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

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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.

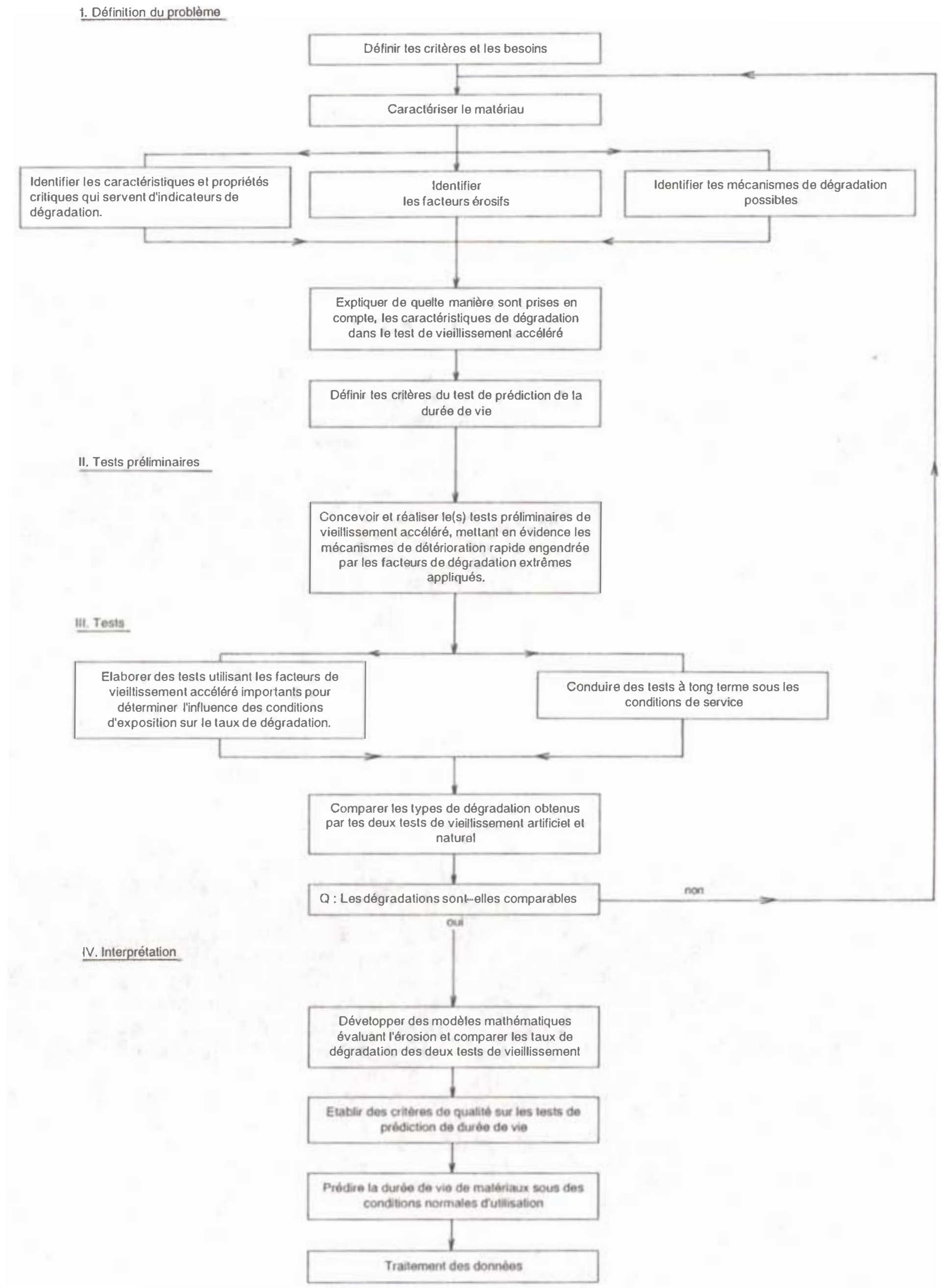

Figure 1 - Méthodologie d'étude du vieillissement des matériaux

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).

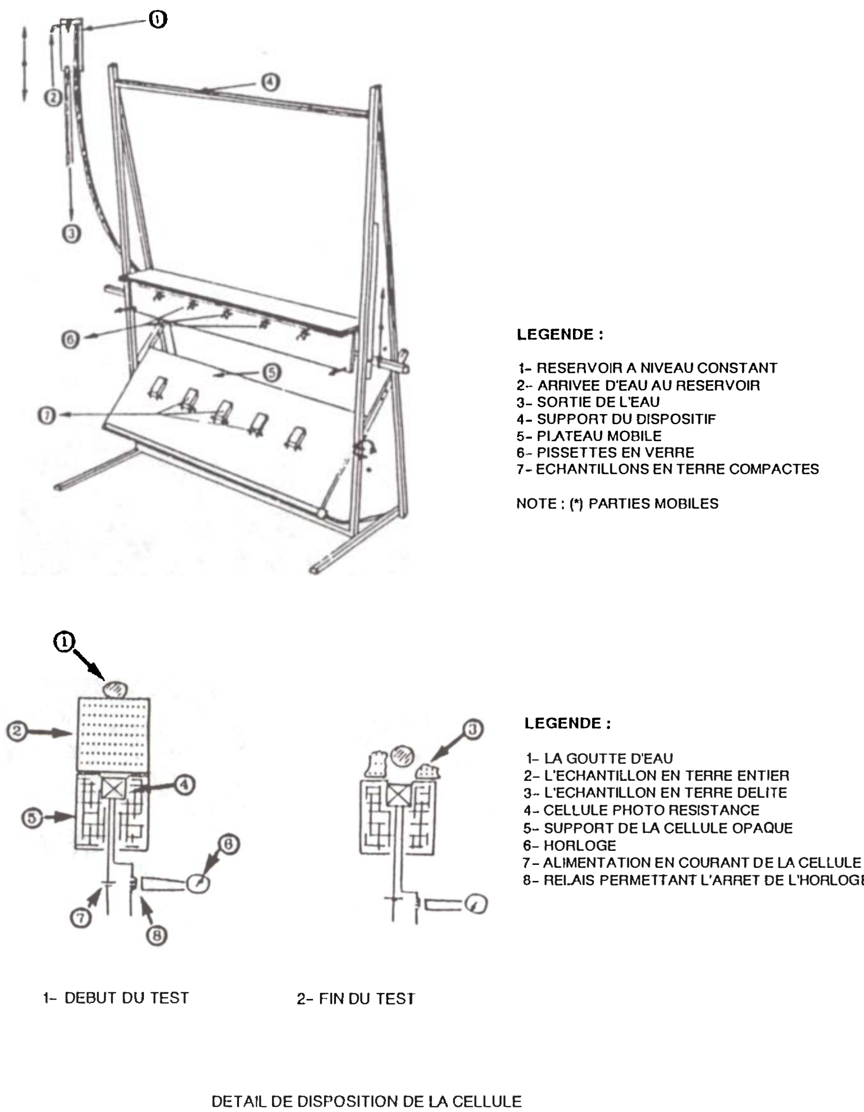

Figure 2 - Test de la goutte d'eau

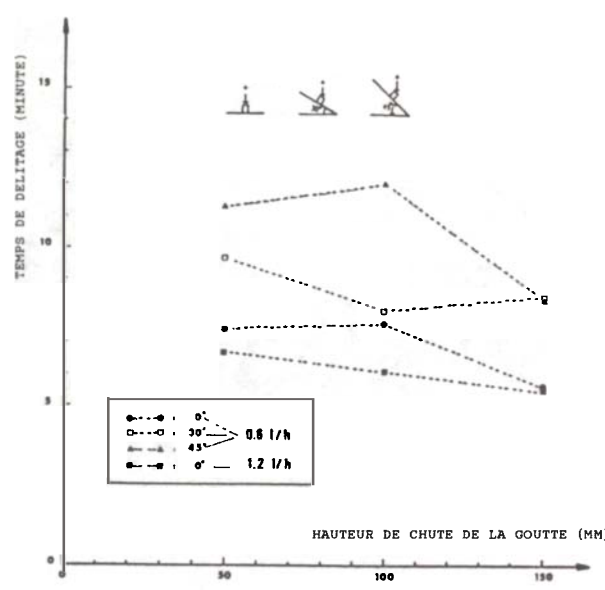

Figure 3 - Temps de délitage en fonction de la hauteur de chute de la goutte

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.

