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The Conservation of Earthen Architectural Heritage in Seismic Areas

NEWMANN Julio Vargas[1, a]

[1]Pontificia Universidad Católica del Perú, Av. Universitaria 1801, San Miguel, Lima, Peru

[a]jhvargas@pucp.edu.pe

Abstract The acceleration of climate change and the increasing frequency of natural disasters mean that there is an urgent need to adapt conservation strategies for architectural heritage to the world's new demands and situations. This is particularly relevant for the most vulnerable constructions, such as earthen structures.

Because of the dramatic effect that earthquakes can have on architecture, and especially on historical monuments, they have been studied for the past 50 years. Earthquakes divide the world in two very distinct geographic areas: seismic and non-seismic.

The seismic vulnerability of earthen architectural heritage, such as earthen structures and mud mortar masonry, evidences in by how weak they are when compared to structures built using other construction materials (10 to 15 times weaker).

Humanity's past experience in the conservation of architectural heritage allows us to be aware of the need to improve and eventually perfect the existing conservation charters, which were discussed and signed in Europe in the last century. These charters do not make a distinction between heritage conservation in seismic and non-seismic areas. It is imperative to address this particular issue, as seismic forces can be too strong for earthen constructions to resist, which can lead to their irreparable collapse.

Inspired by the Venice Charter and China´s principles as well as by more modern documents, such as the Burra, Mexico, Zimbabwe, Lausana Charters, researchers have tried to establish adequate and resistant conservation guidelines, based on achieving the best structural performance using a minimum permanent and reversible reinforcement. Although this involves causing some impact on the architectural heritage, it also means that human lives and buildings can be protected.

The paper will provide real examples to illustrate these cases and will attempt to outline the conservation principles required to protect vulnerable structures, such as those earthen constructions or mud mortar brick or stone masonry built in seismic areas.

Keywords: Earthen heritage, earthquake, conservation, principle

Introduction

Some of the world's oldest architectural heritage was built using earth as the main construction material. Most of it, however, is now gone, destroyed by wars, earthquakes, strong rains and other recurring natural phenomena. While we can control and restrict the effects that war has on certain areas, we can only reduce the damage caused by natural disasters. Climate change is accelerating at rates that have never been seen before and it is our responsibility to preserve the archaeological and architectural testimony of our common past.

This paper focuses on the destruction of earthen heritage caused by earthquakes. It is a well-known fact that the world's seismic geography divides the planet into two areas: seismic and non-seismic. The charters, statements and conservation principles, adopted and ratified by both eastern and western countries, haven't yet addressed how the differences between these two areas affect conservation strategies for earthen heritage.

In the field of structural engineering, earthen architecture refers to constructions that depend on earth for their stability, such as rammed earth; adobe, stone or brick masonry joined with soil mortar; earthen constructions covered with stones; and organic fabrics (made with wood, cane or vegetable fiber) covered with earth.

Mateo Salado, Ait-Ben-Haddou, Chan Chan, Chavin de Huantar, Huique Church in Chile, Teotihuacán and Caral, are some examples of earthen constructions that use different technologies (Figs. 1-7)

Figure 1: Mateo Salado
Cob and stones

Figure 2: Ait-Ben-Haddou
Rammed earth

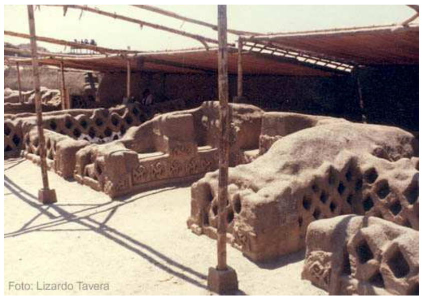

Figure 3: Chan Chan
Adobe

Figure 4: Chavin de Huantar
Stones joined with mud mortar

Figure 5: Huique Church
Bricks joined with mud mortar

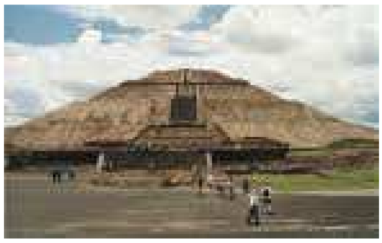

Figure 6: Teotihuacan Adobe
covered with stones

Figure 7: Caral Stones and
mud mortar. Stone core,
wrapped with bags made
vegetable fiber

Figure 8: Acllawasi 1940
Before its restoration

Figure 9: Acllawasi 2008 After
the 2007 earthquake

Figure10: Arg-e-Bam 2000. Reconstruction
From 1970 to the 2003 earthquake

Figure 11: Arg-e-Bam 2004 Re-destruction
After the 2003 earthquake.

