétés de gouttes de pluie dites "battantes". La goutte d'eau arrivant sur la masse de terre exposée éclate en projetant en son point d'impact des gouttelettes chargées de particules arrachées. Ce phénomène sera simulé au laboratoire à l'aide d'un essai de vieillissement accéléré permettant d'apprécier globalement la durabilité du matériau terre face à l'action destructrice de la battance.

II - ESSAIS DE SIMULATION AU LABORATOIRE

C'est à l'aide d'essais de vieillissement que l'on tente dans le domaine de la protection de sélectionner les produits conduisant à la durée de vie souhaitée des ouvrages.

L'approche donnée par la norme ASTM E 632-78 (1982) montre le besoin d'adopter une philosophie d'ensemble, tant à l'égard de la conduite des essais que de leur interprétation (voir Fig. 1).

En l'absence de normes internationales sur le matériau terre, les méthodes expérimentales utilisées sont dérivées de techniques d'essais employées pour d'autres matériaux (le béton, la pierre, etc...). Les essais de vieillissement qui ont été proposés décrivent essentiellement deux aspects de l'érosion. Le premier reproduit l'effet de l'eau, liquide sur les supports et le second, est la combinaison de plusieurs facteurs importants (eau, température, insolation, vent).

Plusieurs essais de simulation de l'érosion ont été proposés :

- Tadanier (1985) fait un trou au centre d'un échantillon compacté et le remplit d'eau pour ensuite déterminer son temps de délitage.

- Azzouz (1983) suit la dégradation d'un échantillon soumis à une lame d'eau verticale continue jusqu'à sa totale dégradation.

- Leroux (1978), Mariotti (1983), proposent de soumettre l'échantillon à l'action-cyclique de séchage-mouillage-rayonnement.

- Auger (1987) simule la dégradation d'un échantillon sous l'action d'une ambiance marine.

Toutes les techniques qui viennent d'étre citées ne peuvent qu'imparfaitement simuler les phénomènes naturels, mais on peut toujours dire que méme une simulation artificielle imparfaite (nombre restreint de facteurs) peut nous renseigner sur la manière dont les facteurs interagissent.

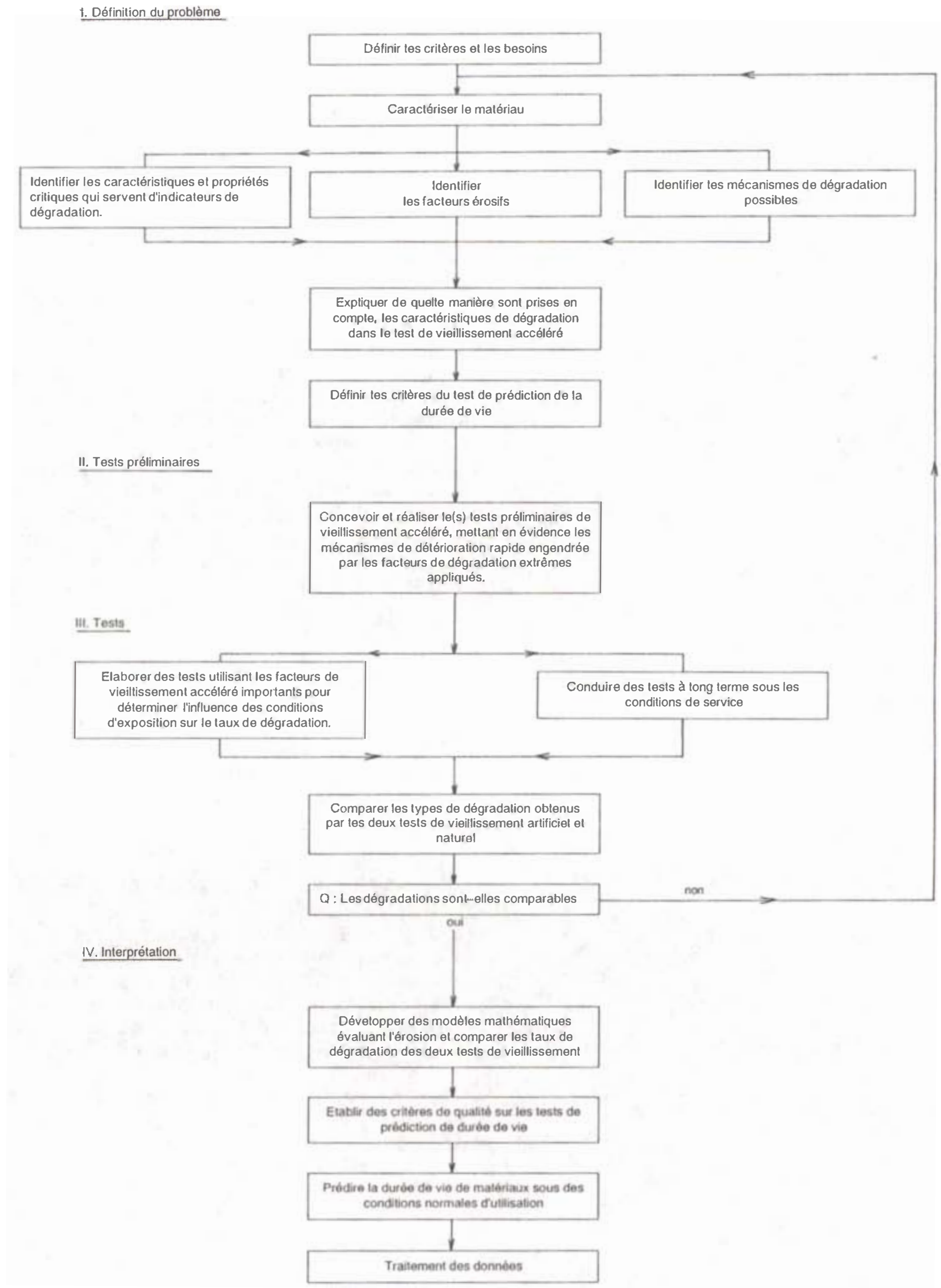
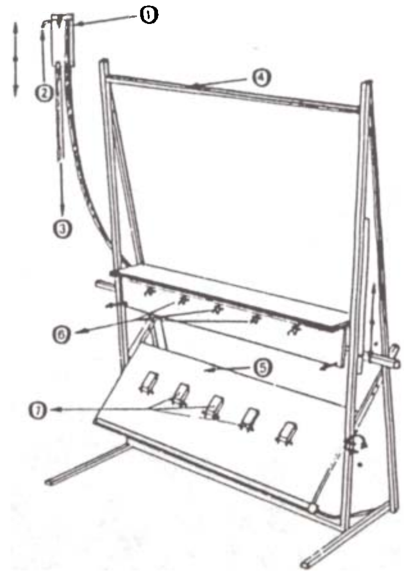


Figure 1 - Méthodologie d'étude du vieillissement des matériaux

III - TEST DE LA GOUTTE D'EAU

L'essai choisi consiste à soumettre un échantillon de terre compactée à l'impact répété de gouttes d'eau et à mesurer le temps de sa totale dégradation.

Le banc d'essai conçu et réalisé dans notre laboratoire, est un bâti doté d'un plateau mobile et de 5 vannes réglables en hauteur. Ces vannes sont alimentées en continu à l'aide d'un réservoir à niveau d'eau constant, la charge étant égale à 2,5 m. Cinq échantillons peuvent être ainsi testés en parallèle. La mesure du temps de délitage (Td) est rendue automatique grâce à des cellules photorésistances, sensibles à la lumière. Ces dernières sont placées dans des supports et reliées à un chronomètre. Avant le début du test, les échantillons sont placés sur les supports contenant les cellules. Le chronomètre est enclenché au moment où les échantillons, placés chacun sous une vanne, reçoivent la première goutte d'eau. Lorsque l'échantillon est érodé sur sa hauteur, celui-ci se rompt et laisse passer la lumière qui est alors captée par la cellule. Cette dernière réagit instantanément en arrêtant le compteur où le temps reste affiché (voir Fig. 2).



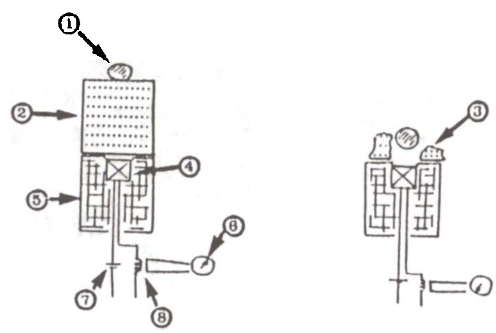


Figure 2 - Test de la goutte d'eau

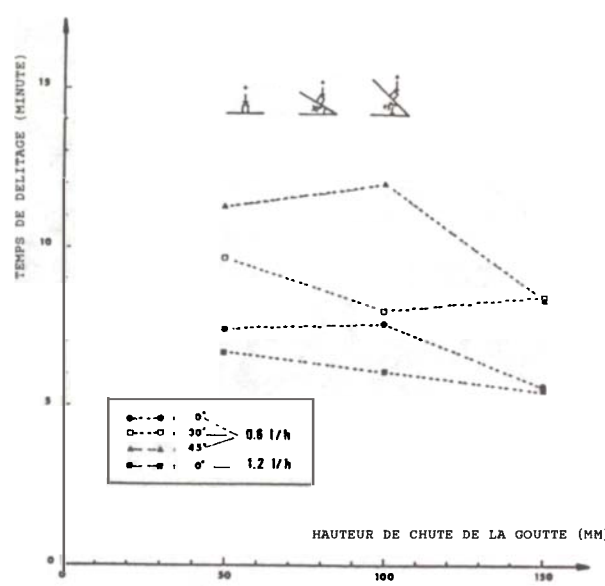


Figure 3 - Temps de délitage en fonction de la hauteur de chute de la goutte

Le banc d'essai permet de faire varier les paramètres suivants :

* hauteur de chute de la goutte (jusqu'à 1,5 m),
* fréquence d'impact (fonction de la charge hydraulique et de l'ouverture de la vanne),
* angle d'inclinaison de l'échantillon à tester (0 à 45°).

Afin d'évaluer l'influence de ces trois paramètres, des tests préliminaires ont été effectués sur une série d'éprouvettes de terre compactée (Voir Fig. 3).

L'énergie mécanique de la goutte d'eau au droit de la section d'impact est fonction de la hauteur de chute de la goutte. Une énergie d'impact plus grande favorisera une érosion plus importante donc un moindre temps de délitage.

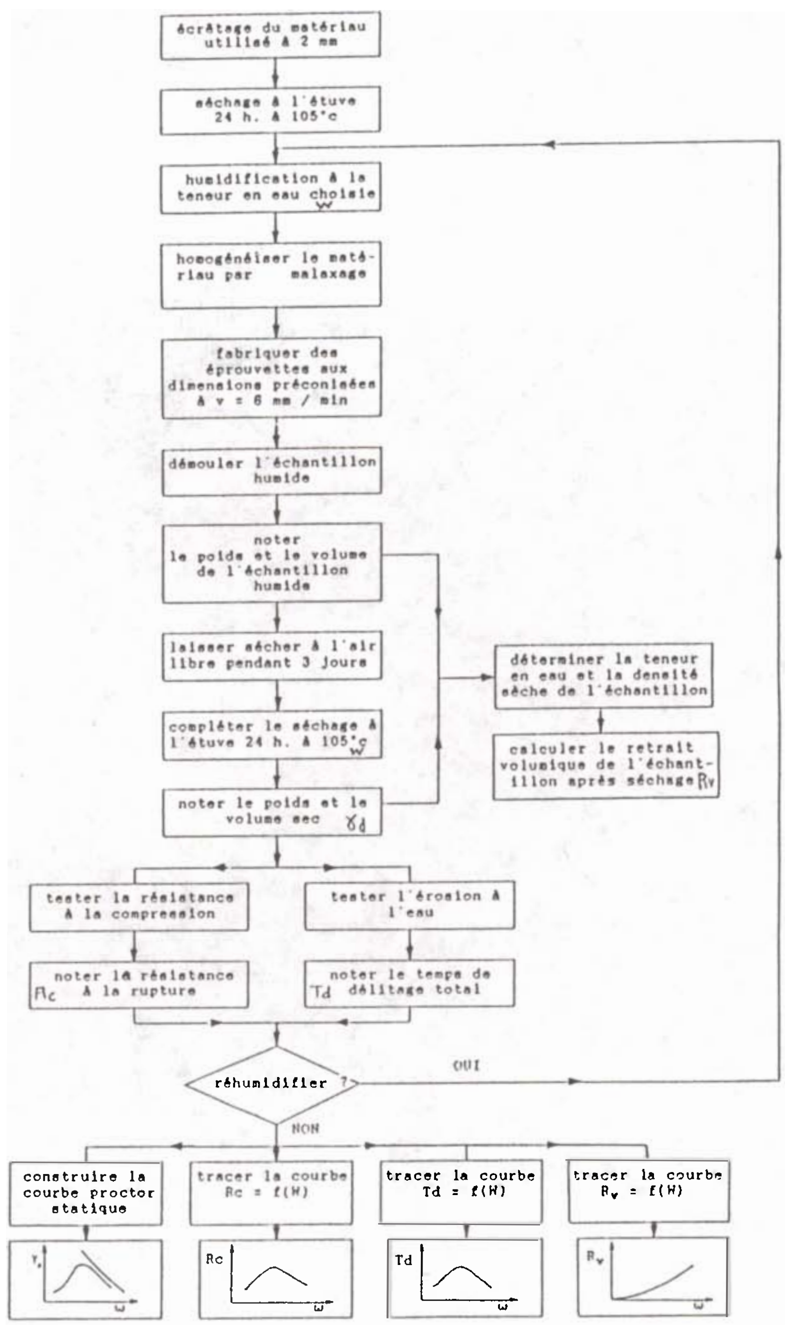


Figure 4 - Protocole de fabrication et d'essais des éprouvettes au laboratoire

Cette énergie est plus importante pour un angle d'inclinaison nul.

L'érosion de l'échantillon est le résultat du cumul des énergies mécaniques correspondant au nombre de gouttes tombées. Si la fréquence augmente, l'érosion augmente nécessairement, par conséquent, le temps de délitage sera plus faible.

La confrontation des résultats de vieillissement naturel et accéléré semble montrer qu'une demi-heure d'exposition au test de la goutte d'eau équivaut à 18 mois d'exposition naturelle (F. GHOMARI 1989).

IV - METHODOLOGIE D'ETUDE

Afin d'apprécier les qualités du matériau terre destiné à la construction en fonction des conditions de mise en oeuvre, une méthodologie d'étude au laboratoire est nécessaire.

Les caractéristiques des éprouvettes compactées statiquement au laboratoire dépendent étroitement de deux facteurs prépondérants : la teneur en eau et la pression de compactage.

Nous présentons figure 4 le protocole de fabrication et d'essais des éprouvettes au laboratoire pour une pression de compactage fixée. Le schéma est identique si pour une teneur en eau fixée on désire faire varier la pression de compactage.

Ce protocole permet de caractériser le matériau sur la base de critères mécaniques et de tenue à l'eau.

Nous présentons dans ce qui suit les résultats obtenus pour un sol en provenance de Limonest (10 km au nord de Lyon). Cette argile peu plastique (Ap) contient 97% d'éléments inférieurs à 80 µm et 11% d'éléments inférieurs à 2 µm. Sa surface spécifique totale est de 106 m2/g.

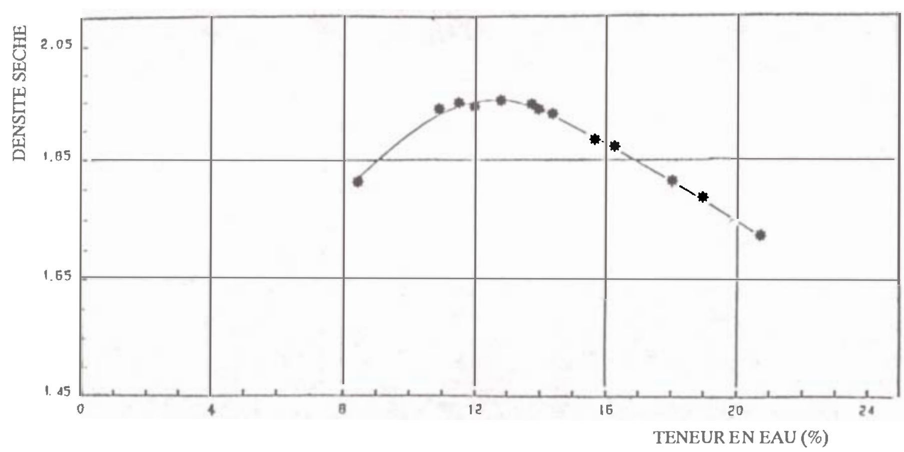


Figure 5 - Variation de la densité sèche en fonction de la teneur en eau (p = 9MPa)

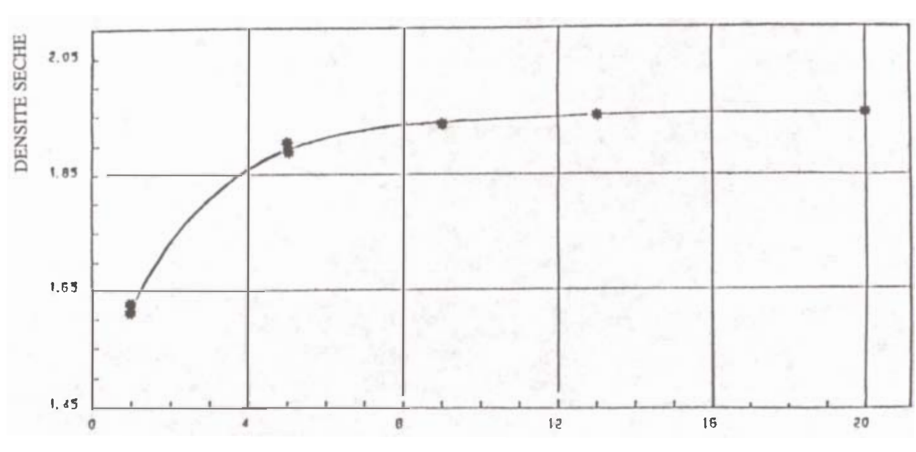


Figure 6 - Effet de la pression de compactage sur la densité sèche (teneur en eau 12,5%)

Les résultats de l'étude réalisée sur ce matériau sont représentés fig. 5-6-7-8. L'effet de la teneur en eau sur la densité sèche, la résistance, la tenue à l'eau et le retrait volumique a été déterminé pour une pression de compactage de 9MPa. Lorsque nous avons étudié l'effet de la pression de compactage, la teneur en eau était alors de 12,5% (teneur en eau optimale pour 9 MPa).

Il ressort de cette étude que

- les courbes de variation de la densité sèche, de la résistance à la compression, et du temps de délitage en fonction de la teneur en eau présentent des optimums. L'optimum de résistance est obtenu pour la teneur en eau conférant au matériau la densité sèche maximale. La meilleure tenue à l'eau est atteinte pour une teneur en eau de 2% supérieure à la teneur en eau optimale, le retrait volumique est alors de 3%.
- Comme le montre la figure 8 la densification des sols s'avère un moyen efficace pour augmenter les caractéristiques précitées. Il apparaît néanmoins qu'au-delà d'une pression de compactage de 9 à 10 MPa les gains de résistance et de tenue à l'eau ne sont pas notables.

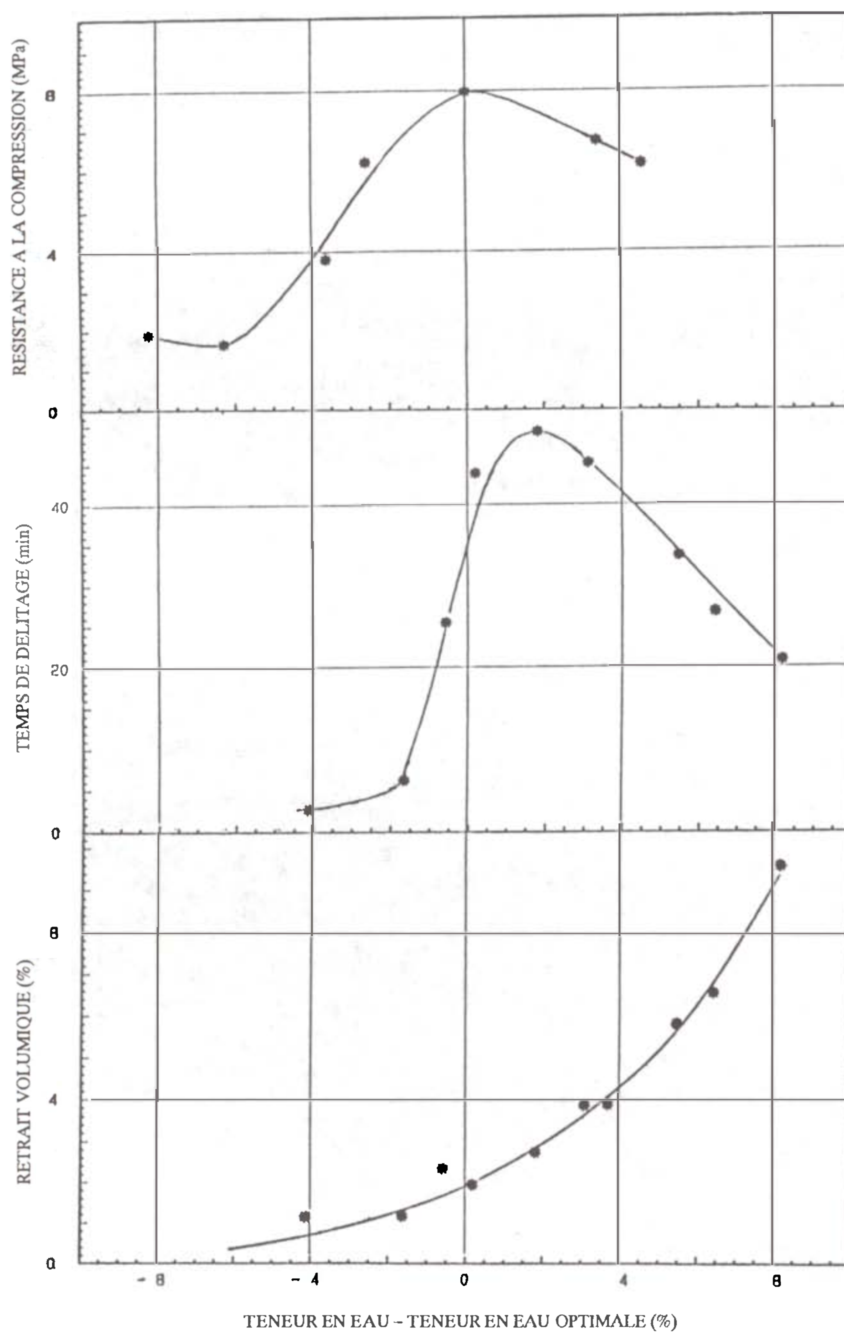


Figure 7 - Effet de la teneur en eau sur la résistance, le temps de délitage et le retrait volumique (p= 9MPa)

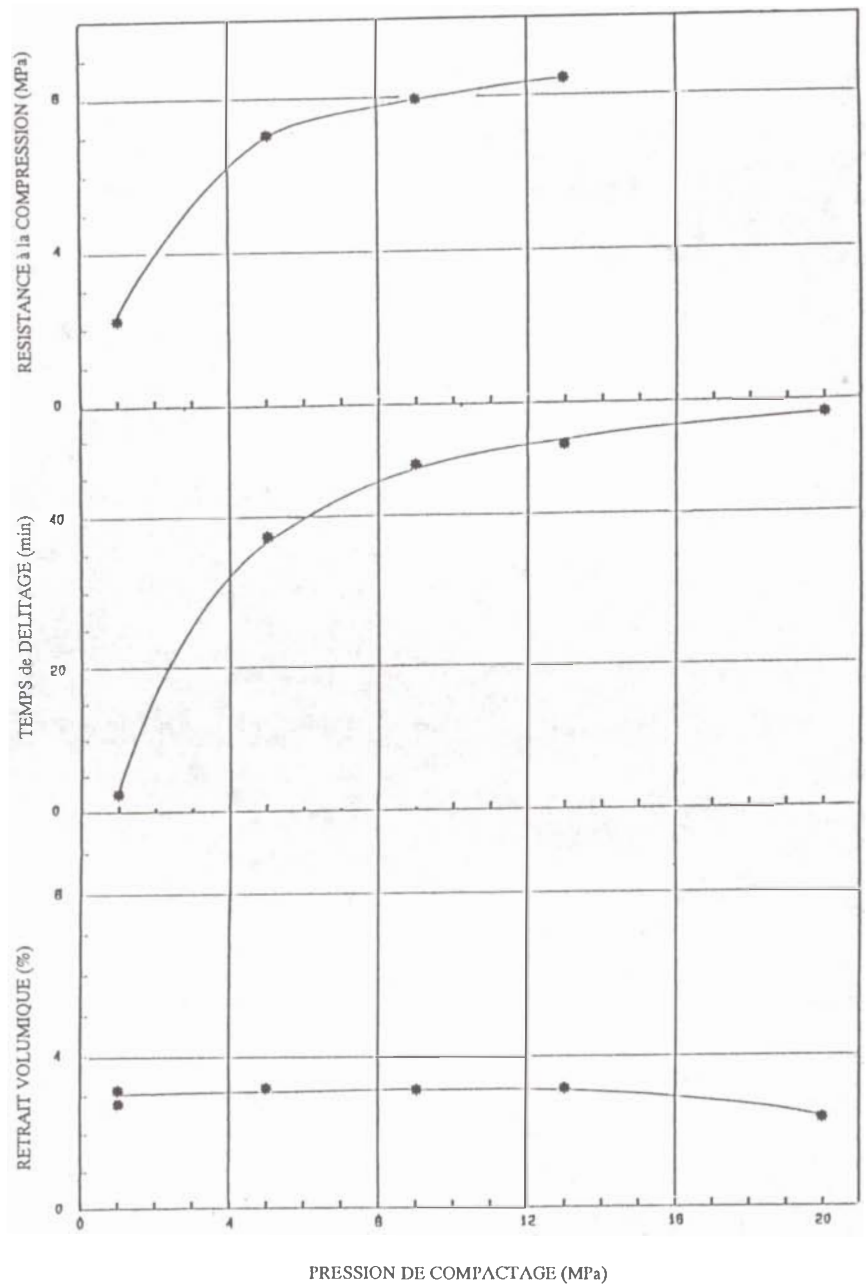


Figure 8 - Effet de la pression de compactage, sur le temps de délitage et le retrait volumique (w = 12,5%)

V - CONCLUSION

L'érosion des matériaux en terre crue soumis à l'action de la pluie est simulée au laboratoire à l'aide du test de la goutte d'eau. Nous pouvons ainsi accélérer le vieillissement sans s'éloigner des conditions réelles et reproduire les phénomènes de dégradation naturelle.

Ce test à caractère qualitatif est un outil simple permettant de sélectionner les sols et de définir les caractéristiques optimales permettant d'obtenir une structure durable. Ce test nous a par ailleurs permis de montrer l'efficacité de la protection du matériau terre par un traitement de surface par divers produits d'imprégnation.

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ABSTRACT

Humidity is a major cause of alteration for earthen architecture. We have envisaged to control the humidity by an electro-osmotic draining. The use of a carbon fibre electrode would bring down the intervention price: we checked the efficiency of the process and tested such an electrode, but the experimental conditions are far from reality. We hope to define the limits of the process by an application on the (archeological) site.

KEYWORDS

Archaeology, architecture, drying, electro-osmosis, earth.

LE POINT SUR LES POSSIBILITES DE L'ELECTRO-OSMOSE POUR LA CONSERVATION DE L'ARCHITECTURE DE TERRE.

Michel Dubus
Musée national de Céramique
1 Place de la Manufacture
92310 Sèvres
France

Introduction

En 1985 une convention de recherche a été établie entre le Musée National de Céramique et la Division des Etudes et Recherches d'Electricité de France pour l'application de procédés électrolytiques au dérouillage d'agrafes sur des oeuvres en céramique, matériau non conducteur de l'électricité. C'est en 1987 que l'idée d'une utilisation de l'électricité pour l'assèchement des bâtiments en terre a été lancée dans le cadre de cette même collaboration; l'idée n'était pas neuve, on le verra plus loin, mais la facette "mécénat" développée par EDF rejoignait un aspect beaucoup plus important de ses préoccupations, à savoir des recherches sur l'assèchement "en grand" des boues industrielles, sur la consolidation des sols meubles par injection de silicates et sur le tassement accéléré de matériaux argileux dans les travaux publics. A la suite de contacts pris avec le Conseil International des Monuments et Sites, des représentants d'EDF et du Musée de Sèvres ont été invités au 5ème colloque sur l'architecture de terre tenu à Rome en octobre 1987. Lors du stage effectué en décembre 1987 on a voulu tester l'efficacité d'une électrode en fibre de carbone: cette expérience de laboratoire, placée dans un contexte de recherche intensive, a bénéficié des connaissances déjà accumulées sur le sujet tout en ouvrant des horizons sur le comportement du matériau à conserver et sur les paramètres mis en jeu.

Dans le monde, 30% des habitations sont en terre; même pour un bâtiment en bon état un entretien de la toiture et des écoulements d'eau est nécessaire, le moindre défaut de protection entraînant une dégradation rapide des murs souvent difficile à réparer. En France, on trouve la brique crue employée à l'intérieur des maisons du Beauvaisis pour les cloisons, à l'extérieur pour les parements. En effet, c'est un matériau beaucoup moins coûteux que la brique cuite (on rencontre de tous temps les problèmes d'énergie). Dans le Puy de Dôme nous avons remarqué des maisons de quatre étages construites de la même manière ainsi que l'utilisation de terre compactée dans des coffrages.