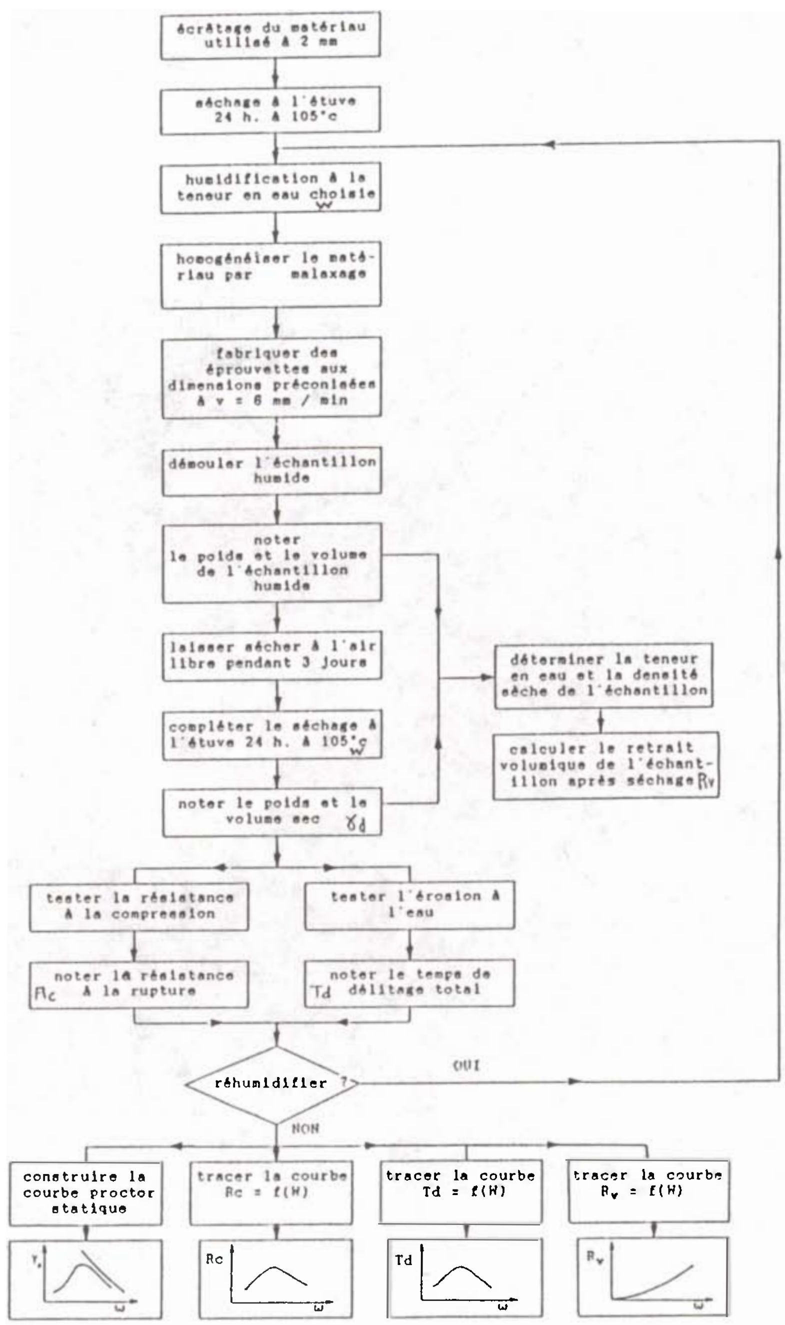

Figure 4 - Protocole de fabrication et d'essais des éprouvettes au laboratoire

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.

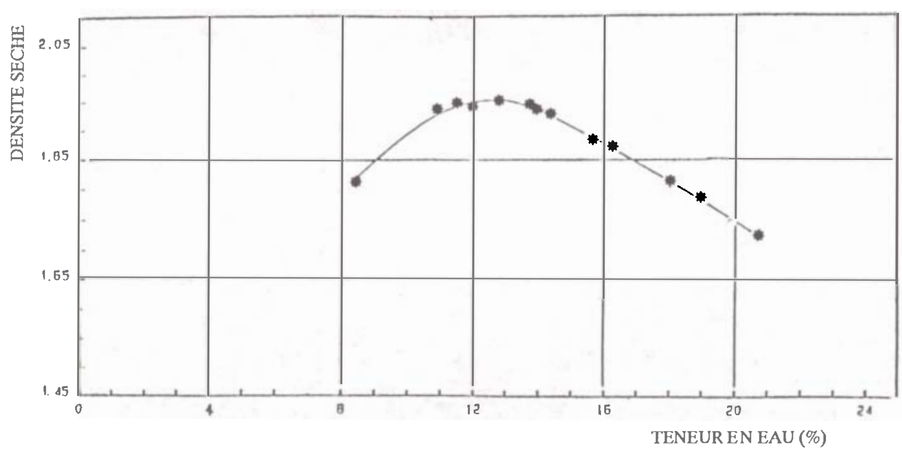

Figure 5 - Variation de la densité sèche en fonction de la teneur en eau (p = 9MPa)

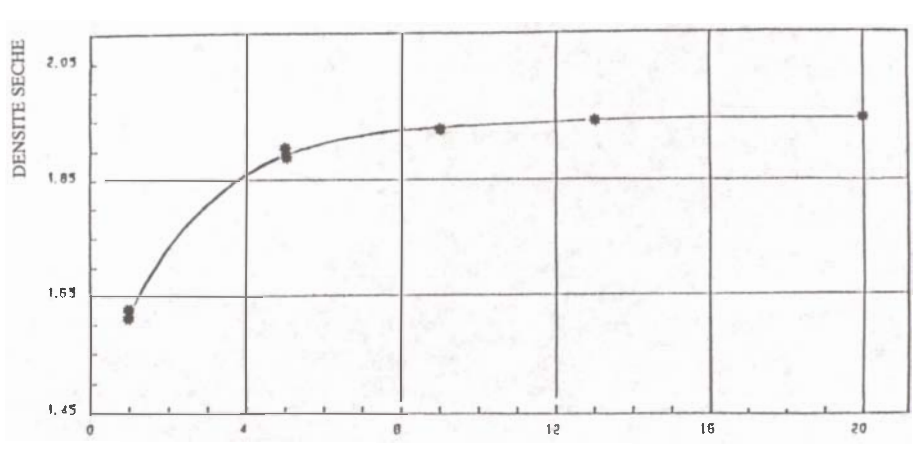

Figure 6 - Effet de la pression de compactage sur la densité sèche (teneur en eau 12,5%)

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.

