DAMAGE ASSESSMENT OF HISTORIC EARTHEN SITES AFTER THE 2007 EARTHQUAKE IN PERU

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Abstract:
The Pisco earthquake of August 15, 2007 resulted in 519 deaths and 1366 injured, with a total of 650,000 people affected and 80,000 dwellings damaged. Preliminary reports indicated that significant earthen sites were damaged. A few months after the earthquake a rapid assessment to better understand the failure of the affected sites was performed by a multidisciplinary team convened by the Getty Conservation Institute (GCI) in response to a request from the Instituto Nacional de Cultura del Perú (INC).

Post-earthquake assessments offer an opportunity to understand why buildings fail and provide information that can serve as the basis for the improvement of seismic performance. Lessons learned from earthquakes and other natural disasters are used to advance construction techniques. More recently, such lessons have fostered the development of the engineering and historic preservation disciplines, as well as the testing and review of current building codes and disaster management policies.

The main objective of the GCI rapid assessment was to evaluate the damaged sites while recording pre-existing conditions (abandonment, deterioration or structural interventions) that might have affected their seismic performance. This paper presents the highlights of that evaluation and its implications for the future design and retrofit of earthen buildings.

1. BACKGROUND

The existence of earthen architecture in Peru goes back to the *formativo temprano* or initial period (1800/1500–900 BC). It has been a construction technique used all over the country for over more than 4,000 years and has proven to be a sustainable resource for the evolution of Peruvian culture. In response to their understanding about the effects of seismic activity on earthen structures, early Peruvian cultures wisely choose to build their sites over rocky soils and developed reinforced construction techniques to dissipate the energy generated by seismic events (Williams, 1980, p. 467 and García Bryce, 1980, p. 382).

The Pisco earthquake tragic human losses resulted from the collapse of buildings in the states of Ica, Lima, Huancavelica, Ayacucho and Junín among others (Johansson *et al*., 2007, p. 1). The damages have been described by several national and international organizations that traveled to the affected region immediately after the earthquake. From October 28 to November 2, 2007 the GCI in collaboration with other Peruvian institutions lead a multidisciplinary team[i] of national and international earthquake engineers, preservation architects and conservators, visiting a total of 14 buildings (Figure 1). The faculty members of the School of Architecture at the Universidad Peruana de Ciencias Aplicadas (UPC) pre-selected the sites according to various criteria[ii]. The survey was limited to a one week timeframe, and therefore does not claim to be fully comprehensive, but rather provides a snapshot of the issues found at typical heritage sites as representative of the earthquake's impact.

2. THE PISCO EARTHQUAKE

On August 15, 2007 at 18h 40min 59sec (local time) a M_W 7.9-8.0 magnitude[iii] *inter*plate earthquake occurred off the coast of central Peru. It had a maximum local Modified Mercalli Intensity (MMI) of VII-VIII (Instituto Geográfico del Perú – IGP) and its epicenter was located at 13.35S and 79.51W at a depth of 39 km (USGS). The earthquake was generated in the boundary between the Nazca and the South American plates, in which the Nazca plate slid underneath the American one (Alarcón, 2007, p. 1). A total of 18 accelerometer stations recorded the time histories of Pisco earthquake indicating a total duration of approximately 300 seconds[iv]. The principal explanations for the duration and distribution of these ground motions are the rupture model having two zones of large displacements which generated the two packs of motions (Tavera *et al*., 2009, p. 83).

There have been numerous studies carried out by several national and international institutions to define the geology of the affected area (Lermo, 2008, p.233-268 and CISMID *et al*., 2008, p. 88-91). According to those, most of the visited sites were located over alluvial deposits from the Quaternary era, not suitable for constructions unless with reinforced, strong and expensive foundations; and where geotechnical effects such as liquefaction and landslides could have occurred. These types of soils amplified the energy frequency or the ground motion acceleration generated by the earthquake producing even more damage to the sites.

3. EARTHEN ARCHITECTURE IN PERU

There has been extensive research and publications on the history of Peruvian culture by well-respected historians but here are few publications that specifically address the history of Peruvian construction and architecture (Williams, 1980, p. 371-371).

