CONSERVATION PERSPECTIVES

THE GCI NEWSLETTER

SPRING 2015

SEISMIC RETROFITTING

The Getty Conservation Institute

A Note from the Director

Photo: Anna Flavin, GCI

Los Angeles, home to the Getty Conservation Institute, is very familiar with the destructive power of earthquakes. In the last fifty years, two major quakes, in 1971 and 1994, resulted in loss of life and extensive damage in the city. The Getty Center, which houses the GCI and its sister programs, was under construction in 1994; the 6.7 magnitude quake that year revealed vulnerability in steel joints already erected at the site, and retrofitting was undertaken to reduce the susceptibility of the center to future seismic damage.

Several years before that event, the GCI had actually embarked on a program of seismic retrofitting research, with a focus on built cultural heritage. In 1990 the GCI initiated two projects to research and develop methods to provide seismic stabilization for historically and culturally significant buildings in earthquake regions. The first, the Getty Seismic Adobe Project (GSAP), investigated alternatives to existing retrofitting methods for earthen structures and developed ways to provide seismic protection at a reasonable cost while substantially preserving the authenticity of historic adobes. The second, undertaken in the former Yugoslav Republic of Macedonia, focused on seismic retrofitting of Byzantine churches constructed of stone and brick.

The feature article in this edition of *Conservation Perspectives* describes the Institute's current Seismic Retrofitting Project (SRP), which grew out of GSAP. The SRP builds on the GCI's expertise and years of research in developing methodologies and standards for the seismic retrofitting of earthen architectural heritage. Its present work in Peru, undertaken with the support of the GCI Council and the assistance of Friends of Heritage Preservation, is the subject of the article by Daniel Torrealva, former dean of the science and engineering school of the Pontifical Catholic University of Peru, and Claudia Cancino, the GCI senior project specialist who is managing the SRP. The project, carried out in partnership with the Ministry of Culture of Peru and the Pontifical Catholic University of Peru, is developing low-tech, cost-effective seismic retrofitting techniques and making recommendations on easy-to-implement maintenance programs that together can improve the seismic performance of earthen buildings while preserving historic fabric.

In their article, conservation architects Stephen Kelley and Rohit Jigyasu use the 1987 landmark Getty publication *Between Two Earthquakes: Cultural Property in Seismic Zones* by Sir Bernard Feilden as a starting point to examine progress made in succeeding decades, as well as areas where more work needs to be done. Professor Zeynep Gül Ünal, a member of the risk preparedness committee of ICOMOS and of Turkey's GEA Urban Search and Rescue Team, examines policy and legislative changes that can better safeguard historic structures from seismic damage. And in his article, civil engineer and professor Paulo B. Lourenço explores advances in research related to reducing the vulnerability of historic buildings to seismic activity. Finally, this edition's roundtable includes Androniki Miltiadou-Fezans, Claudio Modena, and John Ochsendorf, all engineers with notable experience in the area of built cultural heritage; together they grapple with questions related to the roles, responsibilities, and training of engineers involved in built heritage conservation. In sum, this GCI newsletter delineates some of the advances in reducing the risk posed to built heritage by seismic activity—while also charting some of the directions in which we need to go.

Timothy P. Whalen

Contents

SEISMIC RETROFITTING

4 **FEATURE ARTICLE**
IN THE WAKE OF QUAKES
The Seismic Retrofitting Project in Peru
By Daniel Torrealva and Claudia Cancino

10
BETWEEN TWO EARTHQUAKES
From Recovery to Mitigation and Preparedness
By Stephen Kelley and Rohit Jigyasu

14
BRINGING ORDER TO CHAOS
Managing Seismic Risk for Historic Structures
By Zeynep Gül Ünal

16
REDUCING SEISMIC VULNERABILITY
Retrofitting Historic Buildings
By Paulo B. Lourenço

19
MASTERING THE MECHANICS OF THE PAST
A Discussion about Preservation Engineering

25 **KEY RESOURCES**
A list of key resources related to seismic retrofitting

26 **GCI NEWS**
Projects, events, and publications

THE GCI NEWSLETTER
VOLUME 30 • NUMBER 1 • SPRING 2015

ON THE COVER
A 2011 assessment of earthquake damage to Ica Cathedral in Peru, conducted as part of the GCI's Seismic Retrofitting Project. Photo: Scott S. Warren, for the GCI.

www.getty.edu/conservation

IN THE WAKE OF QUAKES

BY DANIEL TORREALVA AND CLAUDIA CANCINO

The seventeenth-century colonial Church of Kuño Tambo sits four thousand meters above sea level in the Peruvian Andes and is the most important building in its small town of five hundred inhabitants. Two hours' drive from the city of Cusco, the town's 150 or so earthen houses, together with the church, represent a historic rural settlement typical of the Andean region found from Colombia to Chile.

Built with thick adobe walls and a wooden truss roof covered with clay tiles, the church has preserved most of its original architectural features, including its three-hundred-year-old mural paintings. Nevertheless, during its history the church has suffered from a series of earthquakes and a lack of maintenance. These factors have resulted in the structure's partial collapse and, sadly, the cessation of its ecclesiastical use.

Four hundred kilometers northwest of Kuño Tambo, near the Peruvian coast, is the city of Ica, founded by the Spanish in 1563. Fronting the city's main square is the Cathedral of Ica, originally built in 1759 by the Jesuits. Throughout its history, the cathedral has hosted the city's important religious events and has been Ica's central place of worship. Its design follows the Jesuit typology established by the Church of the Gesù in Rome—a rectangular base plan consisting of a central nave, two side aisles, a transept crowned by an impressive dome, and an altar—and is thus typical of many cathedrals found on the west coast of South America. Its facade, probably from a later period, has two towers. On August 15, 2007, a 7.9–8.0 magnitude earthquake with an epicenter eighty kilometers northwest of Ica caused widespread damage to the cathedral, which suffered partial collapse of the vaulted roof and the main dome, as well as extensive loss to its adobe walls, wattle and daub pillars, and other architectural elements, including its towers and facade. In 2009 another earthquake led to the total collapse of the dome.

Earthen buildings such as the Church of Kuño Tambo and the Cathedral of Ica are typically classified as unreinforced masonry structures, which are extremely vulnerable to earthquakes and subject to sudden collapse during seismic events—especially if a

The Seismic

The village of Kuño Tambo in the Peruvian Andes. The large building on the far left is the Church of Kuño Tambo, where the GCI is involved in a collaborative seismic retrofitting project. Photo: Wilfredo Carazas.

Retrofitting Project in Peru

building has been poorly or inadequately maintained. Identifying methods to seismically upgrade historic buildings such as the Church of Kuño Tambo and Ica Cathedral could help reduce the risk of damage to or destruction of similar historic earthen sites located in seismic regions.

In the context of its extensive multiyear Seismic Retrofitting Project (SRP), designed to address the seismic threat to historic earthen buildings in the South American region, the Getty Conservation Institute (GCI) has been working at both Kuño Tambo and Ica Cathedral. The community of Kuño Tambo has supported and facilitated efforts that the Cusco branch of Peru's Ministry of Culture and the GCI are undertaking to design and implement retrofitting techniques for the Church of Kuño Tambo that could be applied to similar churches across the Andes, in order to make them seismically safe.

Ica Cathedral structurally resembles other churches along the Peruvian coast, including the Cathedral of Lima in that city's historic center, a World Heritage Site. These coastal colonial churches have brick facades; timber frame structures; thick adobe walls and vaults; and domes supported by pillars of timber, cane, and mud—a construction technique known as *quincha*. In collaboration with the Ministry of Culture and the Diocese of Ica, the GCI designed a shoring system for the cathedral, implemented in 2012. Beyond that, the GCI and the ministry are—as with the

From left to right: Ica Cathedral, the Church of Kuño Tambo, Hotel El Comercio, and Casa Arones. These four buildings in Peru are serving as prototypes for the GCI's Seismic Retrofitting Project,

Church of Kuño Tambo—using the cathedral as a case study to design seismic retrofitting techniques that can be applied to similar churches along the South American coast.

THE SEISMIC RETROFITTING PROJECT

During the 1990s the GCI carried out a major research and laboratory testing program—the Getty Seismic Adobe Project (GSAP)—to investigate the performance of historic adobe structures during earthquakes and to develop effective retrofit methods that preserve the authenticity of these buildings. Results of this research were disseminated in a series of publications in both English and Spanish.[1]

In April 2006 the GCI hosted a colloquium for an interdisciplinary group of sixty international specialists to assess the impact and efficacy of the GSAP seismic retrofitting recommendations and to discuss where and how GSAP guidelines had been implemented. The participants concluded that the methodology was reliable and effective but that its reliance on high-tech materials and professional expertise was a deterrent to its wide implementation in many seismically active places with large numbers of historic earthen buildings, such as throughout South America.

In response to these conclusions, the GCI in 2010 initiated a new seismic retrofitting research project with the objective of adapting the GSAP guidelines to better match the equipment, materials, and technical skills available in many countries with earthen buildings. The project includes the development of low-tech, cost-effective seismic retrofitting techniques and recommendations on easy-to-implement maintenance programs that improve the seismic performance of historic earthen buildings while preserving their historic fabric.

Peru was selected for the project's location because of its wealth of current and historical knowledge, the interest there in retrofitting earthen buildings, and its potential research partners and organizations that could implement new techniques through model conservation projects. Thus the GCI joined the Ministry of Culture of Peru and the School of Sciences and Engineering at Pontificia Universidad Católica del Perú—along with the Department of Architecture and Civil Engineering at the University of Bath in the United Kingdom—to launch the Seismic Retrofitting Project, which receives support from the GCI Council. The SRP aims to design appropriate retrofitting techniques; to verify their efficacy through scientific testing and modeling; to develop a methodology and guidance for implementing suitable retrofitting techniques for practitioners, including conservation professionals, building officials, site managers, and local builders; and to work with regulatory authorities to gain acceptance of these methods, thereby ensuring they are embedded in practice.

The project involves a number of phases: (1) identifying prototype buildings that represent key earthen historic buildings in South America; (2) undertaking detailed site inspections, structural assessments, and material assessments of each prototype, followed by laboratory testing of key building elements and developing numerical models of the prototypes to understand their response to seismic activity; (3) designing, testing, and modeling of potential retrofitting strategies for each prototype building; (4) implementing the retrofit strategies on selected prototypes; and (5) disseminating the results and methods.

THE CASE STUDY BUILDINGS

The first phase of the SRP, as mentioned above, included identifying important building types representing the historic earthen heritage of Peru and of South America in general—and thus with priority for seismic performance improvement. Four buildings exemplifying the identified typologies were selected, each demonstrating significant historic, social, or architectural value as well as retaining a high level of integrity. Developing solutions for a range of prototypes will ensure their relevance across South America and provide lessons for other seismic regions of the world. The partners evaluated a number of buildings in Peru and selected the following:

which is developing retrofitting methods that can preserve the authenticity of historic earthen structures. Photos: (1) Claudia Cancino, GCI; (2, 3) Scott S. Warren, for the GCI; (4) Sara Lardinois, GCI.

- **Hotel El Comercio**, a nineteenth-century three-story adobe and *quincha* building in the historic center of Lima, representing colonial houses in the historic centers of towns and cities along the coast;
- **the Cathedral of Ica**, an eighteenth-century church with thick adobe walls and *quincha* vaults and domes, representing colonial churches built in coastal cities;
- **the Church of Kuño Tambo**, a seventeenth-century building constructed with thick adobe walls and a wooden truss roof, representing colonial churches built in the Andes;
- **Casa Arones**, a seventeenth-century two-story adobe house with a wood truss roof located in the historic center of Cusco, representing colonial houses built in the historic centers of Andean cities.

Both Ica Cathedral and Hotel El Comercio include a considerable amount of timber structural elements, which is a direct reflection of their physical environment. Despite its tropical location, the coast of Peru is extremely arid owing to a cold, low-salinity ocean current (the Humboldt Current) that flows north from the southern tip of Chile to northern Peru. The Peruvian coast is also part of the Pacific Ring of Fire, an area that encircles the basin of the Pacific Ocean, where some 90 percent of the world's earthquakes and 81 percent of the largest ones occur.

These two characteristics of the Peruvian coast—its aridity and its seismic vulnerability—determined the construction techniques of the buildings erected by the Spanish. The lack of rainfall meant that lightweight *quincha* roofs—timber and cane, plastered with mud and/or lime mortars—could substitute for the heavier stone roof structures and tile covering used elsewhere. This adaptation reduced the inertial seismic forces, and it is thought that the colonial builders deliberately chose this method to improve earthquake resilience.