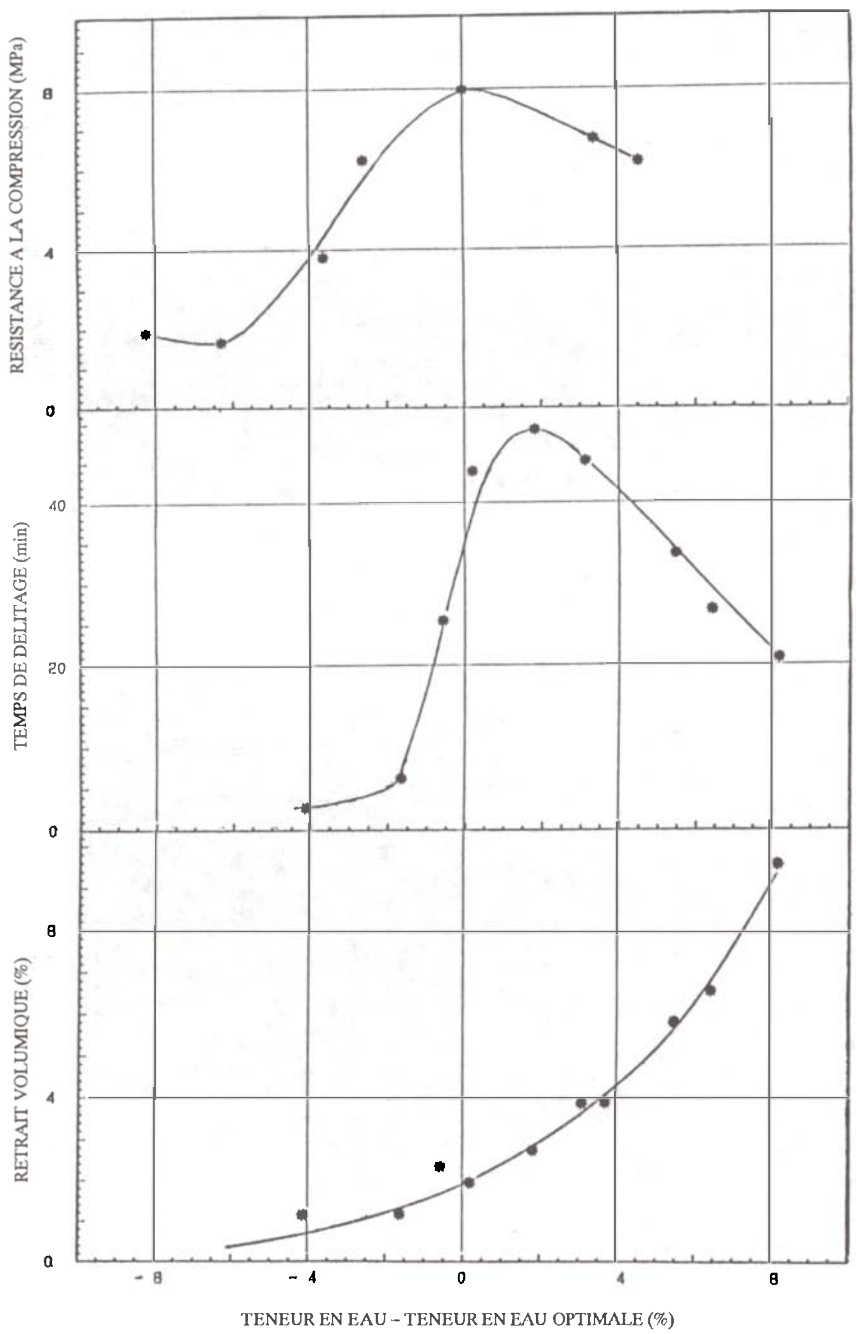

Figure 7 - Effet de la teneur en eau sur la résistance, le temps de délitage et le retrait volumique (p= 9MPa)

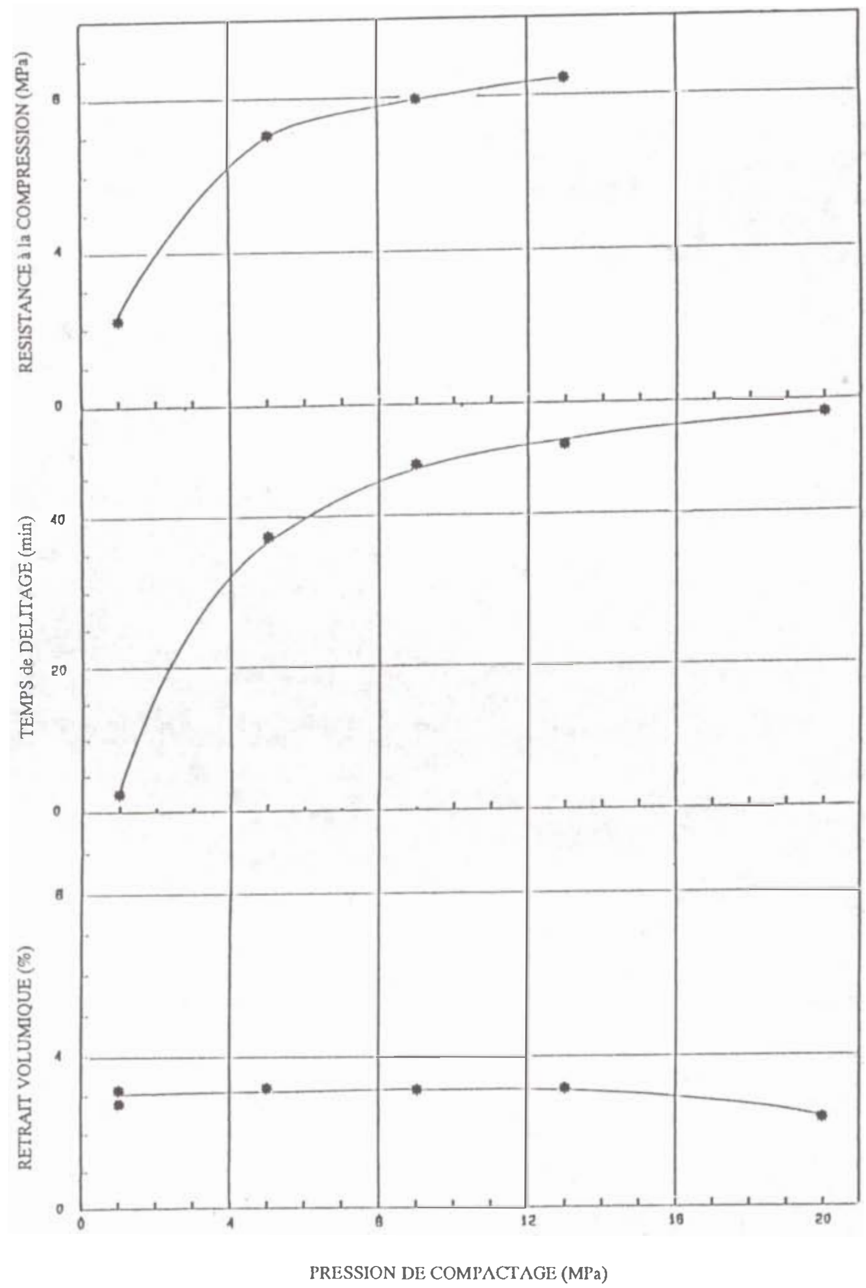

Figure 8 - Effet de la pression de compactage, sur le temps de délitage et le retrait volumique (w = 12,5%)

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.

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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

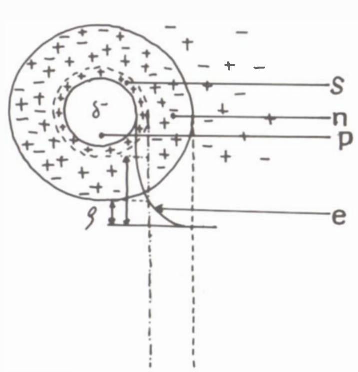

fig 1

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

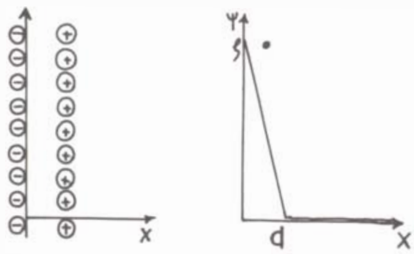

Fig 2: la couche de Helmoltz.

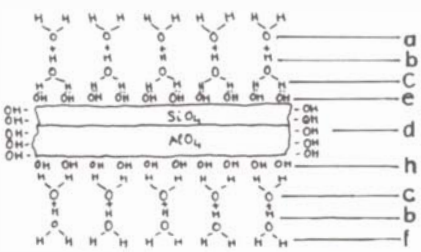

fig 3

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.

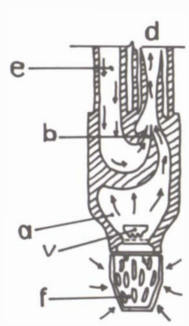

fig 4

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 electrodes, 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

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.

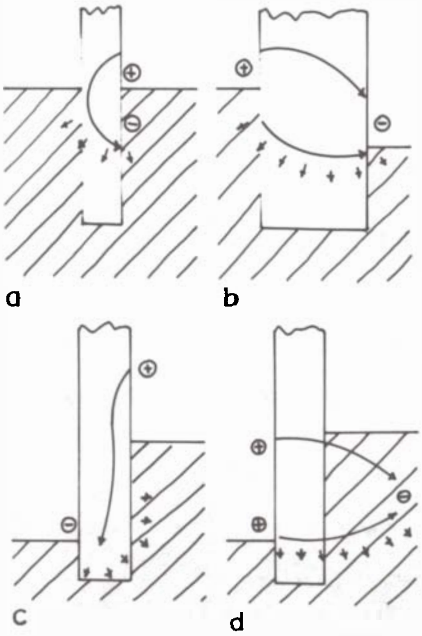

fig 5

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)).

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PATHOLOGIE HUMIDE DE CONSTRUCTIONS EN TERRE : METHODOLOGIE DE DIAGNOSTIC

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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.

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

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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].

Characterization of New Mexico Adobe Soil

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

Geology--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.

<u>Hydrology</u>--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.

<u>Adobe Soils from other Parts of the World</u>

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

<u>Summary and Conclusions</u>

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.