One of the best compilations of the history of ancient Peruvian architecture and urban planning was written by Carlos Williams (Williams, 1980, p. 367-585). Williams describes the evolution of earthen pyramid constructions, known by their ability to withstand seismic events, between 2,000 BC and 500 AD in central Peru. Their materials (adobe for the exterior, earth and stone for the interiors, and heavier rocky materials at the bottom of the structures) dissipated the energy generated by the earthquake (Williams, 1980, p. 403-433). Remarkable examples of these sites are the Huacas del Sol y de la Luna*,* built during the Moche period (100 AD to 800 AD) outside of the city of Trujillo. The Mochican earthen construction was not limited to ceremonial buildings, but applied to residential housing, where the use of stone foundations in combination with adobe and *quincha* walls and flexible roofing systems was common practice[v]. The Wari culture (500 AD to 900 AD) use seismic resistant wooden elements to tie the walls at building corners, seen for the first time at the Wiracochapampa site in Huamachuco (Williams, 1980, p. 513). The knowledge acquired by the Waris and the Mochicas, was picked up by the Chimus. Their vast adobe city of Chan Chan, composed of nine walled citadels, was built by around 850 AD, 5 km north of the city of Trujillo. The pyramidal shape of the city walls allowed the adobe walls to withstand earthquakes, letting them rock but remain stable as a result of their own weight.

Probably the earliest publications mentioning adobe and *quincha* as construction materials during the Spanish viceroyalty comes from Padre Bernabé Cobo (1629) and Juan and Ulloa (1748) respectively. *Quincha* is a traditional construction system consisted on split cane reeds between elements of a wooden panel that creates an earthquake-resistant framework that is covered in mud plaster historically used in all Spanish and Portuguese colonies throughout Latin American[vi]. Ferruccio Marussi is probably the architect who studies the most about *quincha* and its use for the construction of domes, pillars, lanterns and vaults during the Spanish viceroyalty (Marussi, 1986, p. 59-66 and 1990, p. 147-146).

Juan Bromley and José Barbagelata discuss the impact of earthquakes describing the damage to the vaults of the Cathedral of Lima after the October 19, 1609 earthquake (Bromley and Babagelata, 1945, p. 129). The *Libros de Cabildos*[vii]*,* explains that after the 1609 earthquake, authorities decided to rebuild the cathedral reducing the height of the walls supporting the stone vaults. This is probably the first unofficial recommendation for seismic stabilization in Peru during the viceroyalty.

Emilio Harth-Terré (1962, and 1975) describes on detail the training of *maestros and aprendices* responsible for the inventive use of local materials for the construction of buildings in main cities around the Spanish colonies. It seems that the seismic performance of the *quincha* panels encourage these *maestros* to use them for the construction of second stories and complex roofing systems. Fray Diego Matamoros was the first *maestro* who decided to use wood, cane and lime for the construction of the Santo Domingo *quincha* dome in 1666. José García Bryce (1980, p. 11-166) mentions the construction of the San Francisco *quincha* dome between 1657 and 1674 under the supervision of the *maestros* Vasconcellos and Escobar, probably following the Matamoros experience (Garcia Bryce, 1980, p. 64). Later, the 1702 *Ordenanza del Cabildo* commanded the use *quincha* for ceiling construction, including comes and vaults (Harth-Terré, 1975, p. 45). However, it is not until the earthquake of October 28, 1746 that the Ayuntamiento of Lima decided to regulate construction techniques. Viceroy Don José A. Manso de Velasco—known as *Conde de Superunda*—asked the mathematician Don Luis Gaudin to study the buildings damaged by the earthquake and develop technical recommendations to improve their seismic performance (Bromley and Babagelata, 1945, p. 71). Gaudin presented his report to the *cabildo* advocating: i) the use of mud, cane and adobe as construction materials; ii) the use of *quincha* for wall partitions, iii) an increase in width of adobe masonry walls, iv) the addition of buttresses to lateral adobe church walls, v) the lowering of the height of church towers, vi) the limitation of construction of bow windows and vii) assuring adequate plazas to serve as refuge in case of disasters, among other recommendations (Walker, 2008, p. 91).