Hotel El Comercio is located in this coastal zone. The first story has thick adobe walls; the second and third stories are made of *quincha*. The floors are constructed of lightweight flat timber. Over 50 percent of the building's mass is concentrated in its first story; the second and third stories are more lightweight and more flexible. In an earthquake, the second and third stories vibrate differently than does the much heavier first floor. The lightweight floors, roof, and upper story walls have helped this type of building resist strong earthquakes and survive as part of the urban conglomerate of the historic center of Lima. Experimental testing on new and historical *quincha* panels, coupled with numerical model analysis, both undertaken as part of this project, supported the anecdotal and evidentiary confidence in the resilience of this construction system in withstanding seismic movement.

Further down the coast is Ica Cathedral, a timber frame structure with adobe side walls. Its timber structure is concealed by a cane and sand-lime mortar plaster system, which is decorated on the inside with high reliefs and paintings. Because of the building's configuration, the majority of the timber roofing elements are curved and composed of several lapped timbers connected by iron nails. Mortise and tenon connections are commonly encountered in the coupling of timber beams and posts, as well as of timber posts and arches. Since the lightweight roof structure follows the same principle of seismic resilience as the flat roof of Hotel El Comercio and would therefore be expected to be fairly resistant to seismic activity, the SRP team did not initially understand its failure during the 2007 earthquake. One explanation is that because the roof timbers were plastered both internally and externally and were thereby inaccessible, they had not been inspected or maintained over time. On-site evaluation and numerical analysis supported the hypothesis that a critical timber element across the barrel vault—which proved to be severely decayed—was responsible for its partial collapse. Numerical analysis also showed that the interaction between the adobe masonry side walls and the timber structure heavily influenced the seismic behavior of the building's different elements.

In contrast to the coastal buildings, the historic buildings along the Andes are located in a lower earthquake risk zone. However, while Andean faults that trigger earthquakes have a small radius of influence, the earthquakes are nevertheless extremely intense near their epicenter. Because the environmental conditions in the Andes differ greatly from those on the coast—lower temperatures in winter that reach minimums of –15°C and heavy seasonal rain—buildings were constructed with thicker walls and heavy roofs. Unfortunately, the large mass of the roof, with its heavy structural components, increases the inertial earthquake forces that trigger collapse. To address this challenge, local masons developed construction techniques for houses and churches designed to stabilize the thicker adobe walls and enhance their resistance to earthquakes. These techniques included the use of buttresses in long unsupported walls, the installation of tie beams to stabilize parallel walls, and the use of "corner keys" to help maintain the connection between perpendicular walls.

EXPERIMENTAL TESTING AND MODELING

The second phase of the SRP, carried out between 2011 and 2013, focused on research about and investigation of the selected prototype buildings. This included: (1) historical research and on-site surveys; and (2) experimental and analytical investigations, including laboratory testing of materials and structural composite systems, and development of numerical models to help understand each prototype building's behavior. The data acquired through historical research and on-site surveys are available for conservation professionals to consult and can be found at the GCI website as part of the SRP publications.[2] The analytical and experimental information will be available in 2016.

The methodology used in the SRP's second phase required close interaction among the on-site surveys, the experimental testing, and the numerical analyses. Each activity informed the others. The testing helped guide the building of the models and demonstrate their efficacy, and the results of the modeling in some cases directed the team to further testing. The experimental testing proposal and rationale were extensively discussed by the partners and then presented to an international peer review committee. The proposal originally comprised more than two hundred tests on materials (historic and new) and structural characterization of the building prototypes.

As noted, the Hotel El Comercio and Ica Cathedral structures rely heavily on timber; part of the study therefore focused on the structural behavior and material properties of the timber and its interaction with the adobe masonry under earthquake forces. To a lesser degree, brick and stone masonry were present in all building prototypes, so testing for these materials was also carried out.

Three traditional constructions for improving seismic behavior were studied and validated either by numerical analysis (buttresses) or by experimental testing (tie beams and corner keys). The information generated by the experimental testing was fed into the numerical analysis of one of the prototype buildings, the Church of Kuño Tambo. The numerical model, adjusted to include these traditional retrofitting elements, demonstrated significant seismic behavior improvement.

Numerical models for all four building prototypes were developed at the University of Bath, discussed by all partners, and presented to peer review members. The objective of the models was to represent the behavior of the building prototypes as found and, in the case of the Ica Cathedral, to determine the reasons for the collapses during the 2007 and 2009 earthquakes. In 2013 the modeling work was transferred from Bath to the Civil, Environmental, and Geomatic Engineering Department of University College London, which has published papers describing its partial results from this phase. Currently the GCI is working with engineering consultants to continue developing numerical models to guide the project's next phase. This work will seek to confirm the efficacy of traditional retrofitting techniques already tested experimentally, using the numerical models, currently being developed, of the building prototypes.

The third phase of work includes the design and modeling of new, low-tech, and easy-to-implement seismic retrofitting techniques using locally available materials and expertise. The numerical models will then be used to test the proposed techniques and demonstrate their potential response.

The fourth phase of the SRP involves implementing the retrofitting approaches established by the project. Conservation and retrofitting designs for two of the buildings, Ica Cathedral and the Church of Kuño Tambo, will be developed. The GCI is working closely with local authorities and professionals to produce the construction documents and technical specifications for these two sites, with construction to start in 2016. The construction documents and

Three-hundred-year-old wall paintings in the Church of Kuño Tambo, where conservation is being undertaken in conjunction with the seismic retrofitting of the church. Photo: Scott S. Warren, for the GCI.

the implementation of the retrofitting technique designs on these two sites (all of which materials will be available to the professional community) will serve as model case studies for similar earthen historic buildings in the region. Another goal of this phase will be gaining the support of building officials for these suggested techniques.

The SRP provides new information on the characteristics of the materials used in earthen heritage buildings; the effectiveness of traditional retrofitting techniques; the seismic behavior of traditional construction systems; and the appropriate methodology to evaluate, diagnose, and implement seismic retrofitting projects in Peru and other countries in seismic zones. The final phase of this initiative will include the production of guidelines to be used by conservation professionals, building officials, site managers, and local builders—whose traditional knowledge has been an essential source of information for this project—to retrofit earthen historic buildings located in seismic areas, helping ensure that this heritage can survive the threat from earthquakes that it perpetually confronts.

Daniel Torrealva is former dean of the Escuela de Ciencias Ingeniería at the Pontificia Universidad Católica del Perú and a team member of the Seismic Retrofitting Project. Claudia Cancino, a GCI senior project specialist, is the project manager for the Seismic Retrofitting Project.

---

1. www.getty.edu/conservation/our_projects/science/seismic/index.html.
2. www.getty.edu/conservation/publications_resources/pdf_publications/assess_prototype.html.

THE KUÑO TAMBO WALL PAINTINGS

KUÑO TAMBO IS ONE OF MANY INDIAN VILLAGES designed and founded by the Spanish in Peru at the end of the sixteenth century. Its seventeenth-century church, constructed with thick adobe walls and a wooden truss roof, is extensively decorated with historic wall paintings. The paintings not only need conservation but also need protection in situ during the seismic retrofitting the building urgently requires.

A major challenge in implementing retrofitting techniques in historic buildings with decorated surfaces is avoiding removal of the wall paintings—removal having been fairly common in Latin America when the walls behind the paintings were repaired. To circumvent this practice at Kuño Tambo, the GCI, with support from Friends of Heritage Preservation, has developed and carried out a series of interventions to consolidate and then protect the wall paintings during construction work. The interventions were designed to be compatible with the characterization of the original wall paintings and adobe materials—analyses performed by personnel of the Ministry of Culture branch in Cusco, a GCI partner.

Based on the results of this analysis and a detailed wall paintings condition assessment performed by GCI staff and consultants, using rectified photography developed by Carleton Immersive Media Studio of Carleton University, Ottawa, the project designed, tested, and conducted in situ interventions to reattach and consolidate the wall paintings and to protect them during construction.

The first campaign to consolidate the wall paintings prior to retrofitting occurred in February 2015, when an earthen-based grout was used to reattach all wall painting interfaces, in conjunction with the application of facing material to consolidate them. This work will continue during the May and June 2015 campaigns. Once the paintings have been stabilized, their physical protection will include a lightweight and resistant mesh fastened to the top of the wall and temporarily fixed to the church floor. The mesh will have an incline of 45° to prevent any contact between the paintings and material that might fall from the walls or ceiling during construction.

This strategy for protecting the wall paintings during construction can serve as an alternative model to the common practice of removing the wall paintings during retrofitting and can help preserve the paintings' historic, aesthetic, and material values.

Clemencia Vernaza and Luis Villacorta Santamato
Consultants on the Kuño Tambo Project

BETWEEN TWO EARTHQUAKES

From Recovery to Mitigation and Preparedness

BY STEPHEN KELLEY AND ROHIT JIGYASU

IN THE IRANIAN CITY OF BAM IN 2003, BAM CITADEL—ONE of the world's largest adobe forts and a UNESCO World Heritage Site—was devastated by an earthquake. Not only was the citadel almost leveled, but more than 85 percent of the adobe brick houses in Bam were damaged. There are, of course, other vivid examples of heritage loss in recent years: the L'Aquila, Italy, earthquake of 2009; Haiti's 2010 earthquake near Port-au-Prince; the 2011 Christchurch, New Zealand, earthquake with the loss of its namesake cathedral; monasteries and pagodas in Myanmar destroyed by the 2012 Shwebo earthquake; and severe damage to Spanish-era churches on the Philippine island of Bohol in 2013. Earthquakes continue to cause immense damage to built cultural heritage.

Built heritage is exposed to various natural hazards, but seismic events are unique in that—unlike floods, storms, and fires—there is no warning, and thus the loss of life can be staggering. And earthquakes cause damage not just from shaking but also from related hazards. During the 1964 Alaska earthquake there was significant damage from soil liquefaction. The Erwang Temple in Dujiangyan, China, was extensively damaged by a landslide caused by the 2008 Wenchuan earthquake. A tsunami following the Great East Japan earthquake of 2011 swept away entire villages. The fire that devastated historic neighborhoods of wooden houses following the 1995 Kobe earthquake, also in Japan, illustrates the increased vulnerability of cultural heritage due to the interruption of essential services following a major seismic event.

An overlay of World Heritage Sites on a map of earthquake hot spots of the world reveals that many of these sites are vulnerable to earthquakes. Therefore, effective measures must be taken to reduce seismic risks. The importance of thorough methodologies for assessing earthquake damage and of appropriate measures for their mitigation, preparedness, and recovery is recognized, but these measures have been insufficiently developed and implemented.

The Santisima Trinidad Parish Church in Loay, Bohol, in the Philippines. The church, a National Cultural Treasure, suffered enormous damage as a result of an October 2013 earthquake. Its concrete neoclassical facade collapsed during the event. Photo: Stephen Kelley.

The 1987 publication *Between Two Earthquakes: Cultural Property in Seismic Zones* by Sir Bernard Feilden—one of the most respected conservation architects of his day—made a pioneering contribution in this area. This brief book is groundbreaking in its accessibility, speaking to multidisciplinary groups of practitioners in a way that is easy to grasp. And it focuses with prescience on the task of preserving cultural heritage in the face of earthquakes. The book's title conveys the message that mitigation and preparedness are critical to earthquake risk reduction. Restoration and strengthening measures that follow an earthquake should serve to mitigate and prepare for the inevitable next quake.

VULNERABILITIES

Our built cultural heritage is increasingly vulnerable to earthquakes for many reasons. A major factor is poor or inadequate maintenance. Seismic events instantly expose the weaknesses in building structures. The oft-quoted adage "Earthquakes don't kill people, buildings do" remains true, and its meaning is well illustrated by comparing the experiences of Haiti and Chile. Whereas the 7.0 magnitude earthquake in Haiti caused more than one hundred thousand deaths because of the poor conditions of buildings, a much stronger 8.8 magnitude earthquake in Chile caused fewer than six hundred casualties. Rampant termites in Port-au-Prince weakened normally resilient wood-framed Gingerbread houses; dilapidated unreinforced masonry structures also fared very poorly.

Vulnerability can also result from inappropriate repair and additions to heritage structures using incompatible materials and construction techniques that adversely impact structural integrity, causing damage during earthquakes. This dynamic was demonstrated at the Prambanan temple compound, a UNESCO World Heritage Site in Indonesia, where the previous addition of a concrete frame understructure affected the performance of the temples during the 2006 Java earthquake, leading to cracking, splitting, and dislodging of stone units. Haiti's Gingerbread houses were damaged by post-1925 additions of concrete and concrete blocks, which oscillated differently from the wood frames and operated like battering rams.