Characteristics of Earthen Architecture in Seismic Areas

Earthen architecture constitutes a unique case in the field of heritage conservation for some of the following reasons:

- Earth weakness: according to the Peruvian National Buildings Regulation, earth is about 10 times weaker than other constructions materials, such as brick masonry and quicklime or cement mortars with sand.
- Its brittleness and tendency to sudden cracking: there are no visible deformations before the cracks appear. It takes deformations of very few millimeters to cause sudden cracks.
- The massive size of the structures and walls.
- The strong inertial forces produced by earthquakes in earthen architecture. The forces are proportional to the size of the massive structures.
- The recurring nature of earthquakes and their destructive magnitude, which is stronger than the buildings and produces severe damage in the structures.
- The cumulative damage caused by recurring earthquakes, which can sometimes cause the structures' collapse and the irreparable loss of earthen heritage.

Earthen heritage located in seismic areas can't stand the pass of time by relying solely on the materials and traditional technology with which it was built. The conservation or intervention of earthen heritage that uses the original materials and techniques doesn't prevent their collapse during earthquakes.

The History of Earthen Heritage Conservation in Peru

The intervention of earthen heritage began in the past century and it was influenced by the work of XIX conservation scholars (Ludovit Vitet, Prospero Merimeé, Viollet-le-Duc, John Ruskin, Camilo Boito) and by XX century conservation charters, such as the ones ratified in Athenas (1931), New Delhi (1956), Venice (1964), Burra (1979-99) and Lausanne (1990).

The interventions to earthen archaeological heritage were based on the reconstruction of the earthen buildings that had been destroyed by earthquakes in the previous centuries. Nevertheless, less than half a century after they were intervened, subsequent earthquakes destroyed most of these sites, such as Acllawasi in Pachacamac, Peru and the Arg-e-Bam Citadel in Iran (Figs. 8-11).

The interventions of earthen heritage from the colonial or republican period led to careless reparations based on changing some of the materials used (from adobe to brick), demolitions and reconstructions. Such is the case of Historic Center of Lima, declared Cultural Heritage of Humanity, and that had been severely damaged by earthquakes for 4 or 5 centuries. The dramatic earthquakes of 1687 and 1746, and subsequent tsunamis virtually destroyed Lima and Callao. A Royal Ordinance was then issued by Spain, limiting the adobe constructions to one floor and allowing only second floors built with "quincha" (a technique that uses wood, cane and mud), a light and flexible construction technique. The cities of Lima and Callao were almost completely rebuilt following these indications.

The last earthquakes of the colonial and early republican periods caused serious cracking in the adobe walls, although the quincha walls showed cracks that were easily repairable. Interventions to the adobe walls were unsuccessful. This is evident in the present day when conducting restoration works on old houses in Lima; the buildings have been repeatedly intervened by filling the openings, by adding new doors and windows, walls of mixed adobe and bricks, reinforced concrete and wood that is now severely damaged by xylophagous insects. These buildings now evidence a worrying accumulation of damage and their walls have low stability. The damage-reconstruction-damage vicious cycle is evident.

The situation of hundreds of catholic churches is the same. Most of them were built during or after the XVI century following Spanish construction guidelines, which had no experience in seismic constructions. Consequently, they were severely destroyed by subsequent earthquakes and subjected to several reconstructions. The restoration and reconstruction works attempted to improve the buildings' shape and materials by building thicker walls, brick facades and adding lighter roofs, made with wood and quincha. The damage-reconstruction-damage vicious cycle previously mentioned is also quite noticeable here. The San Pedro of Carabayllo Church, built in 1573 and

destroyed by the earthquakes of 1687 and 1746, is a fine example of the use of new solutions, such as huge reinforcing buttresses, that can still be observed today.

This summarized history of earthen conservation evidences how the damage-restoration-damage cycle will continue as long as we keep reinforcing earthen heritage using traditional construction techniques. The only way to prevent this fatal damage is through the use of modern conservation technologies that implement reinforcement compatible with earth, that produce a minimum impact in the structure and that are reversible. The awareness of this vicious cycle doesn't date back to the previous century, it has been observed in seismic areas for the past 40 centuries.

