Introduction

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Across the ages and around the globe, people have constructed buildings of earth. Our earthen architectural heritage is rich and varied—ranging from ancient archaeological sites to living cities, the vernacular to the monumental, individual buildings to large complexes—and the challenges of preserving this precious legacy are equally diverse. Earthen construction is widespread in many seismic regions of the world; consequently, the vulnerability of earthen structures to damage or destruction by earthquake is of great concern. For many years, the Getty Conservation Institute (GCI) has taken a leading role in setting the standards for proper methodologies for the conservation of earthen sites, including seismic retrofitting.

Earth is a nonductile material, and structures built of earth are unable to withstand the tremendous lateral loads imposed by strong earthquakes unless they are properly constructed with walls sufficiently thick to avoid overturning, or are reinforced in a manner that adds tensile strength to the structure. Historic structures that have been subjected to inappropriate interventions or that have been abandoned through time are in particular danger of collapse during an earthquake. To address this issue, the GCI conceived the Getty Seismic Adobe Project (GSAP, 1990–2002), a multidisciplinary research effort that designed, tested, and advocated less-invasive, stability-based retrofit programs for historic earthen structures located in seismic regions.

GSAP addressed the vulnerability of unreinforced historic adobe buildings by analyzing their structural properties and proposing technologically feasible and minimally invasive retrofitting techniques. The project proposed stability-based retrofit interventions that enhance existing structural properties of historic adobe structures, such as the thickness of their existing walls. This enhancement is achieved by anchoring together the roof, walls, and floors; by adding flexible bond beams at the top of the walls; and by applying flexible straps to both sides of the wall—or, alternatively, by placing small-diameter vertical rods in the centers of walls (center coring). These measures are far less invasive than the more commonly used strength-based retrofit methods, which introduce independent structural frames of reinforced concrete or steel and require the removal of large amounts of historic material.

The work developed during GSAP is documented in three GCI publications: *Survey of Damage to Historic Adobe Buildings after the January 1994 Northridge Earthquake* (1996); *Seismic Stabilization of Historic Adobe Structures: Final Report of the Getty Seismic Adobe Project* (2000); and *Planning and Engineering Guidelines for the Seismic Retrofitting of Historic Adobe Structures* (2002), which are available in PDF format on the GCI's Web site (http://www.getty.edu/conservation/). A Spanish translation of the final volume and a brief video of the GSAP seismic shake table testing program are also available on the Web site.

The Colloquium

The Getty Seismic Adobe Project 2006 Colloquium was held at the Getty Center on April 11–13, 2006. The meeting brought together a group of professionals with expertise in earthen conservation, building standards, and earthquake engineering to discuss the current state of knowledge and the challenges of preserving our earthen cultural heritage in active seismic zones. The colloquium was primarily an opportunity to evaluate the impact that the GSAP research and guidelines have had on the field locally and internationally and to discuss the feasibility of implementing the GSAP guidelines in other contexts. It also allowed for the exchange of information and the prioritization of future work in the field of retrofitting historic earthen sites.

The three-day program, which included formal talks, panel discussions, and site visits to several local retrofit projects, was designed to provide maximum opportunity for information exchange among participants representing different disciplines. Formal sessions addressed stability-based earthquake resistant design, appropriate testing methods, and building codes and standards specific to earthen architecture. The case studies presented included examples of traditional earthquake resistant design and repair techniques from around the world, as well as recent retrofit projects. On the final day, roundtables and panel discussions were designed to help participants identify the best steps to further advance the field in the areas of earthen building codes, research and testing for seismic retrofitting, and information dissemination and training. An optional, two-day, post-colloquium tour took participants to nine historic Southern California adobe sites, where they viewed a variety of architectural typologies and examined a range of retrofitting techniques.

Further Dissemination

In order to disseminate the outcomes of the GSAP colloquium more broadly and to raise local awareness of the GSAP guidelines, the GCI sponsored a symposium, "New Concepts in Seismic Strengthening of Historic Adobe Structures," in September 2006. Developed in partnership with the California Preservation Foundation, the California State Office of Historic Preservation, and US/ICOMOS, the symposium was directed at practitioners, managers of historic properties, and government officials responsible for developing and enforcing public safety regulations and building codes. The two-day event, which was attended by more than seventy individuals, took place at the Getty Center and at Rancho Camulos in Ventura County. A well-attended public lecture by architectural historian Stephen Tobriner, entitled "The Quest for Earthquake Resistant Construction in Europe and the Americas, 1726–1908," introduced the topic to the general public.

About This Publication

Much of the value of the GSAP colloquium was a consequence of the discussions and interactions among participants representing many different professional disciplines. This publication is an effort to record and share the core content of these exchanges. It contains a selection of papers presented during the event, as well as several subsequent submissions by colloquium participants. Its intent is to reflect developments in the field of retrofitting historic earthen structures, to document successfully retrofitted sites, and to present colloquium conclusions designed to advance the field. The colloquium papers presented here have been organized into four sections: Research and Testing, Building Codes and Standards, Case Studies, and GSAP Implementation. The decision to make these proceedings a Web-based publication recognizes the need to disseminate this important information as widely as possible in order to safeguard the greatest number of earthen structures and the lives of their inhabitants.