A further cause of vulnerability is the tendency of engineers to maximize structural strength to ensure occupant safety. Overly high standards for strength can result in increased interventions that may actually contribute to a building's destruction, as well as having the unfortunate side effect of sacrificing heritage values. Excessive strengthening may have the unintended effect of causing catastrophic brittle behavior, which counters the capacity of resilient heritage structures to absorb and dissipate forces and can lead to immediate collapse. Resilient structures may be damaged during a seismic event but allow time for people to evacuate before the structure collapses. Safety is important, and we want to save our heritage, but in some instances we need to protect this built heritage from well-intended but inadvertently destructive interventions.

This principle is demonstrated by the evolution of building practices leading to greater resiliency of some traditional structural types in earthquake-prone regions, as a result of knowledge accumulated through trial and error. Significant examples include *dhajji dewari* construction in Kashmir, *himis* construction in Anatolia and the Balkans, and circular *bhungas* in Gujarat in India. Making safety and heritage values paramount is a good strategy. It may allow for economic affordability as more structures can be strengthened using locally known and available resources rather than maximizing safety with more sophisticated and expensive techniques in relatively fewer structures. This is important in developing countries, where there is a severe scarcity of financial and skilled human resources.

The misconception that traditional constructions are inferior has become prevalent in the developing world. At the recently fire-damaged Wangduephodrang Dzong in Bhutan, the debate continues about whether to rebuild and retrofit using traditional methods and materials, including stone, clay mortar, and horizontal timbers, or to use concrete or steel, which are perceived as superior. On Majuli island in the state of Assam in India, traditional houses constructed on bamboo stilts performed well against earthquakes, in addition to being flood resistant. However, the recent use of concrete for the stilts has made these structures vulnerable to earthquakes.

Governmental agencies tend to apply the principles of professional engineering to the evaluation of vernacular structures. As a result, some heritage structures may be categorized as unsafe and worthy of demolition. This judgment has been made in many post-earthquake damage assessments conducted by national and international teams of experts, as in Bhutan following the 2009 earthquake.

Cultural heritage is not static, and we continue to add new kinds of built cultural heritage stock. The Industrial Revolution brought about the use of structural metals, concrete, cement mortars, and composite materials. Engineered structures utilized braced and moment frames that allowed the realization of tall buildings and trusses to cover immense interior spaces. This sophisticated built heritage poses unique challenges and is no less vulnerable to earthquakes.

ASSESSMENT AND POST-QUAKE INTERVENTION

Feilden's book suggests a template for designing damage assessment forms. Experience has shown that such templates should be tailored to building materials, construction systems, relative building condition, geotechnical aspects, patterns of past repair efforts, and hazards to which building stock has been exposed, as well as to cultural aspects. Assessment should be seen as a continuum that includes:

- initial inspections immediately following the emergency, which are aimed at recording the damage level and undertaking immediate action, such as temporary shoring and bracing;
- more detailed assessments for determining the best options for recovery—restoration, rehabilitation,

strengthening, and/or repair, along with a comprehensive work plan for implementation;

- linkage of these assessments to dynamic and comprehensive vulnerability and risk assessments undertaken during mitigation, preparedness, and response, as well as recovery stages. This would also help in the effective monitoring and maintenance of heritage buildings and sites.

Depending on the nature of the damage, post-earthquake treatments of heritage structures may include repairs, restoration, and retrofitting. The scope of these interventions may differ between heritage conservation and engineering perspectives. From the heritage conservation standpoint, treatment may imply reinstating the heritage values while, from the engineering perspective, treatment would lean toward reinstating original structural strength. Reconciling these differences presents a challenge in formulating appropriate post-quake interventions. It must be remembered that any intervention, no matter how slight, will cause loss of heritage fabric, and we should strive to minimize this loss.

Modern research has produced a great variety of techniques to retrofit existing buildings. The majority of these techniques are designed for modern buildings rather than traditional ones, which is not surprising since built heritage represents a small percentage of building stock. With the goal of saving heritage values in mind, there are compelling reasons to start with traditional materials and techniques to strengthen built heritage damaged by earthquakes.

A traditional house in East Bhutan, heavily damaged by earthquake in 2009. Photo: Rohit Jigyasu.

Traditional Techniques

The built heritage that is most vulnerable simply because of its material nature is unreinforced masonry. This includes bricks and stone, adobe, rammed earth, and unreinforced concrete. In North America, cement mortars are ubiquitous and are appropriate for the repair of industrial-era heritage, where cement was the original mortar ingredient. However, cement is a disastrous repair material for buildings constructed with clay, lime or gypsum mortars, plasters, and stuccos. Repair materials must be compatible with the original materials in hardness, density, porosity, permeability, elastic modulus, and moisture expansion. They must weather in the same way as the original materials. If newer, stronger materials are bonded to older, weaker ones, the stronger one will “win” during a seismic event. Another concern is that new materials must not introduce foreign salts that can cause efflorescence or subflorescence.

Buildings composed of soft masonry materials, such as low-fired brick in lime mortar, adobe, and rammed earth, can absorb seismic shock. In contrast, contemporary buildings are typically designed to resist seismic shock. Strengthening systems that are appropriate for contemporary buildings may therefore be damaging when applied to heritage structures realized in traditional materials. Strengthening systems must be compatible in stiffness, flexibility, and deformability. Traditional strengthening techniques should be studied at the regional level and accepted where they prove effective.

Modern Techniques

If traditional strengthening techniques are not effective, then modern techniques must be considered, either on their own or in conjunction with traditional techniques. Modern materials include metal, concrete, fiberglass, and carbon fibers. Some modern techniques are buttressing, bracing, and introducing moment or braced frames, shear walls, and energy dissipation devices. With unreinforced masonry, these systems should work to keep the masonry in the compression zone, since masonry does not perform in tension.

A word must be said about the “bad boy” of heritage conservation: reinforced concrete. This technology had made its debut by the beginning of the twentieth century. As a material it is plentiful, easy to transport, and relatively easy to install in fluid form. Like it or not, reinforced concrete is an icon of modern development, and the desire to use it in tandem with heritage structures in the developing world must be recognized. However, as Feilden wrote, “a blind use of reinforced concrete can be disastrous.” This statement implies that concrete is not the culprit, but the inappropriate use of it is.

Energy Dissipation

Seismic base isolation is a potentially attractive seismic strengthening technique. With base isolation, a major part of the earthquake energy that would have been transferred into the building is absorbed at the base level. Consequently, deformability demand on the structure is reduced; displacement is strictly controlled by an appropriate amount of damping within the base isolation system, and the frequency of the isolated structure is decreased to a value below that which dominates in a typical earthquake. This may eliminate the need for intervention above the level of isolation. However, this approach has two disadvantages: it is costly, and it requires significant intervention on the cultural layer of the surrounding soil. The

The reinforced concrete Cathedral of Our Lady of the Assumption (1884–1914), also known as the Port-au-Prince Cathedral. The cathedral was destroyed in the January 2010 Haiti earthquake. Photo: Stephen Kelley.

technique has been used extensively in the western United States, where neither of these disadvantages is overriding.

Feasibility

Other factors affecting the selection of seismic retrofits include affordability and availability of feasible options. These factors are illustrated by the following range of interventions that were suggested for retrofitting following the 1995 Kobe earthquake: (a) additions using traditional materials and traditional techniques—for example, reinforcement by palm tree rope; (b) additions using traditional techniques and modern materials—for example, reinforcement by carbon fiber sheet; (c) additions using modern techniques and modern materials—for example, burden share by iron frame; and (d) replacement using modern techniques and modern materials—for example, introduction of a base isolator.

Multi-Hazard Consideration

Built heritage is exposed to more than one hazard. Therefore, reduction in vulnerability to earthquakes may, in fact, increase the vulnerability of cultural heritage to other hazards. For example, during the March 2011 disaster that struck Japan, construction of light wooden houses made them resistant to earthquakes but increased their vulnerability to tsunami waves. As the ultimate goal is to compromise as little of the heritage fabric as possible, any post-earthquake intervention should be undertaken with a multi-hazard perspective.

EMPHASIZING PREVENTION

Benjamin Franklin famously said, "An ounce of prevention is worth a pound of cure." This axiom was clearly illustrated in Feilden's book. Since then, we have developed at least a pound of cure—and reacting to earthquakes is addressed in more than one annual conference on the topic. But it is only recently that we have begun to seriously focus on that ounce of prevention. Rather than the expenditure of resources solely for post-earthquake interventions on built cultural heritage, there needs to be more emphasis on pre-earthquake mitigation and preparedness that takes into consideration multiple hazards, minimal loss of heritage values, and affordability. Most importantly, adequate maintenance and monitoring are keys to reducing earthquake risks to cultural heritage.

Stephen Kelley, FAIA, a heritage conservation specialist in the United States, was president from 2008 to 2014 of the International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage. Rohit Jigyasu, a conservation architect currently at Ritsumeikan University in Japan, is president of the International Scientific Committee on Risk Preparedness.

BRINGING ORDER TO CHAOS

Managing Seismic Risk for Historic Structures

BY ZEYNEP GÜL ÜNAL

ACCORDING TO THE *GLOBAL ASSESSMENT REPORT ON DISASTER RISK REDUCTION 2015*—prepared by the United Nations Office for Disaster Risk Reduction prior to the Third UN World Conference on Disaster Risk Reduction—2.9 billion people were affected and 1.2 million people lost their lives because of natural disasters occurring between 2000 and 2012.

The report also stated that economic losses resulting from disasters now average about $250–300 billion per year. It estimated that an annual investment of $6 billion in disaster risk management strategies would reduce economic losses by $360 billion over the next fifteen years.

A separate report prepared for the conference by ICOMOS ICORP (International Council on Monuments and Sites International Committee on Risk Preparedness) focused on the need for proper disaster risk management strategies for historic centers to preserve their heritage values. This document emphasized that historic centers constitute a major part of a city's form and stressed the necessity of applying statutes and regulations to historic centers different from those used for modern structures when building disaster-resilient cities.

Emergency structural support for the Nasuh Ağa Camii (mosque) in Simav, Turkey, following a 2011 earthquake. Photo: Courtesy of the Republic of Turkey Ministry of Culture and Tourism, Cultural Assets Preservation, Regional Directorate Board of Kütahya.

Among natural disasters, earthquakes cause the most damage to, and loss of historic structures. After recent earthquakes in various geographic regions, legislators and government officials have often paved the way for demolition of historic buildings by applying legal articles they have created for emergency situations. For various reasons, including development pressures and lack of awareness, these officials may be unwilling to create legal frameworks to preserve historic buildings. However, as long as laws designed to protect historic buildings also give priority to user safety, it is possible both to mitigate seismic risks to historic buildings and to promote safety by developing and practicing appropriate risk management strategies.

COMMON MANAGEMENT POLICIES

Although risk management strategies in different countries vary according to governmental structures, conservation policies, and the quality of the historical structures' stock, there are some common policies for disaster risk management, including seismic risks, which are described below.

Basic principles must be followed in creating statutes for managing disaster risks for historical structures; these statutes should be based on needs and updated dynamically to reflect changing circumstances. Preparation prior to a disaster, response during a disaster, and post-disaster rehabilitation should be addressed under separate legal codes, and strategic, tactical, and operational phases should be defined in legislative regulations.

If it is unknown, it cannot be protected! An essential first step in managing disaster risk is preparing an inventory showing quantity, type, and present condition of historic structures. Properly selected and collected inventory data can help support the decision-making process in disaster risk management.

To determine risk mitigation needs, risk assessment should be conducted to identify and evaluate primary and secondary disaster risks to historic structures, including inherent structural risks and those from the surrounding environment. And following a disaster, risk mapping should be prepared for heritage sites. Triage methods can help determine which structures require immediate intervention.

Rehabilitation of historic structures—be it seismic retrofitting or post-quake reconstruction—should be carried out by qualified conservation experts. Project proposals should be reviewed by a single committee authorized and specialized to approve such work, and implementation should be overseen and monitored. Input from stakeholders, particularly occupants of historic buildings, should be solicited during preparation and implementation stages; all implementations should consider the needs of the occupants.

The effectiveness of risk mitigation measures on historic structures can be tested only during actual earthquakes. The drills, tabletop exercises, and software simulations that model structural behavior of buildings during an earthquake produce only virtual results that *may* be close to what will actually happen. Any disaster management strategy should anticipate the unexpected, which may be conditioned by time and place, weather, secondary disasters triggered by the first event, and human panic.

Research shows that much damage to historic buildings can occur in the response phase immediately following a disaster. Establishing policies for emergency management prior to a disaster; defining the scenario, actors, and their roles; and periodically testing these by real-time drills are necessary steps for proactively reducing damage and loss.

