Interdisciplinary Experts Meeting on Grouting Repairs for Large-scale Structural Cracks in Historic Earthen Buildings in Seismic Areas

The Getty Conservation Institute
Pontificia Universidad Católica del Perú
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Meeting Objective

From August 13-16, 2007, the Getty Conservation Institute (GCI) and the Pontificia Universidad Católica del Perú (PUCP) hosted a meeting in Lima, Perú, that brought together an interdisciplinary group of fifteen professionals with expertise in earthen conservation, grouting materials and techniques, and seismic retrofitting of earthen sites. The primary objective of the meeting was to share knowledge and evaluate laboratory testing protocols and methodologies for the study of structural grouting in seismic areas in a cross-disciplinary manner.

Introduction

It is common knowledge that earthquakes produce structural cracking, especially in historic earthen buildings. Seismically induced cracks break a wall into independent blocks that pound each other during a tremor. The longer the seismic event, the greater wall or block displacement and damage to the structure. In cases of strong shaking, the damage can lead to partial or total collapse of the structure. More commonly the walls sustain a series of cracks that jeopardize the building's structural stability without causing collapse. Conservation professionals are constantly challenged by the decision whether to repair or demolish entire walls of earthen buildings that have been damaged during an earthquake.

The vulnerability of earthen buildings to earthquake damage is a serious concern to those responsible for safeguarding cultural heritage. The GCI has a longstanding commitment to the preservation of earthen architecture. From 1992 to 2002, the GCI focused on the problem of earthen architecture in seismic zones through the Getty Seismic Adobe Project (GSAP), which sought to find technologically feasible, minimally invasive, and inexpensive techniques with which to stabilize adobe buildings.

To this end, the GSAP team conducted research and shake-table testing of adobe structures to evaluate retrofitting methods that would ensure life-safety while preserving the historic architectural fabric. These retrofitting techniques, however, are considered overly invasive or too expensive for many of the world's seismic regions. Furthermore, even retrofitted earthen buildings will crack during an earthquake event, damaging other valuable components of the building such as wall paintings or decorated surfaces.

In 2006, the GCI organized the Getty Seismic Adobe Project Colloquium, a meeting of sixty international experts, in order to evaluate these retrofit alternatives and to identify current research needs. At its conclusion, colloquium working groups recommended further investigation into less-invasive methods and the viability of structural grouting for wall consolidation and structural stabilization.

In an effort to address this issue, the engineering department at PUCP has undertaken a research program to analyze different methods of repairing seismically induced cracks. Philosophical and theoretical criteria advocate minimal interventions, allowing the maximum retention of original fabric. Thus, any mechanical repair should restore continuity of the wall while ensuring physicochemical compatibility with original materials and construction techniques. Based on the heterogeneous nature of earthen materials, drilling and pinning for reattachment is often rejected as too unpredictable and structurally dangerous. Noninvasive structural grouting, defined as the injection of fluid mortars or adhesives to fill discontinuities and cracks and reintegrate detached wall sections, is seen as a more promising solution to the problem.

The study and testing of grouts in general has been a topic of interest for the conservation community since as early as 1970. The compatibility of lime- or earth-based grouting formulations with adjacent materials has been considered in work carried out at several sites, but studies considering the efficiency of this method for seismic stabilization or the nature of the impact of a seismic event on the grout and/or its relationship with the original materials and structure are lacking.

In 2006, the PUCP started preliminary testing and bibliographical investigations in order to pre-select adequate structural grouting materials for adobe walls using locally available soil. Once this preliminary phase concluded, the GCI agreed to provide financial and technical support for a second research phase addressing both engineering and conservation issues. The objective of this phase is to compile information, conduct research, and perform laboratory testing to identify and evaluate grouting materials that are compatible with original materials, structurally effective, and result in minimal impact on original fabric during a seismic event.

Research Issues and Discussion

Following an introduction to the work conducted by GCI and PUCP, the meeting opened with a series of questions that were printed in the agenda and sent to meeting participants in advance. The purpose of the questions was to identify a wide range of topics and begin to shape the discussions that followed.