Le revêtement du mur doit être surveillé et doit s'accorder avec le support. Il n'est pas question de réparer les dégâts avec n'importe quel enduit. La surface du revêtement d'origine apparaît comme étant très résistante à la pluie et au vent; c'est sans doute pour cette raison que l'on réenduit régulièrement les murs; mais les peintures modernes s'écaillent et ne jouent pas leur rôle protecteur. Comme un objet archéologique, une architecture de terre excavée changeant brutalement de milieu n'est plus en équilibre avec son environnement; c'est alors que commence le processus de dégradation, aggravé par l'absence des protections originales (les structures archéologiques se résument dans bien des cas à des constructions privées de leurs protections - toit, enduit de revêtement - mais l'absence de maintenance est compensée par la protection qu'offre l'enfouissement). Les buts poursuivis ici sont le ralentissement de la dégradation par un drainage des surfaces et subsurface du sol, la durée de vie des moyens mis en oeuvre devant être au moins égale à cinq ans.

Le Matériau

1. La terre: Lors de la 5ème réunion internationale d'experts sur la conservation de l'architecture de terre à Rome les 22 et 23 octobre 1987, le comité a redéfini le terme de terre comme étant générique et contenant les notions de brique crue, d'adobe, etc. La matière première peut être mélangée avec ce qu'un céramiste appellerait des "dégraissants" organiques ou non avant d'être compactée et mise en oeuvre. Quoi qu'il en soit c'est la densité du matériau qui détermine sa résistance à la compression (à sec) et sa perméabilité. Le terme de "terre" pouvant impliciter la présence d'argiles, on va rappeller quelques particularités.

2. Argiles

2.1. Généralités: Le classement d'Atterberg nous présente les particules d'argile comme étant les plus petites (inférieures à 2 µm) après les limons (de 20 à 2 µm), les sables grossiers et fins de 2mm à 0,2mm, les graviers (de 2 mm à 2 cm). Si on divisait les minéraux en treize groupes sur une échelle d'altérabilité, les illites se situeraient au niveau 7 (ce sont les argiles classiques pour briques, tuiles et poterie), alors que les argiles gonflantes de type montmorillonites seraient au niveau 9 et les kaolinites, plus résistantes, au niveau 10. Le potentiel électrocinétique ou potentiel zeta (Voir Fig 1) qui dépend de la concentration en ions et du pH de la solution explique l'attraction des molécules d'argile entre elles ou de leur répulsion; c'est la notion de floculation. Une argile en suspension serait caractérisée d'après J. Briant (1) par sa capacité d'échanges d'ions (la montmorillonite qui possède

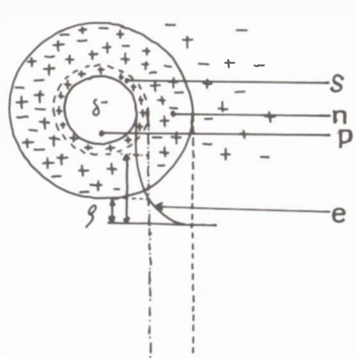

fig 1

Fig 1: le potentiel électrocinétique Zeta: p. particule électronégative, e. potentiel électrique entourant la particule, h. potentiel de Nernst, s. couche de Stern.

fig. 2

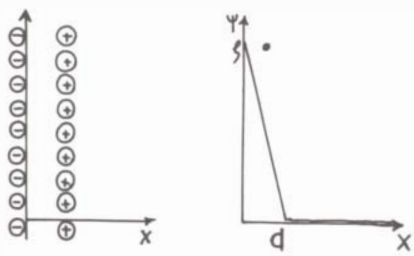

Fig 2: la couche de Helmoltz.

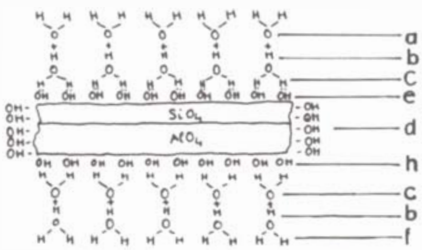

fig 3

Fig 3: schéma théorique d'une particule de kaolinite entourée de son atmosphère ionique: deux feuillets d'argile forment une membrane dissymétrique qui permet l'osmose ou séparation par une membrane semi-perméable: a. eau liée, b. ions positifs, c. eau liée par épitaxie, e. ions OH, h. OH de l'hydrargilite, f. eau liée.

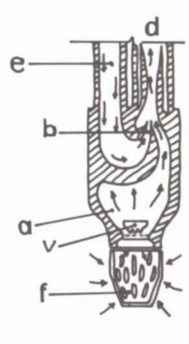

fig 4

Fig 4: Système de puits traité en cathode (pompe aspirante): d. décharge, e. entrée de la pression, b. bec, a. aspiration, v. valve, f. filtre, (d'après Perry).

de fortes capacités d'échanges sera plus stable que la kaolinite par exemple), par la nature de ces ions (les argiles calciques gonflent moins et s'hydratent mieux que les argiles sodiques mais floculent plus facilement), par la concentration en sels de l'eau (les limons transportés par les fleuves se déposent à l'embouchure); la stabilité d'une suspension d'argile est très sensible au pH; elle floculera entre pH 2,4 et 4, c'est à dire quand il n'y aura plus de doubles couches électriques.

Après sa mise en oeuvre, l'argile retrouve sa résistance mécanique initiale: c'est la notion de thixotropie. Comme chacun sait, l'argile est plastique; cette plasticité dépend de la dimension des particules et de leur nature, de leur forme, et de l'eau. Enfin la cohésion est expliquée par les forces électriques mises en jeu d'une particule à l'autre, par la forme de ces particules, par la teneur en eau de l'argile et par la nature de cette eau.

La théorie de Helmoltz nous montrait l'image simplifiée de deux particules d'argile formant condensateur (Voir Fig 2). Aujourd'hui l'origine de la charge électrique des particules d'argile est expliquée par plusieurs théories:
- la théorie électrochimique qui admet que les molécules d'argiles sont ionisées par l'eau se trouvant entre les feuillets,
- les théories basées sur l'absorption des OH- en des points stratégiques du cristal, (Voir Fig 3),
- les théories supposant des liaisons de valence non saturées provenant de la répartition irrégulière des ions des constituants de l'argile,
- par la présence d'aluminium libre qui se comporterait comme un accepteur d'électrons sur certaines faces des cristaux d'argile.

3. Le rôle destructeur de l'eau: l'eau s'infiltre, ruisselle, stagne; son action est dissolvante, hydratante, hydrolysante, mécanique; associée au gel l'eau joue un rôle mécanique dramatique (pour mémoire, $1cm^3$ d'eau donne $1{,}09cm^3$ de glace). Le ramollissement et le gonflement de la terre diminuent sa résistance mécanique et peuvent s'accompagner de microfissures. Si l'eau transporte des sels en solution, on verra ceux-ci se cristalliser à la surface d'évaporation. Les micro-organismes et les végétaux pionniers se développent dès qu'il y a présence d'eau (2).

Electro-Osmose

1. Définition: Casagrande (3) nous définit l'électro-osmose pour les sols formés de particules inférieures à 2 µm et jusqu'à 4 µm comme étant un mouvement forcé de l'eau d'une électrode à l'autre; il fait circuler un courant électrique entre deux électrodes, l'une placée dans le mur et l'autre à l'écart de celui-ci de sorte que l'eau se déplace de la première vers la deuxième. D'après Y. Atlan et coll.(4) la conductivité d'un milieu aqueux est augmentée dès qu'il y a présence d'argile, trois paramètres intervenant: la capacité d'échange de l'argile que nous avons déjà vue plus haut, la structure du matériau en fonction de la nature de l'argile, la porosité du matériau, enfin la nature ionique de l'eau circulante.

2. Paramètres: Le débit électro-osmotique est proportionnel à :
- la densité de courant,
- la section des capillaires,
- la résistivité électro-osmotique du milieu,
- au potentiel électrocinétique,
- à la constante diélectrique du milieu.

3. Antécédents: Le procédé a été très utilisé pour l'amélioration de la stabilité de sols argileux : sur 7 résultats collectés sur 4 sites moyens, les sites ayant obtenu des valeurs extrêmes étant écartés pour ne pas fausser l'analyse, on trouve un pourcentage moyen de 7,4% d'eau extraite; les échantillons les plus représentatifs sont Ayton en Ecosse où furent traités des matériaux argileux contenant des sables, des graviers et des blocs; les anodes y étaient constituées de palplanches et les cathodes de pointes filtrantes en bronze (Voir Fig 4); le traitement a duré 6 mois. A Halle, en Allemagne, on a traité un mélange de loess tendre et de graviers, les électrodes étant constituées de tuyaux à gaz. Dans les deux cas le potentiel était de 110 Volts, l'ampérage n'étant pas mentionné. La société Elkinet(R) (anode, St. Peter-Strasse 25,PO Box 296, A 4020 Linz) commercialise aujourd'hui un brevet d'assèchement pour les bâtiments qui utilise une électrode de polyester conducteur dont le coût d'installation est d'environ 1500 F/m TTC pour une consommation inférieure à 10 mW en 1988. D. Moraru (5) conclut que le problème de la mise en oeuvre d'un tel procédé d'assèchement semble résolu en pratique par la limitation de l'intensité de courant (limitation de la corrosion des électrodes et du coût) et par le choix d'électrodes plates non métalliques résistantes aux ions $SO4^{2-}$, Cl^{-}, No^{3-}; il va même jusqu'à préconiser une ventilation des électrodes en conseillant une densité de courant dirigée à la surface du sol de l'ordre de 1^{-3} A/cm2.

Expérience

1. Choix du matériau: Au cours du stage effectué une manipulation a été mise en route sur un échantillon de kaolinite à 2/3 et de sable à 1/3 en masse pour tester la résistance d'une électrode en fibre de carbone dont l'utilisation

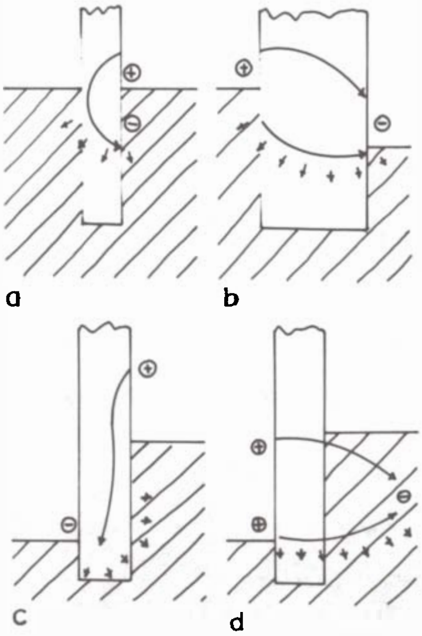

fig 5

Fig 5: exemples de mise en oeuvre: a. électrodes installées à l'extérieur du bâtiment, permettant ainsi d'éviter des travaux intérieurs, b. version pour une maçonnerie exceptionnellement épaisse, c. cave voisinant un sol pavé, d. l'électrode négative est placée en sous-sol, (d'après Elkinet (R)).

diminuerait le prix de revient d'une intervention. Le PH de l'échantillon au départ = 5. Le choix des électrodes a été fait en fonction des produits disponibles sur le marché par rapport à l'électrode "Lida" du brevet Elkinet(R) (Voir Fig 5), où l'on constate que si on exclut les électrodes métalliques comme le conseille D. Moraru (6), il ne nous restait que le graphite. Dans sa demande de brevet J. Lebeda (7) revendiquait lui aussi l'idée d'un matériau conducteur non métallique.

Les résultats sont montrés dans les Fig 8 et 9, où:
- PTH = Poids Total Humide, en grammes,
- PTS = Poids total à sec après étuvage à 100°C,
- W% = Pourcentage d'eau contenue dans les prélèvements.

Conclusion

Une manipulation en vraie grandeur et dans des conditions réelles de conservation est à envisager. Théoriquement le principe ne peut fonctionner qu'en présence d'électrolyte, c'est-à-dire qu'il nécessite de l'eau; l'avantage de ce système auto régulé c'est qu'il ne demande pas de maintenance particulière une fois le "seuil de déclenchement" établi.

On projette de tester sur un échantillon en vraie grandeur tous ces paramètres afin de pouvoir proposer une association du procédé avec d'autres types de protection pour résoudre les problèmes de stagnation d'eau à la base des structures de terre excavées ayant pour origine les remontées capillaires ou le ruissellement. Le procédé nécessitant une mise en oeuvre soignée, notamment au niveau des connexions qui ne doivent pas s'oxyder, sa mise en oeuvre doit être effectuée par des spécialistes. La maintenance devrait être réduite; la faible consommation en courant électrique autoriserait l'utilisation de capteurs solaires dans certains cas. Une telle application permettrait peut-être de réévaluer les résultats obtenus par le passé, de poser les limites du procédé et de définir sa place effective dans la panoplie du conservateur-restaurateur.

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ABSTRACT

Every intervention should be preceded by a thorough understanding of the symptoms of deterioration by humidity, the causes of this deterioration and their origin. Therefore one needs a systematic approach : methodology of analysis and diagnosis. This methodology should allow for the development of intervention techniques within a global approach of knowing how to design with the limitations and potentials of the raw material instead of knowing how to armour by ignoring those limitations and potentials.
The methodology is also based on the hypothesis of maintenance and repair planning being part of the intervention as well as follow-up of the intervention technique.

A comprehensive grid for pathology survey is developed :

- characteristics of the building material involved in the pathology,
- symptoms of humidity pathology,
- causes of pathology,
- possible origins of pathology.

Following methodological aspects of diagnosis have to be dealed with :

- measurement of the symptoms : actual condition and monitoring,
- evaluation of measurements,
- complementary measurements in case of doubts about the origins,
- evaluation of the complementary measurements,
- difficulties of interpretation,
- interpretation of the symptoms.

Major gaps for the achievement of a comprehensive methodology may constitute research priorities for the future :

- interpretation of measurements,
- evaluation of symptoms,
- systematic follow-up of intervention techniques and dissemination of results allowing to verify the validity of the diagnosis.

KEYWORDS

Preservation, rehabilitation, earthen architecture, wet pathology, measurements, analysis, diagnosis.

PATHOLOGIE HUMIDE DE CONSTRUCTIONS EN TERRE : METHODOLOGIE DE DIAGNOSTIC

PASCAL ODUL, Ing.-Architecte
CRATerre / ECOLE D'ARCHITECTURE DE GRENOBLE
10 GALERIE DES BALADINS, 38100 GRENOBLE/FRANCE

I. INTRODUCTION

Chaque intervention sur le terrain doit être précédée par une compréhension des phénomènes de dégradation : symptômes, causes, origine des causes. Ceci nécessite une approche méthodologique systématique basée sur des hypothèses d'intervention clairement explicitées dès le départ et qui guideront le type d'intervention à envisager. C'est pourquoi nous proposons des grilles de réflexion qui se trouvent dans les tableaux de cette communication.

A. RESUME DES PRINCIPALES CARACTERISTIQUES

Par rapport à d'autres matériaux, la terre est extrêmement sensible aux actions de l'eau.
Ainsi, cette caractéristique du matériau induit nécessairement que les constructions en terre soient abritées des multiples actions néfastes de l'eau. Ceci ne veut pas pour autant signifier que les constructions en terre doivent être totalement imperméabilisées, mais convenablement protégées des possibilités de dégradation, dans l'emprise du bâtiment et à proximité.
Quelles que soient les améliorations apportées au matériau terre, ses caractéristiques mécaniques ne lui permettent pas de subir de fortes sollicitations. De tels efforts appliqués aux constructions en terre engagent des risques de fissurations et de pathologies de structure en général qui peuvent à leur tour engendrer des pathologies humides.

B. HYPOTHESES D'INTERVENTION

1. COMPRENDRE LES EFFETS ET CAUSES DE DESORDRES

L'étude des interventions de réhabilitation ou de restauration de bâtiments en terre fait souvent apparaître ce que nous appellerons "l'effet domino". Une réparation au niveau d'un symptôme de pathologie au lieu de la cause va déplacer le problème et créer une nouvelle pathologie. Ce n'est qu'en comprenant les effets et causes des désordres qu'il sera possible de remédier de façon irréversible aux phénomènes de dégradation. La nature très sensible du matériau terre demande cette compréhension, car une intervention fautive peut être plus catastrophique que l'absence d'intervention.

2. REMEDIER AUX CAUSES DES DESORDRES

La tendance actuelle fait davantage appel à l'ingénierie en vue d'accroître la résistance et de préserver le "matériau terre" des agents de dégradation, ignorant la démarche qui consiste à rendre le "bâtiment" résistant et apte à confronter les agents de dégradation.
La démarche de blindage du matériau que décrit par exemple une imperméabilisation totale de l'enveloppe bâtie tend le plus souvent à sophistiquer la mise en oeuvre et à augmenter le risque de malfaçons. Le blindage des constructions en terre est très souvent un costume cache-misère. En plus, l'expérience a montré que le blindage peut être contreproductif et engendrer des nouvelles pathologies parfois plus graves.
La qualité d'une architecture de terre, sa durée tout autant que sa destruction rapide dépendent pour l'essentiel de la qualité du "savoir concevoir" mais également du respect des règles essentielles de l'art de bâtir en terre. Ces règles essentielles peuvent être résumées par :

- la connaissance du matériau, de ses caractéristiques et de ses propriétés fondamentales,
- la connaissance des particularités de la technique de construction employée,
- l'adoption de systèmes constructifs simples et compatibles avec les performances du matériau,
- une exécution soignée des ouvrages.

3. INSPECTION ET ENTRETIEN REGULIER

Il est nécessaire de lancer dès le départ des programmes d'entretien rigoureux qui tiennent compte des facteurs déterminants pour le maintien des bâtiments.
Ce planning tiendra compte des performances des matériaux utilisés, de la facilité d'accès au points de contrôle, du degré d'abandon du bâtiment et de la fréquence des visiteurs.

Il faut établir une liste des endroits à vérifier et la fréquence des visites, établir un listing de priorités pour les entretiens futurs, établir un cahier des charges pour les réparations à faire, établir un cahier des charges concernant les compétences requises de la part du personnel d'entretien et de réparation, établir un budget prévisionnel des frais d'entretien et équipements nécessaires, ...
Cette campagne de maintenance doit être accompagnée d'une campagne de sensibilisation des utilisateurs comprenant des conseils d'utilisation, par exemple : conseils pour le chauffage, la ventilation, points névralgiques à surveiller, ...

4. SUIVI DE L'EFFICACITE DE L'INTERVENTION
Beaucoup d'interventions se limitent à la simple exécution des travaux et omettent d'assurer un suivi pour contrôler l'efficacité de l'intervention et de vérifier la validité du diagnostic. Ceci a pour conséquence que certaines techniques subsistent encore à ce jour, malgré leur inefficacité ou leur contreproductivité.
Il est donc nécessaire d'entamer des campagnes de follow-up suivies d'une phase de dissémination des résultats auprès des utilisateurs potentiels.

II. ANALYSE DE PATHOLOGIE

A. METHODOLOGIE DE DIAGNOSTIC

Les différentes étapes de la méthodologie de diagnostic se résument ainsi :

I. **CONSTAT ET MESURE DES SYMPTOMES DE PATHOLOGIE (CONDITION SURVEY)**
II. **SUIVI DE L'EVOLUTION DES SYMPTOMES (MONITORING)**
III. **INTERPRETATION DES CONSTATS ET MESURES**
IV. **RECHERCHE DES CAUSES**
V. **RECHERCHE DE L'ORIGINE DES CAUSES**
VI. **EVALUATION DES SYMPTOMES**
A DESORDRES METTANT EN CAUSE LE MAINTIEN DU BATIMENT
B DESORDRES SANS CONSEQUENCES POUR LE MAINTIEN DU BATIMENT
C DESORDRES METTANT EN CAUSE LE MAINTIEN DES PARTICULARITES SPECIFIQUES POUR LA VALEUR HISTORIQUE OU CULTURELLE DE BATIMENT

B. SYMPTOMES

Il est nécessaire de mentionner que nous parlons uniquement de constat des symptômes. Il est clair que des formes de pathologie humide peuvent être la conséquence d'une pathologie de structure ou vice-versa. Des pathologies de structure peuvent ainsi créer des fissures qui seront un lieu de prédilection pour l'apparition de pathologies humides du style érosion et infiltration.

Ci-joint nous proposons une grille de réflexion qui systématise et hiérarchise les différents symptômes :

I. **EROSION**
   A. EROSION DE SURFACE
      1. UNIFORME
      2. DIFFERENTIELLE
   B. EROSION LOCALISEE
      1. EROSION DE LA BASE
      2. EROSION DU SOMMET
      3. EROSION PONCTUELLE
II. **DECOMPOSITION DU MATERIAU**
III. **FISSURES**
   A. MACRO
   B. MICRO
IV. **HUMIDITE**
   A. SURFACE
      1. PERMANENT
      2. TEMPORAIRE
      3. CYCLIQUE
   B. PROFONDEUR
      1. PERMANENT
      2. TEMPORAIRE
      3. CYCLIQUE
V. **TACHES**
   A. RUISSELLEMENT
   B. SELS
   C. BISTRE
VI. **PARASITES**
   A. MOISISSURES
   B. CHAMPIGNONS
   C. MOUSSES
   D. INSECTES
VII. **DEFAILLANCE PROTECTION DE SURFACE EXTERIEURE**
   A. UNIFORME
   B. LOCALISEE
VIII. **DEFAILLANCE DE FINITIONS ET PROTECTIONS DE SURFACE INTERIEURES**
   A. UNIFORME
   B. LOCALISEE

C. RECHERCHE DES CAUSES DE PATHOLOGIE

Une grande partie des phénomènes d'érosion sont liés à l'action de la pluie, du vent et des êtres vivants.

La pluie a trois effets principaux :

- impact : l'impact direct et répété de la pluie violente altère la surface des éléments extérieurs et provoque un effritement.
- ruissellement et infiltrations : l'écoulement de l'eau de pluie sur une surface provoque une érosion de surface suivie d'infiltrations dans la masse qui provoque des écroulements.
- rejaillissement et infiltration : impact indirect et répété de la pluie rebondissant sur le sol, auvent, pavement extérieur, éléments saillants ou rentrants, suivi d'altération, effritement et creusement.

Le vent a une action mécanique d'autant plus marquée lorsqu'il transporte des particules en suspension et sous forme de tourbillons.
Les êtres vivants provoquent des chocs ponctuels d'objets ou d'eau.
La seconde source de dégradation de bâtiments en terre trouve son origine dans l'absorption capillaire de la nappe phréatique ou d'eau dispersée.

L'absorption capillaire affecte le comportement du matériau terre de trois façons :

- transports de sels qui cristallisent par évaporation,
- diminution de la résistance mécanique,
- diminution de la résistance à l'érosion.

Les remontées capillaires dans la paroi sont fonction de trois critères :

- la capillarité du matériau,
- pesanteur (poids de l'eau qui remonte),
- évaporation (conditions hygrothermiques/perméabilité/quantité d'eau).

Cette évaporation peut être suivie de cristallisation de sels qui par leur expansivité provoquent un effritement de la matière première ou une humidité hygroscopique.
Les sels solubles peuvent se trouver dès l'origine dans la matière première (formation de carbonates ou sulfates de calcium après hydratation de ciment portland, sels dans la terre,...), ou provenir du sol (drainage, VRD, nappe phréatique, murs construits près de sources de déchets organiques ou construits près de fosses septiques et égouts défaillants,...), soit par apport extérieur sous forme de pluie et vent (par exemple air marin apportant des sels à base de chlore). Dans le premier cas les apports sont limités dans le temps, dans les autres cas les apports ont des sources inépuisables.
La condensation, troisième source majeure de dégradation, et l'hygroscopicité en soi ne sont pas toujours forcément néfastes à condition d'être cycliques et qu'il n'y ait pas d'accumulation permanente ni effets secondaires :
- perte de résistance thermique,
- moisissures et biodégradations,
- décollements des revêtements,
- dégradation des éléments décoratifs,
- risque de gel,
- confort physiologique,
- érosion de surface.

I. **EAU**
   A. IMPACT
   B. RUISSELLEMENT
   C. INFILTRATION
   D. EAU DE CONSTRUCTION
   E. ABSORPTION CAPILLAIRE
      1. NAPPE PHREATIQUE
      2. EAU DISPERSEE
   F. MIGRATION ET CRISTALLISATION DE SELS
II. **VAPEUR D'EAU/HUMIDITE RELATIVE/TEMPERATURE/TAUX DE VENTILATION**
   A. MIGRATION DE VAPEUR D'EAU
   B. EVAPORATION
   C. SATURATION DE LA VAPEUR D'EAU
      1. BLOCAGE DE LA MIGRATION
      2. DESEQUILIBRE HYGRO-THERMIQUE
   D. HYGROSCOPICITE
      1. MATIERE PREMIERE
      2. PRESENCE DE SELS

D. ORIGINE DES CAUSES DE PATHOLOGIE HUMIDE

Dans cette liste d'origine des causes nous retrouvons également les pathologies de structure qui peuvent créer des points névralgiques qui seront un lieu de prédilection pour l'apparition de pathologies humides du style érosion et infiltration.

I. **ORIGINES EXTERIEURES**
   A. EAU
      1. PLUIE
         a) IMPACT
         b) RUISSELLEMENT
         c) EROSION DIFFERENTIELLE
         d) REJAILLISSEMENT
         e) INFILTRATION
      2. APPORT D'EAU EXTERIEUR
         a) RUPTURE DE CANALISATIONS D'ECOULEMENT
         b) RUPTURE D'INSTALLATION TECHNIQUES
         c) COURS D'EAU/SOURCE/EAU DE SURFACE
         d) NETTOYAGE
         e) INONDATIONS
         f) INCENDIES
      3. NAPPE PHREATIQUE
      4. STAGNATION DE NEIGE/GLACE/FONTE/INFILTRATION
      5. STAGNATION D'EAU
      6. ASPERSIONS
      7. JETS
      8. GOUTTES
      9. HUMIDITE DE MISE EN OEUVRE

B. AIR
1. VENT
a) EROSION EOLIENNE
b) PLUIE BATTANTE
c) INFILTRATION
2. VENTILATION
3. FACTEUR DE PRESSION ET SUCCION
C. TEMPERATURE/HUMIDITE RELATIVE/PERMEABILITE A LA VAPEUR
1. CHAUFFAGE DE PIECES AYANT DES PROBLEMES DE REMONTEES CAPILLAIRES
2. CHAUFFAGE DE PIECES PREALABLEMENT NON CHAUFFEES
3. CHANGEMENT DE TYPE DE CHAUFFAGE
4. BLOCAGE DE LA "RESPIRATION"
5. BLOCAGE DE LA VENTILATION
6. MODIFICATION DE L'ISOLATION THERMIQUE ET PARE-VAPEURS
7. CONDENSATION DE SURFACE
8. CONDENSATION INTERNE
9. PONT THERMIQUE
10. HYGROSCOPICITE
11. DILATATION THERMIQUE
12. GEL/DEGEL
13. ALTERNANCE HUMIDIFICATION/SECHAGE
14. ALTERNANCE CONDENSATION/EVAPORATION
15. CHOCS THERMIQUES
D. SELS SOLUBLES
1. CRISTALLISATION
2. CORROSION
E. PATHOLOGIE STRUCTURE
1. FISSURES
a) MICRO
b) MACRO
2. AFFAISSEMENTS
3. TASSEMENTS
4. DEPLACEMENTS
5. FLAMBEMENTS
6. EFFONDREMENTS
7. EFFRITEMENTS
F. BIODEGRADATION
1. INSECTES
a) ABEILLES
b) TERMITES
2. ANIMAUX
a) OISEAUX
b) RONGEURS
c) ANIMAUX DOMESTIQUES
3. PLANTES
a) PLANTES INFERIEURES
b) PLANTES SUPERIEURES

G. ACTIVITES HUMAINES
1. TRAVAUX
2. AMENAGEMENTS DE TERRITOIRE
a) ROUTES
b) BARRAGES
3. CHOCS ET DEGRADATIONS
4. UTILISATION INADEQUATE
5. MAINTENANCE DEFAILLANTE
II. ORIGINES INHERENTES AU BATIMENT
A. MATIERE PREMIERE
B. MISE EN OEUVRE
1. PROCESSUS DE PRODUCTION
2. PROCESSUS DE CONSTRUCTION
III. ORIGINES INHERENTES A L'UTILISATION
A. MODE DE VIE
B. TRANSFORMATIONS
C. ENTRETIEN

E. DIAGNOSTIC

1. MESURE DES SYMPTOMES: CONSTAT ET/OU SURVEILLANCE (MONITORING)

Tous les phénomènes de pathologie humide sont liés à la présence d'eau ou de vapeur d'eau qu'il faut quantifier et dont il faut déterminer l'origine.
Dans un premier temps les appareils électriques portatifs peuvent permettre de déterminer la localisation et l'étendue des zones humides. Pour cela il est utile d'employer une méthodologie rigide de notation.
La méthode de référence pour la quantification de la teneur en eau est l'étuve à 105°C pendant 24 heures. Il existe par contre une multitude de mesures alternatives.

Parmi les méthodes directes, on trouve :

- mesure du poids des solides et différence,
- mesure du poids ou volume du liquide,
- mesure du volume des solides,
- mesure du volume d'air.

Les méthodes indirectes sont :

- résistance électrique,
- limites de consistance,
- diffusion de chaleur.