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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

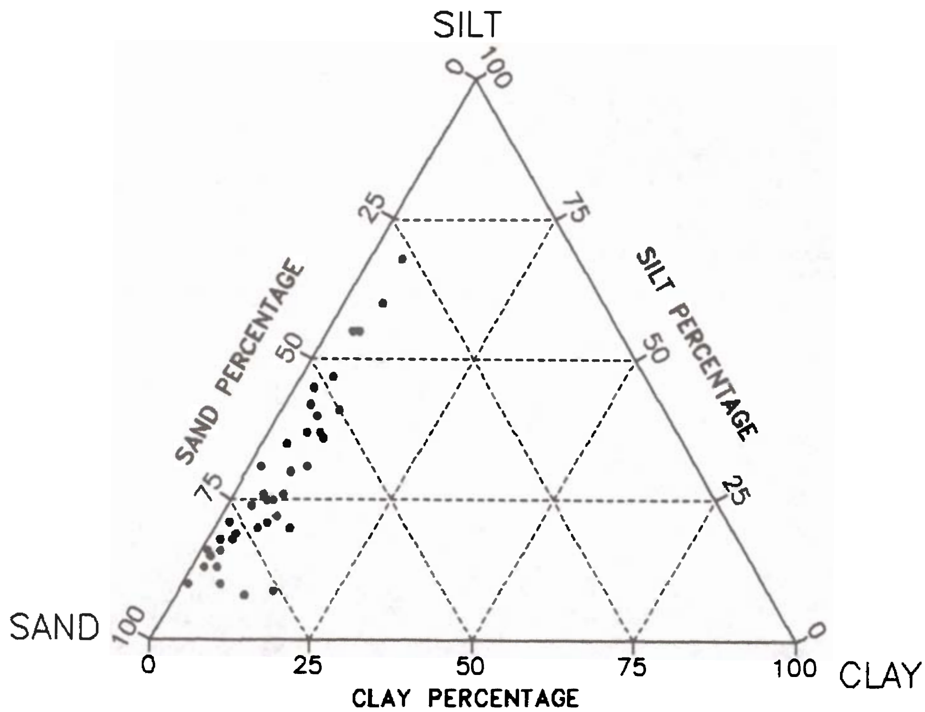

Figure 5. Plot of sand and larger, silt, and clay grain-size fractions of 42 production adobe soils used in New Mexico. The diagram shows the dominance of the larger particle sizes compared to clay grain-size material.

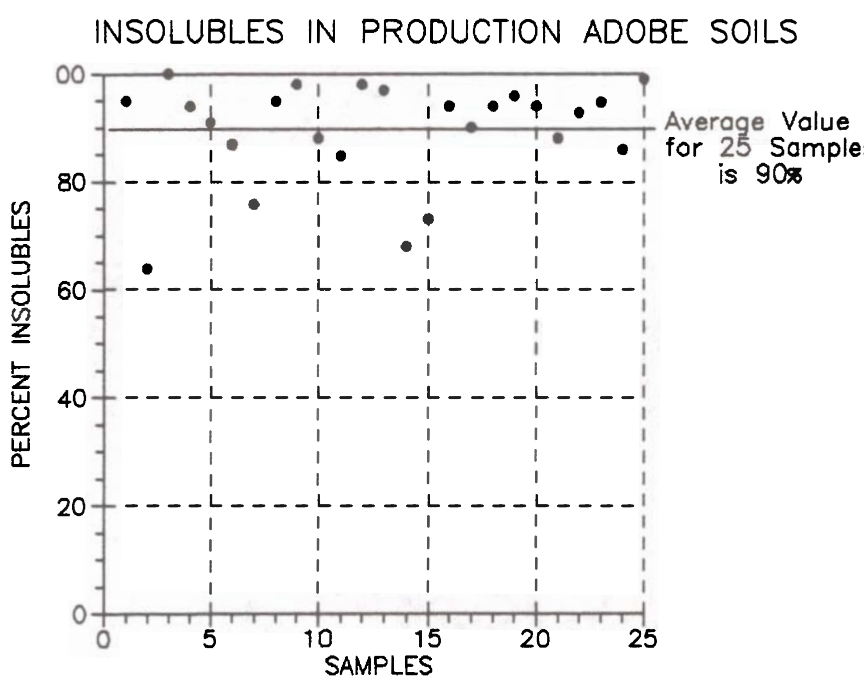

Figure 6. Summary of leaching analysis of 25 adobe soils used in New Mexico. The average insoluble fraction (insoluble in EDTA after boiling for four hours) is 90%.

ADOBE MINERALOGY: Characterization of Adobes from around the world.

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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).

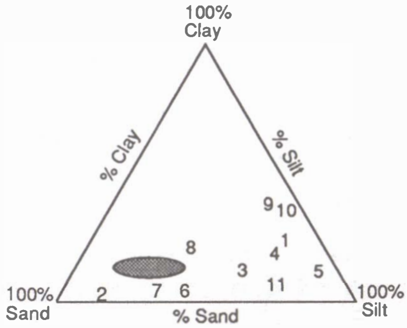
Whole rock and clay mineralogy of the adobes were obtained by X-ray diffraction (XRD) analyses. Particle size distribution was determined using mechanical sieving for the sand-and-larger- (sand+) and silt-size particles, and a settling tube for the clay-size fraction. The grain size distribution is reported 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



Preferred soil composition for adobe
(Adapted from [5])

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

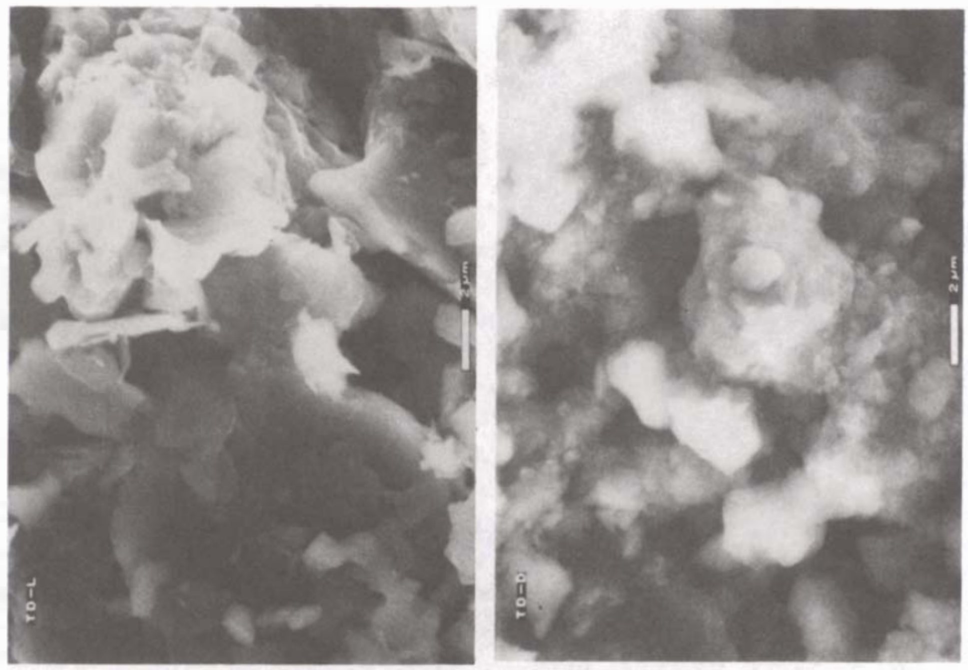


Figure 2. Environmental SEM secondary electron micrographs of clay particles from two different adobes. a) Photograph on left is sample of Tel Dan light adobe (TD-2) which exhibits fairly coarse-grained clay particles with well-developed, crystalline shapes. b) Photograph on right is sample of Tel Dan 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.

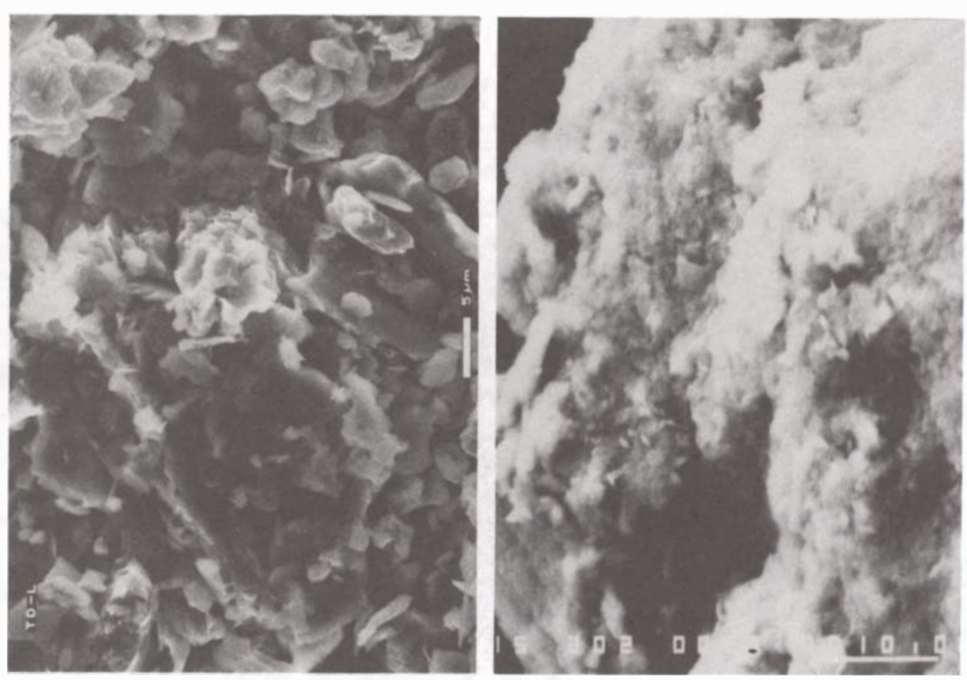
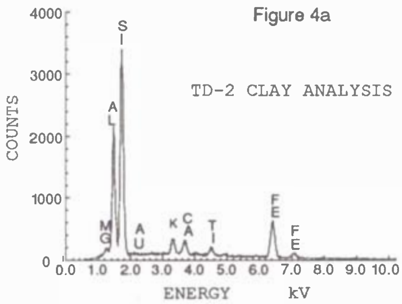