Characteristics of Pre-Columbian Constructions in Seismic-Resistant Earth

The leading role that the Peruvian territory played in pre-Hispanic America means that a large quantity of the world's earthen heritage is located within its borders. This legacy is as magnificent as hard to maintain, due to constant seismic activity. Its conservation requires regional research and work. Let's look at some important examples:

Caral: An archaeological complex built 5000 years ago, in the late archaic era, by the oldest civilization in America. Located in the Supe Valley, 180 km north of Lima and 20 km from the ocean, is a clear example of the construction-reconstruction cycles caused by seismic activity. The remains of Caral's massive public buildings reveal the different stages of reconstruction, which constituted on rebuilding over the previously damaged structures.

Having existed for over 1000 years, this civilization flourished in Peru's most seismic area, standing no less 20 strong earthquakes, according to this area's statistics of seismic recurrence. They were aware of the damage caused by recurring earthquakes, which destroyed their walls, made out of stones and mud mortars, and caused the collapse of their pyramids' platforms. Consequently, they attempted to implement seismic-resistant methods to their construction techniques. In order to build platforms at different heights, they realized that their core material should not cause any pressure on its external vertical borders or facades, built with stones joined with mud mortar.

They discovered that angular stones were more rugged, so the core material had a larger angle of repose that produced less stress on the borders and facades (more friction). Moreover, the angular stones led to a larger percentage of empty spaces, therefore creating walls with lower specific gravity and that produced even less stress. However, it was necessary to eliminate all the stress and the core had to be stable and resistant to horizontal seismic movement.

They then discovered that by "bagging" the stones with the adequate material, they could prevent the stones from pushing each other and create a layered and stable core that didn't produce any stress on the façade walls.

These bags, made with vegetable fibers from the highlands, contributed to the creation of a seismic-resistant technique that increased the buildings' strength during an important lapse, longer than their own life average, although time eventually decomposed the bags' organic material. How could this technique be maintained in a permanent way? They were precursors of the modern day gabions.

Figure12: Main Pyramid, Caral

Figure 13: Bag or Shicra with stones, Caral

Chavín de Huántar: 1000 years after Caral was abandoned, during the formative period, the Chavin culture developed. The Chavin the Huantar complex was a religious, political and cultural

center and an influential peregrination site, located 130 km northwest of Caral at a higher altitude above sea level. The complex's pyramids evidence a different seismic-resistant structure.

Using the same construction materials (earth and stones) as Caral, but working under rainy conditions for almost half of the year, they used neat horizontal stone and earth layers to stabilize their pyramids. This technique was based on an advanced knowledge on how to balance the clayey soil's components, which they used as a binder. Studies conducted by the Catholic University of Peru on samples from the mortars and core materials used in Chavin's pyramids evidence their great knowledge on how to combine clay (used as for cohesive purposes) and coarse sand (granular structure) from different soils to prevent the formation of cracks to obtain a better tensile strength. The quality of the mortars and mud cores is high. As a result the pyramids are very stable.

The containing walls, made out of stones and mud mortars, located outside the truncated pyramids, collapsed with the earthquakes. However, their nucleus evidences a better seismic behavior: the structures have remained in place, although some of their outer material has been lost.

Inside these artificial hills, new stone galleries were built and then buried as new pyramids were constructed. Galleries were left open to facilitate the transit of people and to allow for ventilation and drainage ducts to maintain a hydrological balance.

An alluvium covered the complex in 1945, saturating part of its galleries and ducts and causing the structures' collapse; ruining the site's hydrological and ecological balance. Earthquakes and humidity have caused deformations on the structures, which depend on earth as an important structural material. How can we restore Chavin de Huantar and maintain its seismic and hydrological balance in a permanent way?

Regional Development and Huari Integration: Latter cultures, such as the ones that developed in the Moche Valley (Chan-Chan, the Temple of the Moon and el Brujo) Lambayeque (in the northern coast), Lima, Nieveria and Pachacamac (in Peru's central area) and the Nazca culture (in the southern region) stabilized their massive architecture, which constituted of mostly truncated pyramids, with techniques based on different kinds of adobe masonry and clayey mortars.

The massive nature of these structures has allowed them to resist earthquakes. Their intervention and restoration have revealed new conservation issues for these earthen constructions. How can we, as Peruvians living in a highly seismic territory, preserve our magnificent earthen heritage?