Pour toutes ces méthodes, le résultat n'est pas nécessairement fiable dû à l'influence de certains paramètres :

- influence de la température de séchage,
- influence de l'air confiné dans les vides,
- influence du type de sol,
- influence de l'hypothèse de base de la méthode employée,
- influence de la présence de matières volatiles, organiques et de sels,
- absence d'une relation linéaire entre le phénomène mesuré et la teneur en eau réelle.

Les différentes méthodes ne donnent donc pas forcément le même résultat et sont souvent utilisés à titre indicatif ou comparatif. Cette constatation n'empêche néanmoins pas d'effectuer un diagnostic.

Vu que plusieurs phénomènes sont liés à la pression de vapeur d'eau l'on peut immédiatement procéder aux mesures nécessaires.

Dans certains cas, il sera utile de procéder au dépistage de sels cristallisés en surface afin de pouvoir faire une distinction entre hygroscopicité, eau absorbée et condensation ou afin de vérifier la validité ou de quantifier l'erreur systématique des mesures de teneur en eau par le biais de la résistance électrique.

Le simple constat ponctuel est malheureusement souvent insuffisant et il faudra faire appel à des procédures de surveillance dans le temps (par exemple, les phénomènes de condensation de surface peuvent apparaître seulement à certaines périodes de la journée ou de l'année). Ces procédures de relevé sont généralement de longue durée afin de permettre la distinction entre phénomènes constants, cycliques constants ou cycliques croissants.

Après avoir émis des hypothèses sur la source, il est également possible de procéder à des mesures complémentaires pour vérifier l'hypothèse émise.

Nous recommandons également de procéder immédiatement à la prospection de condition des bâtiments avoisinants. Ce constat élémentaire peut néanmoins être indispensable pour déterminer les origines de la pathologie.

I. TENEUR EN EAU
  A. ESSAIS IN SITU
    1. DESTRUCTIF /EXEMPLES
      a) CARBURE DE CALCIUM
      b) BAIN DE SABLE
      c) RESISTANCE ELECTRIQUE
        (1) ECHANTILLON DE PLATRE IMBIBE
        (2) TIGES DE SONDAGE
    2. NON DESTRUCTIF /EXEMPLES
      a) INFRAROUGES(CAMERA)
      b) RESISTANCE ELECTRIQUE
        (1) POINTES DE SONDAGE
      c) METHODE NEUTRONIQUE
  B. ESSAIS DE LABORATOIRE /EXEMPLES
    1. ETUVE 105°C
    2. METHODE DU PYCNOMETRE A AIR DIFFERENTIEL
    3. BALANCE D'HUMIDITE
II. VAPEUR D'EAU/HUMIDITE RELATIVE/TEMPERATURE/TAUX DE VENTILATION
  A. ESSAIS IN SITU
    1. DESTRUCTIF
      a) COMPORTEMENT DES MATERIAUX
        (1) TEMPERATURE DES MATERIAUX
          (a) INTERIEUR /EXEMPLES
            i) THERMOMETRE A CELLULES SEMI-CONDUCTRICES EN GYPSE
            ii) SONDE DE TEMPERATURE DE CONTACT
    2. NON DESTRUCTIF
      a) COMPORTEMENT DES MATERIAUX
        (1) TEMPERATURE DES MATERIAUX
          (a) SURFACE /EXEMPLES
            i) TORQUE THERMO-ELECTRIQUE
            ii) THERMOMETRE INFRAROUGE OPTIQUE
        (2) PRESSION DE SATURATION DES SURFACES /EXEMPLES
          (a) CONDENSATEST
      b) ANALYSE DE L'ENVIRONNEMENT AMBIANT
        (1) HUMIDITE RELATIVE /EXEMPLES
          (a) HYGROMETRE ELECTRONIQUE
          (b) HYGROGRAPHE
          (c) PSYCHROMETRE
        (2) TEMPERATURE DE L'AIR /EXEMPLES
          (a) THERMOMETRE A L'ALCOOL
          (b) THERMOMETRE INFRAROUGE
          (c) THERMO-HYGROMETRE
        (3) INSTRUMENT MESURANT LE POINT DE ROSEE /EXEMPLES
          (a) THERMO-HYGROMETRE
III. SELS SOLUBLES
  A. ESSAIS IN SITU
    1. NON DESTRUCTIF /EXEMPLES
      a) NITRITEST

2. MESURES COMPLEMENTAIRES

Ce sont essentiellement des tests qui permettent de vérifier les hypothèses d'origine de cause de pathologie et de mieux comprendre les phénomènes constatés en cas de doute. Ils ne sont donc pas fondamentaux pour effectuer un diagnostic.

La première action consiste à vérifier l'emplacement et le fonctionnement de toutes les canalisations d'adduction ou d'évacuation. Ce constat simple et élémentaire permettra dans beaucoup de cas d'identifier l'action de prévention à envisager.
La deuxième action consiste à vérifier la capacité de drainage du sol de fondation et de l'entourage et à détecter la présence d'une nappe phréatique. Ceci permettra de faire une distinction entre les différents types d'exposition d'humidité : humidité permanente, passagère, eau d'accumulation, eau dispersée, humidité naturelle du sol. En même temps ces mesures donneront des indications sur le comportement structurel du sol.

L'analyse du taux de ventilation permettra d'expliquer des phénomènes liés à l'humidité relative : condensation, évaporation.

L'analyse des sels et la mesure du pH de la terre utilisée pour construire et du sol dans l'entourage du bâtiment peut aider à constater ou expliquer des désordres, mais pourra également servir plus tard pour déterminer les caractéristiques de la matière première en cas de reconstruction. Par exemple, le pH affecte la floculation ou la dispersion des argiles. Certaines techniques de préservation (électro-osmose, stabilisation chimique,...) modifient le degré d'acidité et modifient donc le comportement de la terre soit en bien ou en mal.

Lorsque l'hypothèse d'infiltrations d'eau de pluie à travers le mur est envisagée, on peut la vérifier en faisant des essais à la boîte de perméabilité qui peut mesurer le débit absorbé par le mur sous une charge constante.

I. CONTROLE DE LA LOCALISATION DES CANALISATIONS
- A. EVACUATION
  1. ASSAINISSEMENT
  2. EAU DE PLUIE
- B. ADDUCTION
  1. EAU D'UN RESEAU
  2. EAU DE SOURCE
  3. EAU DE PLUIE
- C. INSTALLATIONS TECHNIQUES
  1. CHAUFFAGE
  2. INCENDIE
- D. INSTRUMENTS POUR LA LOCALISATION
  1. PACHOMETRE OU PROFOMETRE
  2. DETECTEUR DE METAUX

II. CONTROLE DE L'ECOULEMENT DES CANALISATIONS D'EVACUATION (DEBIT)

III. CONTROLE DE L'ECOULEMENT DES CANALISATIONS D'ADDUCTION (PRESSION)

IV. HUMIDITE DANS LE SOL
- A. TENEUR EN EAU NATURELLE
- B. NAPPE PHREATIQUE
- C. PERMEABILITE ET CAPACITE DE DRAINAGE
  1. ESSAIS IN SITU
  2. ESSAIS DE LABORATOIRE SUR ECHANTILLON CAROTTE

V. CONTROLE DU TAUX DE VENTILATION

VI. SELS
- A. MESURES QUALITATIVES
- B. MESURES QUANTITATIVES

VII. ACIDITE

VIII. ABSORPTION CAPILLAIRE DES MATERIAUX DE CONSTRUCTION
- A. VERIFICATION INFILTRATION DIRECTE D'EAU DE PLUIE IN SITU
- B. ESSAIS DE LABORATOIRE SUR ECHANTILLON CAROTTE

IX. HYGROSCOPICITE

3. EVALUATION DES MESURES

Il est souvent difficile de faire la distinction entre les humidifications dues aux infiltrations de la pluie et par exemple l'absorption capillaire ou la condensation. Toutefois certaines caractéristiques des désordres peuvent fournir des indications sur la nature du phénomène constaté.
Les infiltrations par la pluie donnent naissance à des taches d'humidité bien déterminées, même si elles sont étendues. Elles peuvent passer par un maximum quelques heures après une pluie importante.

Les manifestations des remontées capillaires se traduisent généralement par une frange humide permanente qui dépend de nombreux facteurs :

- caractéristiques du matériau,
- possibilités d'évaporation,
- épaisseur du mur.

Les condensations de surface se situent généralement à des endroits où la température de surface atteint le point de rosée ce qui est accentué aux angles et aux parties à isolation thermique moins élevée (réduction de l'épaisseur/présence d'autres matériaux moins isolants/ponts thermiques).
La spécificité du matériau terre demande néanmoins une prudence dans l'établissement du diagnostic. Ceci nécessite une recherche systématique plus poussée sur la relation entre les symptômes et les origines de la pathologie.

4. EVALUATION DES SYMPTOMES

Il est important de faire une distinction entre les différents types de désordre car ceux-là dicteront le type d'intervention à envisager. Ces types sont classés selon un ordre décroissant d'urgence et d'importance de l'intervention.

Comme dans beaucoup de cas, la science et l'expérience sont très développées dans le domaine des mesures de phénomènes. L'interprétation et le jugement de ces mesures sont souvent arbitraires et n'ont pas à ce jour de base scientifique.

I. DESORDRES METTANT EN CAUSE LE MAINTIEN DU BATIMENT
II. DESORDRES METTANT EN CAUSE LE MAINTIEN DES PARTICULARITES SPECIFIQUES POUR LA VALEUR HISTORIQUE OU CULTURELLE DE BATIMENT
III. DESORDRES SANS CONSEQUENCES POUR LE MAINTIEN DU BATIMENT

III. CONCLUSIONS

L'objectif principal de cet exposé est de proposer une grille de réflexion concernant l'analyse et le traitement des pathologies humides basés sur des hypothèses d'intervention bien précises :

- comprendre les effets, causes et origine des causes des désordres,
- intervention au niveau des origines des causes de pathologie,
- inspection et entretien régulier.

Cette analyse a permis d'identifier trois lacunes majeures pour l'aboutissement d'une approche cohérente :

- manque de bases solides permettant l'interprétation des mesures dans la phase du diagnostic,
- manque de bases solides permettant l'évaluation de la gravité des symptômes également dans la phase du diagnostic,
- manque de suivi et évaluation systématique des interventions techniques et diffusion des résultats permettant aussi de vérifier la validité du diagnostic

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Clay Chemistry and Microstructure

ADOBE AND RELATED BUILDING MATERIALS IN NEW MEXICO, USA

George S. Austin
New Mexico Bureau of Mines and Mineral Resources
Campus Station,
Socorro, NM 87801
U.S.A.

ABSTRACT

The average grain-size distribution of New Mexican adobe soils was 67 wt% sand-and-larger size, 27 wt% silt size, and 6 wt% clay size. Ground water of the state is mostly "hard" to "very hard," containing up to several thousand parts per million TDS. Adobe soil clay mineralogy is varied, but the clay-size fraction commonly consists of about equal proportions of expandable clay minerals (smectite and mixed-layer illite/smectite) and non-expandable clay minerals (kaolinite, illite, and chlorite). Calcite ($CaCO_3$) is nearly ubiquitous, especially in the clay- and silt-size fractions. Analyses of soil mixes show that the soluble part (principally calcite) averaged 10 wt%, but ranged from 36 wt% to zero. The New Mexican climate in which calcium ions are retained in soils rather than leached produces many of the mineral constituents and physical properties of the state's earthen walls.

Adobe soils from other arid parts of the world are generally quite similar in particle-size, bulk mineralogy, clay mineralogy, and the amount of soluble minerals present, but adobe soils from tropical areas with considerable rainfall can be quite different. The West African nation of Ghana has earthen walls that appear to contain particles with finer average size; quartz and halloysite; and only a very small amount of soluble minerals. Therefore, different climates produce different types of adobe soils; different production techniques produce walls with different physical properties. Conservationists must consider these points when selecting appropriate preservation techniques for earthen architecture.

KEYWORDS

Adobe, clay minerals, mineralogy, climate, New Mexico

Introduction and History

Mud is one of the oldest building materials used by man. Some of the earliest remains of adobe structures are those discovered in the ruins of Neolithic farming villages in Mesopotamia dating as far back as 7000 B.C. [1]. The word "adobe" has its roots in Egyptian hieroglyphs denoting brick and evolved through Arabic and Spanish to its present form [2]. Spanish conquests of the New World spread the use of wooden molds to produce a standard adobe brick. Today, the word "adobe" is used to describe various earth building materials and techniques, usually referring to sun-dried adobe brick now used in the United States, but also applied to puddled adobe structures, mud-plastered logs or branches, and pressed-earth blocks and rammed-earth walls (pisè).

The first recorded use of adobe in the Americas was around 3000 B.C. in the Chicama Valley of Peru [3]; common use of earthen construction in the American Southwest probably does not predate the 10th or 11th century A.D., when the use of puddled adobe and rammed earth began [4,5]. Examples of adobe from this period can be seen at such New Mexican locations as Casa Grande and the multistoried Taos Pueblo (see fig. 1).

What is known as the Indian period of construction concluded upon arrival of the Spanish colonists in 1598; new techniques and forms of architecture were introduced into New Mexico [6,7]. Yet, because of the isolation of the region and bare survival conditions for the new settlers, the Spanish Colonial period was characterized by little technical or cultural advancement. Most buildings of this period were constructed much the way and of the same materials that Indians had used before.

The opening of the Santa Fe Trail in 1821 signaled the beginning of influence from midwestern and eastern states and lessening of the adobe influence in New Mexico. The 1846 occupation of the region by the U.S. Army, and in 1848 the annexation of the Territory of New Mexico, brought a flow of new materials and ideas. In the 1880's the railroad passing through the southwest provided new settlers and eastern building materials that included milled lumber, window glass, burned brick, and corrugated iron. But again, because of the isolation of the area, technology and building materials commonly used elsewhere were only slowly established in New Mexico. As a consequence, the American Southwest is the center for adobe construction of homes, churches, and commercial buildings, as well as of old military forts.

Present Conditions in the American Southwest

Although adobe structures are found throughout the United States, the four contiguous southwestern states--New Mexico, Arizona, Texas, and California--contain 97% of this country's adobe buildings [8]. In 1980, an estimated 176,000 adobe homes occupied by over half a million people were in use in this country, with approximately 1500 new adobe homes built each year. Of the four southwestern states, New Mexico is the acknowledged leader in the adobe market, each year commercially producing between 3-4 million adobe brick. This figure represents about half of the total annual production and represents between 600-800 new dwellings each year. In 1980, about 12% of all buildings in the state, or 59,000 buildings, were estimated to be constructed of adobe and in use.

Earthen Construction

Several different varieties and sizes of earthen brick have been produced throughout the American Southwest; these include traditional adobe, semistabilized adobe, New Mexican terrónes (cut-sod brick), quemado (burnt adobe), and machine-pressed-earth block; in addition, rammed-earth walls are constructed without brick [9]. The two major types of adobe brick currently produced in New Mexico are traditional adobe brick and semistabilized adobe brick.

Figure 1. Five-story Taos Pueblo originally built of puddled adobe (made by patting mud into a wall-shape) before the introduction of Spanish adobe forms. Note mud plastering that is carried out each year to maintain the structure.

Figure 2. Adobe mud placed in 10-brick ladder forms at the commercial adobe yard of New Mexico Earth in Alameda, New Mexico.

Figure 3. Earth Press III pressed-earth-block machine manufactured near Grants, New Mexico, and set up near a wall under construction in Velarde, New Mexico.

Figure 4. Exterior 60-cm-thick rammed-earth wall of home under construction by Soledad Canyon Earth Builders, Mesilla, New Mexico.

Often referred to as untreated or sun-dried adobe brick, traditional adobe is made with soil composed of sand, silt, and clay. Straw is sometimes added to prevent excessive cracking during drying. The moistened soil mixture commonly is packed into a brick-like mold, released (see fig. 2), and allowed to dry or "cure" for several weeks before use.

Semistabilized adobe brick was developed by major adobe producers in New Mexico and is classified as a water-resistant brick because of the addition of 3-5 wt% of a stabilizer or water-proofing agent. The stabilizer is used to protect the brick from damage by rainstorms during the curing process. Asphalt emulsion is the primary stabilizer because of the ease of use and the low cost, but 5-10 wt% portland cement is also used. Semistabilized adobe is made the same way as traditional adobe, except for mixing the stabilizer into the adobe soil prior to packing it into a form.

Fully stabilized adobe brick is defined by the New Mexico Building Code as water-resistant adobe made of soil with certain admixtures that limit the brick's seven-day water absorption to less than 4 wt%. A fully stabilized adobe brick usually is made with 6-12 wt% asphalt emulsion. Exterior walls constructed with stabilized mud mortar and brick require no additional protection and can be left exposed without stucco. The production of fully stabilized adobe brick is very low because most walls are stuccoed with water-resistant plaster, and the additional waterproofing agent adds extra cost without returning added benefits.

A breakdown of New Mexican adobe-brick production in 1987 shows 27% were traditional (untreated) bricks, 68% were semistabilized, and 5% were stabilized. These percentages appear to be fairly typical of the 1980's, as semistabilized adobes were generally accepted as the adobe brick of choice. Prior to the 1970's, most adobe buildings were built with traditional adobes.

Pressed-earth block presently makes up a small portion of earth brick currently used in New Mexico [10]. The CINVA-RAM hand-operated press was developed by a Chilean engineer in the 1950's and has been used in New Mexico, but the majority of pressed-earth blocks in the state are made by gasoline- or diesel-powered machines (see fig. 3) Several have been designed and used in New Mexico in the past to press the adobe soil mixture into a form, minimizing the amount of time required between forming the block and placing it into the wall. Portland cement or asphalt emulsion has been used to partly or fully stabulize pressed-earth blocks. In 1987, 28 pressed-earth-block machines in New Mexico produced about 642,000 earth blocks, but all pressed-earth-block producers were small-volume and/or part-time, or non-commercial.

Rammed-earth homes commonly have much thicker walls than most other earthen dwellings, up to about one m thick. Wooden or metal concrete forms are put in place on stone or concrete footings and 15-20 cm thick layers of moistened soil are put between the walls of the forms. Hand or hydraulic tampers are used to pound the soil into the shape of the form and reduce the volume of the mixture by 25-30%, into a dense and firm compaction. After multiple layers of the tamped soil reach the desired height, forms are removed and the wall is allowed to dry (see fig. 4). Portland cement is the common stabilizer used. Producers indicate that rammed-earth walls continue to harden, or cure, during the first year after construction. During 1987, the state's two rammed-earth construction firms built three homes [11].

<u>Characterization of New Mexico Adobe Soil</u>

Analyses by the New Mexico Bureau of Mines and Minerals Resources of mud bricks from buildings abandoned or under repair show old adobes are compositionally the same as modern adobes, except that they lack stabilizers now in common use. The soils for various types of New Mexican adobe walls are all similar in composition, but with interesting minor variations primarily based on production techniques. These differences may cause variations in the effectiveness of preservation methods used on earthen architecture

<u>Geology</u>--Soils used by New Mexico's present-day adobe producers, and probably past adobe producers as well, are principally from stream deposits, particularly Holocene (Recent) terrace deposits and older, loosely compacted geologic formations, such as the

Santa Fe Group (Tertiary) located in the Rio Grande valley. Although adobe structures are scattered over the entire state, they are most common in abandoned and present-day communities along the Rio Grande and its tributaries. Nearly 80% of commercial adobe producers are between Taos in north-central New Mexico and Belen near the center of the state, and most of them use a sandy loam (50% clay and silt) associated with or derived from the Santa Fe Group.

Particle-size Distribution--Forty one analyses of the soil used in 1988 by 38 commercial earth block and wall producers indicate that the soil material contains 27-89 wt% sand-and-larger-grain-size, 8-68 wt% silt-size, and 1-15% clay-size grains (Table I, see fig. 5). The average grain-size composition was 67 wt% sand-and-larger, 27 wt% silt, and 6 wt% clay. The wide variation of particle sizes, particularly in the sand-and-larger-size and silt-size grains, affects the penetration of preservatives sprayed or painted on walls. The smaller the average grain size, the more surface area is involved, and the more preservative is needed to stabilized a wall to a given depth. Adobe walls with high clay- and/or silt-size content would need the most. Clay-size particles also act as molecular sieves and catalysts in some cases.

Soil used for earthen building materials in New Mexico is coarser than was expected and contained far less clay-size particles than most New Mexico producers indicate. The common statement is that their mix is usually one-half sand and one-half "clay" or "fines" (silt and clay); however, commercial adobe soils range from 85 to 99 wt% non-clay particles. When drying adobes develop excessive cracks because of the abundance of clay-size particles, producers add straw and/or additional sand to the mud mixture.

Large-scale commercial adobe producers use adobe soils with less clay-size material than do small-scale commercial and non-commercial adobe producers. Some of the former are as low as about 1 wt% clay, whereas many of the latter are between 8 and 15 wt% (Table I). In part, this is because large-scale commercial adobe producers use stabilizers which not only protect blocks from rain damage, but aid in consolidation of the drying soil mix as well. These stabilizers, particularly asphalt emulsion, may inhibit penetration by some preservatives into walls.

Bulk Mineralogy--X-ray diffraction analyses of whole-rock samples indicate the major constituents of adobe soils are quartz and feldspar, with lesser amounts of (in order of abundance) calcite, clay minerals, and gypsum. The quartz, feldspar, most of the clay minerals, and some of the calcite are derived from the mechanical/chemical breakdown of older rocks units. Some of the clay minerals, much of the calcite, and all of the gypsum is precipitated from evaporating ground water.

Clay Mineralogy--Although smallest in percentage of size fractions in earth construction material, clay-size grains are the most compositionally variable (Table I). In general, clay minerals in this size fraction consist of about equal parts of expandable clay minerals (smectite and mixed-layer illite/smectite or I/S), non-expandable clay minerals (kaolinite, illite, and chlorite), with minor quartz, calcite, and feldspar [12]. The range of clay-mineral compositions is shown in Table 1. The smectite is universally calcium-rich and the I/S is disorganized, randomly interstratified smectite and illite. Chlorite was found in only two samples, and vermiculite, sepiolite, and palygorskite were not found in this study. While in minor amounts, clay-sized calcite was found in nearly every adobe soil sample.

Expandable clay minerals tend to be more "sticky" than non-expandable varieties and thus are more effective in binding silt and sand particles together. Expandable clay minerals also form colloidal suspensions with water and therefore moisture, whether as rainfall or ground water, has the greatest effect on adobe soils with the largest proportion of smectite and I/S.

For past producers, as well as those in the present, expandable clay minerals were sometimes a problem. Cracking of drying adobe brick in New Mexico is due most probably to the relatively large proportion of smectite and I/S in adobe soil: soils with higher clay content, but lower smectite and I/s content, will have less tendency to crack. Cracking is extreme on windy days when the shrinking clay structure is changing rapidly. Drying slowly over many relatively calm days allows multiple layers of finely crystalline calcite (and some gypsum) to form on a clay-size scale strengthening the bricks and preventing cracks.

Hydrology--Ground water near the Rio Grande valley is generally hard to extremely hard, containing total dissolved solids (TDS) ranging from about a hundred parts to several thousand parts per million [13,14]. Soluble salts, notably calcium carbonate and calcium sulfate, are precipitated as this water evaporates. White crusts of these salts at the surface are common in marshy areas of the state during most of the year. Caliche layers from prolonged precipitation of calcium carbonate from ground water just below stabile surfaces and calcium-rich soils, are common in New Mexico, particularly in the older sedimentary units close to the Rio Grande [15].

Leaching tests with EDTA (ethylenedinitrilotetraacetic acid) on 25 adobe soils (see fig. 6) indicate the soils contain an average of about 90% insoluble and 10% soluble material; the latter is dominantly calcite and some gypsum. In this study, soluble material ranged from 36 wt% to essentially zero. Adobe soils with the smallest amount of soluble material were also the highest in sand and larger-size particles.

Adobe Soils from other Parts of the World

The climate plays a large role in dictating what is acceptable adobe soil. Arid regions, similar to New Mexico, should have similar average grain size, bulk mineralogy, clay mineralogy, and soluble mineral matter [16]. Tropical areas with a great deal of precipitation, at least during some of the year, may have quite different adobe soils. Some parts of the West African nation of Ghana have seasonal high rainfall and considerable earthen construction. Mud is commonly rolled into balls that are then placed into walls, patted into shape, and allowed to dry. Walls produced in this manner stand without a water-resistant stucco for tens of years with only minor damage [17].

Areas with greater rainfall than evaporation have a dominance of aluminum-rich clay minerals, in particular, kaolinite, but only minor soluble compounds of calcium, magnesium, sodium, and potassium. Deeply weathered soils consist essentially of quartz (most commonly as very fine-grained sand and silt) and kaolin minerals. Abundant rainfall commonly produces halloysite, a variety of the kaolin group of minerals with loosely attached structural water; it is probably the most common clay mineral in tropical soils. Halloysite has the poorest crystallinity of any of the kaolins; it expands and contracts with fluctuating water content, but it also irreversibly loses water as dryness approaches.

Patting the mud into shape is an equivalent to the rammed earth technique used in New Mexico and produces a dense wall of very fine-grained material. The thoroughly dried mud wall contains dewatered halloysite, which cements structural (quartz) grains together. Clay-size halloysite grains at the wall surface act as a natural stucco which prevents penetration of moisture into a wall more than a few millimeters. Erosion of the wall is therefore a very slow process, even during torrential downpours

Summary and Conclusions

Samples of commercial earth construction materials from many different parts of New Mexico, the principal adobe-producing state, commonly contain varying amounts of quartz, feldspar, calcite, and clay minerals. The clay-size fraction is the smallest of the particle sizes. Clay minerals in this fraction consist of about equal parts of expandable and non-expandable types, but the proportions of individual clay-mineral groups (kaolinite, illite, smectite, I/S, and chlorite) vary widely. Soluble nonclay minerals in the clay-size fraction, especially calcite, are nearly ubiquitous.

In much of New Mexico, calcium ions are retained in soil and water. When earth block and walls harden, calcium, mainly as carbonate, appears to crystallize on a microscopic scale and aids in binding mineral grains together. This occurs during the "curing" process that may last several weeks and that producers believe is vital for producing high-quality block and walls. Calcium-rich, fine-grained cementing agents in earth blocks and walls in New Mexico are the dominant factor in the hardening of earth bricks and walls. The arid climate that causes retention of calcium ions therefore is essential in the production of the earth-wall construction materials used in New Mexico and the rest of the American Southwest.

The results of particle-size, bulk mineralogy, clay mineralogy, and leaching analyses of New Mexican samples are quite typical of results of tests on adobe soils from similar arid climates in other parts of the world. The results of those tests on adobe soils from tropical counties where soluble ions are leached away are quite different. Therefore, the climate producing adobe soils must be considered in the interrepretation of analytical data. Similarly, the climate may be the deciding factor in which preservation technique to use, because the success of those techniques is very dependent on the physical properties and mineral constituents of earthen architecture.

Acknowledgments

I have benefited greatly from fruitful discussions with Edward W. Smith regarding earthen construction materials. Reviews by Neville Agnew and Michael Taylor helped focus the article on the subject of the conference. Tanya Brickell and John Hall assisted in sample preparation and analysis.