Questions and discussion topics addressed:

- What are the key issues affecting structural grouting for earthen buildings located in seismic areas?
- Dynamics of wall: pre-crack/post crack
- How host material bonds
- How soil grout bonds
- Mechanisms of damping of wall motions
- Damping terms of existing structures
- Property development of adobe over time
- What should grouting achieve and why?
- What are the ideal properties of a grout for earthen building materials?
- How will the injected material restore continuity to the wall?
- How can the ideal properties of structural grouting be measured?
- What are the structural differences between stone or brick masonry vs. adobe masonry?
- What are the structural differences between rammed earth and adobe?
- How will these differences affect the testing protocols as well as injection techniques?
- Bibliography of testing protocols for grouted masonry
- Applicability of testing protocols to structural grouting

Preamble

The group agreed upon the following principles as a prerequisite for undertaking a research program that attempts to address grouting as a possible repair technique:

- Earth is sufficiently different as a building material and construction method to warrant a discussion separate from other types of construction techniques and materials. For the purpose of the meeting, discussion was limited to earthen buildings and for the moment we have not considered the study of composite construction techniques, such as earth and stone.

- The research conducted at PUCP indicates that techniques developed for adobe masonry are likely applicable to rammed earth, but further testing should be conducted in order to scientifically address the effects of grouting adobe or rammed earth walls.
- Grouting is one of many crack repair techniques. In the field, conservators commonly use a combination of interventions, including grouting, pinning, stitching, and/or bracing. Although the range of interventions should eventually be addressed as a whole, the group decided that for the purpose of this meeting we would focus on grouting alone. A second phase could consider the study of complementary interventions if necessary.

Engineering Background

The group was aware of the contribution of the GSAP in designing interventions to enhance the stability of the building during an earthquake event in order to avoid sudden collapse. The generation of cracks is inevitable and will need to be addressed. In order to determine the proper type of intervention, the conservator should be knowledgeable about construction technology, including various types of masonry, soil typology, collapse mechanisms, and different repair techniques. A structural diagnosis of the building or site must be conducted in order to determine whether grouting is an appropriate technique. This diagnosis should consider crack propagation, types of cracks, and crack sizes. In most cases, grouting is only one of a series of interventions.

Grouting of earthquake generated cracks should achieve the following objectives:

- Recover original wall integrity and strength by repairing the earthquake generated wall discontinuity.
- Reduce vulnerability to further damage. Grouting as a repair technique cannot be considered an intervention for retrofitting because of its limited ability to strengthen buildings. Applied grout can act as an energy absorber during a seismic event, inducing crack generation in the grout rather than the wall itself, as historic cracks reopen.

Grout Properties

The group identified general grout properties that need to be further tested. Grout properties cannot be studied in isolation and results should be analyzed in a complementary manner. The final grout formulation depends on the characterization of the host material, as well as the relationship between the host and grout materials (interface).

The group considered the following properties essential in better defining the grout composition and predicting its future performance:

- Viscosity
- Fluidity
- Penetration/Injectability
- Set time (initial and final)
- Stability
- Shrinkage
- Dilation
- Cohesion
- Bonding
- Crack formation within grout
- Compatibility (similar material if possible)
- Durability

As noted above, properties cannot be studied separately. Due to the importance of the chemical and mechanical interaction between the selected grout, the substrate, and the void/crack size between them, the group identified the following areas to be of particular interest for further study:

- Crack/wall interface
- Grain size distribution of the injected material
- Achieve higher fluidity with the minimal amount of water

Grouting Materials

Grouting formulations are comprised of three basic elements: binder (clay types and properties, lime, synthetic), aggregate (sand, synthetic materials) and dispersant (water). Occasionally, additional elements such us additives (organic, inorganic) or thickeners are necessary. The formulation of a grout is a balancing of these elements in the correct proportions to achieve the desirable properties as established by the context and the critical performance properties.

After discussion, it was decided that the field should start testing the use of soil/clay-based grouting materials in repairing different types of cracks.