In the attempt to solve the problems that led to the death of 70 000 Peruvian citizens living in earthen homes during the 1970 earthquakes, the Catholic University of Peru has been conducting for 40 years research programs on earthen constructions and has been studying earthen heritage for the past 30 years, in an attempt to answer the previous questions. The academic study and research has brought us closer to understanding which technological changes work and which don't.

As a result, modern engineering reveals that we should only use reinforced earth, as well as reinforcements that are compatible with earth. In the case of heritage reconstruction, we should only use modern techniques and materials, following criteria of minimum intervention (to maintain the heritage value of the structures) permanence (to achieve the structures' stability) and reversibility (to allow the implementation of better solutions in the future).

The archaeological and architectural past that we inherited from our ancestors, forces us to find a way to respect their heritage, following the guidelines and recommendations issued by both the eastern and western world. The following conservation principles attempt to guide our local practices and will hopefully be useful in other seismic areas. These principles are being studied in the national committee for the Peruvian earthen construction code.

Principles for the Conservation of Earthen Heritage located in Seismic Areas

The purpose of this document is to define the fundamental principles that can serve as guidelines in the protection and preservation of earthen heritage located in seismic areas, in a way that doesn't risk their cultural significance and structural integrity. The main objectives of the conservation process should be to maintain the building's existing conditions and to delay any further deterioration (Agnew, Neville, and Martha Demas, eds).

Description

Earthen Heritage refers to constructions with cultural and historical importance, in which soil acts as the main material responsible for maintaining the structures' overall stability in static conditions and throughout recurring earthquakes. In this context, it is to be understood that when we mention historic earthen structures we include (1) masonry (of chuffy brick or stone) joined with mud mortar, (2) earthen structures covered with stone and (3) earthen structures mixed with organic materials (wood, reed, vegetable fiber). Whenever earthen architectural heritage is mentioned, there is reference to any type of construction that has cultural significance or belongs to a historic site and that evidences, whether totally or partially, the aforementioned characteristics.

Introduction of the Document

Earthen heritage can be either architectural, which means that it can be actively used, or archeological. The same intervention methods do not apply for both of them, as both the interventions strategies and their purposes are different.

When working on architectural heritage, which can be used for activities or projects of public interest, it is imperative to define a strategy that preserves the building's historical value, while keeping in mind that the heritage value of a site includes its aesthetic, historical and material values, which should not be altered.

In archeological sites, the focus of the intervention should be orientated towards maintaining the site's cultural value and historical significance. An interdisciplinary conservation team, with specialized training and practical experience, should participate in this kind of intervention, in order to ensure a global appreciation the site's artistic, historical, scientific and social characteristic.

These teams can determine the best way to transmit the site's historical importance and define the delicate balance between preserving the construction's patrimonial value and presenting it to the general public. It is imperative to define the technology that will be used in the conservation strategy, as well the impact that the intervention will have on the construction. These decisions always must be based on the results of previous research programs.

The assessment of an archeological site's significance and historical influence should always precede the decision to intervene it. Also, the impact of the interventions should be considered within the framework of a global plan decided by a multidisciplinary team (consisting of historians, architects, engineers, archeologists, anthropologists, conservation experts and managers of cultural industries).

A committee of qualified and trained experts should be appointed to review all the relevant aspects of the conservation process.

A few basic definitions are presented in the following considerations:

Considerations

The following principles used in the conservation of earthen heritage should take into account:

- The importance of these constructions, as they are among the first built by men and therefore relevant to all humankind as part of the world's cultural heritage.
- The diversity of the structures that share the aforementioned characteristics;
- The diversity of the soil and stones used, as they are widely used materials due to their availability anywhere in the world.
- The structural vulnerability of constructions that have been built totally or partially with soil, especially in the cases in which the soil is responsible for the construction's global stability. These structures should receive special consideration, particularly when located in seismic areas.
- That this structural vulnerability is caused by the soil's mechanical properties, leading to the constructions' cracking, deterioration, structural degradation and sudden collapse.
- The difference between the strength of earthquakes and the weakness of earthen constructions