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TABLE I.
ANALYSES OF ADOBE SOILS FROM 42 COMMERCIAL NEW MEXICAN PRODUCERS

	PARTICLE SIZE			CLAY MINERALOGY				
PRODUCER	SAND+ %	SILT %	CLAY %	SMEC	I/S	ILL	KAO	CHLOR
				-------parts in 10-------				
A. D. Adobe	85	13	2	4	1	3	2	0
Adobe Internatl.	69	22	9	3	TR	2	5	0
Adobe Bricks of NM	81	16	3	6	1	2	1	0
Adobes Unlimited	67	31	2	1	2	3	4	0
Aguires Services	52	45	3	1	3	2	3	1
Big "M" Sd. & Grv.	34	60	6	3	2	2	3	0
Correction Indust.	54	40	6	0	3	3	4	0
Coyote Adobe	72	24	4	3	3	2	2	0
DeLaO Adobe	71	21	8	1	4	3	2	0
Eloy Montano	61	35	4	2	2	3	3	0
Gallegos Sd. & Grv.	84	10	6	2	4	1	3	0
Huston Constr.	68	25	7	1	4	3	2	0
Huston resample	69	25	6	2	2	2	4	0
Jaquez Constr.	69	26	5	2	2	1	5	0
Paul Martinez	55	36	9	1	4	2	3	0
Medina's Adobe	76	9	15	1	5	2	2	0
Ralph Mondragon	54	42	4	1	5	1	3	0
New Mexico Earth	78	18	4	2	4	1	1	2
Northern Pueblos								
Nambe Pueblo	40	55	5	2	2	4	2	0
Pojoaque Pueblo	57	37	6	3	4	2	1	0
Otero Bros.	68	20	12	3	3	1	3	0
Picuris Pueblo	41	55	4	3	3	2	2	0
Isleta Pueblo	89	10	1	2	3	2	3	0
Isleta resample	89	10	1	2	3	2	3	0
Ridge Adobe	76	9	15	TR	3	3	4	0
Rio Abajo Adobe	77	21	2	1	1	2	6	0
Archie Rivera	83	15	2	1	3	3	3	0
Jim Rivera	60	31	9	1	2	1	6	0
Rodriguez Bros.	63	30	7	1	4	3	2	0
Steve Romero	77	19	4	4	2	2	2	0
Manuel Ruiz	73	20	7	2	4	2	2	0
Roman Sandoval	27	68	5	1	3	3	3	0
Candelario Saucedo	66	26	8	2	2	2	4	0
Carl & L. Steiner	55	37	8	1	4	2	3	0
The Adobe Farm	50	41	9	2	3	2	3	0
The Adobe Patch	80	18	2	TR	2	5	3	0
Tim's Adobe	81	8	11	1	4	3	2	0
Elias Vargas	83	16	1	1	4	4	1	0
Trini Velarde	48	47	5	2	3	2	3	0
Western Adobe	83	13	4	2	4	1	3	0
AVERAGE	**67**	**28**	**6**	**2**	**3**	**2**	**3**	**0**
Maximum	89	68	15	6	5	5	6	2
Minimum	27	8	1	0	1	1	1	0

Sand+ is sand-and-larger-grain size; clay material is divided between smectite (SMECT), random mixed-layer illite/smectite (I/S), illite (ILL), kaolinite (KAO), and chlorite (CHLOR), and in parts of 10; trace (TR) is less than 1/2 part in 10

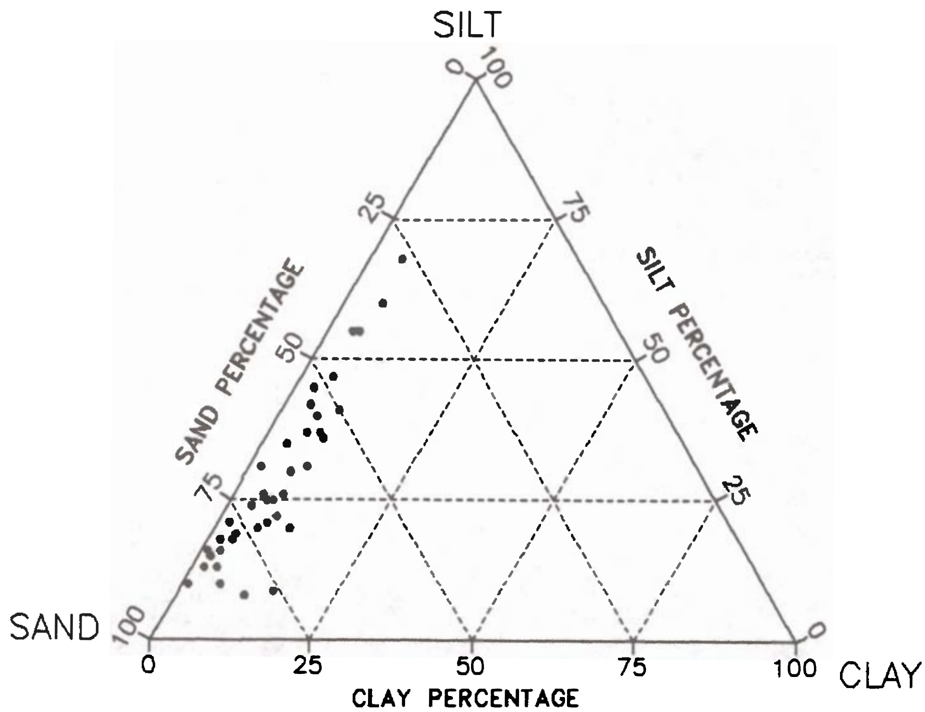


Figure 5. Plot of sand and larger, silt, and clay grain-size fractions of 42 production adobe soils used in New Mexico. The diagram shows the dominance of the larger particle sizes compared to clay grain-size material.

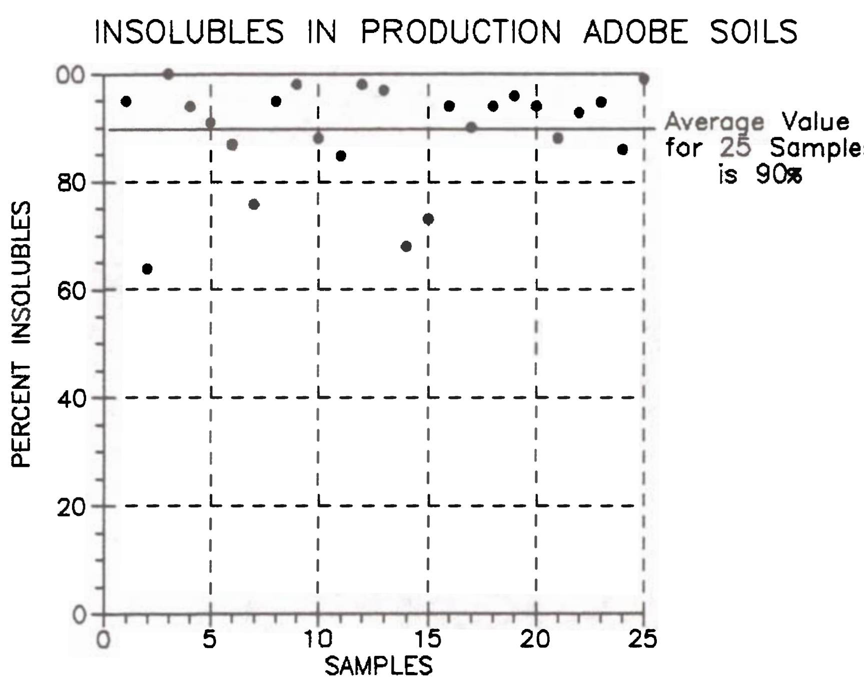


Figure 6. Summary of leaching analysis of 25 adobe soils used in New Mexico. The average insoluble fraction (insoluble in EDTA after boiling for four hours) is 90%.

ADOBE MINERALOGY:
Characterization of Adobes from around the world.

Richard Coffman(*)[1], Neville Agnew[1], George Austin[2], and Eric Doehne[1]

1. The Getty Conservation Institute, 4503 Glencoe Ave., Marina Del Rey, CA 90292.
2. New Mexico Bureau of Mines and Mineral Resources, Campus Station, Socorro, N.M., 87801

(*) Author to whom correspondence should be addressed

ABSTRACT

A mineralogical survey of adobes from several historic and archaeological earthen structures in different parts of the world was undertaken to evaluate the variability in durability and resistance to weathering. The mineral composition (including clay type and quantity) and overall particle size distribution was determined for each sample. A study of the effectiveness of two chemical consolidants (a silane and an isocyanate) on the adobe samples was also performed. Preliminary results indicate that variation in clay mineralogy and grain size distribution play significant roles in the success or failure of chemical consolidation.

KEYWORDS

Adobe, clays, composition, erosional susceptibility, grain-size distribution, mineralogy, x-ray diffraction analysis

Background and Introduction

Earth has been used in the construction of shelters by mankind for thousands of years [1], and approximately 30 percent of the world's present population still live in earthen dwellings [2]. Adobe, and other forms of earthen structures, are manufactured throughout the world and use the simplest of materials: earth (clay, silt and sand) and water. The actual composition depends upon the raw materials which vary around the world. Due to the inherent weakness of earth in water, most surviving archaeological and abandoned historic structures are located in arid or semi-arid environments. Many inhabited, and therefore maintained, earthen structures exist in areas of high rainfall. Because adobe is one of the earliest known materials, it is not surprising that a number of the world's significant cultural structures are composed of adobe. However, many of these historic structures have a very tenuous existence.

Research into consolidation and preservation of historic earthen structures has become an important subject at the Getty Conservation Institute (GCI). The focus at the GCI has been on adobe, or sun-dried earthen bricks. Many important historic adobe buildings, particularly archaeological structures, are in danger of being lost due to exposure to the elements, specifically water. Therefore, the need for an effective method of protecting adobe against deterioration by water has become apparent. For modern adobe construction the solution is much easier because different additives can be combined with the initial adobe mixture. For historic adobe this is not possible. However, one promising method is treatment with chemical consolidants. This approach has been attempted in the past, generally with poor results [3].

Early research into treatment of adobe with chemical consolidants conducted at the GCI demonstrated that hexamethylene diisocyanate-derived polymers and silane esters were most effective in protecting adobe from deterioration by water [4]. Ongoing research has shown that different adobes react differently to attempted chemical consolidation. This appears to be controlled by the composition of the adobe, specifically the clay mineralogy, the particle-size distribution, and the physical condition, especially internal cohesion of the starting material. Because of this it was decided that adobes from around the world would be examined in an attempt to determine the range of responses and most effective methods for consolidating different materials. This involved characterizing the composition (i.e., bulk mineralogy, clay types and their relative amounts, organic matter content, amount of solubles) and particle-size distribution of the different samples.

Materials and Methodology

Adobe samples were collected from eight sites. These include historic adobe from China, Egypt, El Salvador, Israel, and New Mexico, and modern adobe from New Mexico and southern California (USA). The historic adobe from New Mexico (FS-1) is approximately 100 years old and was collected from the ruins of the former army post Ft. Selden in southern New Mexico. Two samples of historic adobe from China were collected from two different sites. One is from a 400 to 600-year-old Ming dynasty fort (CH-1) located near Datong in northern China. The other is from an 1100 to 1400-year-old Tang Dynasty temple (CH-2) located near Dunhuang in northwestern China at the edge of the Gobi desert. Two samples of 1365-year-old adobe from El Salvador (ES-1, ES-2) were obtained from a site located at El Ceren. The Egyptian adobe (EG-1) was obtained from the Temple of Karnak which is located on the Nile and is approximately 3500 years old. Samples of two different 3800-year-old adobes from Tel Dan (TD-1, TD-2) in northern Israel were also evaluated. The modern adobe from New Mexico was made at the site of Ft. Selden (FS-2). Two samples of modern adobe from southern California were also evaluated. One was made near the city of Ventura (CA-1), north of Los Angeles, the other from the

TABLE I.
BULK ADOBE MINERALOGY

SAMPLE	MINERALOGY
CA-1	Q>> Pl >> Cl > Kf
CA-2	Q>> Kf > Pl > Cl
CH-1	Q > Ct > Pl > Cl
CH-2	Q >> Ct >> Kf > Pl > Cl
EG-1	Q > Pl > Kf > Cl
ES-1	Q > Cl > Fs
ES-2	Q ≥ Fs > Cl
FS-1	Q >> Kf > Pl > Ct > Cl
FS-2	Q >> Pl > Kf > Cl > Ct
TD-1	Q >> Cl > Pl
TD-2	Q > Ct >> Cl ≥ Fs

Codes for bulk mineralogy :
Cl = clay, Ct = calcite, Fs = feldspar,
Kf = orthoclase, Pl = plagioclase,
Q = quartz

TABLE II.
CLAY-SIZE FRACTION (<2μ)
MINERALOGY

SAMPLE	MINERALOGY
CA-1	I > K ≥ I/S > S (+/- Q, Fs)
CA-2	I ≥ I/S > K > S (+/- Q, Fs)
CH-1	I/S > I ≥ Ch > K > S (+/- Ct, Q)
CH-2	I > Ch > I/S > K > S (+/- Q, Ct, Fs, D)
EG-1	K ≥ S > I/S (+/- H)
ES-1	Ha (+/- Fs)
ES-2	Ha (+/- Fs)
FS-1	I/S > K > I > S (+/- Q, Ct, Al)
FS-2	I ≥ K > I/S > S (+/- Q, Fs, Ct)
TD-1	I >> I/S ≥ K (+/- Q,H,Z)
TD-2	K >> I/S > I (+/- Q, Ct)

Codes for clay-size fraction mineralogy:
Ch = chlorite, Ha = halloysite, I = illite,
I/S = mixed-layer illite and smectite,
K = kaolinite, S = smectite ; (+/-
indicates non-clay minerals detected
but their relative abundance not
determined : Al = allophane, Ct =
calcite, D = dolomite, Fs = feldspar, H =
halite, Q = quartz, Z = zeolite)

TABLE III.
GRAIN-SIZE DISTRIBUTION

ADOBE	SAND+ >62μ	SILT 62-2μ	CLAY <2μ
CA-1	8 %	65 %	27 %
CA-2	82 %	17 %	1 %
CH-1	30 %	58 %	12 %
CH-2	14 %	65 %	21 %
EG-1	4 %	84 %	12%
ES-1	57 %	40 %	3 %
ES-2	66 %	31 %	3 %
FS-1	43%	33 %	24 %
FS-2	9 %	53 %	38 %
TD-1	5 %	59 %	36 %
TD-2	27 %	67 %	6 %

Santa Fe Springs area of Los Angeles (CA-2).

Whole rock and clay mineralogy of the adobes were obtained by X-ray diffraction (XRD) analyses. Particle size distribution was determined using mechanical sieving for the sand-and-larger-(sand+) and silt-size particles, and a settling tube for the clay-size fraction. The grain size distribution is reported as a percent of sand-size and greater (>62μm), silt-size (62-2μm), and clay-size (<2μm). Examination using scanning electron microscopy (SEM) permitted visual comparison of the clay morphology from different adobes, and elemental compositions were obtained by energy-dispersive X-ray analysis (EDS). Additional analyses include determination of soluble components such as calcium and magnesium carbonates and sulfates by EDTA (ethylenediaminetetraacetic acid) leaching, determination of the amount of volatiles and organic matter by combustion, and natural resistance to disaggregation in water. The amount of volatiles and organic material was determined by taking a representative sample of adobe and grinding it into a powder. This was then placed in a tared crucible and weighed, heated in an oven at 300° C for approximately 18 hours, then removed and allowed to cool in a desiccator, and reweighed. The resulting weight loss includes moisture as well as organic matter. The erosional susceptibility or resistance to disaggregation in water was determined by placing a sample of each adobe into a beaker of deionized water and observing how quickly it disaggregated.

In addition to the above tests, several of the adobe samples were treated with chemical consolidants: a silane, manufactured by ProSoCo Inc. as Conservare Stone Strengthener H™ (SS-H). This is a tetraethylorthosilicate with methyltriethoxysilane for water repellency and contains 75% active solids in an acetone-MEK solvent. The SS-H is applied directly to the adobe without dilution with additional solvents. The other consolidant was an isocyanate, manufactured commercially by Mobay Corporation under the name Desmodur N-3390™ (DN-3390™). This is produced as a 90% solution in an aromatic hydrocarbon and *n*-butyl acetate mixed solvent and must be diluted with appropriate solvents before application to the adobe. Both the silane and isocyanate polymerize by reacting with moisture present in the adobe and from the atmosphere. Some of the adobe samples treated with the above chemicals were reconstituted into plugs prior to treatment. This was accomplished by mechanically disaggregating pieces of the original adobe, mixing the material with water, and pouring the resulting slurry into small (22 mm x 40 mm) cylindrical molds. The filled molds were placed in an oven set at 50° C and allowed to dry. The resulting plugs were removed from the molds and given time to equilibrate with the ambient laboratory conditions (22° C, 40%-50% RH), then treated.

Analytical Results

Bulk and clay mineralogies determined by XRD analyses are listed in tables I and II, respectively. As shown in table I, most adobes are composed of quartz, feldspar, clay, and sometimes calcite. The clay minerals of the adobes are listed in table II, in order of decreasing abundance. Illite, kaolinite, smectite, and mixed-layer illite-smectite are the most common clays detected. However, halloysite was identified as the only clay mineral present in the samples from El Salvador and was not detected in any other sample. Both samples from China contain minor chlorite, which is also absent from all the other adobe samples. Other unusual minerals include an amorphous, hydrated aluminosilicate mineral, possibly allophane. The presence of allophane is inferred based on the appearance of a high background level in the 15° to 40° 2θ range, which was only observed on the FS-1 XRD pattern. A high background signal is characteristic of amorphous materials, in contrast to crystalline materials which generate distinct peaks on an XRD pattern. Trace amounts of halite were also detected in the clay-size fraction of EG-1, and TD-1. Even though halite is a common evaporite mineral found in arid regions, it was surprising to find it in the clay-size fraction since it should have been dissolved out during the separation procedure. Calcite, when identified in the bulk analyses, was also found in the clay-size fraction.

Table III lists the grain-size distribution for the adobe samples. For most of the samples, the majority of the material is silt-sized, followed by clay-sized, then sand+-sized particles. Adobe compositions, based on grain-size, are plotted on a sand-silt-clay ternary diagram in figure 1. The shaded area represents the preferred range of soil composition for making adobe [5]. Most of the adobes examined do not have grain-size distributions

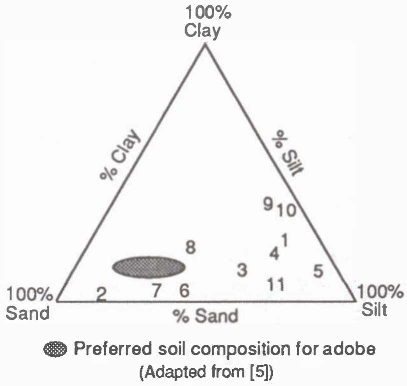


Figure 1

Figure 1. Ternary diagram showing sand-silt-clay compositions of adobe. The cross-hatched area is the preferred range of soil composition for making adobe [5]. Numbers mark the composition of the adobes examined for this study. 1=CA-1, 2=CA-2, 3=CH-1, 4=CH-2, 5=EG-1, 6=ES-1, 7=ES-2, 8=FS-1, 9=FS-2, 10=TD-1, 11=TD-2.

Table IV.
EDTA Leaching Analyses

ADOBE	% Insolubles
CA-1	not analyzed
CA-2	99 %
CH-1	75 %
CH-2	77 %
EG-1	97 %
ES-1	96 %
ES-2	97 %
FS-1	not analyzed
FS-2	not analyzed
TD-1	93 %
TD-2	73 %

Table V.
Combustion Analyses

ADOBE	ΔWT. %
CA-1	5.3 %
CA-2	2.8 %
CH-1	2.0 %
CH-2	3.8 %
EG-1	5.9 %
ES-1	6.4 %
ES-2	9.6 %
FS-1	1.5 %
FS-2	1.3 %
TD-1	6.4 %
TD-2	5.2 %

which correspond to this range.

Figure 2 shows SEM photomicrographs of two adobes (TD-1 and TD-2) demonstrating the variability of clay crystallinity. Figure 2a (TD-2) shows well-developed, crystalline clay particles, whereas in figure 2b (TD-1) the clay exhibits poor crystallinity and appears more colloidal. The SEM photomicrographs in figure 3 demonstrate the range of clay particle size. Figure 3a (TD-2) shows a predominance of clay particles greater than a few µm in size. However, in figure 3b (FS-1), most of the distinguishable

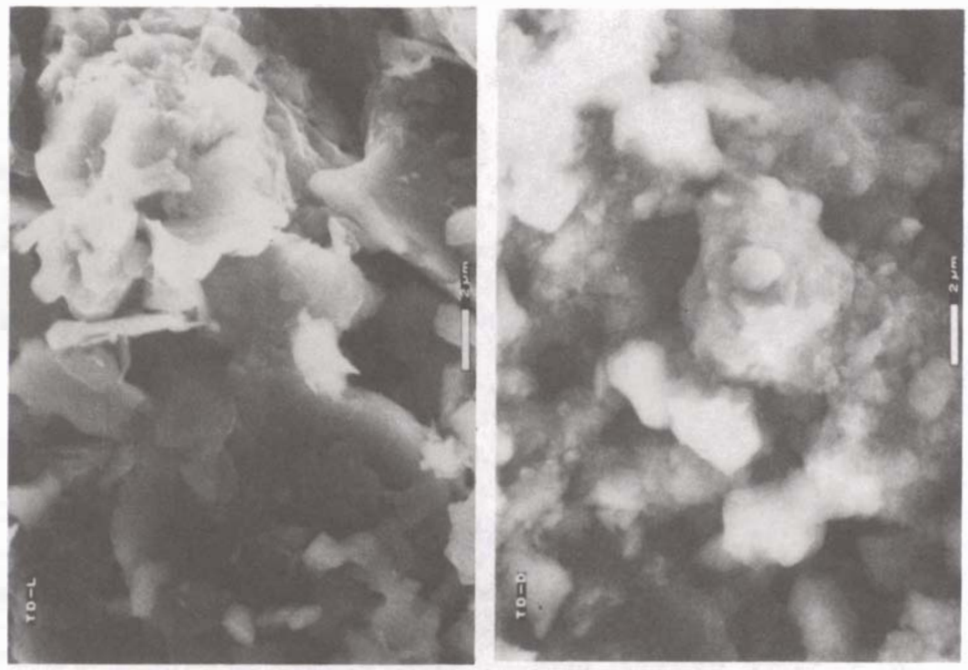


Figure 2. Environmental SEM secondary electron micrographs of clay particles from two different adobes. a) Photograph on left is sample of Tel Dan light adobe (TD-2) which exhibits fairly coarse-grained clay particles with well-developed, crystalline shapes. b) Photograph on right is sample of Tel Dan dark adobe (TD-1) in which the clay is poorly crystalline and more colloidal in appearance. The white scale bar in both photos is 2µm.

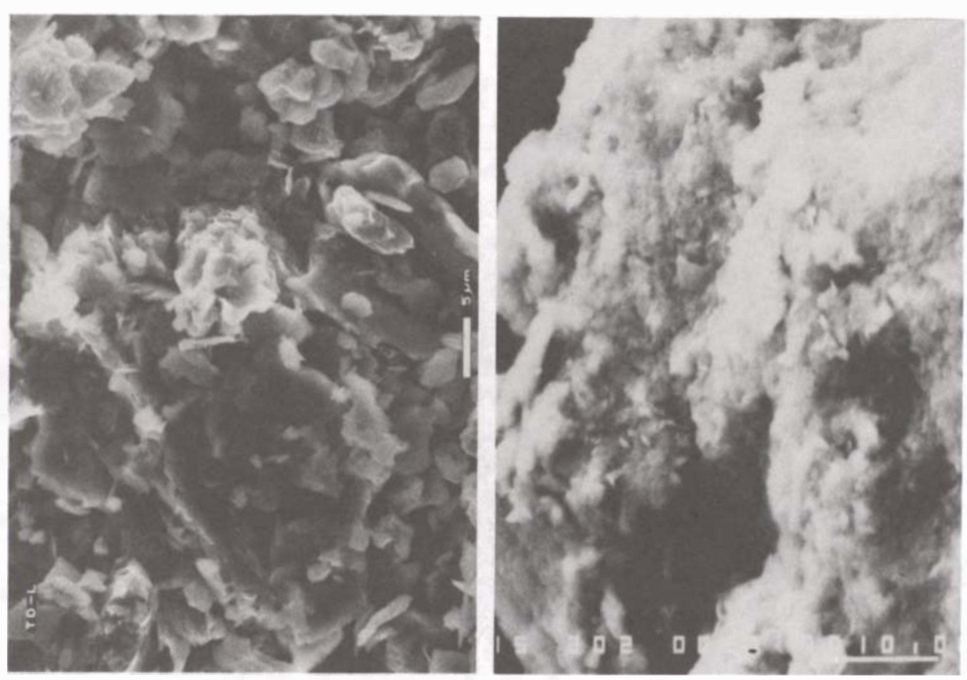
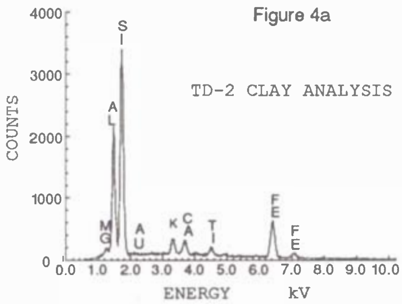


Figure 3. Environmental SEM secondary electron micrographs showing the difference in clay grain size for two adobes. a) Photograph on left is of Tel Dan light adobe (TD-2) with most of the clay particles being several µm in size or greater. b) Photograph on right is of Ft. Selden adobe (FS-1) where most of the clay particles are sub-µm in size. Magnification in both photos is x2000 and scale bar is 5µm in figure 3a and 10µm in figure 3b.



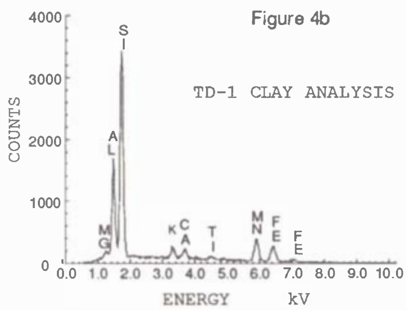


Figure 4. Energy dispersive X-ray spectra of clay particles shown in figure 2. a) Tel Dan-2. Note the low Si/Al ratio and the presence of Mg, Fe, Ca, K, and Ti. b) Tel Dan-1. Note the higher Si/Al ratio and unusual Mn concentrations in addition to Fe, K, Ca, Ti, and Mg. The Mn may be due to the presence of colloidal Mn oxides associated with the clays.

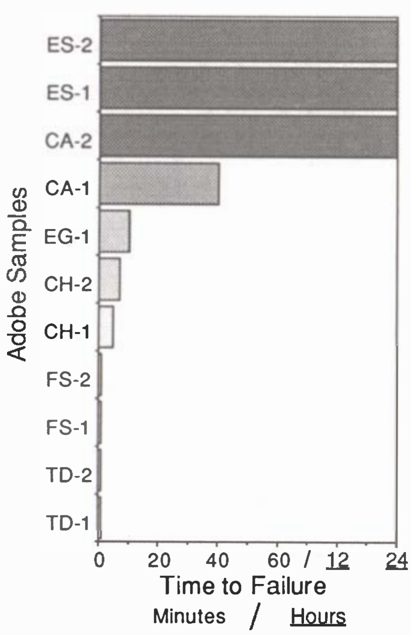


Figure 5

Figure 5. Bar-graph showing length of time adobe samples remained submerged in water before disaggregating. Samples ES-1, ES-2 and CA-2 remained intact after 24 hours of submergence.

clay particles are sub-µm in size. Figures 4a and 4b illustrate the contrasting energy-dispersive X-ray spectra for the clays in figure 2.

The results of the EDTA leaching experiments are presented in table IV which lists the percent of insoluble material remaining after leaching. The leached material should include all carbonates and salts (sulfates and/or chlorides) but not silicates or oxides. Table IV shows that adobes contain varying amounts of soluble materials ranging from only a few percent up to 27% by weight.

Combustion of the samples resulted in varying amounts of weight loss, from 9.6% to as little as 1.3% (table V). This is apparently due to differing amounts of incorporated water and/or organic matter. Initial heating (up to 105° C) indicates that some weight loss (0.2% to 2%) is due to water or other volatiles such as CO_2, within the inorganic fraction. The rest of the weight loss on combustion is interpreted to be from organic matter.

Resistance to disaggregation of different adobes in water is variable. Some types prove to be resistant while others disaggregate immediately upon contact with water. Results of the disaggregation experiment are presented in figure 5. The most resistant adobes appear to be the 1365 year old material from El Salvador (ES-1, ES-2) and the recent adobe from Los Angeles (CA-2). All three of these adobes were in water for more than 24 hours without disaggregating, even when mildly agitated. Although the adobes from Egypt and China survived less than one hour they did require some agitation before they disaggregated. However, the adobes from New Mexico (FS-1, FS-2) and Israel (TD-1, TD-2) experienced complete disaggregation in less than one minute with no agitation.

Samples of original adobe and plugs made by reworking the adobe from New Mexico (FS-1, FS-2) and Israel (TD-1, TD-2) were treated with DN-3390™ or SS-H™ in an attempt to consolidate and render them resistant to deterioration in water. The reconstituted samples of FS-1, FS-2 and TD-2 were effectively consolidated and rendered resistant to disaggregation by water. However, treatment of original pieces of those adobes was not as successful. Although the original pieces were rendered water resistant, they were not consolidated in the same manner as the reconstituted material. Sample TD-1 could not be successfully treated whether it was in its original form or reconstituted. As soon as this material came in contact with the consolidant-solvent solution, it immediately disaggregated. This response is due to the polar organic ketone solvents used with the consolidants. This type of reaction has not been observed for any other adobe or sand-clay mixture, and the reason for this behavior is not, as yet, clear to us.

Discussion

The predominance of quartz and feldspar in adobe is expected since they are the most common minerals on the earth's surface, in addition to being very resistant to mechanical and chemical breakdown. The presence of clay is necessary since it is the binding material in adobe which holds the much larger quartz and feldspar grains together. The most common clays detected (illite, kaolinite, smectite, and mixed-layer illite-smectite) are the by-products of the chemical breakdown of silicates and other less stable minerals which are no longer present. Halloysite forms by weathering, or hydrothermal alteration of feldspars, feldspathoids, or other silicates [6], and its occurrence in the adobes ES-1 and ES-2 was a surprise. However, in a subtropical area such as El Salvador, the weathering and chemical breakdown of feldspars is not as unexpected as it would be in an arid region. The occurrence of chlorite in the China samples indicate a source that is very different from the source of the other adobes, since no chlorite was detected in any other sample. Although the presence of allophane in FS-1 was unexpected, its occurrence is not unreasonable. Allophane is formed by the chemical breakdown of very fine-grained or glassy volcanic material which is common in that area of southern New Mexico. What is intriguing is that no indication of the presence of allophane has been found in the recent adobe manufactured at the same location. The occurrence of calcite is not surprising since it is a common mineral found in arid or semi-arid environments. Calcite also acts as a cement, occurring naturally or by the addition of lime which, when mixed with adobe and water, is converted over time into calcium carbonate (i.e., calcite) by reacting with atmospheric CO_2. In addition, those samples (e.g., CH-1, CH-2, and TD-2) containing significant amounts of material soluble in EDTA also contain a significant amount of calcite. This indicates that much of the EDTA-soluble material may be attributed to calcite instead of salts or sulfates.

The SEM micrographs help relate bulk measurements such as grain size to the degree of crystallinity and morphology of the adobe matrix. Each adobe has a different appearance in the SEM that is related to the clay type, size, and degree of weathering. Samples that tended to disaggregate readily had a more open texture, or less coherent matrix than samples that performed well in those tests. The EDS spectra show that the adobe compositions are fairly similar, with Si, Al, K, Ca, and Mg (rarely Ti, Na, or Mn) as the elements present. One sample (TD-1) contained significant Mn concentrations, suggesting that colloidal Mn oxides might be associated with the clays in that sample.