Two important milestones in Peruvian construction history occurred at the beginning of the Peruvian Republican period. First is the introduction of cement to Peru in the 1860's (Bromley and Babagelata, 1945, p. 94)[viii]. Second is the creation of the Escuela Especial de Ingenieros de Construciones Civiles y Minas in 1876 with a section in Architecture that later became a separate school based on a teaching plan proposed by Santiago Basurco. It is Basurco, whom as a state engineer of the second term of President Nicolás de Piérola (1895–1899), suggested the proscription of adobe for construction. Later, during the first term of President Augusto B. Leguía (1908–1912) and after the M_W 8.2 1908 earthquake, the state banned the use of adobe and *quincha* for the construction of urban housing (Garcia Bryce, 1980, p. 125).

There were four major earthquakes between the 1940 and 1980 that reinforced government's regulations for materials and techniques: The M_W 8.2 May 24, 1940; the M_W 8.1 October 16, 1966; the M_W 7. May 31, 1970; and the M_W 8.1 October 3, 1974 (USGS, 2007). It is most likely that after the 1970 earthquake the seismic engineering community developed a seismic building code which banned earthen construction. In 1976, the Peruvian government created the Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO) in charge of training construction workers around the country, but training in adobe or *quincha* construction was part of the curricula.

Most likely also around the same time, a group of structural engineers decided to further investigate reinforcement techniques to improve traditional earthen construction systems rather than abolish them. Academic efforts lead by Peruvian universities[ix] resulted in the creation the Instituto Nacional de Investigación y Normalización de la Vivienda (ININVI) in 1981. In 1985, ININVI designed the *Norma Técnica de Edificación NTE E. 80 Adobe* (*Technical Standard 80 for Construction in Adobe*) nowadays included in *the National Building Code*. Today, the renovated SENCICO has assumed the core objectives of former ININVI[x] and is currently reviewing the second edition of the *NTE E. 80 Adobe* which intends to include norms for *tapial* and *quincha*, and guidelines for the retrofitting of existing and historic earthen buildings.

4. EARTHEN ARCHITECTURAL HERITAGE IN THE AFFECTED AREA

This section of the paper presents information to characterize the structural damage observed at the visited sites (listed in Figure 1) during the assessment performed by the GCI team.

Figure 1: Location of visited sites in relation to the Pisco earthquake epicenter
From left to right: 1. Church of Chilca, 2&3. Hacienda Arona y Montalván, 4. Church of Coayllo, 6. Church of El Carmen, 6. Tambo Colorado Archaeological site, 7. Hacienda San José, 8. Cathedral of Pisco, 9. Church of Huaytará, 10. Church of San José, 11.Church of San Javier, 12. Cahuachi Archaeological site. (Credits: The J. Paul Getty Trust, 2007)

4.1 Damage assessment typologies

Adobe typically used to build thick and massive walls is a low-strength building material best to resist compression but weak to stand tensile forces. The stresses absorbed by an adobe wall during an earthquake normally exceed the wall's tensile strength developing cracks and isolated blocks that pound against each other until the structure suddenly collapses. *Quincha* on the other hand is a relatively high-strength building construction technique with flexible membranes. The wooden frame and the cane structure can absorb tensile stress. Collapse normally occurs when the decayed and disconnected wood and the cane elements are unable to function structurally.

Tolles *et al*. (1996, p. 17) stated, the extent of earthquake damage to an adobe structure –and *quincha* in the Peruvian case—"is a function of (a) the severity of the ground motion, (b) the geometry of the structure, i.e., the configuration of the adobe walls, roof, floors, openings, and foundation systems, (c) the existence and effectiveness of seismic retrofit measures, and (d) the condition of the building at the time of the earthquake."

The severity of the ground motion is impossible to control or prevent and is conditional to the type of soil on which the structure is built. Soft soils —as the ones where visited sites are located—amplify the ground motion acceleration generated by the earthquake inducing more damage to the sites. The geometry of a building influences its ability to withstanding seismic events. Tolles *et al.* (1996) as part of the Getty Seismic Adobe Project (GSAP) provides excellent descriptions —similar to the ones observed during the 2007 Pisco survey—on how thicker, thinner, constrained or not-constrained adobe walls perform during a seismic event. Complementary to the GSAP project, the Pisco survey focused on damage failures of *quincha* walls, vaults and domes and the impact of the building structural conditions on their seismic performance.