- The recurring nature of earthquakes, which can cause cumulative damage to the structures; leading not only to their deterioration, but also, and depending on the area's seismic activity, to their irreparable destruction.
- The alarming evidence that reveals that post-earthquake restorations that follow the recommended guidelines, declarations and ratified conservation charters, have been damaged by subsequent earthquakes. This has lead to a vicious cycle of restoration and destruction, causing the loss of the sites' heritage value. This occurs in both architectonical constructions and archeological sites.
- That the vertiginous rate at which earthen historical constructions is disappearing has been accentuated by the decline and of craftsmen working with traditional construction techniques. Although seismic activity may cause initial damage to the structures, this can be worsened by decisions made after the earthquakes have occurred. The usual discouragement after an earthquake, the ignorance off an appropriate technology and a general lack of interest in heritage preservation, can cause people to demolish entire sites that have been damaged by an earthquake.
- The variety in methods and strategies required in the preservation and conservation of historic sites, which should always follow a minimum intervention criterion and should always try to use reversible reinforcements, as well as materials that are compatible with the site's original construction methods.
- The importance of following a criterion of minimum intervention, indispensable to prevent any further damage to the structure. By reversible we understand either temporal or permanent reinforcement that can be replaced for a more suitable solution in the future, without producing significant damage to the historic site. By compatible reinforcement we understand one that, even in structures that show advanced deterioration and that are close to a point of collapse, can still help to maintain the construction's displacements under control without damaging or compromising its structural behavior.
- New technologies and statistical methods, which allow us to define the seismic geography associated to seismic activity, severity and recurrence, and to establish the areas in which these principles should be applied. Nevertheless, science still can't predict with absolute certainty the moment in which an earthquake will occur. Within the Peruvian territory, these principles apply to areas 2 and 3 (as indicated in the Seismic-resistant E-030 Regulation).
- The Principles and Conservation Charters adopted by the International Council on Monuments and Sites, ICOMOS, as well as the strategies for the conservation and preservation of earthen structures followed by ICOMOS and UNESCO. The organization strategies and concepts established by the Principles for the Conservation of Heritage Sites in China (Agnew, Neville, and Martha Demas, eds) should also be included.

Background

This document includes relevant background information as well as documents adopted by ICOMOS and ratified by both western and eastern countries, such as Canada and China:

- "Archeological sites must be maintained and measures necessary for the permanent conservation and protection of architectural features and objects must be taken. Furthermore, every means must be taken to facilitate the understanding of the monument and to reveal it without ever distorting its meaning". (Venice Charter 1964).
- Regarding the techniques: It is acknowledged that "where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been should by scientific data and proved by experience" (Venice Charter 1964). While these principles were originally intended for the preservation of architectural heritage, they were then extended to archeological sites with architectural value (Lausanne Charter 1990). The vicious cycle of damage-restoration-damage that has been occurring for centuries and that has been clearly documented

throughout the last century, constitutes a starting point from which to redefine the technologies used in the preservation of heritage in seismic areas.

- Regarding the techniques and materials: “Traditional techniques and materials are preferred for the conservation of significant fabric. In some circumstances modern techniques and materials that offer substantial conservation benefits may be appropriate. The use of modern materials and techniques must be supported by firm scientific evidence of by a body of experience” (Burra Charter 1979). Forty years of experimental studies regarding seismic-resistant earthen structures, conducted within the age of global developments in seismic engineering, recommend the use of reinforcements compatible with earthen structures.
- The weakness and vulnerability of certain construction materials makes it imperative to resort to various conservation agreements, such as the one concerning “structures wholly or partially in timber, due to material decay and degradation in varying environmental and climatic conditions (fire, fungal and insect attacks, humidity fluctuations)” (Mexico Charter 1999). Climatic change and earthquakes can act as similar or even worse threats to earthen structures in seismic areas.
- The Conservation Charters written by Eastern countries and the principles defined in the West (Agnew, Neville, and Martha Demas, eds) haven’t yet acknowledged the world’s geographical division between seismic and non-seismic areas. Some principles regarding architectural heritage advise on the importance of undertaking urgent safeguard measures to avoid the imminent collapse of the structures after an earthquake (Zimbabwe Charter 2003). However, it is imperative to act before the next earthquake occurs, following a preventive strategy rather than acting in emergency conditions right after an earthquake occurs or when then damage is already irreparable.
- The interest and understanding of architectural heritage can lead to a better understanding between different cultures. International cooperation is essential for the protection of heritage and every area of society should promote the implementation and execution of conservation programs (New Delhi Charter 1956).
- The seismic threat to architectural heritage should be controlled by technologically efficient reinforcements, so that it doesn’t limit the conservation efforts nor lead to the site’s eventual re-burial.
- The protection of archeological heritage, which is a fragile and non-renewable cultural resource, “must be based upon effective collaboration between professionals from many disciplines. It also requires the coo-operation of government authorities, academic researchers, private or public enterprise and the general public. The universal declarations should be supplemented at regional and national levels by further principles and guidelines” that address the specific problems of each region” (Lausanne Charter 1990), in the same way these principles address the specific needs of seismic areas. These reinstatements respond to experimental research and to educational purposes, as well as interpretative, of the bygone world.
- “The protection of archeological heritage cannot be based upon the application of archaeological techniques alone. It requires a wider basis of professional and scientific knowledge and skills. Some elements of the archaeological heritage are components of architectural structures and in such cases must be protected in accordance with the criteria for the protection of such structures, as laid down in the 1966 Venice Charter on the Conservation and Restoration of Monuments and Sites” (Lausanne Charter 1990).
- “In archaeological sites, specific problems may be posed because structures have to be stabilized during excavation, when knowledge is not yet complete. The structural responses to a rediscovered building may be completely different from those of an exposed building. Urgent site-structural solutions, required to stabilize the structure as it’s being excavated, should not compromise the building’s concept, form or use” (Zimbabwe Charter 2003).