POST–DISASTER

Immediately after a disaster, authorized agencies arrive at the site and get to work. The first seventy-two hours are critical, especially with earthquakes. Rescuing survivors under the debris, demolishing structures that aren't completely collapsed, and removing debris all occur within a few days. Thus it is crucial for historic structures, as well as for their occupants, that experts participate in the first hours of the response, beginning with the search and rescue stages.

Interior view of the Nasuh Ağa Camii in Simav, several days after the 2011 earthquake. Photo: Zeynep Gül Ünal.

Although many search and rescue teams are theoretically trained in different types of building construction, they generally practice on reinforced concrete construction ruin simulations. Therefore, when carrying out real operations in historic buildings, their lack of familiarity with traditional construction techniques puts both them and the victims at risk. During these operations, on-site advice from experts on historic construction techniques and earthquake behavior of the structures is crucial. Among other benefits, this information can be used to select appropriate equipment for undertaking search and rescue. In areas with high concentrations of historic buildings, guidelines prepared by experts explaining the traditional structures can be extremely helpful during early emergency response.

Historic buildings damaged during earthquakes are sometimes partially or completely demolished to decrease risks during aftershocks. But initiating temporary emergency structural intervention can allow for protection of both the structure and the surrounding environment.

Historic structures contain many different components, some of them highly significant, such as ornamental works or murals. Debris from damaged historic buildings should first be protected on-site, with the various components that can be preserved separated, inventoried, and transferred to secure locations for maintenance and repair, all before the remaining debris is removed. Moreover, historic structures where casualties have occurred are considered "crime scenes" in forensic terms. Therefore, investigation of the structure without changing or destroying the evidence, and gathering the necessary technical and scientific data by experts allows legal procedures to proceed properly and reliable data to be collected to enhance scientific understanding of the building's performance during seismic activity.

Experts doing this work should be prepared to arrive at disaster sites swiftly and to coordinate work with emergency response teams. Furthermore, beyond having specific training and the legal authorization to carry out such work, these experts should also be trained in the behavior of damaged historic buildings during aftershocks, in safe approaches to buildings and their surroundings after earthquakes, in temporary emergency support techniques for damaged historic buildings, and in documentation of damaged and undamaged areas. Training should include the preservation of evidence, personal safety, media relations and communications, and the psychology of working in extreme disaster situations. Such steps, along with the other policies outlined here, can do much to preserve the built cultural heritage that otherwise might be lost.

Zeynep Gül Ünal is a professor in the Restoration Department of the Faculty of Architecture at Yildiz Technical University. She is a secretary general of the ICORP, ICOMOS Turkey, and chair of the ICORP Turkey.

REDUCING SEISMIC VULNERABILITY

Retrofitting Historic Buildings

BY PAULO B. LOURENÇO

THE VALUE OF PRESERVING HISTORIC BUILDINGS IS INCREASINGLY accepted by society, which not only recognizes built cultural heritage as a part of its identity but is also more cognizant of its economic value. In Europe, for example, tourism accounts for 10 percent of the GDP in the EU and 12 percent of employment.[1] Built cultural heritage is a fundamental element of what draws tourists to European destinations.

To a great extent, the value of historic buildings rests in the integrity of their components as unique products of the technology of their time and place. Unfortunately, cultural heritage buildings are particularly vulnerable to disasters, for a variety of reasons. They are often damaged or in a state of deterioration; they were built with materials with low resistance; they are heavy; and the connections among their various structural components are frequently insufficient. The main causes of damage are lack of maintenance, water-induced deterioration (from rain or rising damp), soil settlement, and extreme events such as earthquakes. Earthquakes have caused hundreds of thousands of deaths in the last decade, in addition to the tremendous losses in built cultural heritage.

A METHODOLOGY FOR INTERVENTION

Studies indicate that investment in measures to reduce the vulnerability of buildings yields an average value of four times the amount invested.[2] Retrofitting of buildings to increase earthquake resilience offers a cost-benefit of up to eight times the value of the investment. In the case of built cultural heritage, the structures are invaluable and cannot be reconstituted by post-disaster measures. Earthquakes occur randomly, and they can be larger than those anticipated in safety regulations; it is therefore necessary to take steps, in advance, that can reduce the risk of damage and promote subsequent recovery.

Modern conservation respects the authenticity of a building's historic materials and structure. In practice, interventions must be based on understanding the nature of the building and the actual causes of damage or change. The goal is a minimum of interventions and an incremental approach; much importance is attributed to diagnostic studies of historical, material, and structural issues. In 2003 these considerations were summarized in recommendations issued by the International Council on Monuments and Sites,[3] recognizing that conventional techniques and legal codes oriented to the design of new buildings may be difficult to apply, or even inapplicable, to heritage buildings. These recommendations

The interior of the Church of Santa Maria Assunta in Paganica, Italy, badly damaged by the 2009 L'Aquila earthquake. Photo: Paulo B. Lourenço.

state the importance of a scientific and multidisciplinary approach to built heritage conservation that involves historical investigation, inspection, monitoring, and structural analysis.

The methodology for completing a project includes data acquisition, structural behavior analysis, diagnosis, and safety evaluation. In particular, diagnosis and safety evaluation of the structure are two consecutive and related stages on the basis of which the need for and the extent of treatment measures are determined. Evaluation of the safety of the building should be based on both qualitative methods (some types of documentation and observation) and quantitative methods (experimental and mathematical) that take into account the effect of seismic activity on the building's structural behavior. The challenge to professional practice is to ensure the basic principles of durability, compatibility, reversibility, and nonintrusiveness while maintaining sufficient safety measures to prevent collapse and other unacceptable loss.

The 1910 Rose Historic Chapel in Christchurch, New Zealand, damaged during the Christchurch earthquake in 2011. Photo: João Leite. Courtesy of Paulo B. Lourenço.

Steel-reinforced grouts (SRG) being applied as reinforcement to a vault in L'Aquila, Italy. Photo: Gianmarco de Felice.

Historic buildings are often vulnerable to earthquakes, but simple and moderate cost measures can dramatically change the situation. The most important action to reduce the vulnerability of a building is to increase the connections among its structural parts. This can be done by tying walls to each other (for example, by using externally bonded systems or anchoring elements in corners and intersections) or by connecting walls and floors (such as by anchoring wooden joists to the walls). The second most important action to reduce vulnerability is to prevent disintegration during a seismic event (for instance, by mortar repointing, grouting, or anchoring multiple leaves of a wall using polymer or metallic meshes).

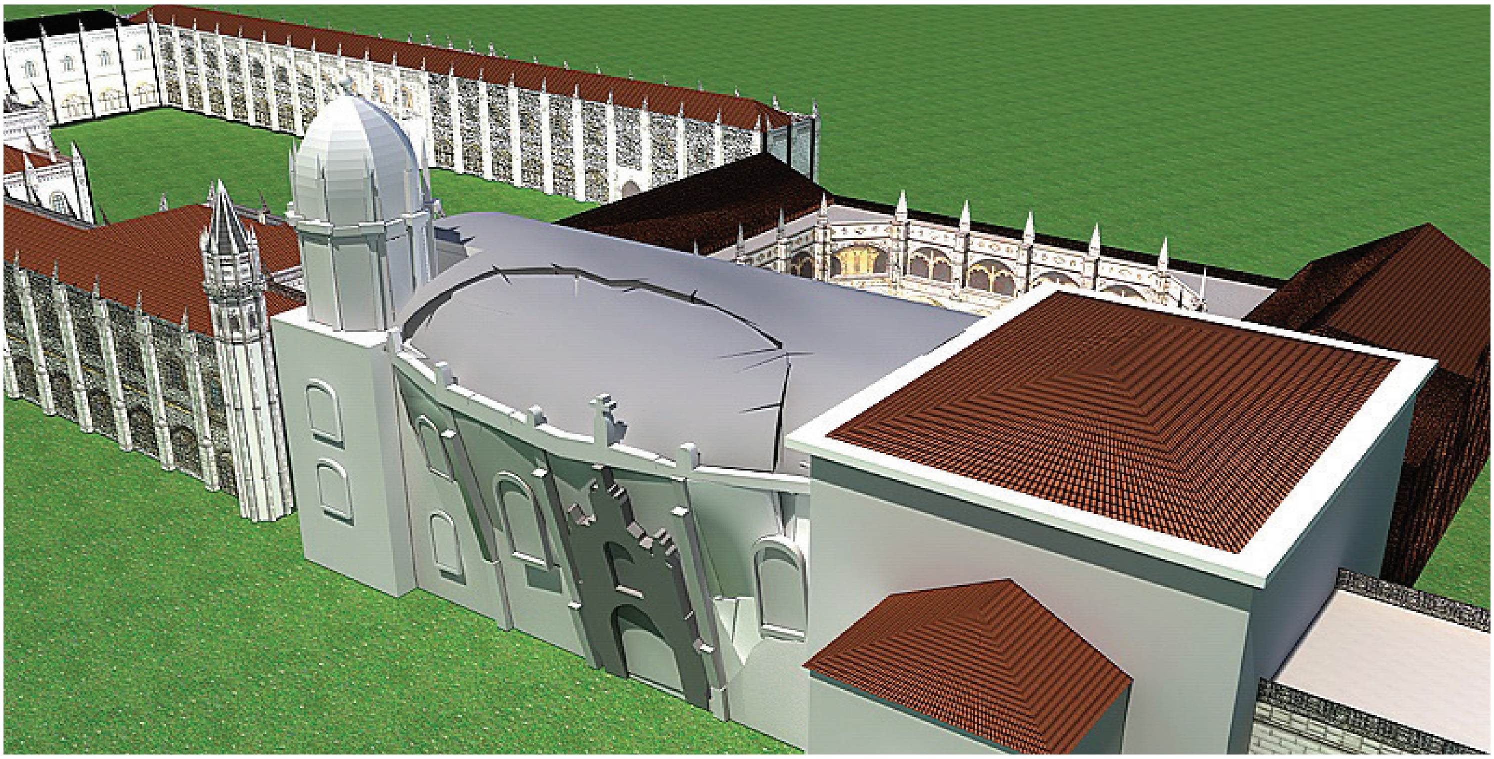
The characterization of irregular masonry remains a true challenge, given that the in-plane and out-of-plane behavior of historic walls is not well understood. Additionally, seismic assessment of historic built heritage is complex, since the safety assessment techniques used for modern buildings are not applicable to historic structures; these techniques fail to accurately replicate the true behavior of such structures. Still, significant developments in the last few decades have permitted reliable engineering for safety assessment and the design of efficient and effective intervention measures.

DEVELOPMENTS IN RESEARCH AND PRACTICE

Some advances in research and practice have occurred recently in nondestructive evaluation and in repair and strengthening techniques for historic structures. While these developments are important, they are often difficult to integrate into undergraduate and graduate courses, and even into practice.

One example of an advance is in procedures for the investigation and diagnosis of historic fabric.[4] These techniques can be invasive (such as coring or otherwise opening up the building) or can be fully nondestructive (using elastic waves or electromagnetic waves). Other advances include the methods and simulation tools available for the safety assessment of historic masonry structures. The methods have different levels of complexity (from simple graphical methods and hand calculations to complex mathematical formulations and large systems of equations), different availability for the practitioner (from well-disseminated structural analysis tools accessible to any consulting engineering office to advanced structural analysis tools available only in a few research-oriented institutions and large consulting offices), different time requirements (from a few seconds of computer time to a number of days of processing), and, of course, different costs. Many structural analysis techniques can be adequate, possibly for different applications, if combined with proper engineering reasoning.[5]

There are several approaches—often combining experimental and numerical techniques—that have received substantial attention in research. Key considerations are both durability and the compatibility of new materials with traditional materials (such as stone, lime-based mortar or plaster, and adobe or clay brick). Injection grouts, for example, are a well-known remedial technique, which can be durable and mechanically efficient while preserving historic values. Still, the selection of a grout for repair must be based on the physical and chemical properties of the existing materials. Parameters such as rheology, injectability, stability, and bond of the mix should be considered to ensure the effectiveness of grout injection. The insertion of bars (ideally stainless steel or composite) within the masonry using coring also has been a popular technique to enhance structural capacity.



A computer simulation of the potential structural failure of the Monastery of Jerónimos in Lisbon, after being subjected to an earthquake load. Image: João Roque. Courtesy of Paulo B. Lourenço.

The development of innovative technologies that apply externally bonded reinforcement systems, using composite materials for strengthening, has gained attention in recent years. Application of fiber-reinforced polymers (FRP) to vaults, columns, and walls has demonstrated their effectiveness in increasing load-carrying capacity and in upgrading seismic strength, even if concerns about durability persist. During the past decade, in an effort to alleviate some drawbacks associated with the use of polymer-based composites, inorganic matrix composites have been developed. This broad category includes steel-reinforced grouts (SRG), unidirectional steel cords embedded in a cement or lime grout, and fabric-reinforced cementitious matrix (FRCM) composites, a sequence of one or more layers of cement-based matrix reinforced with dry fibers in the form of open single or multiple meshes. Currently, natural fibers are becoming more popular for crack control and strengthening, not least because they are "green" materials.