4.1.1 Quincha deterioration mechanism

Most of the visited sites damaged by the earthquake were constructed with domes, vaults and walls made of *quincha.* Regular maintenance of these structures was expected during the Peruvian ancient and colonial times, including the occasional replacement of the wooden structural elements, cane reed and leather straps. With time and lack of maintenance, wooden elements were damaged by the presence of termites and the connections started to fail. The leather straps became brittle and the reed cane detached from the structure losing its flexibility and tensile strength. The state of deterioration of this construction system influenced the way buildings performed during the Pisco earthquake (Figure 2).

Figure 2: State of deterioration of Quincha panel at the Cathedral of Ica
(Credits: INC Lima, 2007)

4.1.2 Dome / Vault failure

4.1.2.1 Shifts or total collapse of domes of Church towers

At the Churches of Chilca, El Carmen, and Huaytara as well as the chapel of Hacienda San José, the difference between the flexible *quincha* pillars and the stiffed adobe tower during pounding precipitated the upper dome failure, shifting first, and collapsing later. Severe termite damage was observed under detached plaster in all the wooden elements and cane reed of the *quincha* pillars, vaults and domes..

4.1.2.2 Partial or total vault collapse

As mentioned before, wooden structural elements and the cane mesh of the *quincha* were heavily damaged by termites. In the case of the vaults, the damage was observed at the wooden arches and at their connections to the top of the adobe walls, pilasters and front facades. Another pre-earthquake condition contributing to collapse is the presence of a heavy layer of dirt or cement mortar over the vault, probably due to lack of or inappropriate maintenance respectively. At the moment of the earthquake, the vault tried to restrain the rocking of the walls, adding stress to the deteriorated trusses and their connections until failure (Figure 3).

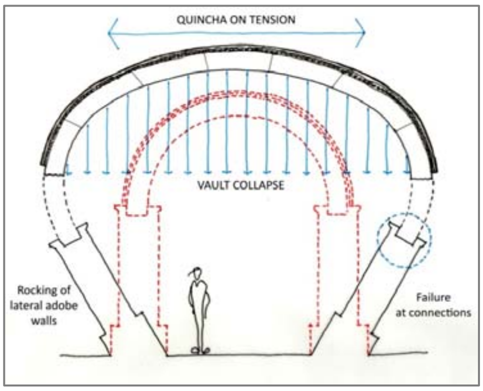

Figure 3: Failure scheme mode of quincha vault. (Drawing, C. Cancino, 2007)

At the churches of Coayllo, Guadalupe and Humay, the presence of reinforced concrete arches at the end of the vaults stiffened the structure at both ends which in conjunction with the deteriorated arches induced the *quincha* vault to fail. At the Cathedral of Ica, the architectural configurations of the building as well as its maintenance helped to partially withstand the earthquake. The better seismic performance of preserved arches, the presence of the lunettes and side chapels between them prevented the total collapse of the vault (Figure 4).

Figure 4: Cathedral of Ica after the Pisco earthquake where arches and lunettes stopped total collapse of quincha vault. (Credits: J. Paul Getty Trust, 2007)

4.1.2.3 Out of plane collapse

When entire vaults or domes collapsed, it was clear that walls (front facades or lateral walls) rocked until connections failed resulting in partial or total vault collapse. In the case of the Church of Guadalupe the concrete tower pounded the earthen façade until collapse of its upper section inducing partial collapse of the vault (Figure 5).

Figure 5: Church of Guadalupe after the Pisco earthquake where out of plane of collapse of front facade induced partial collapse of the quincha vault.
(Credits: J. Paul Getty Trust, 2007)

In the case of the Church of Coayllo, partial out of plane collapse of later walls contributed to the total collapse of the vault triggered by its deteriorated arches. A much more obvious example of this type of failure however, was observed at the stand alone walls at the Church of Chilca and the main house and worker residences of the San José and Arona y Montalván estate respectively where walls sections collapsed. In both cases, the slenderness ratio of the walls didn't resist the rocking during the earthquake.