Figure 3. Environmental SEM secondary electron micrographs showing the difference in clay grain size for two adobes. a) Photograph on left is of Tel Dan light adobe (TD-2) with most of the clay particles being several µm in size or greater. b) Photograph on right is of Ft. Selden adobe (FS-1) where most 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.



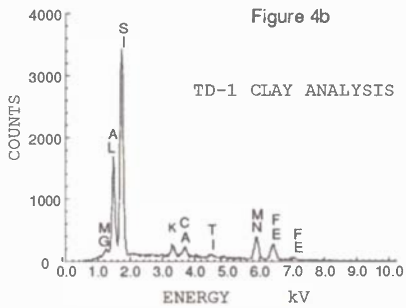


Figure 4. Energy dispersive X-ray spectra of clay particles shown in figure 2. a) Tel Dan-2. Note the low Si/Al ratio and the presence of Mg, Fe, Ca, K, and Ti. b) Tel Dan-1. Note the higher Si/Al ratio and unusual Mn concentrations in addition to Fe, K, Ca, Ti, and Mg. The Mn may be due to the presence of colloidal Mn oxides associated with the clays.

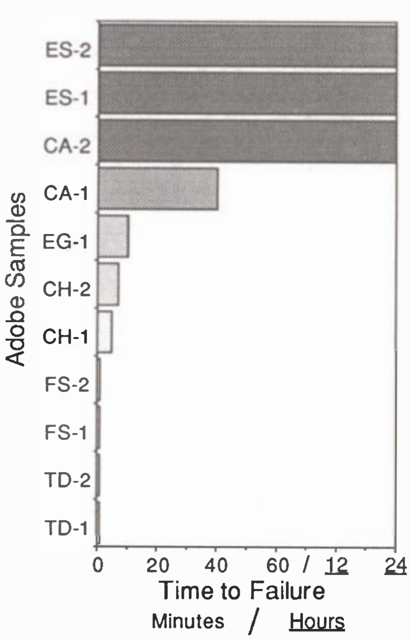


Figure 5

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.

<u>Summary</u>

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

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NINETEENTH CENTURY NEW YORK STATE EARTHEN HOMES: AN INVESTIGATION OF THEIR MATERIAL COMPOSITION

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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

Summary of Test Results

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

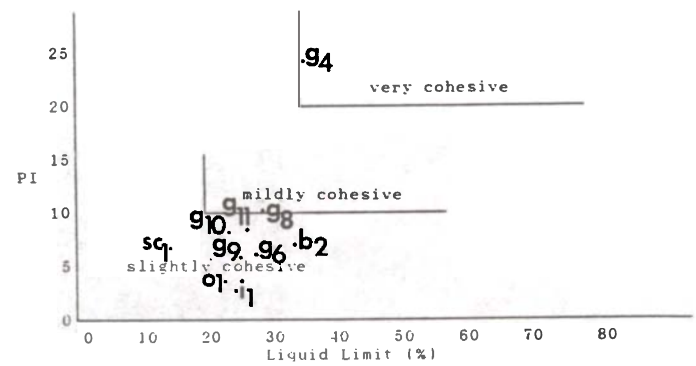

Figure 3: Cohesiveness of Soils

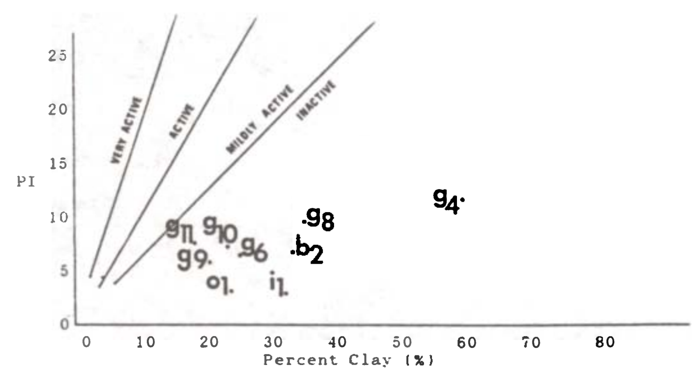

Figure 4: Activity Coefficient of Soils

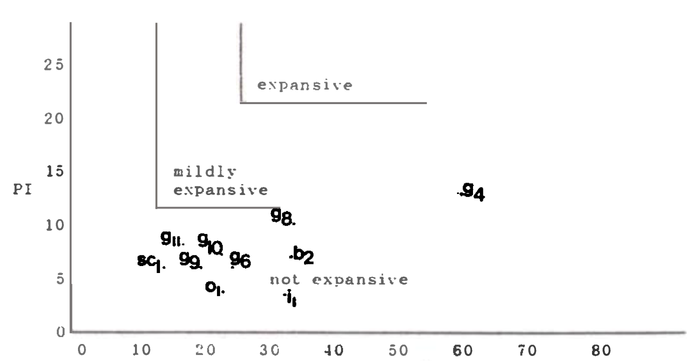

Figure 5: Expansivity of Soils

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

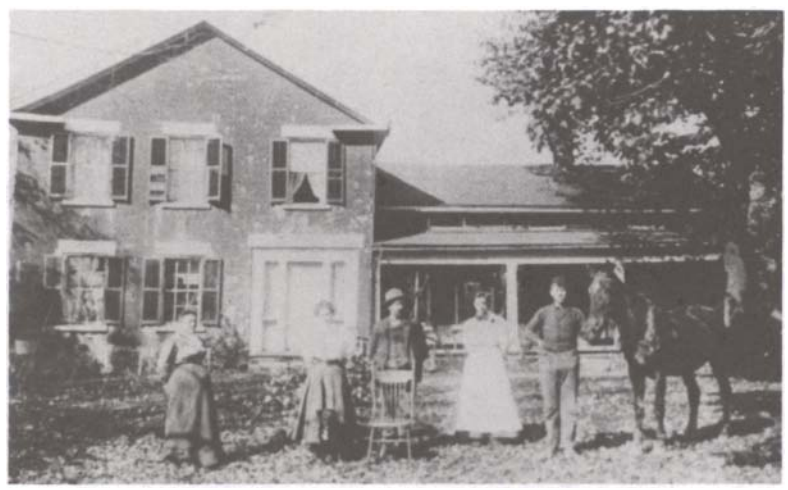

Figure 6: Luther Smith Home, Springfield Center, (19th Century)

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

Completion of this project would not have been possible without the cooperation of Richard Pieper and the guidance of Martin Weaver, Frank Matero, and those at CRATerre and ICCROM who were involved with the 1989 'First Pilot Course on the Preservation of the Earthen Architectural Heritage'. Special thanks to Richard April of Colgate University for running the XRD tests.

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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.

CARACTERIZACION FISICA DE ADOBES DE CASTILLA-LEON (ESPAÑA)

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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.

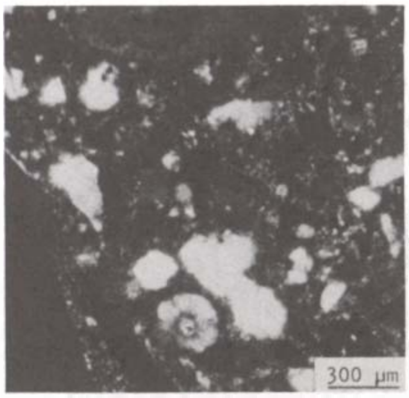

Fig. 1.- Aspecto de la textura del adobe de Villavicencio al microscopio de polarización (N.C.). Pueden observarse granos de cuarzo y la matriz arcillosa.