More conservation research is necessary for a fuller comprehension of the behavior of historic masonry buildings and the reasons for their damage from seismic events. Ideally, a conservation professional should be able to adopt a decision process that includes: a comprehensive understanding of the history of the building; diagnostic work (preferably involving nondestructive or minimally destructive techniques) and a safety assessment (often using advanced analysis tools); design and implementation of remedial measures; and control of the implementation.

Earthquakes are, and will remain, one of the most powerful sources of destruction for cultural heritage buildings. Cracking occurs at early stages of loading, and the traditional methods for the assessment of stability cannot be effectively applied to historic structures. Advanced approaches are available, but the number of practitioners experienced in these methods is insufficient for existing needs; thus more training for the field in general is required.

Recent developments in intervention techniques that better confine and tie together building parts—thereby reducing the risk of separation of parts and disintegration of individual elements during a seismic event—are significant. The implementation of remedial measures requires that safety, durability, compatibility, and removability are considered, together with costs and cultural value. Much knowledge has been gained in recent decades. The challenge is to turn this knowledge into practice both by educating professionals and by allocating financial resources for this endeavor.

Paulo B. Lourenço is a professor of civil engineering at the University of Minho in Portugal.

1. European Commission, "Europe, the World's No. 1 Tourist Destination—a New Political Framework for Tourism in Europe," COM (2010) 352; http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52010DC0352.
2. FEMA, "Mitigation's Value to Society Fact Sheet," Federal Emergency Management Agency, 2011; https://www.fema.gov/media-library/assets/documents/12305.
3. ICOMOS-ISCARSAH, *Recommendations for the Analysis and Restoration of Historical Structures* (2003).
4. L. Binda , A. Saisi, C. Tiraboschi, "Investigation Procedures for the Diagnosis of Historic Masonries," *Construction and Building Materials* 14, no. 4 (2000): 199–233.
5. Paulo B. Lourenço, Nuno Mendes, Luís F. Ramos, and Daniel V. Oliveira, "On the Analysis of Masonry Structures without Box Behavior," *International Journal of Architectural Heritage* 5, nos. 4–5 (2011): 369–82.

MASTERING THE MECHANICS OF THE PAST

A Discussion about Preservation Engineering

ANDRONIKI MILTIADOU-FEZANS, a structural engineer specializing in historic structures, is director of the Directorate Special for the Promotion and Enhancement of Cultural Heritage and Contemporary Creation at the Ministry of Culture, Education, and Religious Affairs of the Hellenic Republic. She has been responsible for many structural restoration projects in Greece and teaches at the Raymond Lemaire International Centre for Conservation in Belgium and at the postgraduate conservation program of the National Technical University of Athens.

CLAUDIO MODENA is a professor of structural engineering at the University of Padua. He has served on a number of research and scientific committees related to earthquake engineering and seismic risk and has done extensive consulting internationally, focusing generally on the conservation of historic masonry structures.

JOHN OCHSENDORF is a structural engineer specializing in the analysis and design of masonry structures and is a professor at the Massachusetts Institute of Technology, holding a joint appointment in the departments of Architecture and Civil and Environmental Engineering. He is a founding partner of Ochsendorf DeJong and Block Engineering.

They spoke with **CLAUDIA CANCINO**, a senior project specialist at the Getty Conservation Institute, and **JEFFREY LEVIN**, editor of *Conservation Perspectives, The GCI Newsletter.*

CLAUDIA CANCINO In recent decades, structural interventions on historic structures, appropriate or not, have sparked a series of discussions about the role an engineer should play in a conservation project. What do you think is the role of a preservation engineer?

ANDRONIKI MILTIADOU-FEZANS Structural intervention on historic structures is a matter that cannot be dealt with only by a structural engineer—it is a project for a multidisciplinary team. Of course within the team, an engineer plays a very important role. His or her main duty is to document a structure's bearing system, to design and supervise the necessary investigations, to assess the structure in its current state, and to design the necessary interventions in collaboration with architects, archaeologists, and others—all in order to ensure as much as possible the survival of the structure from damage or even collapse. Of course, the engineer has the responsibility of ensuring that human life is protected, but at the same time, together with safety, has to propose interventions that take into account all the other values—such as historical, architectural, and aesthetic—in an effort to limit their possible alterations due to intervention. He or she needs to elaborate on alternative solutions and to put them on the table to be debated with other professionals on the team to reach an optimum solution. Consequently, the engineer should have the ability to communicate these structural matters to the team, so the team can discuss them and reach the optimum compromise.

CLAUDIO MODENA I agree that the role of the engineer is to consult with the team and to bring to the team his knowledge about the structural performance of different types of material and the ways to evaluate them.

JOHN OCHSENDORF For me, the first responsibility of an engineer is to work closely with the other disciplines—historians to learn the history of a monument, architects to learn the design intent for future use, conservators to understand the challenges in terms of material conservation, and also the property owner to understand the owner's needs and challenges. Engineers must then offer a range of solutions that can be debated on their merits. Engineering problems never have just one solution. Furthermore, every solution has pros and cons in terms of cost, authenticity, durability, and reversibility. The primary role of the preservation engineer is to put on the table a range of solutions. In many cases, doing nothing should be on the table. Too often, it is not.

CANCINO I also agree that engineers should be part of a team in a conservation project, but I was wondering about their capabilities to intervene in historic structures. Do engineers in general,

Photo: Courtesy of Androniki Miltiadou-Fezans

In most universities, engineers primarily study new concrete and steel structures, and less often masonry and wood structures. So even good and experienced engineers need additional education and training to deal with historic structures.

ANDRONIKI MILTIADOU-FEZANS

or structural engineers, have the knowledge to understand a historic building—to study and to analyze the load forces, and to understand how the building has performed over time?

MODENA I believe that engineers in these cases are aware that they have to work together with other disciplines. But the issue is the capability to do it in an appropriate way. The way of dealing with historic structures is quite different from the way of handling the same problems in recent construction. Engineers are trained to deal with newer projects. In Italy now we have some courses dealing with the problems of historic structures, and the situation is improving, but the main training engineers receive at the universities relates to new construction.

MILTIADOU-FEZANS In most universities, engineers primarily study new concrete and steel structures, and less often masonry and wood structures. So even good and experienced engineers need additional education and training to deal with historic structures. But also young engineers lack training in historic structures, so postgraduate courses and additional job training are very important.

OCHSENDORF I agree—but I would like to emphasize that if an engineer on a team does not take a holistic and thoughtful approach in proposing multiple solutions or a range of alternatives, then it's the responsibility of the client and the rest of the team to say, "We have the wrong engineer." I've often seen an engineer come in with a report that gives one answer—one intervention—and then the client and the rest of the team says, "Ah, the engineer has spoken. Now we must add steel." But it would be better to say, "We need a second opinion." If someone said the *Mona Lisa* was in danger of decay and needed to be dipped in epoxy to be secured for future generations, there would be a second opinion! I can give you examples of some of the greatest monuments on the planet where the word of a single engineer with a single intervention was taken without question.

MODENA This is the problem of having the authorities decide on projects. In Italy, the general secretariat of the Italian Ministry of Cultural Heritage is well aware of this and is producing guidelines for the officials who work in the offices that have to examine these projects. Training those who have to make decisions is a very important and very real issue. This work is very challenging for decision makers, who are often architects. So there is also the problem of training the architects to evaluate the work of the engineers.

MILTIADOU-FEZANS I think that at least in the countries with high seismicity, there has been an evolution in recent decades. A detailed study of proposed structural interventions by a team including at least an architect and an engineer is requested. Moreover, in Greece the final decision on approval for design projects is based on the recommendation of competent multidisciplinary scientific councils set up in compliance with national legislation. This procedure is very important with regard to both the protection of the monument and the burden of responsibility, because—at least in Greece—the structural engineers have a legal responsibility in the case of future damage and may not undertake alone the decision of reducing the severity of the design criteria in the case of monuments. In order to find an optimum intervention scheme that will both protect lives and preserve as much as possible the values of the monument, the seismic redesign action may depend upon acceptable damage levels, varying according to the use of the historic structure and, of course, its importance. Designing interventions for a classical monument like the Parthenon is completely different than for a building in use in a historic center. To this end, a certain categorization of various historic structures, based on their importance and occupancy, would play an essential role in the design of optimum interventions.

CANCINO So there clearly is a need—and there has been for a while—to train engineers on structural interventions for historical constructions. However, it seems to be difficult to include the topic of historic structures within existing engineering curricula.

Why is it a challenge for engineers to study, analyze, and propose interventions to historic buildings?

OCHSENDORF Let's talk about the education of a typical engineer. I teach in the United States, but I've worked in universities in England, Spain, Italy, and Australia, so I have a reasonable understanding of engineering education internationally. First of all, engineering education contains no history. It's almost always the case that there are no courses related to the history of construction or the history of engineering. Second, in the typical engineering education, students are given problem after problem for four to six years, and the problems almost always have one answer. We can all point to exemplary cases of engineering education where there is more open-ended thinking, but in our typical education we are taught that there is only one answer. Engineers could do a calculation on a standing arch, and their calculation may say that the arch should not be standing. I tell students that if their calculation says the structure is not standing—and it is—then it's not the structure that's wrong. It's their calculation. Third, students are taught that there are two materials—steel and reinforced concrete. There is an obsession with these two materials and with new construction. Very often, especially in some economies around the world, most of the work deals with existing buildings, not new buildings. And so that is a major handicap. It's also true of architecture schools, but it's even more true of engineering schools.

CANCINO I frequently come across papers that talk about the problem of engineers facing the unknown when they deal with historic buildings. That is probably because there is no training in materials other than modern ones.

MILTIADOU-FEZANS It is true that a formally trained engineer will have lacunae in his education regarding the difficult problems of historical monuments. These are old structures, usually made from various types of masonry, constructed in different phases, suffering from new and old damage, and repaired or transformed over the past. There is a lack of sufficient understanding regarding their structural behavior, before and after interventions, related to uncertainties in the estimation of resistances and actions, as well as in the methods of analysis and verification. For example, interventions of fifty years ago—which were probably considered the best ones—used a lot of reinforced concrete, but earthquakes that happened later have proven that this approach was very invasive and not adequate. So the problems are quite complex.

MODENA I would say from a conceptual point of view, approaches to the problem of safety of historical monuments are present in some official normative documents. They say, for example, that structural models normally provide solutions that are on the safe side, but these solutions that normally we accept, we cannot accept in the case of existing historical structures. We say, for example, that you should not rely on only one model. We are saying that models can be used for performing sensibility checks, and so we have to check the imprints of some parameters. We teach that when intervening you should try to minimize changes in the structural response—otherwise the models will say nothing sensible. So the job of the engineer in the case of historical structures is much more complex and difficult than when designing a new project. Conceptually, all that is already clear. The real problem is how to put into practice such very general indications. In Italy, substantial efforts are being made to fill the gaps with courses taught for engineers and general architects on the history of architecture and on the structural problems of historic structures—such as the one I am teaching at the University of Padua.

CANCINO Do formally trained engineers today at least have the capacity to adapt the knowledge provided to them to appropriately intervene in historic buildings?

MODENA In my experience, structural engineers are trained for designing new structures, and not for dealing with problems of existing historical structures. In Italy, the so-called engineer-architects do much better. They are less prepared to deal with the most sophisticated structural models but better prepared to deal with holistic approaches to structural safety of historical constructions.

JEFFREY LEVIN Should more attention be paid to traditional or historic repair techniques that have, in fact, at least sustained these structures over time?

MODENA This is a big debate. The problem is the appropriate use of traditional knowledge. But I am absolutely convinced that when we intervene and substantially change the structural behavior, we are not able to control what the behavior will be in the future. But I would also comment at this point on a paper I recently wrote proposing that instead of talking about *compatibility* or *reversibility*, it is much more appropriate to speak in terms of *reparability*. Historic buildings have suffered damage and were repaired. The problem now is when we intervene using modern technologies. I am very much concerned about the use of "innovative solutions." Some novel solutions do not always perform well, and in any case they make things much more difficult to repair. We should be guided by experience, and focus much more on a real understanding of the design and on selecting appropriate materials, no matter if they are traditional or innovative.