4.1.3 Damage on Columns and pillars

In the case of the Cathedral of Ica, the hollow pillars constructed with wooden frames and cane mesh plastered with mud and gypsum suffered from plaster detachment at their bases. It seems that the *quincha* pillars were able to absorb most of the energy and only plaster detachment at the bases was recorded. In the case of the Arona y Montalván main estate house, it seems that the roof of the veranda moved in two directions: Parallel and perpendicular to the building facade. A resulting gap was observed at the roof of the building between the veranda and the main house as well as a crack between the veranda and the main tower. The plaster detachment at the upper section of the columns could be the result of the rotation of the columns. The colonnade balustrade and bases prevented the whole structure to collapse.

4.1.4 Plaster detachment

Although plaster detachment is not structural damage, it is important to mention as a condition worth study and repair. Well maintain plaster layers contributes in a major way to the overall coherence of the structure. Many plaster detachments were observed on vaults, domes, walls, columns, and pillars of the visited sites. Furthermore, and most importantly, previous non-repaired plaster detachments left the wooden elements of the *quincha* roofing systems, as well as columns and pillars, exposed to the environment generating termite damage, as observed at the Churches of San José and San Javier de Ingenio in Nazca. When previous plaster detachments were repaired with non-compatible materials such as layers of cement over the *quincha* vaults or domes, heavier loads were applied to the earthen walls inducing out of plane collapse. That was probably the case at the Church of Coayllo and the Cathedral of Pisco

5. Conclusions

- Earth construction in Peru represents a great piece of its cultural and vernacular heritage and is one of the main materials for the construction of its settlements.
- Over centuries, earth has been used alone and as a part of sophisticated building systems (e.g. *quincha*), demonstrating the abilities of Peruvians to develop appropriate solutions to seismic activity.
- Modernization" at the end of the XIX century introduced new industrialized building technologies to the main cities, leaving earth as the predominant construction material in rural areas. Local knowledge on maintenance declined over time leaving earthen buildings prone to decay and susceptible to earthquakes.
- Concerns about the life safety and seismic performance of earthen buildings have been the impetus for banning earth as a suitable contemporary construction material. Nevertheless, earth remains the predominant building material in the existing buildings stock. Effort is needed to develop solutions to reduce the vulnerability of significant existing earthen sites.
- During the August 2007 earthquake, seismic damage was a result of the accumulative effects of seismic activity, lack of maintenance and repair.

5.1 Impact of the lack of maintenance on the structure:

The seismic behavior of the visited sites was affected by maintenance issues that significantly reduced the structural integrity of the building including:

- Loss of structural integrity and lack of connections between damaged wooden elements of *quincha* vaults, pillars and walls, which isolated parapets, partitions, and façades, affecting their stability. (Figures 6, left)
- Non-repaired structural cracking and weak mortar-block adhesion strength.
- Moisture damage to the *quincha* and adobe walls.
- Beetle damage in adobe blocks that reduced wall strength. (Figure 6, center)
- Termite damage on the wooden framework of the *quincha* walls, which contributed to partial or total collapse of entire structures. (Figures 6, right)
- Addition of different building materials and systems into the structure.

Figure 6, left: Upper dome of Hacienda San Jose Chapel where connections deteriorated inducing loss of structural integrity. (Credits: J. Paul Getty Trust, 2007)
Figure 6, center: Sample of beetle damage at the adobe walls at the worker residences of the Hacienda Arona y Montalván. (Credits: INC Lima, 2007)
Figure 6, right: Wooden trusses damaged by termites at the San Jose Church. (Credits: INC Lima, 2007)

5.2 Modes of failure:

While it is difficult to assess the structural interactions of the systems exhibited in the building assessment, a number of general observations can be made:

- The performance of load-bearing adobe walls was consistent with behavioral expectations for thick and slender adobe walls as observed in previous earthquakes and shake table testing research:
  - Massive or constrained by buttresses adobe walls generally moved and rocked independently of each other, forming (or reopening) cracks, but generally remained standing.
  - Slender adobe walls were unable to resist the rocking movement and collapsed entirely once the vertical cracks isolated them from the structural system.
- In the churches with vaulted wood and *quincha* roofs, the massive adobe walls moved independently of the vaults when connections failed, causing them to lose bearing and then collapse. When the wooden base plates were in good condition or constrained by other elements such as the lunettes, the arches stand still while vaults collapsed between them.