Clay-based Grouts: Variables

The group identified a range of variables and questions regarding clay-based grouts that must be considered in designing a testing protocol. These include:

- The chemical reactions between water and grout components (i.e., percentage and type of clay in mix), between the grouting materials and the crack/wall interface (fluidity characteristics; relationship between grout clay and host clay), and between grouting material and the environment (i.e. variability of mixing time).
- The effect of crack width on grout performance (fine and large cracks vs. thicker ones; crack tips)
- Advantages and disadvantages of adding other constituents (stabilizers, amendments, etc.) to basic grout material.
    - There is a need to control micro-crack formation within grout. It is well known, for example, that adding plant fibers to mud slows the drying process in adobe. The inclusion of such additives could produce positive effects to reduce shrinkage, increase suspension of particles, reduce the water evaporation rate or increase tensile strength across cracks.
    - Further testing is needed to better explain the bonding between particles in the substrate and the grout and whether added or extant materials such as dust will improve the adhesion between them.
    - Further testing is needed to understand the effects of pre-wetting the substrate through the crack.
- In establishing the range of acceptable properties for soil/clay-based grouting materials, both the working and cured properties of the grout must be considered.
- Standardized test methods and parameters for results that have been developed for other grouting materials can serve as references, but these must be modified for clay-based grouts.
- The testing protocol should consider the difference between proprietary, premixed materials prepared in the lab under a controlled environment and materials made in the field.

Testing

The group focused the discussion on properties that need to be tested, either as small-scale lab tests or large-scale structural tests. Small-scale tests were divided into two categories: testing the grout alone and testing the interface between the grout and its support. This is a preliminary list of testing to be designed/modified and later performed:

Small-scale lab tests

- Grout only:
    - Materials characterization (Both chemical and geotechnical characterization)
    - Water absorption/desorption
    - Shrinkage
    - Segregation
    - Viscosity
    - Consistency (Flow)
    - Injectability
    - Strength
    - Water resistance
- Interface between grout and support at differing crack widths:
    - Bond strength
    - Injectability (Extent)
    - Evaluate grout in place (thin sections)
    - Failure modes

Large-scale structural tests

- Changes in grout over time
- Pressure of injection
- Method of sealing cracks
- Cyclic repair testing (shake-repair-shake) considering various widths of cracks
- Failure modes
- Changes in grout over time

Related Studies

The group identified a number of related studies that should be developed to further this work:

- Glossary and/or standardized terminology
- Bibliography
    - GCI is working on a preliminary bibliography, which will be organized by category
    - A literature review will follow
- Nondestructive testing (NDT) to measure cracks pre- and post-grouting
- Testing procedures for rammed earth construction

Institutions that expressed interest in participating in research:

- GCI (could act as coordinator)
- PUCP
- CRATerre
- National Park Service
- University of Pennsylvania – Architectural Conservation Laboratory
- Politecnico of Milan

Meeting Outcomes and Next Steps

1. Draft meeting report and distribute for review and comment by meeting participants.
2. Post final meeting report to GCI Website.
3. Participants interested in conducting further research to identify areas of interest, with GCI acting as coordinator.
4. Consider additional group members with specific areas of expertise:
   a. Expert on soils
   b. Structural engineer with expertise in bonding properties
5. Consider creation of an intranet site for sharing of research and information
6. Plan for next meeting

Proposed Schedule

03/05/2008	Draft meeting report to Steve Farneth for review and comment
03/13/2008	Draft meeting report to meeting participants for review and comment
04/07/2008	Group review of draft meeting report completed
05/05/2008	Individuals/institutions file statement of interest (informal research proposal) to GCI
07/2008	Possible one-day meeting during Structural Analysis of Historical Construction (SAHC) conference in Bath, England, 2-4 July 2008

Meeting Participants

The GCI would like to thank all participants for their valuable input during the discussions, to Stephen Farneth for keeping us on track, and especially to the engineers at the Pontificia Universidad Católica del Perú for hosting the event.

Moderator

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Architects/Architectural Conservators

Jake Barrow, Senior Exhibit Specialist, National Park Service, Intermountain Region USA

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