Part one includes four papers on the research and testing of appropriate retrofitting methods and materials for extant earthen structures, as well as seismic design criteria and materials for new earthen construction. Perhaps the most active research institution for seismically resistant new earthen buildings is the School of Engineering at the Catholic University of Peru (PUCP) in Lima. Here, PUCP researchers present the static and dynamic testing programs carried out there over the past thirty years, including the effective use of polymer mesh as an external reinforcement technique.

The added cost of reinforcing new construction or retrofitting existing earthen buildings is a serious deterrent in many of the seismically active regions where earthen architecture is abundant. Papers from researchers at Saitama University in Japan and from Australia's University of Technology, Sydney, address this problem. The first identifies low-cost methods for strengthening adobe blocks, while the second reviews the design and dynamic testing of low-cost and low-tech methods for reinforcing new and existing earthen buildings using alternative and locally available materials. It should be emphasized that the materials, costs, and techniques designed to allow for minimal intervention and loss of fabric in historically significant earthen buildings are different from those for new or existing, nonhistoric vernacular earthen structures.

This section concludes with a summary of the GSAP project, presented by the project's primary research engineer. The paper recaps the shake table testing program and explains the stability-based retrofit measures developed as part of the project.

The papers in part two highlight the importance of incorporating earthen materials and building techniques into building codes and standards. These legal codes establish earth as a legitimate construction material and serve as specific enforceable guidelines that help assure building safety in seismic regions while preserving existing historic structures. Codes can be important educational devices, instructing those who would build using earthen materials, as well as those who inspect and enforce the code, about proper design, construction, and maintenance of such structures.

The first three papers in this section review the development of building codes or national standards that specifically address earthen architecture. First, researchers from PUCP describe the development and content of the highly influential Peruvian Adobe Building Code, which has informed guidelines for earthen construction in other countries. A second paper describes the New Zealand Earth Building Standards, which are organized in three volumes, each focused on specific aspects of earthen design or construction and directed at particular user groups with different needs and technical skill levels. A third paper argues for the inclusion of traditional earthen building materials and techniques in the Moroccan seismic building code; currently pending Moroccan codes require the use of steel or reinforced concrete. The final paper in this section provides an overview of *The Secretary of the Interior's Standards for the Treatment of Historic Properties*, historic structure reports, and project regulatory review processes in California and discusses the ways in which these documents are applicable to best practice in the conservation and seismic retrofit of historic adobe structures.

Part three of these proceedings comprises five case studies that discuss structural interventions to enhance earthquake resistance at historic sites in a number of countries. Throughout history, the designers and builders of earthen structures in seismic regions have exhibited a remarkable understanding of earthquake forces and intuitive structural design solutions. The damage inflicted by each past major earthquake has increased the understanding of how buildings behave under seismic loads. Well-designed historic interventions, such as buttresses constructed following an earthquake, instruct us on the ways in which traditional structural reinforcement improves the ability of earthen sites to withstand future earthquakes.

Since severe and destructive earthquakes occur infrequently, the cumulative memory of lessons learned over generations is often lost as regional building traditions are modified, eliminated, or forgotten. The first three papers of this section are investigations into the continuing use of traditional and historic construction techniques that improve the overall seismic performance of structures in Turkey, Central Asia, Trans-Himalaya, Western China, and India.

The last two papers in this section highlight the importance of conducting thorough structural studies in order to prioritize areas of intervention and to facilitate high-quality design for retrofit proposals. In the first, a study of the historic earthen architecture of the Kathmandu Valley in Nepal, the relationship between construction details and the buildings' seismic vulnerability was analyzed in order to devise suitable strengthening strategies to reduce seismic risk. In the final paper in this section, preliminary guidelines based upon structural assessments were designed for the seismic retrofitting of seventeenth-century earthen churches located in the central Andes of Peru.

Part four of this publication is dedicated to the implementation of the GSAP guidelines at nine historic California adobe sites. The three papers detail plans addressing different retrofitting challenges and architectural typologies at sites as varied as Rancho Camulos, Mission San Miguel, and the Las Flores Adobe. The retrofit designs are described, along with the rationales behind the designs and the selection of materials for implementation. Most important, the papers speak to the difficult challenge of simultaneously meeting engineering requirements and conservation principles.

These proceedings conclude with a summary of discussions detailing the colloquium participants' recommendations for advancement of the field. As a final remark, we wish to emphasize that the GSAP colloquium provided the opportunity for a multidisciplinary group of professionals to compare experiences and discuss the state of the art of the conservation of historic earthen structures located in seismic areas, and for the GCI to assess the implementation of the GSAP guidelines in the United States and abroad. The case studies in particular promoted dialogue on the suitability of the guidelines in situations where local materials and traditional techniques must be used in their implementation. The ultimate objective of this publication is to capture the content and energy of the colloquium and to point the direction toward future areas of research that will further the application of seismic retrofit techniques to preserve the world's earthen architectural heritage.