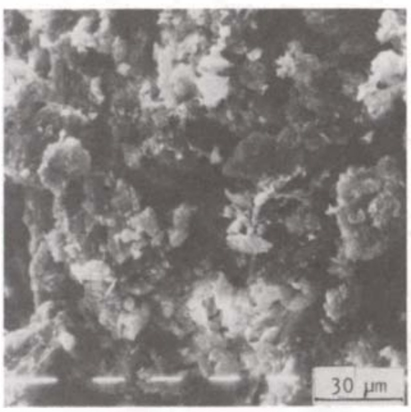

Fig. 2.- Detalle del adobe de Villavivencio al microscopio electrónico de barrido. Nótese la morfología de los granos y de los poros.

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.

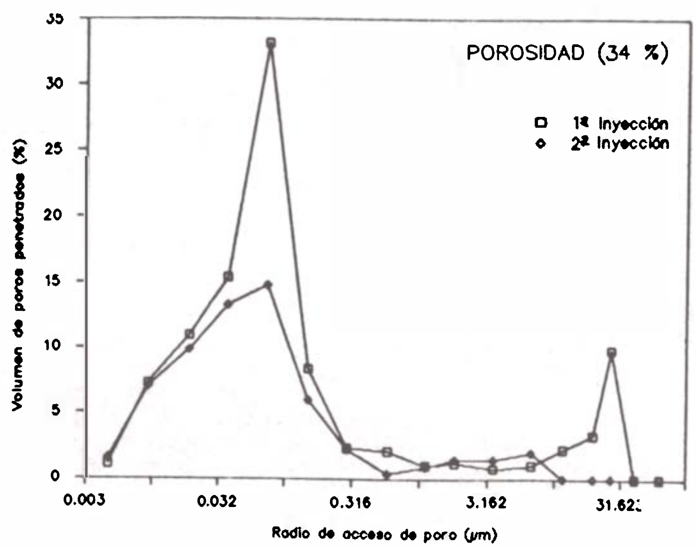

Fig. 5.- Curvas de frecuencia de la porosidad en función del tamaño de acceso a los poros en el adobe de Villavicencio. Se muestra la porosidad accesible al Hg (1ªInyección), la porosidad libre (2ªInyección) y su complementaria (porosidad atrapada).

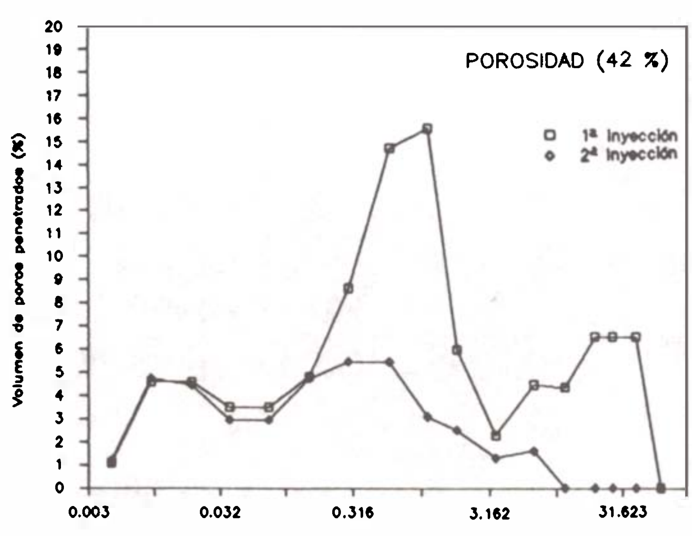

Fig. 6.- Curvas de frecuencia de la porosidad en función del tamaño de acceso a los poros en el adobe de Portillo.

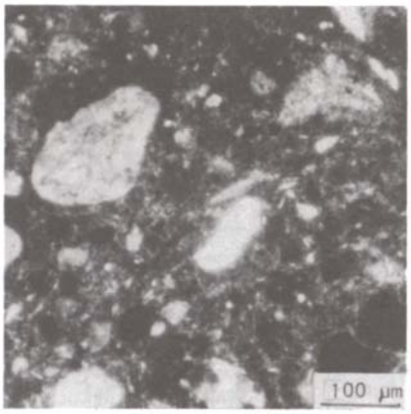

Fig. 3.- Aspecto de la textura del adobe de Portillo al microscopio de polarización (N.C.). Se observan algunos granos de cuarzo y calcita, inmersos en una matriz más carbonatada (micrita).

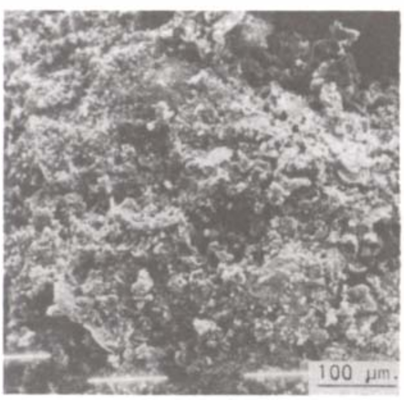

Fig. 4.- Detalle del adobe de Portillo al microscopio electrónico de barrido. Se pueden observar los componentes finos (arcillas) recubriendo los granos minerales.

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.

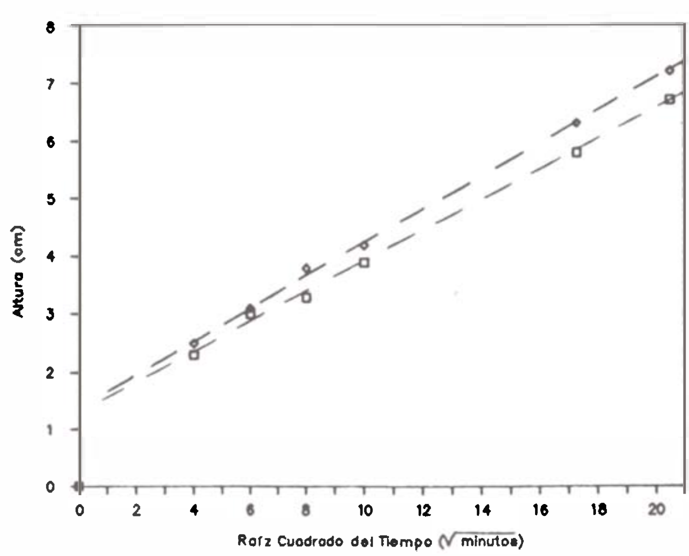

Fig. 7.- Ascensión capilar: Altura ascendida por el agua en función del tiempo durante las primeras horas de ensayo.

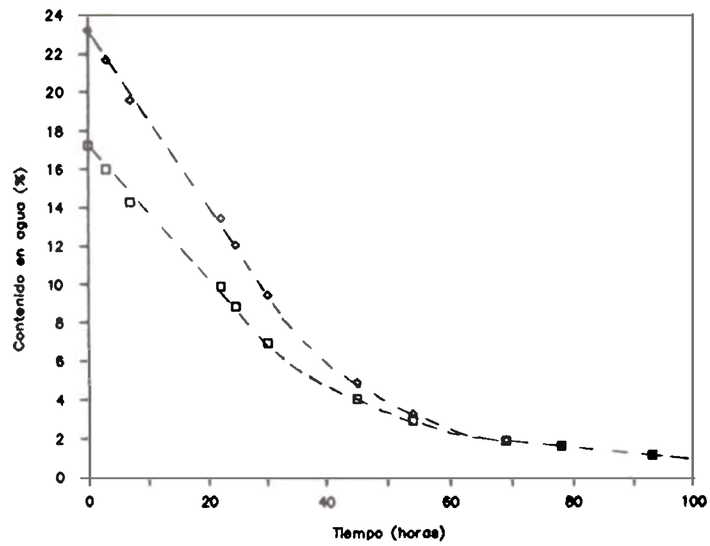

Fig. 8.- Curvas de evaporación: Contenido en agua en función del tiempo durante los primeros días de secado.

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.

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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 deberia caracterizarse por el bajo costo de su preparación y por los parámetros fisicos 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 técnica gravimétrica empleando una balanza analítica (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 péndulo 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 flexión sobre cilindros de varios diámetros, tal como lo describe la PN-76/C-81528.

3.3. Resultados de estudios.

3.3.1. Cambios de color.

Después de 104 días de exposición a la radiación (dósis de radiación H=11.25 mmol/cm2) no se han observado cambios de color en las muestras preparadas del Imlar CPC 1175T. Por otro lado, se observó el amarilleo en los recubrimientos del preparado de la Cola Sintética, lo que se percibió después de 46 días de radiación (dósis de radiación 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 (dósis) de radiación (ver Tabla III). En cambio, al tratar con Cola Sintética, el decrecimiento de masa promedio alcanzó el 16% (dósis de radiación H=11.25 mmol/cm2) y fue directamente dependiente de la radiación (ver Tabla IV).