The amount of combustible material varied from sample to sample. Sample ES-2 exhibited the greatest weight loss with 9.6%, while the least weight loss occurred in the case of FS-2 with 1.3%. Although a number of the adobes contained visible organic matter such as straw, grass or wood, they did not demonstrate the greatest weight loss. For example sample TD-1, which did not contain observable organic material, lost more weight (6.4%) than did some samples containing visible organic matter (CH-1, CH-2, and TD-2). Sample TD-1 also exhibits more swelling upon mixing with water than any other adobe examined. This may be attributed to the presence of amorphous or colloidal material which absorbs and releases large amounts of water during hydration and dehydration. At the other end of the spectrum two of the adobes (FS-1 and FS-2) contain minimal amounts of combustible material (1.5% and 1.3%, respectively). This indicates that the amount of weight loss by combustion is controlled more by the presence of inorganic, hydrophilic components, such as absorptive clays or colloids, than by visible organic matter.

The variability in the rate of disaggregation in water may be due to several reasons. Adobe samples ES-1 and ES-2 were buried in 625 A.D. by a volcanic eruption [7]. It is very possible these adobes were hardened by baking since the temperature of the ash fall which buried them has been estimated to have reached 1000° F (~540° C)[7]. This baking is also demonstrated by the presence of carbonized organic material which is very apparent in the samples. The heat would render the adobe much more resistant to disaggregation than unbaked adobe. Adobe sample CA-2, which was also very resistant to disaggregation, had a water-repelling additive mixed in when the adobe was manufactured. This was confirmed during attempts to disaggregate and analyze the sample. This is not surprising since additives have been used in the manufacturing of adobe since the 1930's [8]. Samples EG-1, CH-1 and CH-2, while less resistant than the above adobes, survived noticeably longer than the New Mexico and Israel adobes. This may be a result of the presence of organic material which acted as a binder, coupled with nonabsorbent clays and/or calcite.

The difference in performance of the chemical consolidants on reconstituted and original pieces of adobe appears to be a function of the physical condition of the samples. Reconstituted adobe is very compact with the sand, silt, and clay particles in close contact. However, the sample, as collected, is often less compact, with more pore space separating the grains. When chemical consolidants are applied to reconstituted adobe the constituent particles are very closely packed and the chemical is able to chemically consolidate the adobe by reinforcing the existing clay-silt-sand bonds. When weathered adobe is treated the particles are not as close together, therefore the consolidant does not perform as effectively as on reconstituted material. The reaction of sample TD-1 is puzzling and at this time we can only speculate on the cause. It is possible that TD-1 contains amorphous or colloidal material which rapidly absorbs the polar solvents used with the silane and isocyanate and causes expansion.

Summary

The composition of most historic adobes is, as expected, comprised mainly of quartz, feldspars and clays, and sometimes calcite. The most noticeable differences between the various adobes are the type and amount of clays present, the grain-size distribution and mineralogical proportions. The presence or lack of organic material is dependent upon the local adobe building customs. The durability of the adobe is a function of the clay type, grain-size distribution, and presence of additional binding material. Those adobes which proved to be most resistant to disaggregation had been heat- or chemically-treated. The weakly resistant adobes contained either clays which are not especially absorbent (e.g. kaolinite or illite), calcite which acts as a cementing agent, or sufficient organic matter to inhibit rapid breakdown upon exposure to water. Those adobes which disaggregated quickly in water contained more clay than the resistant adobes, or the same amount of clay and a higher sand content, and/or less organic material. Thus, as is well known, either too much clay or too much sand will result in an adobe which will not be resistant to rapid deterioration by water.

The ability or inability of adobes to be chemically consolidated appears to be controlled by the clay mineralogy, and/or the physical state of the adobe. Adobe containing a clay component which is incompatible with the solvent-consolidant solution being used will prove difficult to treat. Likewise very dry, friable, and weathered adobe is more difficult to consolidate than fresh, compact adobe. This latter problem may be countered by pre-treating the adobe with an acetone-water solution to re-hydrate the clays, as shown by preliminary tests. This may also re-compact the adobe sufficiently to permit consolidation. The former problem is still unsolved, and present work is attempting to find a technique to overcome the solvent incompatibility.

Acknowledgements

We would like to thank Bryan Amiri of the Getty Conservation Institute and Tanya Brickell and John Hall at the New Mexico Bureau of Mines and Mineral Resources, who prepared adobe samples and helped to evaluate them. ElectroScan Corporation (Wilmington, MA) generously made their environmental SEM available for some of the images. We would also like to extend our appreciation to our colleagues in China, Egypt, El Salvador, Israel, and Ft. Selden, New Mexico for their assistance in obtaining adobe samples from those localities.

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NINETEENTH CENTURY NEW YORK STATE EARTHEN HOMES: AN INVESTIGATION OF THEIR MATERIAL COMPOSITION

Lee Dassler
238 West 106th St., apt. 4D
New York, N.Y., 10025
U.S.A.

ABSTRACT

Preliminary materials analysis of the wall matrices of the two dozen extant earthen buildings constructed in New York State during the nineteenth century expose several intriguing factors regarding original design, overall durability, and historic interpretation of these uncommon structures. Samples taken from the historic earthen walls of the puddled-clay and clay-lump homes were analyzed to determine their basic behavioral properties. Standard granulometric analysis, salt tests, tests determining liquid and plastic limits, plasticity indices, x-ray diffraction analyses of clay and silt components were conducted, as well as earthen mortar and stucco analysis.

KEYWORDS

New York State, nineteenth century, clay-lump, puddled-clay, x-ray diffraction.

Introduction

> I will arise and go now, and go to Innisfree,
> And a small cabin build there, of clay and wattles made:
> Nine bean-rows will I have there, a hive for the honey-bee,
> And live alone in the bee-loud glade.
>
> William Butler Yeats

At least since the Roman Empire, earthen building materials have been employed by masons in Europe and on the British Isles in attempts to create healthy, efficient, and inexpensive living environments. From the center of Lyon to the "bee-loud glades" of Yeats' Innisfree, theories, recipes, and technologies were transferred from mason to mason until the late 18th century when architects and other progressive thinkers began publishing their theories and building designs relating to earthen construction. 19th century earthen homes in the eastern United States manifest the transport of these technologies across the Atlantic: new world translations of an old world lexicon. In New York State, at least forty earthen buildings were constructed in the 19th century as evidence of some form of trans-Atlantic communication.

The purpose of this project was threefold: to begin an analytical survey of the construction methods and materials of the extant New York State earthen homes, to document the present condition of the structures, and to outline preservation guidelines for future conservation efforts. In light of the thorough historic investigation of these buildings presented by Pieper at this conference, historic documentation was considered secondary to materials analysis in this study.

The primary questions addressed were: are any patterns discernible regarding clay/aggregate/fiber proportions, binders such as lime or dung, or brick size; and does the evidence conform to specifications which appear in period publications regarding earthen construction? Do construction patterns conform to geographic or geologic distribution? Do trends fall into chronological or typological periods? Can findings delineate specific masons? In addition, can the materials analysis define the parameters of further testing programs needed to aid owners in the conservation of their homes?

Testing Program

Wall and exterior coating samples from the two dozen extant homes were taken during site visits throughout 1989-1990. Sample quantity and location varied considerably, depending upon building design, condition, and the owner's ease of mind; sample quantity ranged from full brick to film-canister size. As optimum test results arise from numerous random samples, an attempt was made to spread out inquiries. In general, the earthen walls were accessible at the gable-ends of attics, behind built-in cabinets, in basements between sill and floor joists, and behind exterior clapboard.

Once the samples were coded, photographed and logged relative to origin (see table I), initial classifications were made according to the Munsell Soil Chart and ASTM D2488-84, "Description and Identification of Soils-Visual/Manual Procedure". Chemical spot tests were run determining salt content, pH levels, and the presence of urea. Combustion tests performed on partial samples determined relative quantities of organic components. Polarized light microscopy was used to determine specific fiber content of stuccoes and wall matrices, and cross sections of all samples were observed microscopically as well as macroscopically. Qualitative sedimentation analysis (Ashurst) and partial quantitative granulometric tests (Teutonico) followed defining particle-size distribution. Further quantitative tests were run on a sub-group of ten samples, including a full granulometric analysis and the derivation of plasticity indices (Teutonico). In order to ascertain any possible link between structural behavior and clay type, x-ray diffraction analysis of silt and clay particles was performed on ten samples selected for their geographic distribution.

Where possible, samples of bearing wall mortars were analyzed, as well as exterior stuccoes. While it is known from the literature and from material evidence that lime/hair/sand stuccos were the standard exterior finish originally, 75% of the homes have had their surface treatment redefined by either "Sacrete", wood clapboard, brick veneer, pressed shingle, or some type of exterior siding. What triggered the shift from stucco to the other siding options? Were there problems with incompatible materials, architectural design flaws, or were maintenance routines and skills the culprit?

Coupled with historic and pathological evidence, it was hoped that these tests would provide some answers, or at least momentum to otherwise stubborn questions regarding building technology and chronology, as yet unanswered. Considering the publications available at the time in the Northeast regarding design, manufacture, and assembly of unburnt brick and earthen buildings, how does the physical evidence of the mason's labor compare?

Figure 1: Location of Earthen Homes in New York State

<u>Summary of Test Results</u>

Contrary to specific procedures detailed in period publications known to be responsible for the fifty-year building movement, New York State earthen home builders added inorganic binders to their unburnt brick matrix, and seemingly varied the dimensions of brick molds from site to site. While knowledge of local clay type or behavior was not deemed important to earthen home builders in the nineteenth century, x-ray diffraction results of clay components of the extant earthen homes verifies that the clays employed were relatively inactive, and common to all the homes despite their dispersed geographic locations.

75% of the New York State earthen homes have had their original exterior lime stuccoes redefined by cementicious stuccoes, clapboard, or siding, in either the nineteenth or twentieth century. To date it has been thought that these alterations were responding to material failures. Results from this testing program offers evidence to the contrary: clays in the wall matrices are inherently inactive, and original lime stuccoes still adhere to the earthen walls, even to those walls which have been camouflaged. Poor initial design or construction which may have triggered stucco failure was ruled out as well. Therefore, conclusions drawn from this study point towards lax maintenance routines as the cause of replacement sidings.

date	Location	Code	Clay Lump Size	Orig./Current Siding
1833	Penfield	PN2	monolithic-puddled	Lime wash/mud-lime slurry
1835	Penfield	PN1	monolithic-puddled	Lime stucco/clapboard
1836	S.Dansville	SD1	6"l x 11"w x 6"h	Lime stucco/'sacrete'
1844*	Geneva	G1	11"l(?) x 5½"w x 5"h	Lime stucco/press shingle
1844	Bath	B2	11½"l x 5¼"w x 5½"h	Lime stucco/ lime stucco
1845	Bath	B1	unknown	Lime stucco/cement.stucco
1845++	Geneva	G9	15"l x 6"w x 5¼"h	Lime stucco/ 'sacrete'
1845++	Geneva	G11	11½"l x 10½w x 5½"h	Lime stucco/ lime stucco
1846	Geneva	G10	15"l x 12"w x 5"h	Lime stucco/lime-concrete
1847	Geneva	G2	14"l x 10"w x 6"h	Lime stucco/clapboard/siding
1847*	Interlaken	I1	14"l x (6½/14)"w x 5"h	Lime stucco/clapboard
1848	Trumansburg	T1	unknown	Lime stucco/lime stucco
1849++	Geneva	G3	unknown	Lime stucco/clapboard
1849	Phelps	PH1	10"l x 10"w x 5"h	Clapboard(?)/clapboard
1850*	Geneva	G7	10"l x 10"w x 5"h	Lime/stucco/clapboard/siding
1850++	Geneva	G4	16"l x 10"w x 6"h	Lime stucco/lime stucco
1851	Oswego	O1	10"l x 5"w x 6"h	Lime stucco/ brick veneer
1853	Springfield Ctr.	SC1	12"l x 12"w x 6"h	Lime stucco/clapboard
1855*	Geneva	G6	10"l x 10"w x 5"h	Lime wash or stucco/clapboard
1855*	Geneva	G8	18"l x 12"w x 6"h	Lime stucco/clapboard/siding
1855*	Geneva	G12	14"l x (?")w x 6"h	Lime Stucco/clapboard/siding
1855*	W. Bloomfield	WB1	unknown	Lime stucco/clapboard/siding
1855*	W. Bloomfield	WB2	unknown	Lime stucco/ clapboard/siding

* Denotes that the house was built by or before this year.
++ It is thought that these homes were all built by the same contractor.

Table I: Chronological Listing of New York State Earthen Homes

Carbonate and Salt Tests

Although treading by oxen or cattle was the suggested mode of wall material preparation, none of the period treatises published in the United States concerning earthen construction advised the addition of animal dung binders; nor were carbonate binders mentioned. However, all twenty-four earthen samples included chemical as well as mechanical binders.

All samples tested negative for chlorides and sulfates and positive for phosphates and nitrates. Those samples which tested negative for carbonate binders were also those which tested strongest for phosphates and nitrates, indicating the use of animal dung as binder. Lime additives were either visible with the naked eye in small lumps, or microscopically apparent as thin washes in those samples which tested positive for carbonates.[1] While the addition of lime most likely reflects an adaptation of standard masonry practices, the presence of organic binders (given the lack of published information on the subject) suggests a vernacular common sense approach towards earthen materials. (See table II).

New York State Earthen Buildings:
Combustion Test Results/ Fibers present/ Nitrates-Phosphates

Sample	Combustion % Weight Loss	Non-digested Fibers	Digested Fibers	Nitrates/ Phosphates
B1A1	5.1	whole straw	+	++
B2A1	5.7	straw/ wood	+	++
G1A1	7.14	whole straw	+	++
G2A1	3.25	whole straw	-	-+
G3A1	4.7	confer. wood	-	+
G4A1	5.14	whole straw	+	++
G5A1	4.8	straw	+	++
G6A1	4.8	whole straw	-	++
G7A1	3	whole straw	+	++
G8A1	5.3	whole straw	+	-+
G9A1	5.4	straw/wood	-	-+
G9A2	2.4	straw	+	++
G9A3	2.4	straw/wood	-	++
G10A2	4.6	straw/wood	-	+
G11A4	5.3	straw/wood	+	+
G12A1	5.8	wheat straw	+	+
I1A1	4.3	wheat straw	+	++
O1A1	4.1	wheat straw	+	+
PH1A1	5.0	wood/grasses	+	+
PN1A1	31.0	whole straw	+	+++
PN2A1	33.5	whole straw	+	+++
SC1A1		whole straw	+	++
SD1A1	4.9	straw/wood	+	++
T1A1	5.9	grasses/wood	+	++
WB1A1	5.3	whole straw	+	+++
WB2A1	5.6	whole straw	+	+++

Table II: Organic, Carbonate and Physical Binders in Earth Walls

Combustion Tests

5g (untreated and ground with mortar and pestle) of each sample were placed in a crucible and heated for 15 minutes over a hot flame: the resultant weight losses, indicative of the presence of organic matter such as dung, were then compared. All samples lost approximately 5% of their original weight via combustion (representing a variety of organic components: straw, hair, wood bits, and minor amounts of dung), except for the two monolithic-walled homes in Penfield (PN1 and PN2) which lost 31% and 33.5% relatively, indicative of a far greater inclusion of organic components in their earthen walls.

Fiber Examination

Small grasses, wheat straw, mechanically chopped soft and hard woods, human and animal hair were the fibers found via unaided and microscopic visual techniques. Logically, the same samples which tested negative for carbonate binders were also those which included digested straw and grass fibers along with whole stalks, whereas digested fibers were not apparent in the bricks which contained lime.

The four whole and half brick samples donated to the study illustrate the mason's understanding of the importance of fibers in reducing unwanted shrinkage: in the larger samples whole pieces of straw intertwine to form a complete organic armature for the clay/silt/sand body to rest upon (see fig. 2). The two clay daubin homes located in Penfield include layers of whole straw in nearly equal volumetric proportions to the layers of soil.

Figure 2: SC1A1 Partial Brick Exposing Straw Binder

Granulometric Composition of New York State Earthen Matrices				
Sample	%Gravel	%Coarse Sand	%Fine Sand	%Silt/Clay
B1A1	0	1.1	3.2	95.7
B2A1	0	.35	2.11	97.54
G1A1	0	4.02	19.32	76.66
G2A2	0	1.12	15.63	84.2
G3A1	0	24.93	47.94	9.67
G4A1	0	19.9	59.40	18.2
G5A1	0	.75	31.23	68.3
G6A1	0	13.7	67.4	24.3
G7A1	0	.34	3.8	93.24
G8A1	2	37.26	51.4	17.9
G9A1	3	3.4	42.6	48.9
G10A1	0	7.73	67.20	24.1
G11A1	0	11.8	73.3	13.6
G12A1	0	6.9	75.6	2.1
PH1A1	3	12.5	39.1	46.3
PN1A1	0	12.21	16.7	79.0
PN2A1	0	6.0	24.8	65.3
SC1A1	0	25.	5.0	70.o
SD1A1	4	12.5	20.9	57.5
T1A1	0	7.3	38.4	53.06
WB1A1	0	2.3	31.4	61.5
WB2A1	0	.34	13.0	83.1

Table III: Granulometric Composition of Earthen Walls

Granulometry

A schism is apparent between the granulometric mix of the earthen matrices of homes built in Geneva during the mud wall building movement phase, and the other earthen homes in the study. Except for G5 (1881) and G12, (built before 1855 as a simple cottage) which exhibit slightly coarser mixes, the Geneva homes are composed primarily of lean clays: 80+% passing the #200 sieve (75μ). The homes outside of Geneva, both clay lump and daubin, contained a more diverse granulometric matrix. (See table III.)

Liquid Limit, Plastic Limit, and Plasticity Indices

Plasticity indices of the ten samples tested ranged between 11.9 and 2.6, classifying most of the fines as either lean clays or silts (ASTM D 2487). Interlaken and Oswego (the distinctly grey soils in a collection of otherwise brown soils) were the only silty soil classifications derived. By plotting liquid limit vs. plasticity indices, it was found that only one of the homes tested, G4, had what could be considered a cohesive matrix, the others fall into the mild to slightly cohesive range (Guillard and Houben).(See fig. 3.)

The activity coefficient of the clays was estimated graphically as well, the activity coefficient being equal to the ratio of the plasticity index and the percentage of particles less than 2μ contained in the samples. All samples tested fell into the non-expansive, inactive range: activity coefficient ≤ 0.75 (see figs. 4,5). This alone helps to explain why the 150 year old mud walls have held without considerable deformation despite waning maintenance routines and failed protective surf

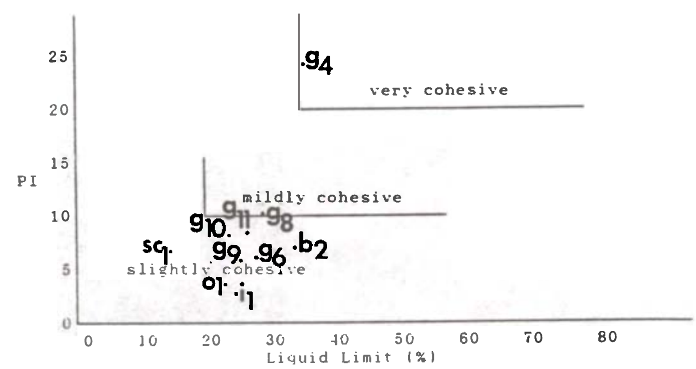

Figure 3: Cohesiveness of Soils

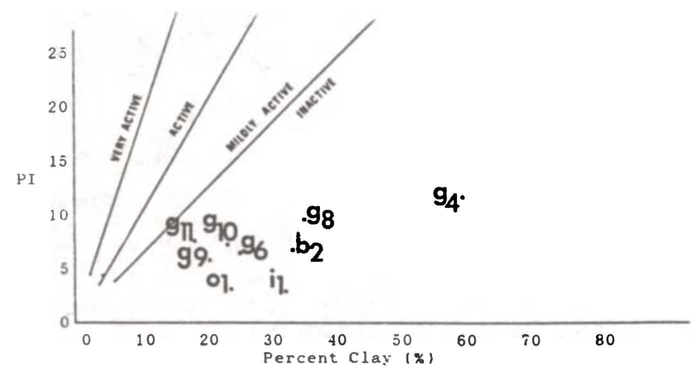

Figure 4: Activity Coefficient of Soils

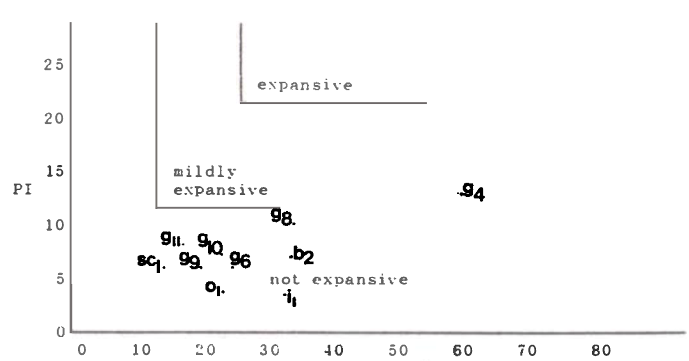

Figure 5: Expansivity of Soils

Given Geological Information and XRD Results

In general, the topology and surface geology of the area of New York State under concern reflects the presence and recession of the Pleistocene Age Wisconsin Glacier which deposited large masses of clayey beds in its wake. These Pleistocene clays are either lacustrine (deposited beneath post-glacial lakes Erie and Ontario) or formations of more recent local lake deposits. The clays are all slightly calcareous (Ries).

X-ray diffraction analysis of clay-sized particles was performed by Richard April at Colgate University on ten samples culled from the entire group representing earthen buildings in Bath, Geneva, Interlaken, Oswego, Penfield, South Dansville, Trumansburg, and West Bloomfield. The samples were ground, acid digested, sieved and centrifuged; the retained clay particles (diameter ≤ 2μ) were tested dry and saturated (with ethylene glycol). Despite the dispersed geographic locations of the earthen homes, silt components were consistently quartz and feldspars while the clay components were predominantly chlorites and illites (see table IV,V).

Sample	≤75μ/ Air Dry
B2A1	mica/ quartz/feldspar
G2A1	quartz/feldspar
G6A1	quartz/feldspar
G11A1	quartz/feldspar
I1A1	quartz/feldspar
PN1A1	quartz/feldspar
SD1A1	quartz/feldspar
T1A1	quartz/feldspar
WB1A1	quartz/feldspar

Table IV: Summary of XRD Results: the Silt Components

Sample	≤2μ/Carb Rem/Air Dry	≥2/Carb Rem/Ethylene Glycol
B2A1	chlorite/illite very minor I/S	chlorite/illite
G2A1	chlorite/illite weathered mica or mixed layer I/S	chlorite/illite trace expandable clay
G6A1	chlorite/illite	chlorite/illite minor smectite/ mixed I/S
G11A1	chlorite/illite weathered mica or mixed layer I/S	chlorite/illite trace expandable clay
I1A1	chlorite/illite mixed layer I/S	chlorite/illite trace smectite
O1A1	chlorite/illite possible mixed I/S	chlorite/illite trace smectite
PN1A1	chlorite/illite mixed layer I/S	chlorite/illite trace smectite
SD1A1	chlorite/illite mixed layer I/S	chlorite/illite
T1A1	chlorite/illite mixed layer I/S	chlorite/illite

Table V: Summary of XRD Results: the Clay Components

Earthen Mortar and Exterior Stucco Analysis

Earthen mortars employed in the clay lump walls contained an average of 16% lime, while the bricks themselves contained an average of 2.3% lime.

No pattern exists between the plasticity indices of the earthen walls, the percentage of lime in the exterior stuccos or earthen matrices, and circumstantial evidence of exterior stucco failure (i.e. current surface treatment). Therefore it is concluded that the inherent or composed nature of the original materials was not responsible for stucco adhesion problems. (See table VI.)

Plasticity Index and Surface Treatment, verses
% Binder in Original Stucco and Earthen Wall

Sample	PI	Surface Treatment	% orig.stucco	% earthen wall
B1	-	cement stucco	-	1.8
B2	6.5	lime stucco *	17	0
G1	-	shingle	1.8	1.7
G2	-	siding	-	3.2
G3	-	clapboard	-	1.5
G4	11.9	lime stucco *	-	0
G5	-	cement stucco	-	3.0
G6	8.8	siding	-	2.8
G7	-	siding	-	3.0
G8	9.4	siding	-	0.6
G9	5.1	cement stucco	17	1.9
G10	6.6	lime stucco *	30	0.4
G11	5.3	lime stucco *	20	1.9
G12	-	siding	17	2.3
I1	2.6	clapboard	22	3.0
O1	3.1	brick	24	2.2
PH1	-	clapboard	-	1.3
PN1	-	mud plaster	22	2.5
PN2	-	clapboard	-	9.3
SC1		clapboard	-	3.7
SD1	-	cement stucco	34	4.9
T1	-	lime stucco *	-	2.7
WB1	-	siding	-	0.6
WB1	-	siding	-	0.6

* original surface treatment

Table VI: Current Surface Treatment vs. Soil Activity and Binders

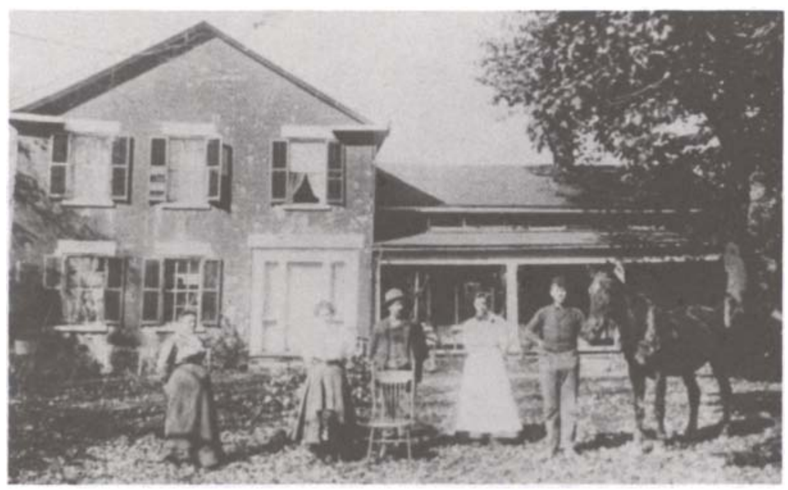

Figure 6: Luther Smith Home, Springfield Center, (19th Century)

Figure 7: Luther Smith Home with Wood Siding, (April 1990)

Conclusions

The two dozen homes built of earthen materials during New York State's period of rapid expansion represent a small but important phase in the history of American building technology. They manifest a democratic dedication towards affordable and healthy housing via cheaper building materials. The momentum of their construction was halted by an offset of its own evolution: the concrete industry. As a result of the development of the gravel wall, and eventually of Portland Cement, an entire facet of masonry was laid aside; the knowledge of traditional mason's materials, techniques, and recipes for proper stuccos to maintain the homes as they were originally designed, was lost. An overall aesthetic which relied upon the maintenance of exterior finishes became confused and desperate as repairs demanded attention from tradespersons who no longer understood the proper use of slaked lime/ hair and sand plasters; the results speak for themselves behind camouflaging layers of vinyl and aluminum siding.

What is needed is a complete study and documentation of the earthen homes in New York State so that they can receive a typological historic designation legitimizing their importance and encouraging proper care of the mud walls; an index and study of the other earthen homes in the Northeast and in Eastern Canada needs to be addressed as well. Unlike adobe homeowners in the American Southwest, owners of earthen homes in the Northeast have no one to turn to for advice when considering repairs or restoration projects; I suggest that the Historic Preservation Offices of eastern Canada and the northeastern U.S. states collaborate on a maintenance manual for earthen structures in the non-arid regions of North America in order to educate homeowners and tradespersons of appropriate analytical and maintenance techniques.

Acknowledgements

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CARACTERIZACION FISICA DE ADOBES DE CASTILLA-LEON (ESPAÑA)

J. Ordaz, F.J. Alonso y R.M. Esbert
Departamento de Geología. Universidad de Oviedo
c/ Jesús Arias de Velasco, s/n
33005 Oviedo (España)

ABSTRACT

Two Spanish adobes from localities of the Valladolid area (Villavicencio and Portillo), in the region of Castilla-León, have been selected in order to study their composition and some physical characteristics. Special attention was paid to the porosity and the properties most directly related to the presence and movements of water through their interior. The open porosity and pore size distribution was measured by means of mercury injection porosimetry. Some hydric tests -water immersion, water vapour absorption (hygroscopicity), capillary suction and water desorption (evaporation) -have been carried out. The open porosity is higher in those adobes with a higher content in carbonatic components (Portillo). In these materials, the pore-throat sizes are higher than in the adobes with a greater clay fraction (Villavicencio). On the contrary, the hydric behaviour of both types of adobes is similar.

KEYWORDS

Adobe, composition, physical properties, porosity, Spain.

Introducción

El barro crudo, sin cocer, ha venido empleándose en España desde la antigüedad en algunas construcciones populares, especialmente en la región de Castilla-León. Las aplicaciones han sido diversas (mortero de unión para mampostería de piedra, como revoque o entramado en muros, etc...), si bien el uso más importante y extendido en la arquitectura tradicional de esta región es como adobe en construcciones de diversos usos. El sistema de fabricación continúa siendo artesanal y muy similar en las diferentes comarcas, aunque el tipo de tierra sea distinto (1).

El objetivo de este trabajo es caracterizar una serie de adobes, tanto desde el punto de vista composicional y textural, como de sus propiedades físicas más directamente ligadas a la porosidad y al comportamiento frente al agua.