MILTIADOU-FEZANS I agree that reversibility and re-interventionality—as we say in the relevant Greek draft regulatory document for seismic protection of monuments—are basic performance requirements for structural interventions. When reversibility cannot be ensured, we must try to give future generations the possibility to intervene again. I also totally agree that models cannot be the only guiding factor for our decisions. Models are just one tool. They should be calibrated on the basis of the evidence existing in the monument as such, adequately investigated and assessed by the expert team. In old structures, there are a lot of secrets, and we must spend time in situ to understand and evaluate what has happened in the past in order to make a proposal for the future.

OCHSENDORF I do not believe that we understand the seismic performance of historic buildings very well at all. That includes university researchers—but even more so practitioners. I think we are in our infancy. If you ask how a complex structure like the Basilica of St. Francis of Assisi behaves, I don't think we understand it well—even if we remove the seismic issue and talk only about durability of materials. Of course structures are maintained over the centuries. The great cathedrals of Europe had large maintenance campaigns about every hundred years. But many of our solutions have shortened those maintenance intervals in recent years, primarily because we have had too much confidence in new materials. If you look at the history of preservation engineering, it's one idea after another that was shortly discredited. So I think we need to be skeptical of new materials. The interventions of the nineteenth century were often better than the interventions of the twentieth century.

CANCINO Would it be useful for engineers and architects to have training in interventions that failed—the process of how the interventions were designed and implemented and the impact that those interventions had on historic buildings? At least we could learn from mistakes in the field.

MILTIADOU-FEZANS In my postgraduate courses, I always start with the failures of the past. These are vital guides for the present. It is also very educative if one has the opportunity to see some historic structures after an earthquake—to directly and personally observe the eventual problems caused by past interventions. For instance, when I visited Kalamata in South Peloponnese after the 1986 earthquake, I was shocked by the fallen cupolas, framed in concrete, that were lying in the interiors of the churches.

MODENA I agree that it is better to avoid using materials of which we know little regarding their interaction with original existing material. But we also have the problem of preserving historic centers where people live. There are hundreds of thousands of historic buildings where people live and make changes. In these cases, the problem is even more complex. Those buildings are different than empty monuments. And this is a big issue in Italy, where the owners, the architects, and the contractors are not aware of the problems.

CANCINO Even when you have an adequate team, with an architect and structural engineer, and you offer multiple solutions to city building officials, these officials can have problems accepting minimal interventions or nonstructural solutions. Why do you think that's the case?

MODENA In Italy in the case of historic buildings, it is almost compulsory to improve safety, but it is not necessary to demonstrate the same level of safety with historic buildings as it is with newer buildings. In our codes, in the case of existing structures, there are three possible ways to intervene. First, by retrofitting. This means to formally demonstrate that the safety of the existing structure after intervention is the same as it would be for a new building constructed in the same place with the same designation. But it is also considered a possibility—almost an obligation in the case of historic constructions—to intervene by "only" improving the safety, demonstrating that the safety after the intervention is better than the safety was before. This is actually the main normative support to the design approach of "minimum interventions." And it is also possible to intervene without demonstrating that the intervention that is proposed will improve the "global safety" of the structure, but rather simply repair a local damage or prevent possible failures. This is written into our code in Italy. So we accept the idea that with regard to existing structures, we have to form an approach that is different from the one we use for new construction. I must say, however, that the debate on such issues was still heated, even in the committee (of which I am a member) that recently updated our national structural code.

MILTIADOU-FEZANS In my country, within the Earthquake Planning and Protection Organization, we are now working on the preparation of a code for structural interventions on existing masonry buildings. It has not been finalized yet, but certainly the aforementioned approach of "safety improvement" is also under consideration. The problem is that the criteria to judge the level of "an improvement" are not so clear, owing to lack of knowledge regarding the behavior of historic masonry structures at an international level. Existing masonry buildings—not historic ones—that are not engineered have the same problems, because they are inhabited and because there is danger during an earthquake. Thus, one has to find a solution, at least for the time being, based on the knowledge available today. One cannot wait for the necessary research work to be completed to elaborate a code. We are trying to quantify existing knowledge and to produce code documents to be applied to existing masonry structures, because we must never forget that while thousands of historic masonry structures have survived, many have been damaged, and many others have collapsed.

OCHSENDORF I think codes are a major problem. Italy is doing very good work and is among the best in the world in trying to make the codes relevant to historic structures. Claudio is a major leader in that. Here in the United States, it's possible for engineers to use their judgment and to make exemptions, but that does not happen enough. I think we rely too much on codes that are inappropriate. Returning to your question about the building officials, Claudia, I think the desire to intervene is natural. With older structures, people think we must do something. There's


Photo: Courtesy of Claudio Modena

We should be guided by experience, and focus much more on a real understanding of the design and on selecting appropriate materials, no matter if they are traditional or innovative.

CLAUDIO MODENA

a lot of cultural pressure to make an intervention because we believe in a progressive world in which the technology we have today is better than what we had a hundred years ago—which is true in neuroscience and in many other fields. I also think that building officials have an expectation to intervene, which is not so healthy sometimes.

LEVIN What can be done in the United States to further the kind of approach that Italy has taken? What steps would you suggest to change the way that we look at historic buildings in the context of the codes?

OCHSENDORF It's a long process. Codes take a long time to change. I think what can help are case studies that can provide examples of interventions that are appropriate or inappropriate—as well as instituting certification programs for engineers to work in preservation. This is something that the United Kingdom has recently pioneered, and I think this it is applicable in many countries where engineers work on historic structures.

MODENA Master courses for graduate students and special training courses for engineers after graduation can certainly help.

MILTIADOU-FEZANS It is not only the engineers who need training, but contractors as well. Because while the project ideas and the drawings may be good, the personnel implementing the interventions—the workers, the technicians, and the contractors—should also be experienced and effective to achieve improvement of structural behavior. So all need to be trained and to be able to provide certifications that ensure their capability to undertake the work. Interventions must be carefully applied, because if they are not applied correctly they can be very invasive and even dangerous.

MODENA One of the most important advances in the technology field is in the tools used to conduct analyses that help us better understand a structure and its materials. By using a combination of nondestructive and minimally destructive monitoring in the case of important monuments, we have the technological tools to make investigations and appropriate user models, and to combine experimental and numerical models. These advances can be very useful in designing minimal interventions.

OCHSENDORF I agree completely, but I will also say that oftentimes we don't have the patience to wait. For example, if there's a crack in a monument that is worrying people—and it's been there for two hundred years—I would say, "Well, let's monitor for five years, and then we can talk." Often the timeline is so short. People want to spend the money and do a project in six months. We need to have more patience.

MODENA Absolutely. In the big projects, it is much better to have more time. We have to consider that some of these monuments took decades or even centuries to be built. So we cannot intervene as we would with new construction. We need time to deal appropriately with their problems.

MILTIADOU-FEZANS In our guidelines, we have included this concept of incremental progress in design and in the implementation of interventions. This means that one can undertake a first step of limited interventions, and then monitor the behavior of the structure and continue with another set of interventions, if necessary. Needless to say, in parallel with the first series of interventions, various hidden elements of the monument may be investigated, while real information on the dynamic response of the structure, through a monitoring system, may serve to calibrate future models for the design of the next phase of interventions. This was the case of the katholikon of Daphni Monastery in Attica, Greece, a World Heritage Monument.

CANCINO We have touched a lot on the topic of capacity-building of engineers and officials, and what I'd like to ask now is what

Photo: Courtesy of the John D. and Catherine T. MacArthur Foundation

Engineering problems never have just one solution. Furthermore, every solution has pros and cons in terms of cost, authenticity, durability, and reversibility. The primary role of the preservation engineer is to put on the table a range of solutions.

JOHN OCHSENDORF

you all think needs to be done to improve the training of preservation engineers.

MILTIADOU-FEZANS I think that the improvement of education and training should go in the following directions. First, in technical universities the mechanics of masonry and timber structures should be taught systematically, together with an advanced technology course on materials. Second, institutionalized continuous education should be permanently organized for the training of the professionals who have completed their university education but have no time or means to go on to postgraduate programs. For example, in Greece we have a state institution that organizes training courses for engineers and other state officials responsible for the design and application of a project or the approval of project designs. Third, master courses should be further enhanced. In these master courses, it is vital to give the various professionals who work together—engineers, architects, art historians, and so forth—the opportunity to gain an understanding of their mutual interests and knowledge, and of the need to work together.

MODENA Certainly special training is needed for structural engineers who deal with preservation problems. In Padua at my university we have a course for engineers/architects, but we recently decided to start a new engineering course that is more concerned with existing structures—and historic structures in particular. This certainly is a need that is not presently being addressed in courses for structural engineers. As I said before, structural engineers are very well trained to design new structures but they don't know anything about history and traditional solutions. So in Italy we are trying to develop these courses for people who will work on historic structures.

OCHSENDORF I want to make a very central point, which is related to education. There are really three big reasons why an engineer might intervene or be pushed to intervene in a historic structure. The first is fear and liability. If a building collapses, the engineer is responsible, and that can motivate interventions. The second motivator is financial reward. Often the engineer's fee is a portion of the overall contract, and engineers have offices that they're trying to support—and so that is a motivator to do a bigger intervention. And the third motivator is a lack of knowledge—such as in the behavior of a brick vault or in the behavior of a timber truss. Education can address the lack of knowledge, and we can do that through case studies, training programs, and certification programs, which I think should be a postgraduate degree in preservation engineering. Still, those other issues remain—the fear and liability, and the financial motivation. So training is important, but it will only solve one part of what drives the interventions in historic monuments.

MILTIADOU-FEZANS Training and postgraduate studies for engineers can also have an impact on the financial issue. If more engineers are educated in a better way to understand the structural behavior of historic structures, then they will avoid possible invasive interventions that might be dangerous or not useful. And this will happen because if they are aware of the danger, they will not sign off on inappropriate interventions for which they are responsible in case of failure. So I think that the training and education of engineers can have a broad impact.

KEY RESOURCES **SEISMIC RETROFITTING**

ONLINE RESOURCES, ORGANIZATIONS & NETWORKS

For links to the online resources listed below, please visit http://bit.ly/keyresources_30_1

Earthquake Engineering Research Institute (EERI), a national nonprofit technical society of engineers, geoscientists, architects, planners, public officials, and social scientists.

Federal Emergency Management Agency (FEMA). The FEMA Hazard Mitigation Grant Program offers a framework for protecting US historic structures from natural disasters.

Institute of Disaster Mitigation for Urban Cultural Heritage, Ritsumeikan University, a hub in Japan for education and research in disaster mitigation for cultural heritage.

International Scientific Committee on Risk Preparedness (ICORP), a technical committee of the International Council on Monuments and Sites (ICOMOS).

International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH), a technical committee of the International Council on Monuments and Sites (ICOMOS).

NIKER Project. This European project aims at developing and validating innovative technologies and tools for systemic improvement of seismic behavior of cultural heritage assets.

Reducing Disasters Risks at World Heritage Properties, a strategy for risk reduction approved by the World Heritage Committee in 2007.

USGS Earthquake Hazards Program monitors and reports earthquakes, assesses earthquake impacts and hazards, and researches the causes and effects of earthquakes.

BOOKS, JOURNALS & CONFERENCE PROCEEDINGS

Between Two Earthquakes: Cultural Property in Seismic Zones, by Bernard M. Feilden (1987), Rome: ICCROM; Marina del Rey, CA: Getty Conservation Institute.

A detail of exterior earthquake damage to Ica Cathedral in Peru. Photo: Scott S. Warren, for the GCI.

California Historical Building Code, by California Building Standards Commission (2010), Sacramento: California Building Standards Commission.

Canterbury Earthquakes Royal Commission Final Report, vol. 4: "Earthquake-Prone Buildings," by Canterbury Earthquakes Royal Commission (2012), Wellington, New Zealand: Canterbury Earthquakes Royal Commission.

Controlling Disaster: Earthquake-Hazard Reduction for Historic Buildings, by Rachel S. Cox (2001), Washington, DC: National Trust for Historic Preservation.

Earthen Architecture Initiative Seismic Retrofitting Project: A Bibliography, edited by Claudia Cancino, Sara Lardinois, Tim Michiels, and Poornima Balakrishnan (2014), Los Angeles: Getty Conservation Institute.

"Earthen Structures: Assessing Seismic Damage, Performance, and Interventions," by Frederick A. Webster, in *Terra Literature Review: An Overview of Research in Earthen Architecture Conservation,* edited by Erica Avrami, Hubert Guillaud, and Mary Hardy (2008), Los Angeles: Getty Conservation Institute.

International Journal of Architectural Heritage 9, no. 4: "Conservation, Analysis, and Restoration" (2015), Abingdon, UK: Taylor and Francis.

Managing Disaster Risks for World Heritage, by UNESCO, ICCROM, ICOMOS, and IUCN (2010), Paris: UNESCO.