After these considerations and background information, this paper proposes the implementation of the following guidelines:

Identification of the Site's Values, Inspection, Data Collection, Documentation and Security Measures

When dealing with archaeological or architectural earthen heritage, where the main elements are massive soil structures or walls, these are the first four tasks that should be carried out and documented in a methodic manner:

- Research and evaluate the site's historical value.
- Define the building's geometry, structure and state of conservation.
- Learn about materials, models and methods of analysis.
- Evaluate all the activities operating daily on the site, as well as those that might occur during an earthquake, to estimate the maximum stress that the structural elements of the site will endure.

A multidisciplinary team will perform these tasks, following qualitative and quantitative research methods. The first must be based primarily on historical and archaeological research, which includes previous repairs and conservation works, enlargements and any other alterations. This will require the observation of any structural damage as well as material degradation.

The latter will be based on tests conducted both in laboratories and in situ, in the probabilistic analysis of seismic activity, in the structure's behavior, in the constant monitoring of the used data and in the analysis of the structure's response under different stresses (Zimbabwe Charter 2003). Any relevant previous studies regarding the site's seismic risk and the subsoil's dynamic behavior should also be included.

All tasks should be carefully documented in accordance with Article 16 of the Venice Charter and ICOMOS' Principles for the Recording of Monuments (archaeological and architectural), Groups of Buildings and Sites. All the relevant information, which might include records of structural or decorative characteristics and materials, information regarding the techniques used or the traditional ways of doing and any other relevant historical information, should be compiled, cataloged, safely stored and made accessible when appropriate.

Evaluation of the Site's Current State

A thorough and accurate diagnosis of the structures' condition and degradation level and of the causes of their deterioration will be conducted using all the abovementioned information and guidelines. This diagnosis should rely on documented evidence, in situ inspection, on a careful analysis of the obtained information and, if necessary, not just in the assessment of the constructions' physical conditions, but on the results obtained from non-destructive tests. This will not, however, prevent any necessary minor interventions or emergency measures.

Planning of the Project's Intervention

The background information and guidelines have helped to define a set of concepts that should be taken into account for each particular case. The planning of the project's intervention constitutes only the culminating stage for the multidisciplinary team. This planning will take into account not only the stages of implementation and execution, but also aspects of the site's management and organization. A conservation master plan should be then established and periodically reviewed to correct and improve it in accordance to any new knowledge obtained during the intervention. "A typical master plan includes strategies for the following four components: conservation measures, appropriate use, exhibition and interpretation and management" (Agnew, Neville, and Martha Demas, eds).

Once the information is compiled and evaluated, and the diagnosis is made, conservation measures can be proposed. They used describe and include reference to any structural details, connections, relevant precautions and the materials used in the construction.

The documentation should also explain the specific reasons that led to the selection of the materials and methods used in conservation works. There should be reports, descriptive notes, technical specifications, sketches and execution plans from all of the different specialties involved

in he project: history, archaeology, architecture, conservation and restoration of heritage, engineering, seismic risk assessment, dynamic expansion (seismic) of the subsoil as well as other that were considered appropriate for the project.