Materiales

Se han seleccionado, para el presente estudio, cuatro adobes, correspondientes a dos tipos distintos. Dos de ellos fueron muestreados en una casa particular (de unos cien años de antigüedad), en el término de Villavicencio de los Caballeros (a unos 70 Km al noroeste de la ciudad de Valladolid). Los otros dos adobes fueron extraídos de edificaciones actuales de la localidad de Portillo (a unos 20 Km al sureste de Valladolid).

Su aspecto macroscópico difiere en ambos tipos. Los de Villavicencio son de color pardo-marronáceo, mientras que los de Portillo son de tonalidades blanco-grisáceas. En los primeros, además, se distinguen fragmentos irregulares de ladrillo y caliza, de tamaño arena y grava (de hasta unos 2 cm). También se observan huecos o coqueras de algunos milímetros de diámetro. Los adobes de Portillo son de aspecto parecido, con fragmentos líticos y de ladrillo, de similar tamaño que los anteriores, y huecos de hasta 1 cm de diámetro.

La composición mineralógica media de los adobes estudiados, de acuerdo con los análisis de difracción de rayos X, se muestra en la Tabla I.

Tabla I
Composición mineralógica (%)

Mineral	Villavicencio	Portillo
Cuarzo	48	22
Feldespato	10	28
Illita	23	5
Caolinita + Clorita	7	-
Calcita	12	25
Dolomita	Indicios	20

Como puede observarse, los adobes de Villavicencio son mucho más ricos en componentes terrígenos que los de Portillo, siendo el porcentaje de granos siliciclásticos del 58 % y el de la fracción arcillosa (illita, clorita y caolinita) del 30 % . El tamaño de los granos apenas supera las 200 μm. El 12 % restante corresponde a los carbonatos (calcita). Figs. 1 y 2..

Los adobes de Portillo presentan menores contenidos en minerales terrígenos, destacando la elevada proporción de feldespato, y la pequeña fracción arcillosa, constituida exclusivamente por illita. El tamaño de los granos es también mayoritariamente fino. Los minerales carbonatados son cuantitativamente importantes (45 %), destacando la abundancia de dolomita. En algunas muestras se ha detectado yeso en porcentajes significativos (hasta el 15 %). Figs. 3 y 4.

Características físicas

Con el fin de caracterizar físicamente los adobes seleccionados se ha medido su porosidad abierta o efectiva, y se han realizado ensayos hídricos, determinándose diversos parámetros relativos al comportamiento del agua en dichos materiales.

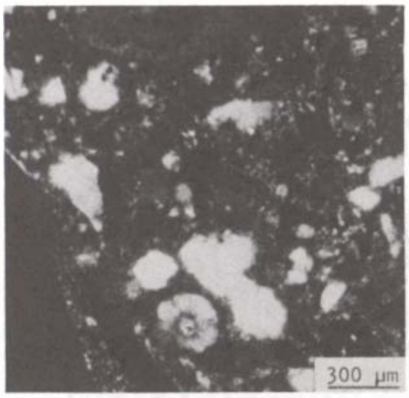

Fig. 1.- Aspecto de la textura del adobe de Villavicencio al microscopio de polarización (N.C.). Pueden observarse granos de cuarzo y la matriz arcillosa.

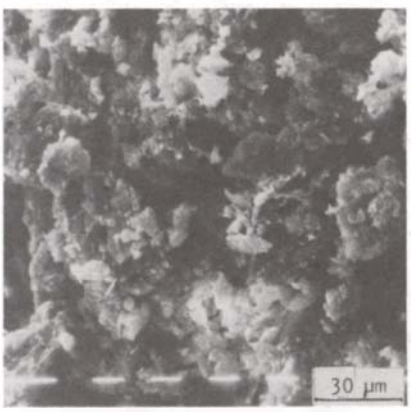

Fig. 2.- Detalle del adobe de Villavivencio al microscopio electrónico de barrido. Nótese la morfología de los granos y de los poros.

Porosidad: La porosidad abierta se ha medido mediante un porosímetro de inyección de mercurio, obteniéndose la distribución de tamaños (accesos) de los poros comprendidos entre 70 y 0,0037 μm. La técnica seguida fue la de doble inyección, la cual permite obtener el porcentaje de porosidad atrapada (2, 3).

Dos ejemplos representativos de curvas de frecuencia de tamaños de poros se muestran en los figuras 5 y 6. Los porcentajes medios de macropororos (radio superior a 7,5 μm), de microporos (radio inferior a 7,5 μm) y de la porosidad atrapada pueden verse en la Tabla II.

Tabla II
Porcentajes de porosidad

Muestra	Por. abierta	Por. atrap.	Macropor. r>7.5μm	Micropor. r<7.5μm
Villavic.	34	12	5	29
Portillo	42	18	11	31

En cuanto a los radios de acceso de poro, éstos son menores en las muestras de Villavicencio, situándose su valor más frecuente alrededor de 0.1 μm. Las muestras de Portillo, en cambio, presentan una bimodalidad más acusada, correspondiendo la microporosidad (11 %) a tamaños de acceso de poro de 0.5 μm y la macroporosidad (31 %) a 30 μm.

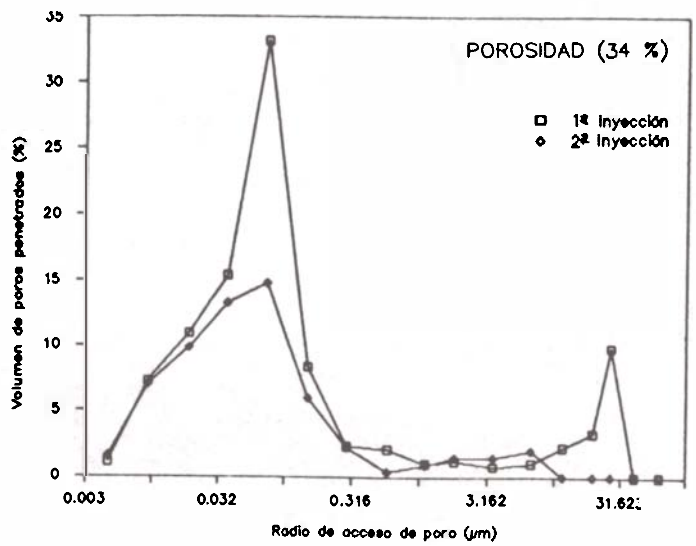

Fig. 5.- Curvas de frecuencia de la porosidad en función del tamaño de acceso a los poros en el adobe de Villavicencio. Se muestra la porosidad accesible al Hg (1ª Inyección), la porosidad libre (2ª Inyección) y su complementaria (porosidad atrapada).

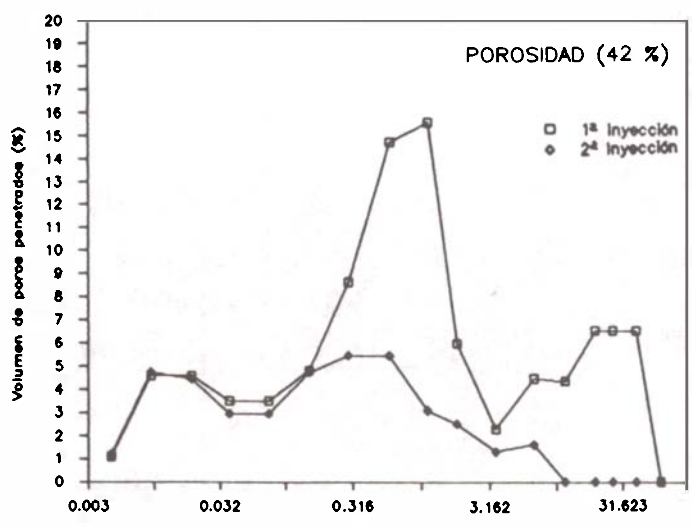

Fig. 6.- Curvas de frecuencia de la porosidad en función del tamaño de acceso a los poros en el adobe de Portillo.

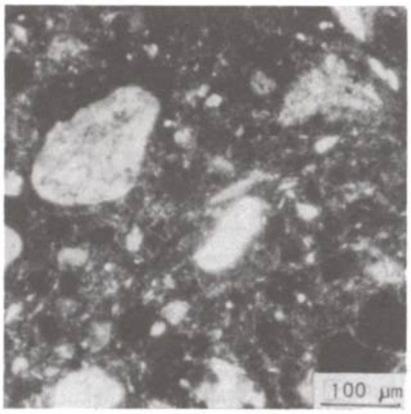

Fig. 3.- Aspecto de la textura del adobe de Portillo al microscopio de polarización (N.C.). Se observan algunos granos de cuarzo y calcita, inmersos en una matriz más carbonatada (micrita).

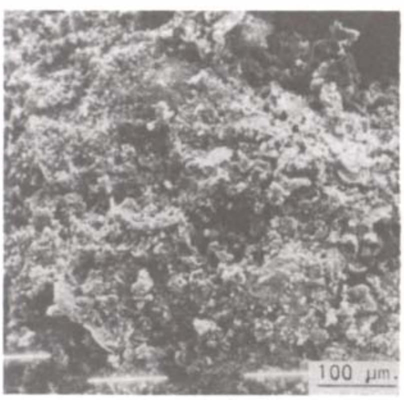

Fig. 4.- Detalle del adobe de Portillo al microscopio electrónico de barrido. Se pueden observar los componentes finos (arcillas) recubriendo los granos minerales.

Con objeto de conocer las propiedades hídricas y el comportamiento cinético del agua en los adobes bajo distintas condiciones, se han llevado a cabo cuatro tipos de ensayos: inmersión en agua, higroscopicidad, capilaridad y desorción. En todos ellos se han utilizado probetas de forma cúbica de aproximadamente 5x5x5 cm. Información complementaria sobre los procedimientos seguidos puede verse en (4).

Inmersión en agua: Las probetas, colocadas en cubetas individuales, se sumergieron en agua hasta alcanzar las 4/5 partes de su altura. La pérdida de material fue inmediata y muy rápida en todas las muestras en los primeros minutos del ensayo. A partir de los 10-15 minutos la pérdida de material tiende a disminuir. Las primeras grietas importantes en la superficie aparecieron a los 20-25 minutos.

Los desmoronamientos comenzaron a partir de los 40 minutos, tanto en los adobes de Villavicencio como en los de Portillo, aunque no en todas las probetas. El colapso total tuvo lugar al cabo de una hora aproximadamente, si bien algunas probetas mantuvieron todavía una cierta coherencia interna, sin agrietamientos evidentes al cabo de varias horas.

Higroscopicidad: Las probetas, previamente secas (a estufa, T: 60°C) y pesadas, fueron colocadas en una cámara a diferentes valores de humedad relativa: 65%, 75% y 95% ; y 20°C de temperatura. A intervalos de tiempo se pesaron las probetas, a fin de medir la cantidad de vapor de agua absorbida por las mismas en las condiciones ambientales fijadas.

Los resultados obtenidos para condiciones de equilibrio, expresados en forma de porcentaje respecto al peso seco inicial de las probetas, se muestran en la Tabla III.

Tabla III
Porcentajes de contenido en agua: Higroscopía

Muestras	H.r.:65%	H.r.:75%	H.r.:95%
Villavic.	0.95	1.15	1.85
Portillo	1.15	1.40	2.35

Capilaridad: Las probetas fueron colocadas en una cubeta sobre una base de más de 1 cm de papel de filtro, alcanzando el agua unos 3 mm de altura en las probetas al comienzo del ensayo. Las condiciones ambientales fueron: 75% de h.r. y 20°C de temperatura. La altura del agua alcanzada en las probetas fue midiéndose a intervalos regulares de tiempo. Con dichos valores se obtuvieron las curvas de ascensión capilar (Fig. 7), y a partir de ellas se determinó el coeficiente de penetración capilar (A), expresado en la fórmula (5): $X=A\sqrt{t}$; donde X es la altura (en metros) alcanzada en el tiempo t (minutos).

Los resultados han dado unos valores medios del coeficiente A para el adobe de Villavicencio de 2.7x10^{-3} m/min$^{1/2}$, y de 2.8x10^{-3}m/min$^{1/2}$ para el de Portillo. Estos coeficientes pueden considerarse normales, para este tipo de materiales porosos.

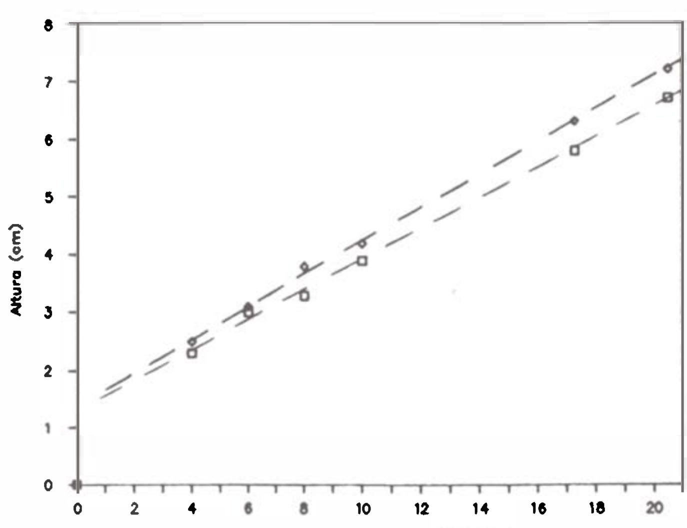

Fig. 7.- Ascensión capilar: Altura ascendida por el agua en función del tiempo durante las primeras horas de ensayo.

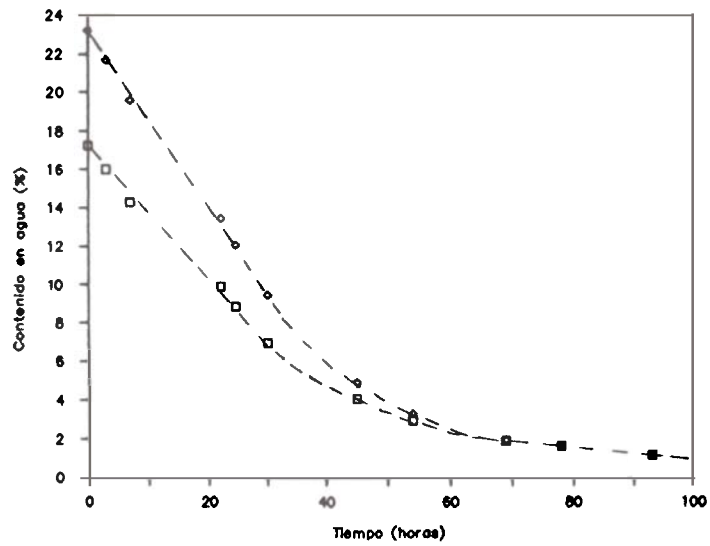

Fig. 8.- Curvas de evaporación: Contenido en agua en función del tiempo durante los primeros días de secado.

Desorción de agua: Probetas húmedas, que habían absorbido agua por succión capilar, fueron pesadas al inicio del ensayo, y dejadas secar en condiciones ambientales (70% de h. r. y 20°C de temperatura). Las probetas fueron pesadas a intervalos regulares, obteniéndose el contenido en agua de las muestras en función del tiempo (Fig. 8).

Puede observarse una pérdida de peso lineal durante el primer día. Los valores próximos al equilibrio no se alcanzan hasta pasados cuatro días.

Conclusiones

De los datos obtenidos y observaciones realizadas se deduce que, en general, las propiedades físicas de los adobes estudiados, y especialmente las hídricas, están relacionadas con la mineralogía y textura de los mismos. Así, la porosidad efectiva es mayor en aquellos adobes (Portillo) que muestran un mayor contenido en carbonatos. A su vez, en estos mismos materiales, el radio de acceso a los poros es mayor que en los adobes con mayor fracción arcillosa (Villavicencio).

El agua líquida (por inmersión) afecta prácticamente por igual a ambos tipos de adobes, ocasionando su colapso total en un término de aproximadamente una hora. La absorción de vapor de agua es similar en ambos tipos de adobes, a pesar de mostrar diferentes grados de porosidad y de tamaños de acceso a los poros. Esto podría explicarse teniendo en cuenta que los adobes que presentan las mayores porosidades (Portillo) son, a su vez, los que exhiben mayores tamaños de poro. Estos parámetros, al contrario que en otros tipos rocosos (6), parecen influir muy poco en el proceso de absorción de agua por capilaridad, que también es similar en ambos tipos de adobe.

Es sabido que el proceso de secado de los adobes húmedos está controlado por la difusión del agua a través del material y la evaporación en superficie (7). En las muestras estudiadas la tasa de pérdida de agua durante la desorción se mantiene lineal durante las primeras veinticuatro horas, no alcanzándose los valores próximos al equilibrio hasta más allá de los cuatro días de ensayo. El contenido en agua que resta en las muestras de adobe, es del mismo orden de magnitud que el obtenido por higroscopía.

Agradecimientos

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PROBLEMAS DE LA INVESTIGACION Y CONSERVACION DE LAS ESTRUCTURAS DEL CENTRO CEREMONIAL DE LA CULTURA PARACAS-NAZCA, PERU.

Slawomir Skibiński
Nicholas Copernicus University
11 Gagarin Street
87-100 Toruń
Poland

ABSTRACT

During the laboratory and field investigation in 1987-1988 the technology of making adobe was reproduced. The recipe of the clay mortar for refilling westages in walls was worked out. The main component of the mortar was the montmorillonit clay gained from the Cahuachi buildings area. Moreover the superficial preconsolidation technology of the walls by the water dispersion - Cola Sintetica was worked out, as well as the surface hydrophobing method by the water dispersion - Imlar CPC 1175 T. Thus for the structural consolidation technology of the adobe walls containing the montmorilonit clay is not yet worked out. Investigation is carried on.

KEYWORDS

Peru, Nazca, Cahuachi, conservation, adobe.

1. Investigaciones sobre la elección de medios para un reforzamiento preliminar de la superficie de muros.

1.1. El objetivo de la investigación.

El objetivo consistió en especificar el medio para la protección preliminar de la superficie de paredes que se desprendían y que a la vez fuese accesible en el mercado peruano. Una vez protegida la pared se pueden llevar a cabo otras tareas de su conservación.

1.2. Materiales.

Se tomaron en cuenta los siguientes medios (estos fueron accesibles en el Perú):

Cola Sintética	hecho en Perú
Primal	hecho en Italia
Colla Forte	hecho en Italia
Vinavil Rapid	hecho en Italia

Las dispersiones acuáticas de estos medios sirvieron para reforzar la superficie de paredes de modo preliminar.

1.3. El método de trabajo.

Las dispersiones acuáticas (del 25%) de los polímeros mencionados se pusieron sobre los portaobjetos. Después de secarse, la mitad del portaobjetos fue cubierta con el papel negro y se le expuso durante 14 días en el muro experimental "in situ" (Montículo I). Al terminar el estudio se hicieron las comparaciones organolépticas del grado de amarilleo de las partes expuestas y cubiertas del portaobjetos y la resistencia de medios al agua. La resistencia al agua fue definida por los cambios en recubrimientos después de poner una gota de agua sobre ellos.

1.4. Discusión de resultados.

Los medios mencionados se pueden poner en hilera tomando en cuenta su grado de amarilleo y resistencia al agua e iniciando con los más resistentes:

Cola Sintética > Primal > Colla Forte > Vinavil Rapid

Por eso para reforzar preliminariamente los muros se escogió la emulsión acuática de Cola Sintetíca.

Hay que mencionar aquí que del mismo modo se determinó el grado de amarilleo y la resistencia al agua del preparado CPC 1175T, que fue escogido, para la hidrofobización, como el mejor medio. Las pruebas de impregnar adobes de modo estructural utilizando los disolventes de resinas termoplásticas y silicoorgánicas no dieron resultados esperados.

2. El estudio de la elaboración de las argamasas para rellenar los decrecimientos de las paredes de adobe.

2.1. El objetivo y la esfera de la investigacion.

La meta del estudio fue la de obtener las argamasas para rellenar los decrecimientos y para la reconstrucción de los muros del centro ceremonial. La argamasa debería caracterizarse por el bajo costo de su preparación y por los parámetros físicos semejantes a las argamasas originales pero, al mismo tiempo, menos higroscópicos.Por estas razones se decidió que las argamasas se prepararían utilizando el limo de montmorillonita de los yacimientos localizados cerca del sitio arqueológico en Cahuachi.

2.2. Método del trabajo.

2.2.1. Materiales:

- limo de montmorillonita (se tomaron las muestras del limo del lugar cercano a la Gran Pirámide en Cahuachi),
- arena para vidrio de granulación de .3 a .15 mm.
- agua.

2.2.2. La preparación de las argamasas.

Se colocó el limo de montmorillonita en un recipiente y se humedeció rociándolo con agua de modo que su exceso se infiltraba rápido. En caso de aparecer gotas de agua sobre la superficie, ya no se rociaba más. Después de 24 horas de rociar, los pedazos del limo se trituraron. Luego se dejó el aglutinante limoso en un recipiente por otras 24 horas. Este procedimiento se repitió diariamente. Al pasar una semana al aglutinante limoso se agregó arena cuarzosa de granulación .3 - .15 mm en proporción de 2 cantidades para una del aglutinante. La segunda parte del aglutinante se uso para preparar el argamasa compuesta de 3 partes de arena y una del limo. Luego se prepararon argamasas y colocaron en moldes. Al cabo de una semana, las formas se desmoldaron y se midieron las propiedades físicas y acústicas (veánse Tablas I y II) de las argamasas.

2.2.3. Discusión de resultados.

Al comparar las propiedades de las argamasas preparadas en laboratorio podemos ver una gran convergencia con las propiedades de argamasas originales (compáranse las magnitudes presentadas en las tablas 1 y 3 de Skibiński (1990) para argamasas originales y las tablas I y II sobre argamasas preparadas en laboratorio). Para rellenar los decrecimientos en la pared durante la prueba de conservación en Cahuachi se utilizo la argamasa de contenido 1:3 con una pequeña adición de coagulante que es la emulsión acuática de Cola Sintética. La arena cuarzosa con gran contenido de minerales oscuros de origen local sirvió de agregado. La solución saturada del hidróxido cálcico fue usada para plastificar el limo de montmorillonita proveniente de la Gran Pirámide (sector 1). La montmorillonita cálcica demuestra mayor resistencia después de secarse. El objetivo de aplicar la argamasa fue:

1° - limitación de la penetración del vapor del agua y con eso la restricción de la interacción del agua adentro del muro al rellenar los decrecimientos, delaminaciones y fisuras de la superficie.

2° - reforzamiento de trama de muros.

3° - elaboración estética del muro.

3. El estudio de la resistencia a la luz de los medios empleados para la protección preliminar e hidrofobización (preparado por dr J. Ciabach).

3.1. El objetivo del estudio.

Se trató de determinar la resistencia a la luz de la dispersión acuática de la Cola Sintética (hecha en Perú), la que fue utilizada para la protección preliminar de las partes de muros desintegrados, de la dispersión acuática de la resina acrílica y del politetrafluoretileno Imlar CPC 1175 T (de Du Pont) escogidos para realizar la hidrofobización.

3.2. Método de la investigación.

3.2.1.Preparación de las muestras para el estudio.

Se prepararon las muestras en forma de recubrimientos sobre la lámina de aluminio según el método descrito por J. Ciabach. Las muestras fueron expuestas a las radiaciones de manera continua, al aire a una temperatura de 40° C y a la humedad relativa de 30% en la cámara Feutron 3001. La intensidad de la radiación ultravioleta de onda mayor de 390 m, alcanzó 4.5 x 10-3 de mmol del ácido oxálico por cada cm2 por 1 hora. Más detalles sobre la investigación se encuentran en el trabajo de J. Ciabach.

3.2.2. Estudio de los cambios de color.

Para identificar los cambios eventuales de color se compararon visualmente las muestras expuestas a las radiaciones y las que no fueron expuestas.

3.2.3. Estudios del decrecimiento de la masa.

Este estudío se hizo con la tècnica gravimètrica empleando una balanza analìtica (ver Tablas III y IV).

3.2.4. Estudios de los cambios de la dureza de superficie.

Estos cambios se registraron por medio de un dispositivo con el pèndulo de Koenig de manera descrita por la PN-73/C-81530 (ver Tabla V)

3.2.5. Estudios de elasticidad.

Se determinó la elasticidad de los recubrimientos, obtenidos por medio de la flexiòn sobre cilindros de varios diàmetros, tal como lo describe la PN-76/C-81528.

3.3. Resultados de estudios.

3.3.1. Cambios de color.

Despuès de 104 dìas de exposiciòn a la radiaciòn (dòsis de radiaciòn H=11.25 mmol/cm2) no se han observado cambios de color en las muestras preparadas del Imlar CPC 1175T. Por otro lado, se observò el amarilleo en los recubrimientos del preparado de la Cola Sintética, lo que se percibiò despuès de 46 dìas de radiaciòn (dòsis de radiaciòn H=4.97 mmol/cm2).

3.3.2. Decrecimiento de masa.

El decrecimiento de masa media del Imlar CPC 1175T, no sobrepasa el 2% del peso y es independiente del tiempo (dòsis) de radiaciòn (ver Tabla III). En cambio, al tratar con Cola Sintética, el decrecimiento de masa promedio alcanzò el 16% (dòsis de radiaciòn H=11.25 mmol/cm2) y fue directamente dependiente de la radiaciòn (ver Tabla IV).

3.3.3. Dureza de superficie.

La dureza de superficie del Imlar CPC 1175T es muy pequeña y no cambiò durante la radiaciòn (el aumento de .04 al .06 durante los primeros 20 dìas, al iniciar la radiaciòn, se puede explicar por la evaporizaciòn de los restos del agua u otras substancias volatiles).

La dureza de la Cola Sintética aumenta el 44% durante la radiaciòn y depende de su tiempo (consultar Tabla V).

3.3.4. Elasticidad.

El recubrimiento del Imlar CPC 1175T antes y despuès de la radiaciòn (hasta 104 dìas) no cambia su elasticidad. No se resquiebra en el cilindro de diàmetro de 1 mm. En cambio la Cola Sintetica no se resquiebra en el cilindro con un diàmetro de 1 mm antes de exponerla a la radiaciòn pero despuès de ella - se requiebra en un cilindro con un diàmetro de 7 mm.

3.4. Discusiòn de resultados.

Ambas resinas demuestran tener una resistencia a la luz totalmente distinta. La Cola Sintética se amarilla, pierde su peso a causa de la volatilizaciòn del suavizador o la fotòlisis de polímero, se hace màs dura y menos elàstica. Imlar CPC 1175T conserva sus propiedades iniciales durante la exposiciòn a las radiaciones que provocan los cambios de las propiedades esenciales de muchas otras resinas artificiales consideradas comúnmente como resistentes al ultravioleta (p.e. resinas acrílicas con Paraloid B-72).


Foto 1

4. La prueba de la conservación del muro de adobe.

Se ha escogido un fragmento de la pared a los pies del Montículo I (ver Fot. 1) para la conservación a prueba. Se hicieron los siguientes trabajos:
- se limpió mecanicamente la superficie del muro usando pincel y aire comprimido.
- esta superficie se consolidó utilizando la emulsión acuática de Cola Sintética en la disolución 1:15.
- la exfoliación de argamasas y el mortero se adhirieron con la emulsión acuática de Cola Sintética en la proporción de 1:3.
- se rellenaron los decrecimientos del muro con la argamasa preparada con montmorillonita y arena de los yacimientos de Cahuachi en la proporción de 1:3.
- al secarse el muro se puso la disolución acuática de la emulsión Imlar CPC 1175T a través del pulsador y parte del muro fue cubierta 1 vez y la otra 2 veces para objetivos científicos.

Un mes después de hacer observaciones "in situ" se puede constatar que estas partes del muro que se habían preservado bien o bastante bien se consolidaron muy bien a causa de los trabajos realizados, preservaron un efecto hidrófobo del muro (ver Fot. 2). Sin embargo, la corona del muro la que fue expuesta en el pasado a la acción intensiva del agua (inundaciones) no se había consolidado en un grado satisfactorio. En este caso se deben cambiar las capas circumsuperficiales en un mortero nuevo. No se hizo hasta ahora ya que no se disponía del programa completo de la revalorización de la estructura sobre el Montículo I en este tiempo.


Foto 2

5. Conclusiones finales.

Se reconocieron las posibilidades de conservar la estructura situada en el sector A del centro ceremonial de Cahuachi mediante los estudios de campo y de laboratorio en los años 1987 y 1988. Se reconstruyó la tecnología de fabricar el ladrillo secado al sol, se preparo el mortero para rellenar los huecos en muros que se basa en margas de montmorillonita tomadas de los lugares vecinos a la estructura. Además, se elaboró la tecnologia del reforzamiento preliminar de las superficies de paredes que se lleva a cabo durante los trabajos de la conservación con el empleo de la emulsión acuática Cola Sintética. Para la preservación superficial hidrófoba se empleó la emulsión acuática acrilíco-perfluorita Imlar CPC 1175 T.

No se habia logrado, hasta la fecha, obtener la tecnología de reforzar estructuralmente (al interior) los muros de adobe. El material reforzador se componía de limos de montmorillonita y en el laboratorio ya se obtuvieron los resultados prometedores con el apoyo de las muestras de morteros de caolinitas. Los trabajos van a continuarse.

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TABLA I
Las propiedades bàsicas fìsicas de las argamasas.

