Conservation of Earthen Architectural Heritage in Seismic Areas

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HUARAZ EARTHQUAKE
1970
Due to the availability of these natural materials, monumental architecture built using earth and stones joined with mud is the world’s oldest and most common type of construction.

Huaaca de la Luna and Chan Chan, Trujillo

VULNERABILITY FACTORS

1. Earth makes up for an extremely weak and brittle construction material. It represents a unique case in the field of architectural heritage conservation.
2. There is a tragic correlation between the location of earthen architecture and the world’s seismic areas (De Sensi 2003). 

3. The International Conservation Charters approved by ICOMOS do not provide any specific technical guidelines regarding the conservation of architectural heritage built using earth as a construction material in seismic areas nor do they alert about the risk of their disappearance.

CARAL
Stone and mud mortar masonry
Seismic forces are too strong and earth is an extremely weak construction material.

Adobe Masonry
Huaca de la Luna
Trujillo, Perú

Stone Masonry joined with mud mortar
Chavín de Huántar 1500 years after CARAL

Advanced Design
Vulnerability
The strength of these structures depend on the material used: earth, which is the weakest construction material.
Vulnerability of mud mortar masonry

Organized earth and stones infill

Chavín de Huántar Retaining wall

Seismic Damage and Collapse

- Seismic damage is accumulative
- Recurrent earthquakes will damage earth constructions that have been restored following a traditional intervention criterion. It is therefore imperative to end the damage cycle.

The International Conservation Charters should expand to include modern and innovative solutions. They should contemplate the use of modern restoration techniques and the rational use of reinforcement methods that follow a criterion of reversibility and minimum impact.
The original Inca construction was built using stones around the XIII century and was subsequently destroyed by earthquake activity. It was rebuilt over the remains of the original structure using earth, which was the local construction material, in the XIV century. Julio C. Tello rebuilt the temple between 1941 and 1945.

Only some ruins remain.
Reconstruction by Julio C. Tello between 1941 and 1945 using traditional materials and techniques.

Damage, traditional reconstruction and seismic damage once again. Could this be a vicious damage cycle?

After 500 years, up until 1940


The accumulative damage caused by earthquakes affects first the restored parts of the buildings, which are usually weaker.
The damage caused to the structure is too serious to attempt to reconstruct it using the original materials and technology.


The 2003 earthquake re-destroyed everything that had been restored during the previous century.
Reconstruction and re-destruction. Damage Cycle?

Traditional intervention without reinforcement

International Conservation Charters approved by ICOMOS

Venice Charter 1964-1965: “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 shown by scientific data and proved by experience.”
“... No action should be undertaken without having ascertained the achievable benefit and harm to the architectural heritage, except in cases where urgent safeguard measures are necessary to avoid the imminent collapse of the structures (e.g. after seismic damages)”. 

Structural Criteria of Vulnerable Patrimonial Intervention Research

In the last 40 years it was development some research on the two structural criterion:

Strength-based Design Criterion
Performance-based Design Criterion.
Strength-based Design Criterion: Crack repair on historic earthen walls in seismic areas

Ongoing research conducted by the Catholic University of Peru, from 2005 up to date, with the support of the Getty Conservation Institute. The cracks on the adobe walls were repaired with the injection of clayey soils with high water contents and sifted with fine screens. Tests have shown that it is possible to restore the masonry strength by 100%.

Friendly solutions: Restored area of Acllawasi, Pachacamac.

Restoring before reconstructing.
Injection Methods for Cracks Repair

Mateo Salado, Ychsma/Inca Culture XII-XIII
Pedro Espinosa, Archeologist – Mirna Soto, Conservator – Julio Vargas N., Structural Advisor
National Institute of Culture

Antes  Después
Beginning of the Intervention: One of the Truncated Pyramid Structure

Crack repair and wall intervention
Structural performance-based design criteria.

**Reinforcement use.**

35 years of earthen construction studies conducted by the Catholic University of Peru evidence the importance of incorporating reinforcements as a safe solution in modern design methods.

The reinforcement should have strong tensile resistance and should also be compatible with the earth walls, in order to prevent the structures’ irreparable displacement caused by seismic activity.

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**Reinforcement use**

Reinforced walls can still retain their strength after the initial cracking.

Reinforced earth is currently available, as well as earthquake resistant construction methods.
International Outlook

The Getty Seismic Adobe Project (GSAP) studied the behavior of earthen architectural heritage in California for 6 years.

The international conservation community objects to the use of irreversible reinforcement methods, which can affect the value of architectural heritage. This situation calls for a restricted and rationalized use of reversible and permanent reinforcements.

GSAP Reinforcement Solutions

“Las Flores Adobe Seismic Retrofit”

Jake Barrow, Doug Porter, Steve Farneth, Leroy Tolles

Upper steel cable
Reversible Solution
Incompatible and irreversible solutions (Chile)

Recoleta Dominica Cloister

Steel frames inlaid within the walls

National Center for Conservation and Restoration (CNCR)

Tarapaca Cathedral

- The reinforced concrete beam that was supposed to offer support to the Cathedral destroyed its main adobe wall during the 2005 Iquique earthquake
Aggressive and irreversible solution
Second reconstruction of the southwestern wall’s tower. Bam Citadel.
“Tecnica de Recuperación y Refuerzo Estructural” Valter Santoro, Italia

Building’s conditions after the 2003 earthquake
Destruction of the tower’s inside

Cross section with the reinforcements
View of the scaffolding used for perforations and for the reinforcement placement.

Drilling equipment
Video endoscopy conducted during the placement of the glass fiber rods.

Detail view of the external anchorage.
Final state, rendered anchorage

It is imperative to establish “Conservation Principles for Earthen Structures or masonry built with mud mortars”

Earthen constructions are an exception because of their vulnerability

THANK YOU