If the structural risk associated with seismic activity is high, following criteria based on stability or performance might be considered, aiming to control the cracking of the building's structural elements and its excessive displacement, which might lead to irreparable damage. This involves the use of compatible reinforcements of minimum impact and reversibility. Special attention should be given to ensure that the compatible reinforcements fulfill their role without damaging the original materials and structure at all stages of their seismic dynamic behavior.

"A practical plan for the conservation of a site –both during and after excavation- should be submitted for all sites programmed for excavation. Excavation and conservation plans should be submitted together" (Agnew, Neville, and Martha Demas, eds).

Excavation works can then begin following the master plan. During the intervention, new issues will continuously arise and will have to be resolved, regarding concerns related to purpose of the excavations, the use and sustainable management of the site and its consolidation in order to be presented to the general public and relevant circuits.

The presentation to the public is part of an educational process and must therefore contribute to the sharing of scientific knowledge. Consequently, any information about the site should be submitted to frequent and periodic revisions by the multidisciplinary team. Moreover, the team should be in charge of designing the strategy for the site's presentation.

The answers to these questions relate to the justification of the degree of intervention in the conservation efforts, the seismic stability of the ruins and the personal safety of the site's visitors or users. These issues might lead to alternative decisions, such as defining the excavation limits, choosing to re-bury the site, or lead to the new solutions based on the use of efficient, friendly and non-obtrusive reinforcements. The site's management will then be in charge of the continuous execution of the conservation plan.

A criterion of minimum intervention on archaeological sites should always be followed, leaving an open window into the future, so that these issues can be resolved in a more efficient way by new technologies and future knowledge

Surveillance, Monitoring And Maintenance

It is extremely important to maintain a coherent strategy based on continuing surveillance and routine maintenance, as recommended by the conservation charters for the conservation of earthen historic structures and of structures dependent on soil for structural stability. "Regular maintenance is the most basic and important means of conservation", and should always be implemented to repair any minor damage before it worsens (Agnew, Neville, and Martha Demas, eds).

Conservation Interventions

The prevention of seismic disasters should evaluate any possible threat to the visitors and to the site. Visits should only be permitted on sites with reasonable security against earthquakes. Any activities that risk the visitors or the site should be avoided (Agnew, Neville, and Martha Demas, eds).

Conservation interventions are technical activities that attempt to solve the damage and deterioration caused to a site or structure, while attempting to maintain its historical authenticity and integrity. Any intervention should be based and justified by relevant studies and evaluations, assessing not only the construction's resistance to weather conditions and natural decay, but also to earthquakes. Problems should be solved according to each case individual conditions and needs, respecting the aesthetic, historical, scientific (physical, material, technological, stability) and social values of the structure or historic site. All interventions should, when possible, aim to:

- Maintain the use of traditional materials and techniques,
- Follow a criterion of minimum intervention,
- Be as technically reversible as possible,

- Allow its conservation, which may subsequently be required,
- Facilitate future access to the information incorporated into the structure.

The choice between using "traditional" or "innovative" techniques must be evaluated in each particular case, always giving preference to the least obtrusive ones and to those that are compatible with the values of cultural heritage. Moreover, they should always meet requirements of seismic-security and perdurability standards.

The minimum intervention in the fabric of historical earthen structures constitutes an ideal. However, in some cases, following a minimal intervention criterion, aimed at ensuring the preservation and conservation of structures damaged by earthquakes, could mean the dismantling, either total or partial, and subsequent reassembly of the structure. This will ensure its adequate preservation and will allow for any other posterior reinforcements.

Whenever possible, the anastylosis methods in which where the joining material is made with a solution of soil mortars or liquid mud grout (sifted soil) should be considered. These should always try to use construction's original materials. The use of industrial chemicals or binders should be avoided in the injections, especially if there is no real evidence of their durability or if there is reason to suspect that their behavior over time might result in new discontinuities in the structure, in its eventual dismemberment or any other subsequent damage.

Whenever interventions are performed, earthen heritage should be considered as a whole and every one of its parts should be given the same importance and receive equal attention. When possible, the conservation methods should maintain the use of the previously used materials. This preservation criterion should be extended to finishing details, such as ornaments, friezes, plaster, paint, etc. If it is imperative to renew or replace the finishing, methods that blend with the structure should be used, as long as the result is still distinguishable from the original materials, techniques and textures.