3.3.3. Dureza de superficie.

La dureza de superficie del Imlar CPC 1175T es muy pequeña y no cambió durante la radiación (el aumento de .04 al .06 durante los primeros 20 días, al iniciar la radiación, se puede explicar por la evaporización de los restos del agua u otras substancias volatiles).

La dureza de la Cola Sintética aumenta el 44% durante la radiación y depende de su tiempo (consultar Tabla V).

3.3.4. Elasticidad.

El recubrimiento del Imlar CPC 1175T antes y después de la radiación (hasta 104 días) no cambia su elasticidad. No se resquiebra en el cilindro de diámetro de 1 mm. En cambio la Cola Sintetica no se resquiebra en el cilindro con un diámetro de 1 mm antes de exponerla a la radiación pero después de ella - se requiebra en un cilindro con un diámetro de 7 mm.

3.4. Discusión 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 volatilización del suavizador o la fotólisis de polímero, se hace más dura y menos elástica. Imlar CPC 1175T conserva sus propiedades iniciales durante la exposición 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 después de t días				
	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 radiaciòn.

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 radiaciòn

tiempo de radiaciòn /dìas/	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

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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.

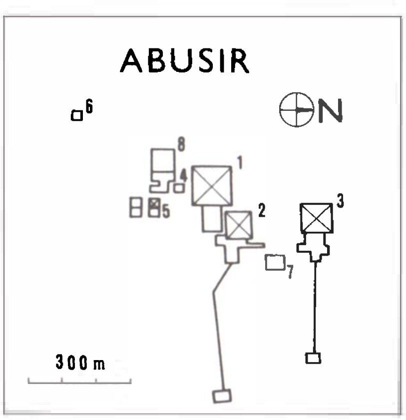

Fig. 1 Map of ancient Egyptian monuments at Abusir 1-pyramid of Neferirkare, 2-pyramid of Novoserre, 3-pyramid of Sahure, 4-pyramid complex of Raneferef, 5-pyramid complex of Khentkaus, 6-shaft tomb of Udjahorresnet, 7-mastaba of Ptahshepses, 8-unfinished pyramid.

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 Neferirka-re'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.

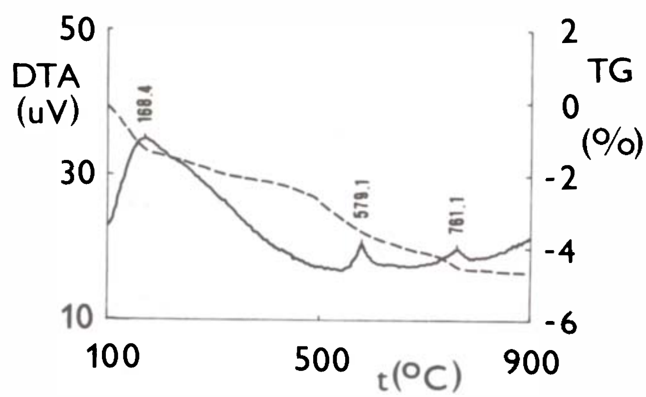

Fig. 5 The DTA/TG analysis of mud bricks from complex of Khentkaus
(air atmosphere /100 ml/min/, sample 217.70 mg, TG 250 mg, DTA 500 μV, Netzsch STA 409).

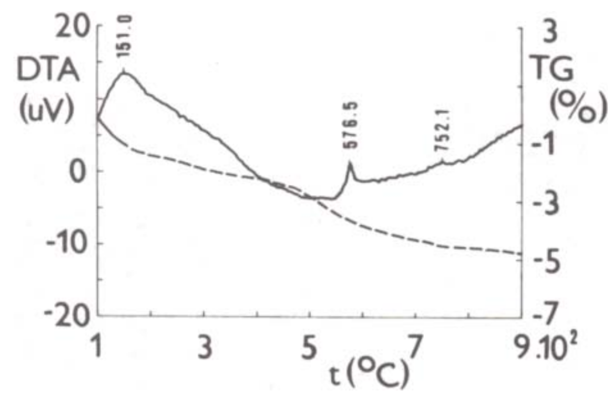

Fig. 7 The DTA/TG analysis of mud bricks from the shaft tomb of Udjahorresnet
(air atmosphere /100 ml/min/, sample 206.64 mg, TG 250 mg, DTA 500 µV, Netzsch STA 409).

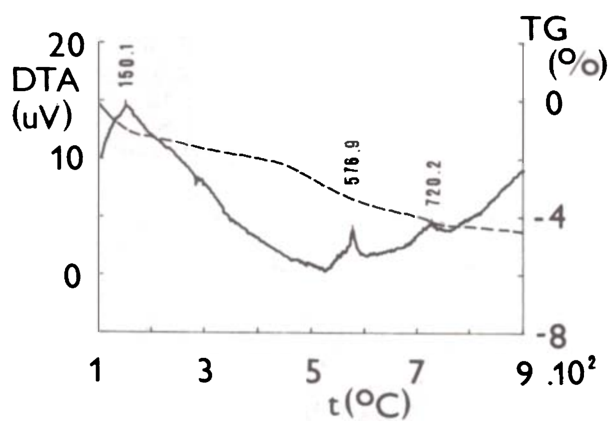

Fig. 6 The DTA/TG analysis of mud bricks from complex of Raneferef
(air atmosphere /100 ml/min/, sample 161.44 mg, TG 250 mg, DTA 500 µV, Netzsch STA 409).

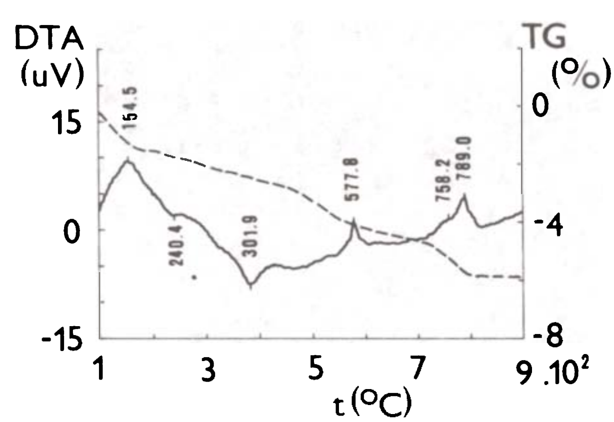

Fig. 8 The DTA/TG analysis of recent mud bricks from today's Abusir village
(air atmosphere /100 ml/min/, sample 235.00 mg, TG 250 mg, DTA 500 µV, Netzsch STA 409).

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.

Acknowledgements

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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

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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.

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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 l/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.

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.