No.	composiciòn de las argamasas	higroscopicidad	densidad aparente g/cm3	absorbibilidad gravimètrica /%/	porosidad abierta % - vol.
1	1:2	4.1	1.78	13.7	24.4
2	1:3	3.8	1.5	14.2	22.6

TABLA II
Propiedades acùsticas de las argamasas medidas con ultrasonido (realizado con la cabeza de 25 kHz)

No.	composiciòn de argamasas	propiedades acùsticas		
		velocidad de la propagaciòn de onda longitudinal km/s	impendencia de onda acùstica g/cm2	mòdulo de Young N/m2
1	1:2	1.52	2.71 x 105	4.11 x 103
2	1:3	1.64	2.61 x 105	4.28 x 103

TABLA III
Aumento de la masa de las muestras del Imlar CPC 1175T al exponerlas a la radiaciòn

No de muestra	% m despuès de t dìas				
	32	46	70	93	104
1	1.59	1.66	1.23	1.30	1.55
2	1.57	1.80	1.35	1.05	1.39
3	1.74	1.83	1.55	1.19	1.74
4	2.04	1.84	1.43	1.27	1.68
5	1.94	2.03	1.62	1.53	1.80
6	1.78	1.78	1.50	1.57	1.68
promedio	1.78	1.82	1.45	1.32	1.64

TABLA IV
Aumento de la masa de las muestras de Cola Sintetica al exponerlas a la radiación.

No. de muestra	% m después de t días 32	46	70	93	104
1	4.52	6.86	11.70	14.51	16.30
2	4.01	5.87	10.86	--	--
3	5.05	7.39	11.98	--	--
4	4.52	6.71	11.24	--	--
promedio	4.53	6.71	11.45	14.51	16.30

TABLA V
Dureza de superficie de los recubrimientos estudiados en dependencia del tiempo de la radiación

tiempo de radiación /días/	dureza de superficie Imlar CPC 1175T	Cola Sintetica
0	.06	.31
20	.06	.40
30	.06	.40
48	.06	.41
57	.06	.45
76	.06	.44

OUTLINE OF MUD BRICK STRUCTURES CONSERVATION AT ABUSIR, EGYPT

Jiri Sramek and Ludvik Losos
State Institute for Restoration
Pohorelec 22, 118 00 Prague 1
Czechoslovakia

ABSTRACT

In the last 30 years the uncovered mud brick structures at Abusir have started to deteriorate. Rain is believed to be the main cause of decay as well as wind abrasion. Preservation of these mud brick complexes has been carried out in collaboration with the Egyptian Antiquity Organization. Until roofing can be installed, the most important areas such as the slaughterhouse in the Raneferef's complex will be consolidated by acrylic copolymers (Paraloid B72 and KP-lak 709) and hydrophobized by siloxanes (Wacker H and Silgel JHM 20). The differential thermal analysis and thermogravimetry revealed that the composition of mud bricks of 5th and 26th Dynasty are very similar in clay mineral content but differ significantly from the recent mud bricks in the region. The nearby Aswan High Dam prevents flooding in the region and thus the long-term equilibrium in mud composition has changed recently.

KEYWORDS

Mud brick complexes, Abusir, conservation, clay composition, DTA/TG analysis, earthen architecture.

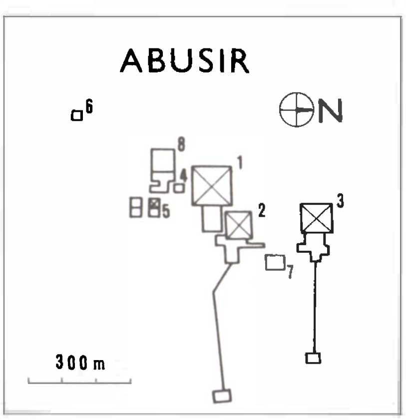

Fig. 1 Map of ancient Egyptian monuments at Abusir 1-pyramid of Neferirkare, 2-pyramid of Novoserre, 3-pyramid of Sahure, 4-pyramid complex of Raneferef, 5-pyramid complex of Khentkaus, 6-shaft tomb of Udjahorresnet, 7-mastaba of Ptahshepses, 8-unfinished pyramid.

Introduction

The branch of the Czechoslovak Institute of Egyptology in Cairo was established in 1959 and soon gained recognition in Egypt itself. Research at that time started at Abusir (see fig.1) around 20 km south of Giza in the area of the great tomb of Ptahshepses, the vizier of the 5th Dynasty. A limited project had already been carried out here by a German expedition at the beginning of the century, but the excavation was not completed until the mid-1970s by the Czechs. In addition to this work, several expeditions during the 1960s also took part in UNESCO's International Campaign to Save Monuments in Nubia. In 1976, the bulk of field work moved to the Abusir Southern Field which was assigned to the Czechoslovak Institute of Egyptology by the Egyptian Antiquity Organization.

By 1980, the large rectangular structure close to the southern side of the pyramid of Neferirkare (5th Dynasty) had been uncovered and designated as belonging to the Neferirkare's wife Queen Khentkaus (see fig. 2). The construction of the structure was finished during the rule of Neuserre, the younger son of Neferirkare, who continuously used cheaper material like mud bricks rather than limestone. The other pyramid complex next to the Khentkaus' was that of Raneferef, the oldest son of Neferirkare, excavated up to 1982 and almost exclusively made of mud bricks (see fig. 3). The outstanding finding within this complex was the slaughterhouse (Sanctuary of the Knife) with mud brick walls 60 cm to 1 m thick with four rounded corners. Here the offering animals were slaughtered, quartered and possibly skinned (see fig. 4) [1].

Also in 1982, excavation of the shaft tomb approximately 500 m SW of the above-mentioned pyramid complexes was begun (see figs. 1 and 2). Recently, a burial chamber with double sarcophagus of limestone and basalt was uncovered. The inscriptions clearly indicated that the shaft tomb belonged to Udjahorresnet, a well-known "dark" personage of the late 26th Dynasty, who has been suspected of calculated opportunism, treachery and collaboration with Persian conquerors [2].

All the uncovered mud brick masonry of the objects previously mentioned (including smaller ones like the Mastaba of Prince Neserkauhor or mud brick walls by Mastaba of Khekeretnebty) started to deteriorate immediately after exposure to weathering. The rains, even when rare in the area, melted the upper one or two brick layers which formed a crust at the very surface. A pulverized mass with some empty spaces lay beneath this crust. The vertical surfaces eroded mostly within the joints of bricks and in some places the remnants of plaster peeled off. The other erosion factor was abrasion due to wind and sand particles; deterioration due to rising damp seemed to be minimal. It was clear that conservation of at least selected parts of the masonry was urgently needed. The State Institute for Restoration in Prague was invited to collaborate in establishing a project to stabilize the mud brick structures.

Observing the situation in situ, it has been evident that there could be only two ultimate solutions to the problem: to build a roof covering the structures entirely or to bury them in the Sahara sand. The number of walls and their surface is so huge that it would be impossible to conserve them fully. In the same way burying the structures is equally impossible, because in accordance with the ideas of the Egyptian Antiquity Organization, the whole Abusir pyramid complex is to be opened to the public in the future. It was therefore decided to launch a project to roof the Raneferef's mud brick complex. Since this could take several years, another project was devised which allowed for the selective conservation of the most significant parts (such as vaults or remnants of plaster) which could be protected against further deterioration. This would preserve the selected areas for the next decade before the roofing can be built.

Fig. 2 View of Khentkaus' complex from the Neferirkare's pyramid with the Djoser step-pyramid in the backround.

Experimental

A detailed study was carried out on the quality of mud bricks, their dimensions and the kinds of brick masonry. The bricks are quite homogeneous as far as the particles are concerned, with the largest grains on average not exceeding 1.2 mm. With the exception of the upper brick layers, the mud bricks in general were in good shape and sufficiently hard. There were primarily two sizes of mud bricks: 27-29 x 13 x 8-9 cm and 33 x 16 x 11 cm, resp. The technique of brickwork according to Spencer's classification [3] could be ascribed as A3 or A4 with vaults FD1.

Two basic types of conservation material were chosen for carrying out experiments in mud brick consolidation and hydrophobization and for tests in situ: acrylic copolymers, because of their stability against water and UV-rays, and methylalkoxysilanes, because of their long-term hydrophobization effect and expected durability in severe climate.

The acrylic products tested were Paraloid B72 (R) (copolymer ethylmethacrylate-methylacrylate), and KP-lak 709 fy VUSLP, Czechoslovakia (copolymer methylmethacrylate-butylacrylate). The siloxane products were Steinverfestiger Wacker OH (R), and Silgel JHM 20 fy UTZCHT CSAV, Czechoslovakia (oligomeric methylalkoxysilane, 20 % in toluene-acetone mixture).

To impregnate mud bricks requires a proper technology that can guarantee a depth of penetration of several centimeters; a key point in the treatment is the type of solvent system. It was proved that all kinds of polar solvents such as water, alcohols, and acetone are quickly absorbed by clay minerals in mud brick, causing it to decay rapidly due to expansion. This is actually the principle of the main deterioration process occuring in mud brick structures in the open air at Abusir. On the other hand, nonpolar solvents such as toluene or xylene proved to be completely safe for mud brick. Eventually xylene was used because of its lower evaporation rate (b.p. 140°C) as the only solvent for all kinds of treatments in which the acrylic products were applied for deep consolidation. The siloxanes for hydrophobization were used with acetone as a part of solvent system; this was carried out only on preconsolidated surfaces by acrylic copolymers and by rapid brushing to prevent the deep penetration of hydrophobization means.

All the mud brick structures at Abusir Southern Field except that of the shaft tomb of Udjahorresnet date from the 5th Dynasty; the latter date from the 26th Dynasty - a difference of almost 2000 years. It was therefore interesting to investigate the composition of mud bricks, since in the underground of the shaft tomb mud bricks were also used for blocking the room system. Elemental chemical analysis was not very productive and showed only similar composition of Ca, Mg, Al and Si in particular mud brick samples. The X-ray diffraction in all the samples qualitatively determined the clay minerals like illite or

Fig. 3 View of Raneferef's mud brick complex; to the top right of the view the shaft tomb of Udjahorresnet.

montmorillonite as well as gypsum and traces of calcite. Thus, a method of "finger printing" in which the standardized samples could be compared was sought. The classical IR-spectroscopy was found to be unhelpful since the spectra by KBr-technique were plain without special peaks. The simultaneous measurements by differential thermal analysis (DTA) and thermogravimetry (TG) was finally found to be useful since it enabled the assessment quantitatively of the amount and type of clay minerals, and in the case of recent mud bricks also revealed the presence of organic materials. Both DTA and TG techniques are based on following the behaviour of sample in continuously increasing temperature, in this particular case in the region from 100 to 900 °C.

The samples for DTA/TG analysis were homogenized from a dozen probes and removed statistically so as to represent the whole masonry. Initial results showed that the composition of mud bricks from the time of 5th and those of 26th Dynasty are very similar. Therefore, the idea arose of comparing them with recent mud bricks used in the masonry of today's Abusir village. The pyramid complexes and the Abusir village are namely so close to each other (about 1 km) that the source of mud for mud bricks probably is from the very near Nile channels. A NETZSCH STA 409 DTA/TG instrument was used in all the measurements. In general, 50 samples (each about 50 - 70 g) were removed at a depth of several centimeters from the masonry, homogenized by a pulverizer and then measured as an average standard sample. The small stones and other particles larger than 2-3 mm were removed during predrilling so as not to influence the DTA/TG analysis of original material.

Results

From the beginning it was considered that if deep penetration is from the point of view of mud brick consolidation necessary then only acrylics would be used since they have better binding properties compared with siloxanes. They can then supply the mud brick with the missing or decayed net structures which originally were based mostly on clay and a physical bond of chopped straw or hair. The compressive strength of acrylic materials is greater than that of siloxane ones but by penetration of acrylics into a depth of several centimeters there were never found any cracks or deformation of mud bricks.

Fig. 4 Raneferef's complex, a part of slaughterhouse with remnants of plaster.

The exact measurements of the depth of penetration of the conservation products was carried out on mud brick samples placed in a solution with a constant depth level of 1 cm. The penetration over time of pure solvents and of solutions with different concentrations was followed visually as it was quite simple to distinguish the darker zone of the penetrated part of brick. The results clearly showed that the penetration of acrylic product in concentrations up to 5 % in xylene reaches the depth of 10 - 12 cm in about 30 minutes. Paraloid B72 penetrated in the same concentration more easily than KP-lak 709, and the 2 % concentrations of both products penetrated quicker and deeper than those of 5 %. On the cross sections it was possible to distinguish the zone of penetration from the surface about 2 cm in area that was enriched in acrylic polymers, apparently due to the chromatographic separation of the polymer molecules on clay. The investigation for hardness nevertheless showed that the acrylic compounds were transported to some extent up to the farthest point with xylene as a solvent. These experiments yielded information about the optimal concentrations of impregnation solutions for mud bricks, as well as for readhering the remnants of plaster to mud brick underground.

The DTA/TG measurements revealed interesting results which are summarized in fig. 5 - 8. As can be seen from the DTA/TG, results of bricks from the Khentkaus' and Raneferef's complexes are very similar to the mud bricks of the shaft tomb of Udjahorresnet which is actually almost 2000 years more recent (6th century B.C.). The spectra clearly prove that the basic material of mud bricks is clay, since the peak of 580 °C can be interpreted as the dehydroxylation of clay such as illite and those of 750 °C as changes in montmorillonite. The peak of 150 °C can be ascribed to gypsum. The small shifts in peak positions are probably caused by partial decomposition of individual clay minerals. No exothermic peaks in the DTA/TG analysis of ancient bricks were observed, which indicates that all the originally used organic materials, chopped straw, hair or even humic compounds were fully degradated.

On the other hand, the DTA/TG analysis of the standardized sample of mud brick made in the recent two decades show a fundamental difference (compare fig. 8 with fig. 5, 6, and 7, resp.). These mud bricks still contain the organic parts even when the macroscopic particle-like straw were removed before pulverizing the samples (the exothermic peaks of 240.4 and 381.9 °C). The other difference is in the peak of 789.0 °C which can be attributed to some other clay mineral which had not been present in ancient muds.

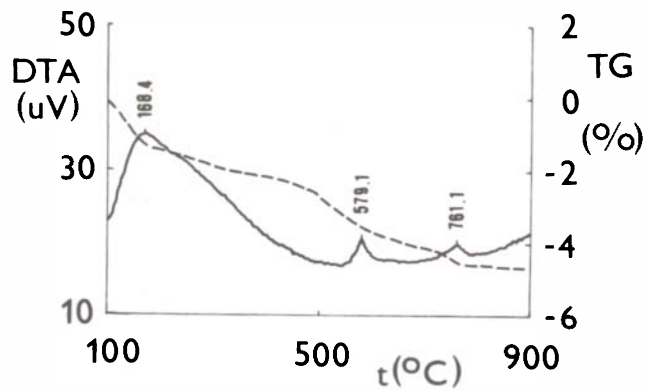

Fig. 5 The DTA/TG analysis of mud bricks from complex of Khentkaus
(air atmosphere /100 ml/min/, sample 217.70 mg, TG 250 mg, DTA 500 μV, Netzsch STA 409).

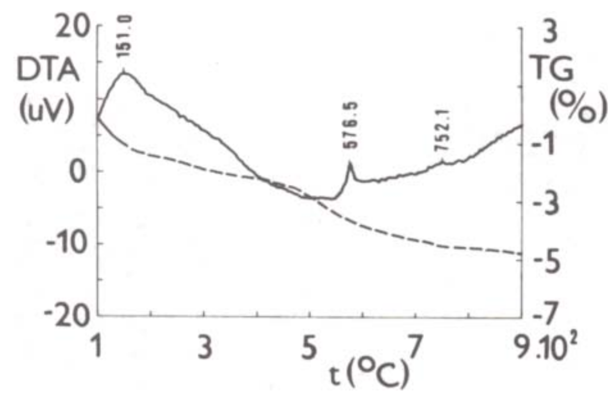

Fig. 7 The DTA/TG analysis of mud bricks from the shaft tomb of Udjahorresnet
(air atmosphere /100 ml/min/, sample 206.64 mg, TG 250 mg, DTA 500 μV, Netzsch STA 409).

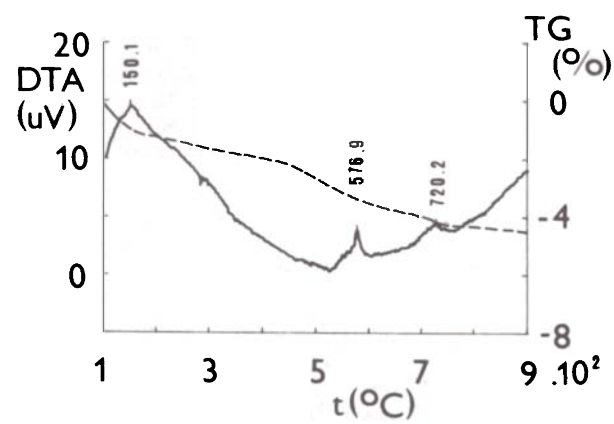

Fig. 6 The DTA/TG analysis of mud bricks from complex of Raneferef
(air atmosphere /100 ml/min/, sample 161.44 mg, TG 250 mg, DTA 500 μV, Netzsch STA 409).

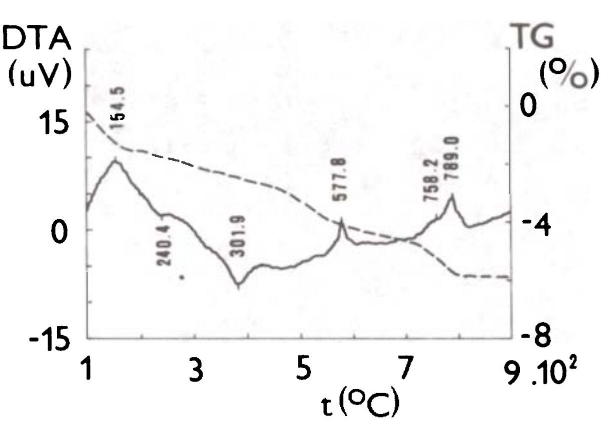

Fig. 8 The DTA/TG analysis of recent mud bricks from today's Abusir village
(air atmosphere /100 ml/min/, sample 235.00 mg, TG 250 mg, DTA 500 μV, Netzsch STA 409).

Conclusion

The uncovered mud brick monuments of 5th Dynasty at Abusir urgently need conservation treatment, at least for the most important sections. A project to roof the complex of Raneferef has been proposed by the Czechoslovak Institute of Egyptology and the Egyptian Antiquity Organization. In the meantime and on the basis of the research described in this paper, certain areas were chosen for impregnation of the masonry. Paraloid B72 (5 % in xylene) or KP-lak 709 (5 % in xylene) were used for tests in situ. They were applied by brush and penetrated to a minimum depth of 5 - 7 cm. This was done on horizontal upper surfaces and on vertical areas of walls. After a week, the consolidated surfaces were hydrophobized by Wacker OH (R) and by Silgel JHM 20 (20 % in toluene-acetone mixture). The hydrophobization was again carried out by brushing. It can be expected that the hydrolysis and polymerization of siloxanes could be negatively inhibited in the very dry conditions of the Saharan climate, and therefore 2 ml of distilled water was added to the siloxane solutions before application.

The test areas will be kept under surveillance for at least three years and if the results are favourable the same treatment will be extended to the other most significant parts of masonry. The effect of hydrophobization after almost one month was nevertheless still very high and it was not possible to deteriorate the treated surface even with high amounts of water. In some areas at the slaughterhouse in the Raneferef's pyramid complex such a treated upper surface was covered by two layers of freshly made mud bricks separated by straw from the ancient ones. In that case a part of hydraulic lime in proportion of 10 % was added to enhance the durability of new bricks against rain. The method was chosen as an ethically possible solution which excludes the use of different materials such as concrete plates.

The remnants of plaster were fixed to the mud brick by KP-lak 709, 7 % in xylene. In this case the solution was put into the backround of the plaster through small holes of 2 mm diameter using syringe needles. The plaster was also consolidated by 3 % solution of KP-lak 709 in xylene [4].

The investigation of mud brick composition by differential thermal analysis and thermogravimetry revealed that the ancient mud brick in the area is composed of very similar mud whether the mud bricks come from the 5th or 26th Dynasty. These mud bricks differ nevertheless strongly from the recent ones used within the region. It is perhaps possible that the Aswan High Dam caused the sudden change in clay minerals in today's mud in the nearest Nile channel.

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Future Directions

ABSTRACT

A methodological scheme for the conservation and restoration of earthen structures is proposed; two case reports are presented.

The first case analyzed, the Hospital San Juan de Dios, provides the basis for our proposal for restoring the Church of Inmaculda Concepcion of Tumbaco.

This methodology encompasses the study of physical environmental elements, historical research. Detailed photographic documentation provides a thorough knowledge of the monument and guarantees an adequate practical approach.

KEYWORDS

Methodology, conservation, physical environment, analysis of earthen architecture.

AN INTERVENTION METHODOLOGY PROPOSAL FOR THE CONSERVATION AND RESTORATION OF EARTHEN ARCHITECTURE

Ruth Marcela Aleman Andrade
Diego Vaca de la Vega No. 327
Quito, Ecuador
South America

Introduction

Two case reports are presented: The first is the Hospital San Juan de Dios built in the historical center of Quito.

The intervention proposal, methodology, and execution of the work done by engineer Mario Moran on the mud brick wall of the southern ward is analyzed. The second case, the Church of Inmaculda Conception of Tumbaco, will be used as a model for our proposal (see figs. 1 and 2).

Historical Summary of the Hospital San Juan de Dios and Intervention

This hospital was built originally in 1565 and has undergone repeated transformations since that time. In 1973 the roof of the southern ward collapsed as a consequence of malpractice, and this led to evacuation in 1974. In 1975-1977, a proposal was presented for restoring the structure to provide new use for the hospital, but the work was only partially completed.

Historical research revealed that the southern and western wards belonged to the original primitive structure. The earthquake of 5 March 1987, which affected the historical center of Quito, severely damaged the arch of the church, the bell tower, and the mud brick wall of the southern ward of the hospital.

Engineer Mario Moran was in charge of the restoration. He analyzed the old structure, taking into account the past earthquakes in the area of Quito, the vulnerability of the wall which exhibited cracks of various depths, the compressive strength, the physical characteristics of the mud brick and mortar, the resistance of the soil, the depth of the foundations. This research led to the conslusion that aged material with a resistance loss of 70% must be replaced by new material with similar or improved physical mechanical characteristics.

Engineer Moran proposed the use of micropilots piercing the wall and anchored to an iron net on the wall surface. The goal was to consolidate the wall in order to guarantee its stability. The iron net was adhered to the irregular wall surface by means of rendering composed of cement, sand, and small stones.

This proposal rested on the hypothesis that the wall system would recover its resistance and stability by being tightly enclosed. This methodology was based on the structural analysis as an approach to solving a specific problem: the lack of wall cohesion derived from its building material, mud brick; it may prove useful in other similar situations. But architectural restoration is aimed at preserving structures and revealing the aesthetic and historic value of the monument and is based on respect for the original material (1). Wherever the traditional setting exists, it must be kept. In the course of any intervention, these values should prevail over technology.

The conservation and restoration of monuments must have recourse to all that science and technology can contribute to the study and safeguarding of architectural heritage (1). Also, an adequate methodological approach must be considered in order to guarantee an adequate intervention in earthen buildings.

Proposal for the application of a new intervention methodology in the Church of Inmaculada Conception of Tumbaco

Analysis

1. Study of the environment: atmospheric agents (climate, temperature, direction of wind, solar exposure, intensity of the rain), geographic characteristics of the area (geomorphology, geology), seismic activity.

It is also important to obtain information about the urban area and the traditional techniques and workmanship available.

The Church of Tumbaco is situated in the province of Pichinch, at 2.335 meters above sea level, 6 kilometers from Quito. This area corresponds to equatorial isothermic climate with a mean temperature of 10-20° C, relative humidity of 65 to 85 percent and the pluviometry of 1,300 to 2,000 mm/year, the hydric resource for the region averages 20 to 30 1/sq/Km (30%). Geology is characterized by quaternary volcanic formation of pyroclastic material known as "cangahua" (2).

The development and modernization of Quito has affected Tumbaco by altering the vernacular architecture and the rural network. The use of new materials and the creation of structures in which mud brick is replaced by brick and roof tiles by zing plates provides evidence of this transformation.

2. Historical research: written and iconographic documents concerning the monument from archives or artistic literature, including the restorations performed, establish the chronology of the monument.

The Church of Inmaculda Concepcion of Tumbaco was built in the second half of the sixteenth century. The bell tower was probably erected in 1833, and the chapel fo the Order of Franciscans, built between 1860 and 1885, is lacking information until the second half of this century. The parish house, probably from the same time as the bell tower, was destroyed due to urban transformation (1954-1979), and later the church was abandoned (1979-1983). The new church was built during that period, as well as a sport court with stone steps two meters high discharging on the back mud brick wall.

The complete restoration of the chapel of the Third Order of Franciscans was performed bewtween 1983 and 1985. Traditional systems and materials were used, and it resisted two earthquakes that severly damaged the church. During this period the new roof of the church collapsed; part of the apse and sacristy, as well as the dividing wall, were exposed to rain.

A temporary roof was built as a solution to this problem. This structure aimed to protect the mud brick walls covering approximately 270 square meters. The bell tower was damaged by the earthquake of 1987 but was rebuilt. In 1988 the church lost the old roof over the choir.

3. Study of the building and present situation: A knowledge of the building is essential to determine the causes of the deterioration and to evaluate their effects. It should include the following steps:

- Temporary protection (cleaning, fumigation, support, inspection of drainage, plumbing and electrical systems).
- Scale drawing (topographic plans, elevations, sections, etc.)
- Study of traditional designs and guidelines.
- Structural deterioration (cracks and seismic vulnerability, buckling, collapse, shrinkage cracks)
- Analysis of the resistance of materials, mechanics of soils, physical and chemical properties of the materials.
- Archeological research (depth and quality of basements, original level of the floor, determination of old foundation).
- The elements of the building should be analyzed: wall (plasters, mural paintings, humidity, type of window openings, door type), floor (quality, old designs), roof (cover type, overhang, gutters). All these data need photogrpahic documentation. Environmental and historical studies must also be taken into account. (3)

Present situation of the Church of Tumbaco: The church has a long main nave with a polygon apse and a magnificent inner space 59 meters in length by 8.60 meters width and an interior height of approximately 7 meters. The sacristy is perpendicular to the apse; it measures 7.60 meters by 8.00 meters by 4.00 meters and at present serves as the debris cellar. The bapistery, situated perpendicular to the choir and probably similar in size to the sacristy, has disappeared.

NOTES

1. International Charter for the Conservation and Restoration of Monuments and Sites (article 2, 6, 9).

2. Delavaud Collin A, Atlas del Ecuador (Les Editions J.A. 1982).

3. Alva, Alejandro, Odul, Pascal, Preservation du Patrimoine Architectural en terre (Premier cours pilote, Grenoble, 23 octobre - 4 novembre, non publié).

The church masonry has a thickness of 1.80 meters and is made of mud brick and plaster. The masonry of the sacristy, made of the same material, has a thickness of 1 meter. The posterior wall of the church has severe damage in three places. A 13 meter section was destroyed by the apse wall collapse; it corresponds to the dividing wall between apse and sacristy. The collapse of the choir roof (caused by the 1988 earthquake) damaged the masonry. And, the introduction of the stone steps interfered with drainage, causing erosion in part of the wall.

Only 7 out of 10 windows, specially designed to facilitate drainage of rain, are preserved.

Access to the church is through a main entrance with a brick portal, consolidated by a previous restoration and now partially damaged as a result of wind erosion, and a side door.

In order to diminish erosion of the wall by rain, the church has a special system consisting of two rows of diagonal brick arranged on top of the wall.

Emergency intervention in 1988: As a result of the April 1988 earthquake, the church lost the choir roof and consequently the mud brick wall was exposed directly to rain.

The first action was aimed at covering the building with a temporary roof. The second action was the removal of debris. The third was the support of both sides of the back wall, while the forth action involved covering the outside surface with plastic bands fixed to the top of the wall.

Two years later, the plastic bands have disappeared; the support of the external wall was removed; some zinc plates are loose or broken. This temporary structure can't stand indefinitely.

Conclusion

The proposed methodology is useful for the analysis of this monument.

First, an accurate knowledge of the historical aesthetic and building values ensures comprehension of its unique quality and how different causes could produce the present deterioration.