Planning and Engineering Guidelines for the Seismic Retrofitting of Historic Adobe Structures, by E. Leroy Tolles, Edna E. Kimbro, and William S. Ginell (2002), Los Angeles: Getty Conservation Institute.

Proceedings of the International Conferences on the Conservation of Earthen Architecture: 1990, 1993, 2000, and 2008.

Proceedings of the International Conferences on the Structural Analysis of Historical Constructions: 1997, 1998, 2005, 2007, 2008, 2010, 2012, and 2014.

The Seismic Retrofit of Historic Buildings: Keeping Preservation in the Forefront, by David W. Look, Terry Wong, and Sylvia Rose Augustus, *Preservation Briefs* 41 (1997), Washington, DC: Technical Preservation Services, National Park Service, US Department of the Interior.

Seismic Retrofitting Project: Assessment of Prototype Buildings, 2 vols., by Claudia Cancino, Sara Lardinois, Dina D'Ayala, Carina Fonseca Ferreira, Daniel Torrealva Dávila, Erika Vicente Meléndez, and Luis Villacorta Santamato (2012), Los Angeles: Getty Conservation Institute.

The Survey of Earthquake Damaged Non-Engineered Structures: A Field Guide by EEFIT, by Richard Hughes and Zygmunt A. Lubkowski (2000), London: Earthquake Engineering Field Investigation Team.

A Tutorial: Improving the Seismic Performance of Stone Masonry Buildings, by Jitendra Bothara and Svetlana Brzev (2011), Oakland, CA: Earthquake Engineering Research Institute.

Twenty Tools That Protect Historic Resources after an Earthquake: Lessons Learned from the Northridge Earthquake, by Jeffrey Eichenfield (1996), Oakland, CA: California Preservation Foundation.

Uniform Code for Building Conservation, by International Conference of Building Officials (1991), Whittier, CA: International Conference of Building Officials.

For more information on issues related to seismic retrofitting, search **AATA Online** at **aata.getty.edu/home/**

GCI News

The new Visitor Center for the Mogao Grottoes. Photo: Courtesy of the Dunhuang Academy.

New Projects

MODERN OILS RESEARCH CONSORTIUM FORMED

The Treatment Studies research area within GCI Science undertakes scientific investigations of particular conservation treatments and materials for indoor and outdoor works of art. It has conducted research into conservation issues associated with modern paints (both proprietary industrial coatings and artists' types) and the cleaning of works of art in acrylic paint media.

The Treatment Studies research group is now expanding its research to include treatments for modern artists' oil paints. Last fall the GCI became a founding partner in the newly formed Modern Oils Research Consortium (MORC), a collaboration with Tate and the Courtauld Institute of Art (both in London), the Hamilton Kerr Institute of the University of Cambridge, and the Cultural Heritage Agency of the Netherlands (RCE). These five organizations have signed a memorandum of understanding, which formalizes their commitment to work together and to share knowledge about:

- chemical and physical properties of modern oil paints and their behavior over time;
- development of treatments;
- research relating to the use of these materials by artists;
- production and adoption of modern oil paints in the twentieth and twenty-first centuries.

Members of the consortium will meet regularly to exchange information on current research, to explore further development of scholarly research, and to create opportunities for the exchange of staff and the sharing of equipment. They will also look for ways to communicate new developments via conferences, symposia, and publications.

M O R C Modern Oils Research Consortium

This research collaboration was catalyzed by awareness that twentieth- and twenty-first-century oil paintings and other painted surfaces present a range of complex treatment challenges to conservators that are distinct from those noted in works from previous centuries. These phenomena include the formation of "surface skins" of medium on painted surfaces, efflorescence, unpredictable water and solvent sensitivity, and unusual occurrences such as previously stable, solid paints liquefying and beginning to drip.

Modern oil paints have been used by artists in the creation of paintings and sculpture, typically without any protective coating of varnish, and are often exposed directly to the environment with all the attendant harmful effects of pollutants, dirt deposition, physical alteration, and more.

More information on the Modern Oils Research Consortium can be found on Tate's website: www.tate.org.uk/about/projects/modern-oils-research-consortium. Questions regarding the consortium can be directed to MORC@tate.org.uk.

Project Updates

MOGAO GROTTOES VISITOR CENTER OPENS

For more than two decades, the Getty Conservation Institute has worked with the Dunhuang Academy, the managing agency of the Mogao Grottoes at Dunhuang, China, on conservation issues related to this World Heritage Site. Part of that effort has included research work to establish a visitor-carrying capacity for the site in the context of a comprehensive visitor management plan.

The Dunhuang Academy has long been attentive to the need to provide interpretive resources for visitors. Since the late 1980s, various facilities have been developed at the site, beginning with an exhibition center housing eight facsimile caves hand-painted at a 1:1 scale. These exact copies of the wall paintings and sculptures have been a hallmark of the scholarly and documentation work of the staff since the 1940s.

Other displays at the exhibition center have followed over the years, on topics such as the history of the so-called Library Cave, conservation of the wall paintings and site, and the early days of the Dunhuang Academy. Constrained by operators' rigid schedules, a typical visitor experienced only the standard two-hour guided tour of the caves and then departed. The sharp increase in visitor numbers in recent years has put enormous stress on the caves. Some eight hundred thousand people are now coming annually, mostly in the summer months.

After several years of design and construction, a new visitor center opened in September 2014 with a flurry of celebrations. Located fifteen kilometers off-site, the Visitor Center is a state-of-the-art facility that draws architectural inspiration from the great sand dunes visible to the west. Now all visitors begin at the center with a site orientation. This consists of two audiovisual experiences: a film reenacting the history of Dunhuang—founded in 111 BCE to protect the border from incursions by nomad horsemen from the steppe—and a digital presentation in a domed theater covering all the major dynastic styles of the art of the caves. From here visitors are transported to the site to see the actual caves and the other on-site exhibitions.

Together with an online reservation system, the new Visitor Center is part of the site's comprehensive visitor management plan, which also includes the recently completed visitor capacity study, *Strategies for Sustainable Tourism at the Mogao Grottoes of Dunhuang, China* (2015), jointly undertaken by the Dunhuang Academy and the GCI and published through SpringerBriefs in Archaeology (http://bit.ly/visitorcapacity).

CONSERVATION OF SHUXIANG TEMPLE, CHENGDE

At the height of the Qing Empire, the Mountain Resort at Chengde, northeast of Beijing, was effectively the alternate capital of China. Founded in 1703 by the Kangxi emperor, its apogee was under his grandson, Qianlong (r. 1736–95). This enormous site, inscribed on the World Heritage List in 1994, comprises a palace area, gardens, pagodas, pavilions, lakes, landscapes, and, originally, twelve temples outside the resort walls, eight of which survive today.

The interior of Shuxiang Temple at Chengde. Photo: Courtesy of the Chengde Cultural Heritage Bureau.

Among the surviving temples is Shuxiang, the family temple of the Qianlong emperor. In 2002, the GCI in collaboration with the Chengde and Hebei Cultural Heritage Bureaus, under the State Administration of Cultural Heritage (SACH), began conservation planning for this temple following the China Principles, as presented in *Principles for the Conservation of Heritage Sites in China*. Shuxiang Temple was chosen for application of the Principles because it posed particular preservation challenges.

The surviving buildings retain considerable historic fabric, sculpture, and furniture dating both from the original construction in 1774 and from the beginning of the nineteenth century, when repainting was undertaken. At Chengde, as elsewhere in China, restoration of Qing architecture has been the norm for decades. Based on a multiyear comprehensive research and assessment process (http://bit.ly/Shuxiang), a decision was made by the partners to conserve the increasingly rare Qing imperial building fabric that has survived in Shuxiang Temple. A concept plan was developed for conservation and stabilization treatments to protect wood, painted architectural decoration, and ruined structures, and extensive research and testing were undertaken.

Beginning in 2013, following the development of detailed specifications, implementation by the Hebei and Chengde Heritage Bureaus and the Chinese Academy of Cultural Heritage (funded by SACH) was begun and is now largely completed. The work has generally followed the minimal intervention concept agreed upon for conservation of historic fabric, with respect to extant buildings, painted architectural decoration, and ruins of subsidiary buildings. The project now provides a comprehensive case study of a systematic approach to the conservation of Qing dynasty imperial architecture.

CONSERVATION AND REHABILITATION PLAN FOR THE KASBAH TAOURIRT

The Getty Conservation Institute continues its work with CERKAS (Centre de Conservation et de Réhabilitation du Patrimoine Architectural des zones atlasiques et subatlasiques) to develop a Conservation and Rehabilitation Plan (CRP) for the Kasbah Taourirt in Ouarzazate, Morocco. The main objective is to create a methodology for preserving and reusing this traditional ensemble as a model for the other three hundred *kasbahs* and four thousand *ksour* located across southern Morocco.

In March 2015 the GCI team returned to Morocco for a seventh campaign. The work consisted of implementation of urgent structural conservation measures and in situ training demonstrations in emergency wall painting stabilization methods with CERKAS staff for the Caid Residence of Taourirt. This campaign also included final meetings with CERKAS personnel and authorities from the Ministry of Culture to plan for future management and use of the building as part of the Taourirt CRP.

The GCI is also working with Carleton Immersive Media Studio to design and populate the CERKAS website. During the March

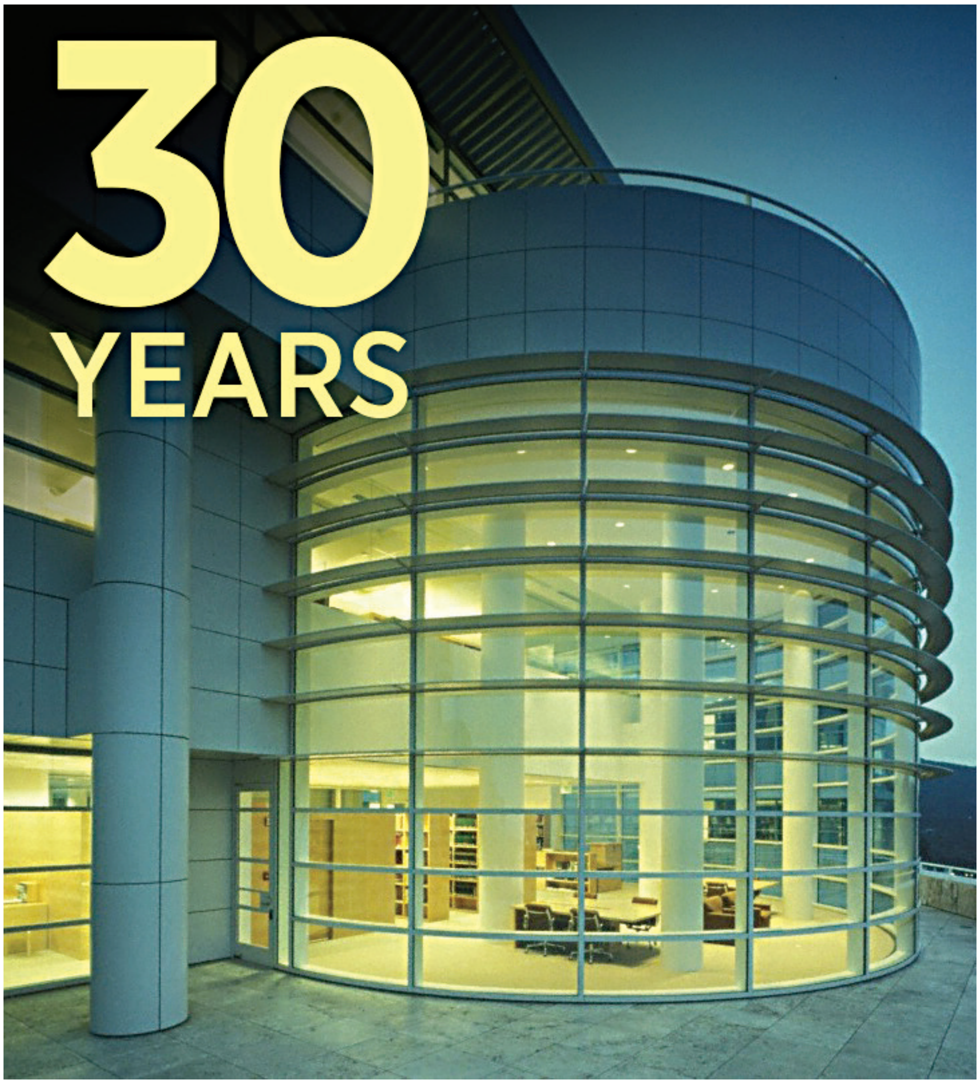
A view of the Kasbah Taourirt in Ouarzazate, Morocco. Photo: Mario Santana Quintero, for the GCI.

campaign, the project organized all information generated by the CRP and collected existing data related to other similar earthen sites in the region, with the goal of making this information available to the general public, Moroccan professionals, and scholars, while disseminating the methodology used to develop the CRP.