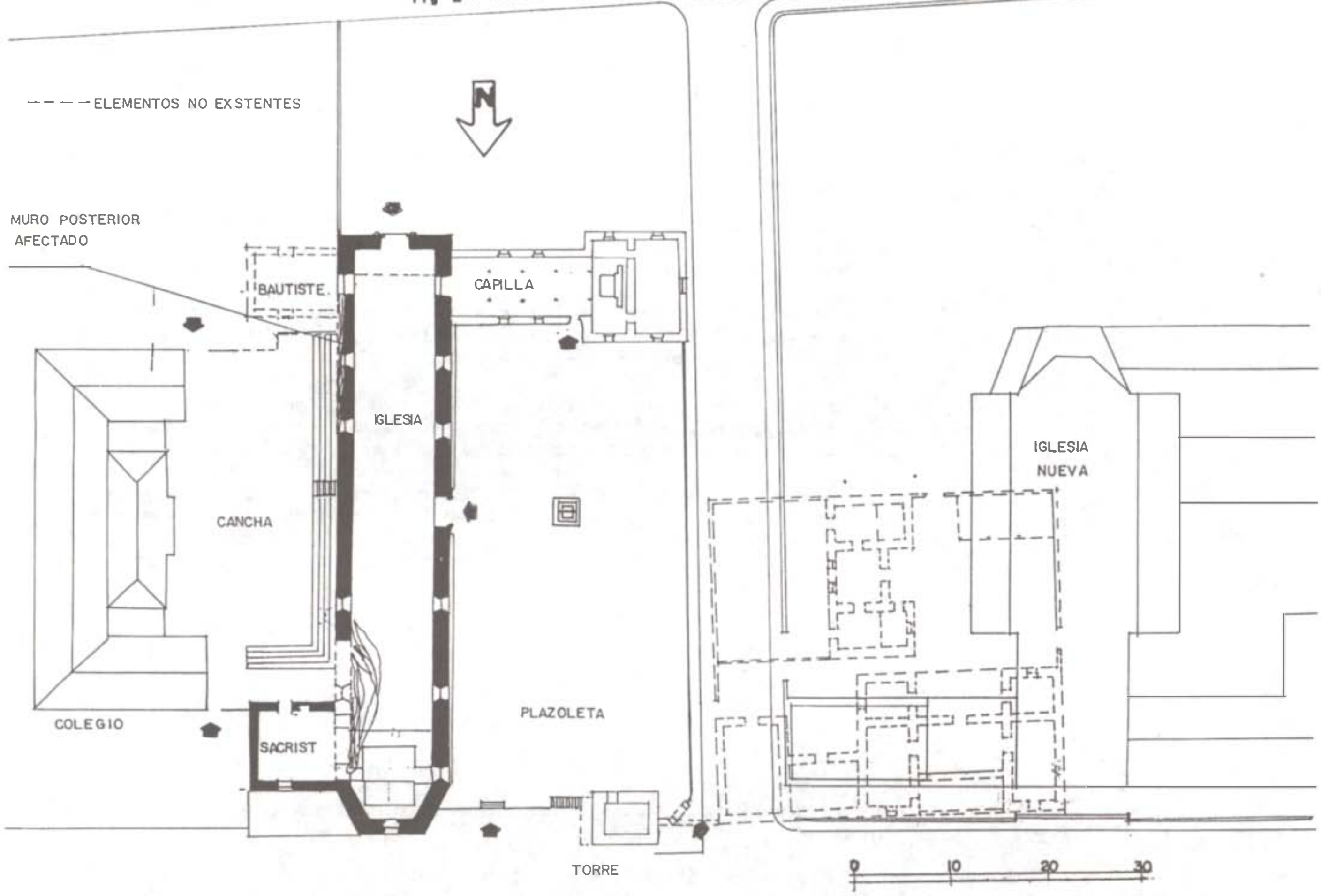
Following the scientific method, the chosen proposal must be subjected to further experimentation and analysis and prove to be the best solution for the problem.

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.

TUMBACO

Fig 2: IGLESIA DE LA INMACULADA CONCEPCION



CRATerre-EAG, ICCROM LONG-TERM PLAN FOR THE PRESERVATION OF THE EARTHEN ARCHITECTURAL HERITAGE: THE GAIA PROJECT

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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.

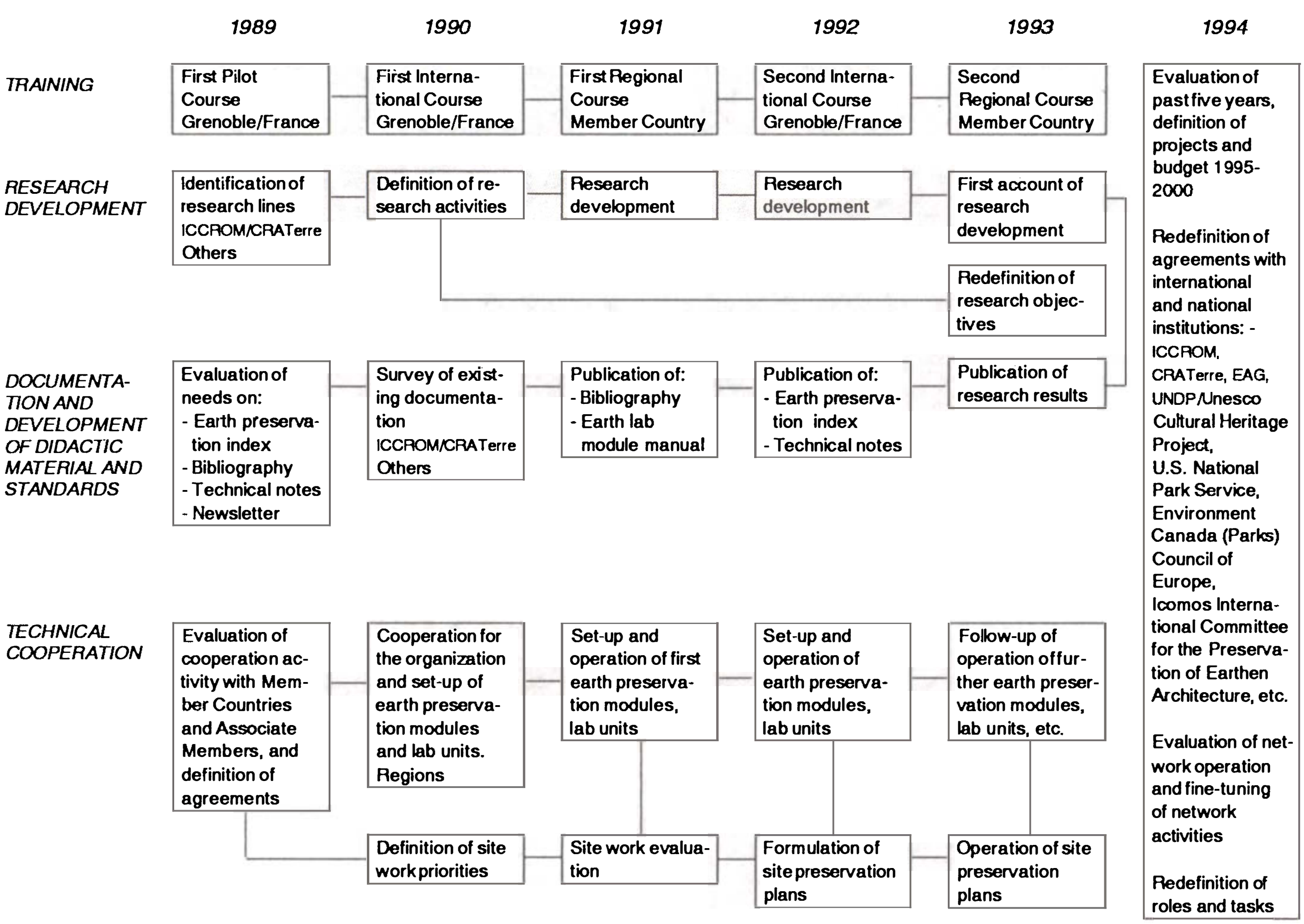
In the context of this ten-year plan, an agreement was subsequently signed by ICCROM, the International Centre for Earth Construction (CRATerre), and the School of Architecture of Grenoble (EAG).

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; Backfilling of structures with no further scientific or touristic interest; If necessary, structural stabilization through partial reconstruction of the structure; Protection of horizontal surfaces by means of roof shelters or capping; Maintenance of existing renders on vertical surfaces; Application of renders, where missing; Surface treatments with water-resistant materials: Stabilized soil-cement, Diluted epoxy resins, Ethyl silicates, Bitumen; Regular maintenance for buildings in current use, with special attention to: Roofs, vertical surfaces and drainage systems; Use of compatible materials.	Excavation budgets should include preservation interventions; Backfilling following thorough recording and documentation; Prompt, expedite interventions; Temporary shelters and capping; Chemical treatment of vertical surfaces; Lab research on: mechanical behaviour of the material, composition, stabilization, treatment products; Definition of pilot research field projects on specific sites; Creation of a data bank for concentration, divulgation of research results; Regular inspection and maintenance Up-grading of installations in buildings in use: electricity, water and sewage, heating, etc.	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; Development of a glossary of building techniques; Institution of an International Committee for field and lab test standards; Coordinated field pilot projects; Development of an international information exchange network	Introduction of the expression "earthen architecture" in the preservation lexicon and attempts to better define the universe of this field; Encourages the use of traditional materials and techniques for preservation purposes, based on considerations of compatibility and continuous use; Stresses the need to provide temporary protection to earthen structures while excavations proceed; Specifies the characteristics and properties of such protective structures; Recommends research on: Modular protective shelters, to be tested in field pilot projects; Development of Standards for test procedures in lab and field situations; Includes a specific recommendation for cases of partially burnt earth structnres.	Reiterates the urgent need to develop an earthen architecture preservation network; Recommends a systematic inventory of earthen sites; and further studies on building techniques; Intensive training in established centers; Specific training for the preservation of painted surfaces on earthen walls; Mentions general considerations concerning rehabilitation and up-grading of earthen architecture.	Prompts participants of the meeting to take responsibility for the implementation of international recommendations Changes the name of the International Icomos Committee (...preservation of earthen architecture); 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 Recommends contacts with industrial research; The activation of National committees; Reiterates need for an inventory; Pilot projects, A "State of the Art" report.

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