6. RECOMMENDATIONS

1. There are already a certain number of technical options available to build safely with earth and to retrofit historic earthen sites located in earthquake zones based on scientific research that is worth disseminating.
2. There is potential to develop less invasive alternative retrofitting techniques by adapting traditional methods and materials. Scientific data needs to be acquired to apply engineering concepts and values to traditional retrofitting systems.
3. In Peru, there are important institutions, organizations and a community of experts with a comprehensive understanding of the problem who exhibit a strong will to support and initiate research, implementation and dissemination of enhanced retrofit methods and conservation methodologies for site maintenance.
4. There is a strong need to develop guidelines for seismic retrofitting using local materials and low-tech solutions for its implementation. A program of intervention for minimal strengthening methods, easy repair techniques, and site maintenance would reduce loss of life and damage in future earthquakes.

7. BIBLIOGRAPHY:

Alarcon, John, and Emily So. *2007 August 15 Magnitude 7.9 earthquake near the central coast of central Peru.* Luxembourg: Office for Official Publications of the European Communities, 2008. www.istructe.org/eefit/files/EEFIT_Peru_Fonal_Report.pdf.

Bromley, Juan, and José Barbagelata. *Evolución Urbana de la Ciudad de Lima.* Lima: Concejo Provincial de Lima, 1945.

Centro Peruano Japonés de Investigaciones Sísmicas y Mitigación de Desastres (CISMID), Fondo del Reconstrucción del Sur (FORSUR), Universidad Nacional de Ingeniería (UNI), and World Bank. “Informe Final del Estudio de Microzonificación Sísmica y Zonificación de Peligro de Tsunami en las Ciudades de Chincha Baja y Tambo de Mora.” Lima: CISMID, 2008. http://www.cismid-uni.org/redacis/articulos.php.

Cobo, Bernabé. *Historia de la fundación de Lima.* Lima: Imprenta Libera, 1629.

García Bryce, J. *La Arquitectura en el Virreinato y la República*. Historia del Perú, Procesos e instituciones, 9. Lima: Editorial Juan Mejía Baca, 1980.

Harth-Terré, E. *Perú, Monumentos Históricos y Arqueológicos.* México: Instituto Panamericano de Geografía e Historia, 1975.

Harth-Terré, E., and A. Márquez Abanto. "Historia de la Casa Urbana Virreinal en Lima*." Revista del Archivo Nacional del Perú* (XXVI) (Entrega 1) (1962): 1–100.

Johansson, Jörgen, Paola Mayorca, Tatiana Torres, Edwin Leon. "A Reconnaissance Report on the Pisco, Peru Earthquake of August 15, 2007." CISMID, 2007. http://www.jsce.or.jp/report/45/content.pdf.

Ji, Chen, and Yuehua Zeng. "Preliminary results of the August 15, 2007 Mw 8.0 coast of central Peru earthquake." United States Geological Survey Report, 2007. http://earthquake.usgs.gov/eqcenter/eqinthenews/2007/us2007gbcv/finite_fault.php.

Lermo, Javier, Marlene Limaymanta, Yanet Antayhua, Fernando Lázares. "El Terremoto del 15 de Agosto de 2007 (MW+7.9), Pisco, Peru. Mapas de Classificación de Terrenos con fines de diseño sísmico para las ciudades de Pisco, Ica y Lima-Callao" In *El Terremoto de Pisco (Peru) del 15 de Agosto de 2007 (7.9 M_W)*, edited by Hernando Tavera, 233–268. Lima: Instituto Geofísico del Perú, 2008. http://khatati.igp.gob.pe/Webs/cns06/libro/trabajo_17.pdf.

Marussi Castellan, F. "Bóveda a base de Quincha en las Edificaciones Monumentales del Virreinato del Perú." *Informes de la Construcción* **37**(377) (1986): 59-66.

———. "El adobe y la Quincha." In *Navapalos 1987: Año internacional de las personas sin hogar, III Encuentro de trabajo sobre la tierra como material de construcción,* 147–156. Madrid: Ministerio de Agricultura y Pesca y Alimentación, 1990.

Silgado Ferro, Enrique. "Historia de los sismos más notables ocurridos en el Perú (1513–1970)." *Geofísica Panamericana* 2(1) (1973): 179-243.

Tavera, Hernando, Isabel Bernal, Fleur O. Strasser, Maria C. Arango-Gaviria, John E. Alarcón, and Julian J. Bommer. "Ground motions observed during the 15 August 2007 Pisco, Peru, earthquake." *Bulletin of Earthquake Engineering* **7**(1) (2009): 71-111.