A large earthen village and oasis dating from the sixteenth century, Taourirt is strategically located at the intersection of major trans-Saharan trade routes that once brought spices, gold, and other goods across the Sahara from Timbuktou to the rich imperial cities of Morocco. Registered as a National Monument, Kasbah Taourirt was originally one of the residences of the Glaoua family, which ruled the region during the late nineteenth and early twentieth centuries. It comprises different earthen building types of high architectural, social, and historic significance, and it includes important features such as wall paintings and decorated wooden ceilings.

Recent Events

GCI TURNS THIRTY



This year the Getty Conservation Institute turns thirty, and throughout 2015 we are commemorating this anniversary by looking back at some of the accomplishments, projects, and events that have shaped the GCI since its founding in 1985.

Our social media channels, Facebook and Twitter, include weekly thirtieth-anniversary posts, which will be accompanied by periodic posts on *The Getty Iris*. In addition, the fall issue of *Conservation Perspectives* will reflect on the work of the Institute and its relation to the conservation field over the last three decades.

HISTORIC PLACES LA

On February 24, 2015, at a ceremony held at City Hall, the GCI and City of Los Angeles officially launched HistoricPlacesLA, the Los Angeles Historic Resources Inventory. HistoricPlacesLA is the first online information system specifically created to inventory, map, describe, and help protect significant cultural resources in Los Angeles. The system will be an important tool for protecting and preserving the character of the city's distinctive neighborhoods as Los Angeles continues to grow and change.

HistoricPlacesLA showcases the diversity of cultural resources in Los Angeles, including places of social importance, architecturally significant buildings, historic districts, bridges, parks, gardens, and streetscapes. This inventory can be accessed online by anyone interested in cultural resources, including policy makers, property owners, developers, visitors, students, history and architecture enthusiasts, and other stakeholders.

In creating HistoricPlacesLA, the GCI customized the Arches system, an open source, web- and geospatially based information platform built to inventory and ultimately protect cultural heritage places. Arches was jointly developed by the GCI and World Monuments Fund. HistoricPlacesLA is the

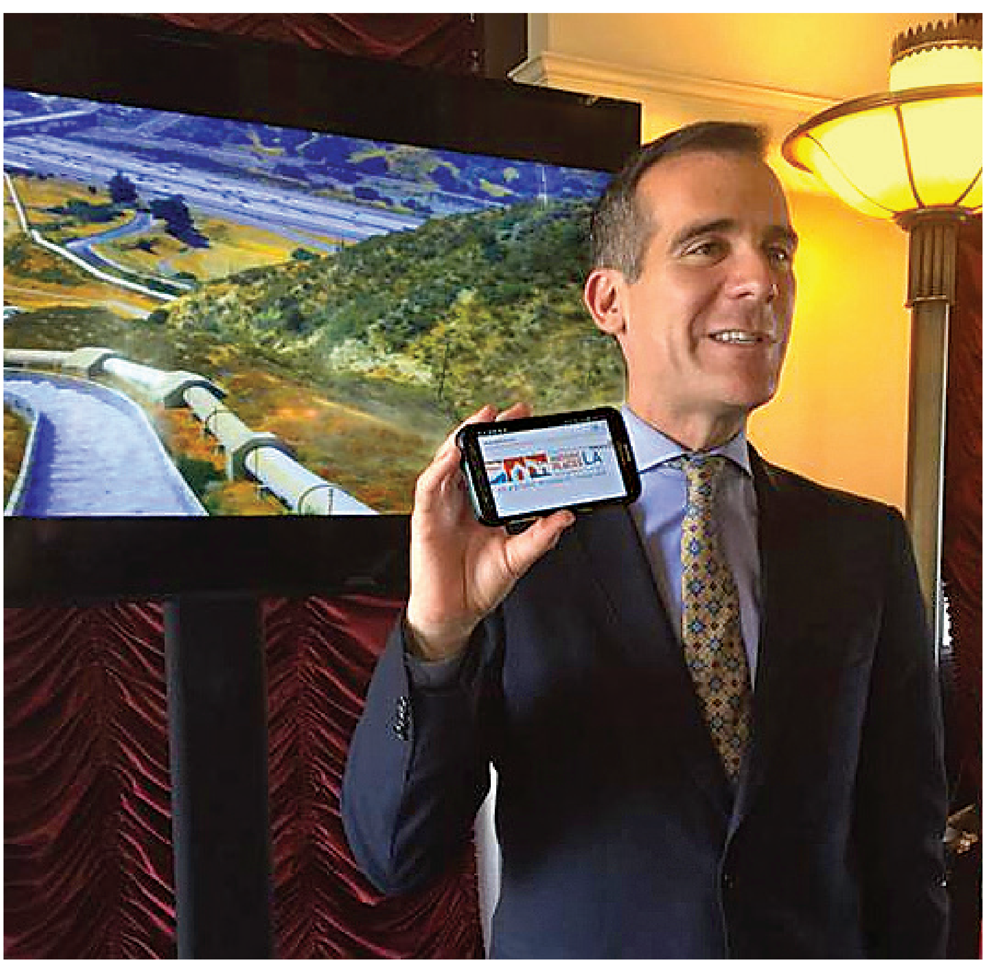
HISTORIC PLACES LA

LOS ANGELES HISTORIC RESOURCES INVENTORY largest implementation of the Arches platform to date and offers a preview of the powerful search capabilities available in Arches Version 3.0. The software is available at no cost, and organizations using it may modify it to meet their specific needs.

HistoricPlacesLA contains information gathered to date through SurveyLA, the citywide survey to identify significant historic resources. It is the largest and most ambitious historic resources survey project to date in the United States. SurveyLA is a multiyear public-private partnership between the City of Los Angeles and the Getty, including both the Getty Conservation Institute and the Getty Foundation. Significant cultural resources identified through SurveyLA are accessible and fully searchable online via HistoricPlacesLA, as are other historic resources that have been previously identified and designated. Information in the system will continue to be updated.

Prior to 2010 only 15 percent of the city had been surveyed for historic resources. Since 2010 SurveyLA has been surveying the remaining 85 percent of the city. SurveyLA is now approximately 75 percent complete—and information continues to come in.

To explore cultural sites in Los Angeles, visit www.HistoricPlacesLA.org. To learn more about the Arches open source software, visit www.archesproject.org.



Los Angeles Mayor Eric Garcetti at the official launch of HistoricPlacesLA, held at Los Angeles City Hall.
Photo: Tom Nakanishi.

PROCEEDINGS PUBLISHED

Conserving Outdoor Painted Sculpture: Proceedings from the Interim Meeting of the Modern Materials and Contemporary Art Working Group of ICOM-CC, Kröller-Müller Museum, Otterlo, the Netherlands, June 4–5, 2013

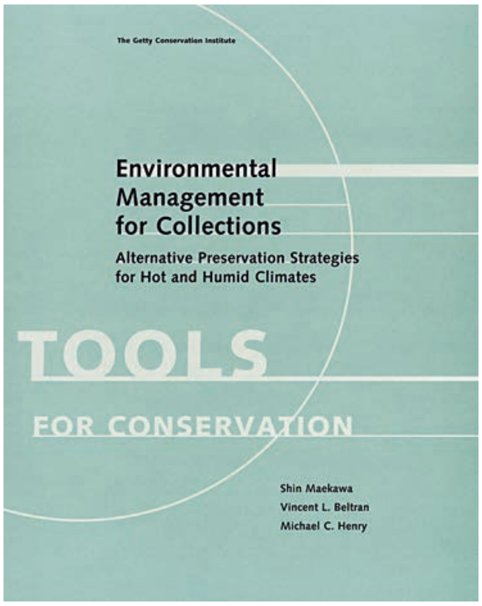
Edited by Lydia Beerkens and Tom Learner

This volume is a collection of seventeen papers presented at the June 2013 symposium held at the Kröller-Müller Museum (see *Conservation Perspectives* 28.2). The papers include case studies of works from Europe, North America, and Asia and cover works by Alexander Calder, Christo, Niki de Saint Phalle, Jean Dubuffet, John Hoskin, Roy Lichtenstein, Claes Oldenburg, Nam June Paik, Shinkichi Tajiri, and Franz West. Also featured are papers on issues facing conservators of outdoor painted sculpture—ethical/philosophical, technical/material, legal, management, and information exchange—and possible responses to those; also addressed are technical issues, such as how paints or coatings can be developed or tailored to conservators' or artists' needs.

This symposium was the interim meeting of the Modern Materials and Contemporary Art working group of ICOM-CC, in collaboration with the Kröller-Müller Museum, the Getty Conservation Institute, and the International Network for the Conservation of Contemporary Art.

Available in PDF and print-on-demand formats from the GCI website at http://bit.ly/outdoorpaintedsculpture.

New Publication



Environmental Management for Collections: Alternative Conservation Strategies for Hot and Humid Climates
By Shin Maekawa, Vincent L. Beltran, and Michael C. Henry

In recent years, many cultural institutions in hot and humid climates have installed air-conditioning systems to protect their collections and provide comfort for employees and visitors. This practice, however, can pose complications, including problems of installation and maintenance, as well as structural damage to buildings, while failing to provide collections with a viable conservation environment.

This volume offers hands-on guidance for facing the specific challenges involved in conserving cultural heritage in hot and humid climates. Initial chapters present scientific and geographic overviews of these climates, outline risk-based classifications for environmental control, and discuss related issues of human health and comfort. The authors then describe climate management strategies that offer effective and reliable alternatives to conventional air-conditioning systems and that require minimal intervention to the historic fabric of buildings that contain collections. The book concludes with seven case studies of successful climate improvement projects undertaken by the Getty Conservation Institute in collaboration with cultural institutions around the world. Appendices include a unit conversion table, a glossary, and a full bibliography.

This book is an essential tool for cultural heritage conservators and museum curators, as well as other professionals involved in the design, construction, and maintenance of museums and other buildings housing cultural heritage collections in hot and humid climates.

This publication can be ordered at shop.getty.edu.

For more information about the work of the GCI, see getty.edu/conservation and

CONSERVATION PERSPECTIVES
THE GCI NEWSLETTER

VOLUME 30 • NUMBER 1 • SPRING 2015

The J. Paul Getty Trust
James Cuno, *President and Chief Executive Officer*

The Getty Conservation Institute
Timothy P. Whalen, *Director*
Jeanne Marie Teutonico, *Associate Director, Programs*
Kathleen Gaines, *Associate Director, Administration*
Kathleen Dardes, *Head of Education*
Tom Learner, *Head of Science*
Susan Macdonald, *Head of Field Projects*

Conservation Perspectives, The GCI Newsletter
Jeffrey Levin, *Editor*
Angela Escobar, *Assistant Editor*
Carol Hahn, *Production Assistant*
Picnic Design, *Design*
Color West Lithography Inc., *Lithography*

Conservation Perspectives, The GCI Newsletter is distributed free of charge twice a year to professionals in conservation and related fields and to members of the public concerned about conservation. Back issues of the newsletter, as well as additional information regarding the activities of the GCI, can be found in the Conservation section of the Getty's website, www.getty.edu/conservation/.

The Getty Conservation Institute works to advance conservation practice in the visual arts, broadly interpreted to include objects, collections, architecture, and sites. It serves the conservation community through scientific research, education and training, model field projects, and the broad dissemination of the results of both its own work and the work of others in the field. In all its endeavors, the Conservation Institute focuses on the creation and dissemination of knowledge that will benefit the professionals and organizations responsible for the conservation of the world's cultural heritage.

The GCI is a program of the J. Paul Getty Trust, an international cultural and philanthropic institution that focuses on the visual arts in all their dimensions.

FSC Mixed Sources
AMERICAN FORESTS

This publication was printed on Forest Stewardship Council (FSC)–certified recycled paper with vegetable-based inks at a facility using wind power. A donation to the American Forests ReLeaf program has been made on behalf of the GCI for its use of FSC-certified paper.

The Getty Conservation Institute

1200 Getty Center Drive, Suite 700
Los Angeles, CA 90049-1684
Tel 310 440 7325
Fax 310 440 7702
gciweb@getty.edu
www.getty.edu/conservation

CONSERVATION
PERSPECTIVES
THE GCI NEWSLETTER

Arg-e Bam citadel almost a year after a 2003 earthquake. This earthen World Heritage Site in Iran suffered extensive damage as a result of this major seismic event. Photo: Kaveh Kazemi/Getty Images.

The Getty Conservation Institute

www.getty.edu/conservation