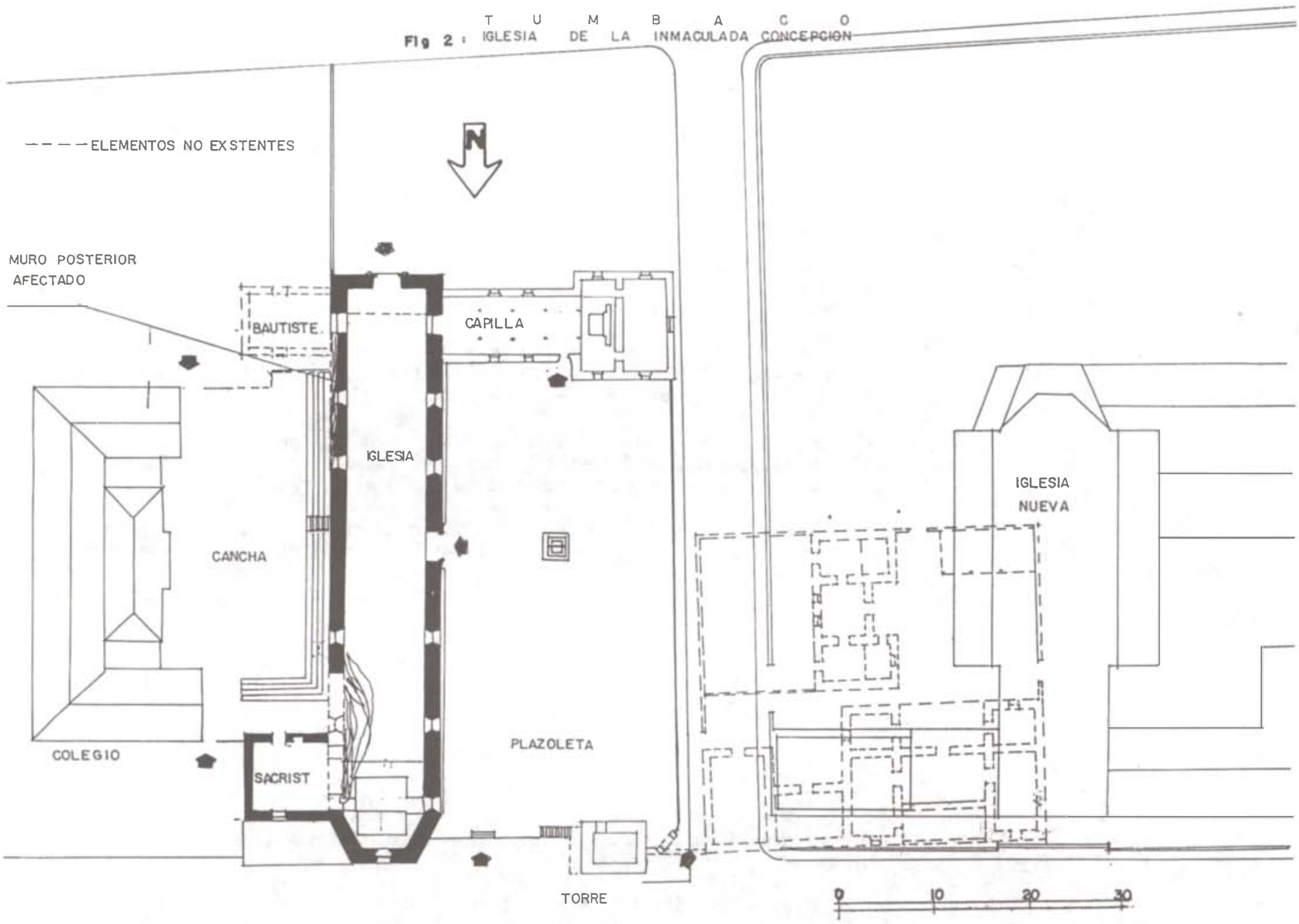
The second step will encompass the formulation of a series of alternative proposals to find out (after laboratory and field experiments) the best treatment approach.

Following the scientific method, the chosen proposal must be subjected to further experimentation and analysis and prove to be the best solution for the problem.

Up to now restoration of earthen architecture has taken into account:

- The use of a single material, earth
- Building systems using traditional workmanship. Other materials are included only if they are compatible with earthen materials.

But these trends do not preclude the incorporation of new alternatives to face the specific problems of restoration of this type of building.


T U M B A C O
Fig 2 : IGLESIA DE LA INMACULADA CONCEPCION
ELEMENTOS NO EXSTENTES
MURO POSTERIOR AFECTADO
BAUTISTE.
CAPILLA
IGLESIA
CANCHA
COLEGIO
SACRIST
PLAZOLETA
TORRE
IGLESIA NUEVA
0 10 20 30

CRATerre-EAG, ICCROM LONG-TERM PLAN FOR THE PRESERVATION OF THE EARTHEN ARCHITECTURAL HERITAGE: THE GAIA PROJECT

Alejandro Alva (**) - Patrice Doat (*) - Hubert Guillaud (*)
Hugo Houben (*) - Thierry Joffroy (*) - Pascal Odul (*)
Jeanne Marie Teutonico (**) - Marina Trappeniers (*)

* CRATerre-EAG
10, galerie des Baladins
F-38100 GRENOBLE

** ICCROM
13, Via di San Michele
I-00153 ROMA RM

ABSTRACT

A critical evaluation of international recommendations for the preservation of the earthen architectural heritage, the often limited implementation of such guidelines, and an increased awareness of the measures required to ensure the safeguard of this heritage have called for the formulation of a comprehensive plan in this domain.
Five years of collaboration between CRATerre-EAG and ICCROM have resulted in an integrated proposal for joint activities in training, research, documentation, development of didactic material/standards, and technical cooperation. ·
This paper presents a summary of the long-term project planned by CRATerre-EAG and ICCROM in fulfilment of their international roles.

CRATerre: The International Centre for Earth Construction.

EAG: l'Ecole d'Architecture de Grenoble.

ICCROM: The International Centre for the Study of the Preservation and the Restoration of Cultural Property.

KEYWORDS

Preservation of earthen architecture, long-term plan, training, research, documentation, technical cooperation.

Introduction

Twenty years ago, the first international concerns about the need to preserve the world's earthen architectural heritage were expressed in the City of Yazd, Iran [1]. Since then, a recommendation to organize specialized training in the field was approved in Lima, Peru [2], and a concrete commitment to face this task was undertaken in 1987 by ICCROM and CRATerre in Rome, Italy [3]. Last year, a formal agreement for continuous activity in training, research, documentation and technical cooperation in this matter was signed by the Directors of ICCROM, CRATerre and the School of Architecture of Grenoble [4].

These 20 years - and certainly many more of unrecorded efforts - constitute a very rich process that leads to the present project which must be placed in the context of silent efforts for the gradual recognition of values in specific cultural expressions. For their contributions to this process, mention is due to Prof. Piero Gazzola, who in the early seventies, as President of the Italian Icomos National Committee, played a significant role in promoting concern for this field, and to Prof. Giorgio Torraca, scientist, former Deputy Director of ICCROM, who was active through the seventies and early eighties in coordinating international exchange of information oriented towards the preservation of the earthen architectural heritage.

Following these initiatives, the past decade has seen ICCROM actively involved in promoting the development of activities in the field. These include our contributions to the meeting organised in Ankara, Turkey in 1980 [5], the organisation of the meeting in Lima, Trujillo and Cusco, Peru in 1983, the jointly-organized ICCROM/CRATerre meeting of Rome in 1987, and the gradual exchange of experiences in the context of the CEAA-Terre of the School of Architecture of Grenoble and CRATerre.

Nevertheless, a critical evaluation of the implementation of international recommendations for the preservation of the earthen architectural heritage has required the formulation of a comprehensive plan - The Gaia Project [Ge or Gaia (myth.): the goddess Earth] - including activities consonant with ICCROM's four statutory functions in this domain.

This paper outlines ICCROM/CRATerre/EAG's five-year plan in the field of preservation of earthen architecture.

Background situation

The international recommendations approved from 1972 to 1987 (see Appendix 1), reflect the thoughts and concerns at various times regarding the need for specific activities in the field. Yazd (1972) and Yazd (1976) [6], may be seen as the first systematic attempts to characterize the earthen architectural heritage and to outline preliminary recommendations for its preservation. The interim meeting in Santa Fe, New Mexico (1977) [7] clearly identified the urgent need to carry out research on specific aspects of the field. An attempt to follow up the Santa Fe recommendations was made by researchers of the Institute for Applied Technology and the Center for Building Technology/National Engineering Laboratory (National Bureau of Standards/USA) [8]. The following meeting (Ankara, 1980) did not record further development of the previous recommendations. This event encouraged a broader view of the field by introducing the expression **earthen architecture** for the first time and fine tuned all previous recommendations. In Lima (1983), specific concerns about the development of a network for this field were expressed and intensive training in established centers was recommended. In Rome (1987), specific commitments and decisions were finally taken to carry out monitored activity in this field.

The Long-Term Plan of ICCROM (1990-2000)

Based on current perceptions regarding the implementation of ICCROM's four statutory functions, the Long-Term Plan of ICCROM (1990-2000) [9] encourages the development of integrated activities in training, research, documentation and technical cooperation in conjunction with its Associate Members, with the aim of developing programmes of scientific cooperation at the highest possible level.

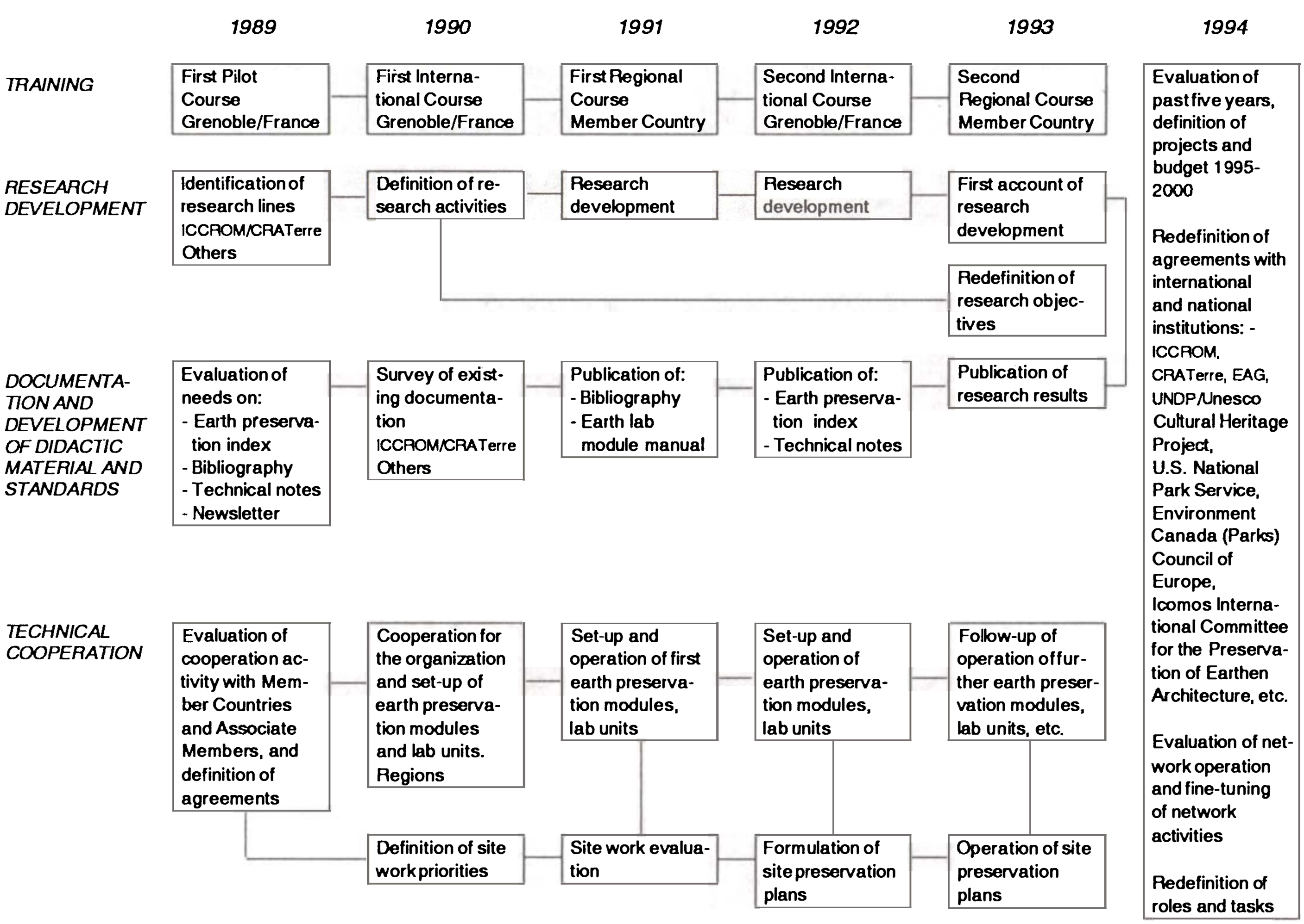
In the context of this ten-year plan, an agreement was subsequently signed by ICCROM, the International Centre for Earth Construction (CRATerre), and the School of Architecture of Grenoble (EAG).

The background for this agreement is a result of over five years of cooperation between these three institutions in the exchange of professionals, the joint organization of scientific events and publications, the exchange of information and the development of related activities.

ICCROM/CRATerre/EAG 1989-1994 Term Plan for Activities in the field of Preservation of Earthen Architecture

Based on the experience described above, and the need to meet short and medium-term requirements concerning programme and budgetary definitions, ICCROM, CRATerre and the EAG have prepared an overall scheme (see Chart 1) to organize six years of activities related to this field of expertise.

Chart 1



Available budgetary resources made it possible to initiate pilot activities towards the end of 1989, with the First Pilot Course on the Preservation of the Earthen Architectural Heritage held in Grenoble (France) from October 23 to November 03.

The completion of this pilot activity proved extremely helpful in providing indications for further development of the project. Previous perceptions in relation to curriculum development, didactic material, appropriate timing, selection of instructors, training strategies, real demand for specific training in this domain have been certainly enriched by this experience. Moreover, the unique opportunity for continuous exchange of information among course participants and instructors which this experience provided, has already activated an efficient network of professionals with responsibilities in this field. In addition, a number of related activities, relevant to specific cultural regions, were discussed and are in the process of better definition. A full report on this pilot course has been prepared [10].

Sub-project: Training

While the first attempt to provide specialized training in the field of architectural conservation began in 1958-59 at the School of Architecture of the University of Rome, it was not until 1964 that ICCROM was invited to assume a commitment to develop training in this domain.

Moreover, it was not until 1977 that ICCROM established its own architectural conservation course to meet international requirements. In this context and following growing demands regarding course contents, the preservation of the earthen architectural heritage took its place among the various disciplines already present in previous training programmes.

The decade that followed the establishment of ICCROM's International Architectural Conservation Course witnessed an increasing concern for the development of a methodological approach to the problems of the preservation of the earthen architectural heritage. In response to this need, ICCROM undertook a systematic search for expertise in all related disciplines, including that of earthen construction. In the evolution of their own activities, CRATerre and the "Ecole d'Architecture de Grenoble" had also identified urgent needs for training in this field.

On the occasion of the International Colloquium on "Earthen Construction Technologies Appropriate to Developing Countries" (Brussels, December 1984), a first contact was established between ICCROM and CRATerre-EAG. Following this event, there ensued five years of cooperation in the development of training on this topic, both at ICCROM and at the EAG, which have led to the definition of a long-term plan for this specific activity within the Gaia Project.

The training activity of the Gaia Project must be seen in its close and indispensable relationship to the other sub-projects, namely research, documentation, development of didactic materials and standards, and technical cooperation for preservation (see Chart above). Only through such an integrated approach can a sound training curriculum be developed. In fact, while the project sub-divisions are useful to define specific activity, it must be remembered that each activity influences and is dependent upon the others. Research, documentation and technical cooperation will all contribute to training content and structure. Training needs will, likewise, identify priorities for the other sectors.

In the overall structure of the Gaia Project, training includes an initial five-year period of courses, beginning with the Pilot Course in 1989, followed by two International Courses (one in 1990, the other in 1992) and possibly two Regional Courses (1991, 1993) if the objective conditions necessary for the organization of such regional programmes can be created. The fifth year, 1994, would be reserved for a first overall evaluation of the long-term plan.

Given the considerable effort and resources necessary for the organization of regional activity, it is important to consider the minimum requirements for undertaking such ventures. Among these requirements, the issue of continuity must be very carefully examined. Too often, the development of regional training activities follows solely political imperatives while failing to create the conditions essential to ensuring continuity. The earthen architectural heritage is too important to be subject to such ephemeral activity which only leads, in the long run, to a serious neglect of our heritage. Training at the project headquarters (Grenoble) should, therefore, not only prepare the professionals necessary in this domain but also promote real possibilities for further regional activity which would ultimately be the responsibility of local operators working in collaboration with the international network of ICCROM and CRATerre-EAG's Gaia Project. In this way, the international role of our institutions in initiating and coordinating activity would be significantly increased.

From the point of view of content, this collaborative training endeavour should gradually define the role, scientific knowledge, and professional skills required by the architectural conservator who will be called to preserve the earthen architectural heritage. A course curriculum is being elaborated in constant consultation with the instructors and field experts active in this area.

Training is still a seriously-neglected aspect of the field, even though it has been repeatedly identified as an important area of concern. The Gaia Project seeks to rectify this situation by providing a structure for a systematic, scientific approach to this problem, thereby filling an immense gap in activities oriented toward the preservation of an important part of the world's cultural patrimony. These general trends proposed for the training portion of the Gaia Project should be followed by further developments which will depend on the outcome of each specific activity scheduled for the next five years.

Sub-project : Research Development

Research concerning the preservation of the earthen architectural heritage has been repeatedly recommended in international meetings. As a result, some projects have been carried out and others are in progress. These initiatives are certainly important. Yet, within the broad scope of research activities, two recurrent problems need to be addressed. The first is the fact that most research carried out to date has focused on "solutions" to conservation problems associated with the earthen architectural heritage (i.e. new products, techniques, alteration of the material, etc.) rather than on a characterization of the material/problem itself. The second is the need for coordination of research in order to avoid duplication of effort and to establish priorities.

This sub-project aims to develop and coordinate an international research effort. CRATerre has already carried out exploratory work on the material "earth" as a project for the French Ministry of Urban Planning and Housing in January 1983. Thus, a methodology exists which can certainly be applied to preservation concerns. Similarly, the Gaia team has taken initial steps towards the development of an international network concerning the preservation of earthen architecture. It has, therefore, already become a reference point for international efforts, and established ties with representative preservation institutions and important sites. Perhaps, most importantly, research will be coordinated within the context of the entire Gaia Project and will, consequently, influence and be influenced by the other sub-projects. Only through this type of integrated approach will research priorities be defined by the real needs of the field and results be disseminated effectively to the largest possible audience.

Activity is envisaged in two stages:

Stage one, to be carried out together with the sub-project on documentation, will involve an exploratory survey in order to define priorities. It will be necessary to evaluate existing knowledge about earth as a material, its use in construction and its preservation, as well as research currently in progress. The results of this exploratory phase will form a research index to be developed by the documentation sub-project as part of its data-base.

Stage two will involve the development of specific research activities, based on the exploratory survey carried out in stage one. The Gaia Project will function in the capacity of promotion and coordination of research to be carried out in close collaboration with the international network.

Priority will be given to those areas where knowledge is most vitally needed - based on the survey - and where no current research activity exists. Emphasis will be placed on methodology as opposed to the misguided quest for a unique "optimal" solution. Advanced technology will be viewed not as an end in itself but will be examined for possible inferences regarding "low" technology solutions.

Research is critical to the advancement of any field, and the preservation of the earthen architectural heritage is no exception. To be effective, however, research activities must be directed at issues of critical importance, and carefully coordinated so as to maximize efforts.

Sub-project: Documentation and Standards

The need to develop an international information network concerning many aspects of the preservation of the earthen architectural heritage has also been expressed in the recommendations of international meetings. Little has been done, however, toward the actual implementation of such recommendations. The Gaia Sub-project on Documentation and Standards will seek to promote and develop activity in this context.

The combined resources, expertise and on-going experience of ICCROM and CRATerre-EAG provide an especially strong foundation for documentation on this subject. Both ICCROM and CRATerre have well-established libraries in their own disciplines which together contain an impressive number of publications about the preservation and/or construction of earthen architecture. Similarly, both organizations have an existing network of professionals and institutions active in their respective fields which can be utilized and expanded. In addition, in the area of publications, established institutional forums (ICCROM's Newsletter, CRATerre's Bulletin d'Information) are effective tools for the dissemination of information. Activity has also been initiated on development of standards through participation in and coordination of international efforts such as CRATerre's Presidency of the RILEM/CIB Committee TC96EB/WC90 "Earth Technology for Building Construction". There is, thus, a strong foundation for the management of information on our topic.

From a general standpoint, the Gaia Sub-project on Documentation and Standards is primarily concerned with the creation, collection, and dissemination of **information** regarding the preservation of the earthen architectural heritage for a range of purposes and audiences. The targeted audience groups include the Gaia Project members (as well as the greater project network), professionals active in the preservation of the earthen architectural heritage, participants in training activities (both teachers and students), and the general public.

Specific activities, to be carried out in close collaboration with the other sub-projects, must be conceived in relation to the needs of these target groups.

Of primary importance for the Gaia Project and network is the creation of a continuously updated, international data base containing information on professionals active in the field, equipment/techniques, training activities, and on-going research as well as an inventory of the earthen architectural heritage, a bibliography of existing publications and a multi-lingual glossary of terms. Work has already begun on the bibliography and glossary as a first step toward the fulfilment of this goal. Publication of a regular newsletter, based on the updated data base and voluntary contributions, and of a biannual research index and bibliography are also foreseen.

For the professional audience, the Gaia Sub-project on Documentation and Standards envisages the production, publication and distribution of technical notes on crucial issues. Targeted subjects for the first two years of the project include soil identification, humidity survey, and structural monitoring. Other activities will include assistance in the editing, publication, and dissemination of research results and specialized documents as well as active participation in the development of national and international standards for both laboratory and field procedures concerning earth and the earthen architectural heritage.

In connection with training activities, this sub-project will focus on the production, publication and distribution of manuals and didactic materials. Plans for the first phase of the project include a laboratory manual on soil analysis and the production of several complementary video tapes explaining laboratory procedures. Work is also in progress on various video simulations of preservation treatments. Another activity in this area will be the actual installation of basic laboratory modules for didactic purposes on a regional level. Work is already in progress on model specifications for such a facility.

Information for the general public will be aimed at raising consciousness regarding the earthen architectural heritage. Activities will include the publication of selected monographs on earthen architecture as well as exhibitions and high-visibility media events. In the first phase of the project, new material on preservation and technical issues of earthen construction will be added to existing exhibitions.

The generation, collection, management and dissemination of information is critical to the success of any endeavour. The Gaia Project aims to become a clearing-house for information which will aid those already active in the field as well as promote an increased awareness of this important and often neglected component of the world's cultural patrimony.

Sub-Project: Technical Cooperation

An overview of current international technical cooperation in preservation of the earthen architectural heritage suggests a very serious situation. Some of the problematic aspects of this situation are: total absence of information in wide geo-cultural areas, limited assistance by foreign experts, frequent requests for specific advice resulting in missions by only a limited number of professionals, or else by consultants with insufficient knowledge and experience of the problems concerning this field, restricted scope in the recommendations for preservation, and lack of specific follow-up activities.

The role of international institutions in coordinating technical cooperation with national conservation services requires a revised and more systematic approach. This falls within the context of ICCROM's third statutory function which mandates that the institution provide advice on general and specific points connected with the preservation and restoration of cultural property. It is also in line with the recommendations of the meetings in Yazd, Santa Fe, and Rome, which reiterated the need to initiate field pilot projects in an integrated plan of activities, and also the agreement signed by ICCROM/CRATerre-EAG.

In this regard, the Gaia Project again aims to promote, create and develop the conditions necessary for rational and effective technical cooperation oriented toward the formulation, implementation and management of overall site preservation plans.

The first step toward achieving this goal is to identify and establish contacts with national conservation services and with those professionals responsible for the preservation of specific sites in urgent need in order to discuss these problems and to proceed systematically in formulating preservation plans. The training sub-project of the Gaia Project has already provided a unique opportunity for some of these professionals to meet and initiate such discussions. During the 1989 Pilot Course, the project staff met with professionals responsible for earthen archaeological sites of global importance, such as Chan-Chan/Peru, Mari/Syria, Tulor/Atacama, Chile as well as cities such as Quito/Ecuador, Popayán/Colombia, and Alcântara/Brazil. Further development of this initiative has led to contacts and on-going discussions with professionals responsible for the study and preservation of the Albaicín in Granada/Spain and Evora/Portugal. From these preliminary discussions, we have confirmed our perceptions regarding the generalized need for preservation plans and we have defined two levels of action.

On a general level, in order to better characterize the form and quality of existing international technical cooperation, it is indispensable to initiate a careful evaluation of previous activities with countries and/or cultural areas that possess a significant earthen architectural heritage. This can be effectively carried out through a summary review of the activity of each of the institutions involved in the Gaia Project (ICCROM/CRATerre-EAG) in the above-mentioned countries. Through systematic research, this can then be supplemented with further information about the activities of other institutions.

On a more specific level, contacts with field professionals (some mentioned above) have initiated processes for immediate action. These activities are aimed at the formulation of overall preservation plans and include the definition of conservation priorities for each site based on the evaluation of previous site preservation work, systematic condition assessment, installation and subsequent utilization of earth preservation modules (site laboratories and monitoring equipment), and conservation/maintenance of the sites based on the plans. As always, a close connection with the other Gaia sub-projects of training, research, and documentation is foreseen in the long-term scheme.

Continuity can be guaranteed only in the context of this kind of integrated activity, based on the promotion and technical support of national conservation services and professionals in this domain.

The preservation of the world's earthen architectural heritage cannot rely on the questionable effect of sporadic actions, the production of countless mission reports/recommendations which are never implemented, the circumstance of emergency, the ephemeral opportunism of practical politics or similar factors. It is essential to promote a consistent scientific approach to this problem. In this respect we hope that the Gaia Project will offer a frame of reference for much-needed integration of activities and the efficient utilization of means and resources.

NOTES

1. Premier colloque international sur la conservation des monuments en brique crue, Yazd-Iran, Conseil International des Monuments et des Sites et Icomos-Iran, 25-30 nov., 1972.

2. International Symposium and Training Workshop on the Conservation of Adobe, Lima-Cusco (Peru), The Regional Project on Cultural Heritage and Development UNDP/Unesco and ICCROM, 10-22, Sep., 1983.

3. 5th International Meeting of Experts on the Conservation of Earthen Architecture, Rome, ICCROM and CRATerre, 22-23, Oct., 1987.

4. Agreement between ICCROM, CRATerre and EAG, Rome-Grenoble, jul.- aug., 1989.

5. Third International Symposium on Mud-brick (Adobe) Preservation, Ankara, ICOM-ICOMOS Turkish National Committees, 29 Sep.-4 Oct., 1980.

6. 2ème colloque international sur la conservation des monuments en brique crue, Yazd-Iran, Conseil International des Monuments et des Sites et Icomos-Iran, 6-9 mars, 1976.

7. US/ICOMOS - ICCROM Adobe Preservation Working Session, Santa Fe, NM, 3-7 Oct., 1977.

8. James R. Clifton, Preservation of Historic Adobe Structures - A Status Report, Washington DC, U.S. Department of Commerce, (NBS Technical Note 934, 1977), and, James R. Clifton, - Paul Wencil Brown, Methods for Characterizing Adobe Building Materials, Washington DC, U.S. Department of Commerce, (NBS Technical Note 977, 1978).

9. A. Tomaszewski, "The Long-Term Plan of ICCROM", ICCROM NEWSLETTER 15, (Rome: ICCROM, 1989), 3-6.

10. CRATerre-EAG - ICCROM, Final Report of the First Pilot Course on the Preservation of the Earthen Architectural Heritage - A methodological approach, Grenoble/Rome, CRATerre-EAG/ICCROM, Dec., 1989.

Appendix 1

Summary of the international recommendations for the preservation of the earthen architectural heritage.

YAZD/IRAN - 1972	YAZD/IRAN - 1976	STA.FE,NM/USA-1977	ANKARA/TUR - 1980	LIMA/PERU - 1983	ROME/ITALY - 1987
Excavation plans should include simultaneous preservation interventions;	Excavation budgets should include preservation interventions;	Research on: Building techniques and compatible materials; Seismic response; Non-destructive methods to determine water content, distribution, and migration; plastic deformation, salt migration, and crystallition; Damp-proof coursing; Surface and sub-surface drains; Traditional and modified mortars for capping, renders and in-fill materials; Chemical surface treatments for decorated elements; Grouting techniques for structural stabilization;	Introduction of the expression "earthen architecture" in the preservation lexicon and attempts to better define the universe of this field;	Reiterates the urgent need to develop an earthen architecture preservation network;	Prompts participants of the meeting to take responsibility for the implementation of international recommendations
Backfilling of structures with no further scientific or touristic interest;	Backfilling following thorough recording and documentation;	Development of a glossary of building techniques;	Encourages the use of traditional materials and techniques for preservation purposes, based on considerations of compatibility and continuous use;	Recommends a systematic inventory of earthen sites; and further studies on building techniques;	Changes the name of the International Icomos Committee (...preservation of earthen architecture);
If necessary, structural stabilization through partial reconstruction of the structure;	Prompt, expedite interventions;	Institution of an International Committee for field and lab test standards; Coordinated field pilot projects; Development of an international information exchange network	Stresses the need to provide temporary protection to earthen structures while excavations proceed;	Intensive training in established centers;	Encourages the Committee to activate roles in the collection and diffusion of information, and in the preparation of annotated bibliographies, possibly through the Conservation Information Network, and Decides to create of a specialized training programme on the preservation of earthen architecture in Grenoble at the seat of CRATerre EAG & USTMG
Protection of horizontal surfaces by means of roof shelters or capping;	Temporary shelters and capping;		Specifies the characteristics and properties of such protective structures;	Specific training for the preservation of painted surfaces on earthen walls;	Recommends contacts with industrial research; The activation of National committees; Reiterates need for an inventory;
Maintenance of existing renders on vertical surfaces;	Chemical treatment of vertical surfaces;		Recommends research on: Modular protective shelters, to be tested in field pilot projects;	Mentions general considerations concerning rehabilitation and up-grading of earthen architecture.	Pilot projects, A "State of the Art" report.
Application of renders, where missing;	Lab research on: mechanical behaviour of the material, composition, stabilization, treatment products;		Development of Standards for test procedures in lab and field situations;		
Surface treatments with water-resistant materials: Stabilized soil-cement, Diluted epoxy resins, Ethyl silicates, Bitumen;	Definition of pilot research field projects on specific sites;		Includes a specific recommendation for cases of partially burnt earth structnres.		
Regular maintenance for buildings in current use, with special attention to: Roofs, vertical surfaces and drainage systems;	Creation of a data bank for concentration, divulgation of research results;				
Use of compatible materials.	Regular inspection and maintenance				
	Up-grading of installations in buildings in use: electricity, water and sewage, heating, etc.				

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