Categories of Conservation Interventions

"Conservation interventions are technical measures for the treatment of damage and deterioration to a site and its setting. Treatment includes the following four categories: regular maintenance, physical protection and strengthening, minor restoration and major restoration. Every intervention should have clear objectives and use tried and proved methods and materials" (Agnew, Neville, and Martha Demas, eds).

Maintenance is a preventive measure taken to reduce any cumulative damage caused to a structure by natural causes and human actions.

Physical protection and strengthening measures are intended to prevent or reduce damage to a site or building. These measures themselves must not damage the original fabric and must as far as possible retain the original character of the setting. New protective structures should be simple, practical and unobtrusive as possible.

Minor restoration comprises a general set of intervention measures which may be undertaken provided the original structure is not disturbed new components are not added, and the existing condition is basically unaltered. This type of intervention most frequently involves rectifying components that are deformed, displaced, or collapsed; repairing a small number of damaged elements; and removing later additions that are without significance. Detailed records should be kept of elements that were removed or added.

Major restoration is an intervention involving the most impact to the original fabric. It includes returning a structure to a stable condition through the use of essential reinforcing elements and repair or replacement of damaged or missing components. The decision to restore through complete disassembly of the structure should be taken with caution. All problems revealed in the course of disassembly should be rectified so that the structure should need no further treatment for a considerable time. Restoration should, as far as possible, preserve the vestiges and traces of periods judged to have significance. Both the design and materials for replacement elements should be consistent with the evidence provided by existing fabric. Only those contents or components liable

to damage during the restoration work should be dismantled and removed, after restoration is completed, they must be returned in their historic condition. Relocation, when approved, also belongs in this category of intervention.

Reconstruction in situ is an exceptional measure undertaken only in special circumstances. When approval has been given to undertake reconstruction in situ, priority should be given to conserving the remaining ruins without damaging them in the process. Reconstruction must be based on direct evidence. Conjectural reconstruction is not permitted (Agnew, Neville, and Martha Demas, eds).

Repair, Substitution, Reintegration and Reinforcement

When working in the restoration of historic buildings, it is possible to use the structural materials of the original materials to replace the old and deteriorated ones and to use permanent and reversible structural reinforcements. This should only be done when the site's existing conditions requires it to ensure the visitors safety and the site's stability during earthquakes. However, this type of intervention should always respect the construction's historic and aesthetic values.

Reinforcements should be compatible with soil used as a construction material and with the original technologies used in site. As abovementioned, compatible reinforcements should keep the building's displacement levels under control, so that its repair is possible and its global stability guaranteed without causing damage to the original materials.

To replace part of a structural element that is indispensable in maintaining the global stability of the construction or its neighboring elements, traditional methods and materials should be used whenever possible. Moreover, this type of intervention should eventually be complemented with other reinforcements, to properly secure the new and old parts together.

It should always be possible to tell the new elements in the construction from the old ones, although the differences shouldn't be too noticeable. It is not recommended to copy the natural decay or deformation of the elements that have been replaced, or to level off the height or the alignments of the existing walls. This should only be done when indispensable for technical reasons. The structure's authenticity should never be altered for the sake of cosmetic reasons or to complete non-structural details.

Contemporary Materials and Construction Techniques

Contemporary materials such as compatible structural reinforcements and modern application techniques must be selected and used with extreme caution, and only in cases where their durability and structural behavior have been successfully tested over a long period of time or proven by rational methods.

Chemical products should be avoided when using contemporary materials. They should only be used if their long-term advantage has been proven and as long as they do not involve any risk to people or to the environment.

Formation

It is extremely important to promote a new appreciation of the value and cultural importance of earthen heritage located in seismic areas. This can only be achieved through educational programs, which constitute an essential prerequisite to develop conservation policies that are lasting and sustainable.

Training programs concerning the protection, preservation and conservation of historic earthen structures should be created and implemented in areas where earthquakes are a recurring natural phenomena. The programs should be based on a strategic plan and provide the strategic skills required for the effective restoration of earthen structures, as they have weak mechanical characteristics and will demand work under extreme conditions of structural behavior.

It is imperative to develop programs on a local, regional, national and international scale. They should be orientated to all professionals dedicated to the conservation of heritage, especially to archaeologists, architectures, engineers, conservation experts, craftsmen and site managers.

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