Tolles, E. Leroy, Frederick A. Webster, Anthony Crsoby, and Edna E, Kimbro. *Survey of Damage to Historic Adobe Buildings after the January 1994 Northridge Earthquake.* GCI Scientific Reports. Los Angeles: The Getty Conservation Institute, 1996.

Ulloa, Antonio de, Jorge Juan, Andrés Saumell. *Viaje a la América Meridional*, 2. Madrid: Historia 16, 1990.

United States Geological Survey (USGS). *Magnitude 8.0 – Near the coast of central Peru*. Earthquake Summary. http://earthquake.usgs.gov/eqcenter/eqinthenews/2007/us2007gbcv/#summary.

———. Historic Worldwide Earthquakes. Peru. http://earthquake.usgs.gov/regional/world/historical_country.php#peru.

Walker, Charles F. *Shaky Colonialism. The 1746 Earthquak-Tsunami in Lima, Peru and its long aftermath.* Durham and London: Duke University Press, 2008.

Williams León, Carlos. *Arquitectura y Urbanismo en el Perú*. Historia del Perú, Procesos e instituciones, 9. Lima: Editorial Juan Mejía Baca, 1980.

8. CURRICULUM:

Claudia Cancino: Architect, Project Manager of the Earthen Architecture Initiative at the GCI. She holds a Certificate in Conservation from *ICCROM* (1995), Business Degree from *ESAN* (1997) and a Master's of Science and Advanced Certificate in Historic Preservation from the University of Pennsylvania (2002).

Stephen Farneth: Architect, Founding Principal, Architectural Resources Group. Expert in the rehabilitation of architecturally significant buildings. Served as project principal for the Presidio of San Francisco and numerous award-winning rehabilitations at Stanford University. He is currently vice chairman of the ICOMOS U.S and holds a Certificate in Conservation from *ICCROM*.

Philippe Garnier: Architect, Human Settlements director and professor of “Earthen Architecture and Building Cultures” at *CRAterre-ENSAG* His involvement in seismic earthen architecture dates back from Bam when he coordinated the French Aid. He is currently involved in post-seism reconstruction and disaster risk management projects with UNESCO, UNDP, EuropeAid, etc.

Julio Vargas-Neumann: Engineer and consultant for the rectory at Pontificia Universidad Católica del Perú. He has been chief of the engineering department (1969), president of *ININVI* (1980) and vice-minister of housing (1985). As a result of his work, he received the *Premio Nacional de Cultura en Ciencias y Tecnología* of Peru.

Fred Webster: Ph.D. in Structural Engineering from Stanford University has participated in seismic upgrade of earthen structures sponsored by the National Science Foundation (1980s) and the GCI (1990s). Dr. Webster designed seismic retrofits and upgrades for several historic adobe buildings in California (Mission San Miguel, San Luis Rey de Francia).

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[ii] Criteria included type, historical significance and quality, distance to epicenter, damage, access and time

[iii] The moment magnitude scale (MMS; denoted as M_w) measures the size of earthquakes in terms of the energy released. The MMS scale was developed in the 1970s to succeed the 1930s-era Richter magnitude scale, M_L.

[iv] From the 18 accelerometer stations, only four time histories from the city of Lima and one from the city of Ica were available to the public by mid-November 2007 by the Centro Peruano Japonés de Investigaciones Sísmicas y Mitigación de Desastres (CISMID)

[v] Cristobal Campana developed comprehensive research studying ceramic scale models of residential housing of the Mochica period.

[vi] *Quincha* is a Spanish term borrowed from the *Quechua* word “qincha” (kincha in Kichwa), which means "fence, wall, enclosure, corral, animal pen”. Real Academia Española, http://www.rae.es/.

[vii] The *Libros de Cabildos* of Lima are 45 volumes of the meetings proceedings of the *ayuntamiento,* or Municipality of Lima, from 1535 and 1824.

[viii] Its first recorded use was for the construction of a drainage system made of brick and cement mortar in Lima in 1869. It is important to mention that in 1916, Peru had its first cement company called *Compañía Nacional de Cemento Portland* followed by its affiliate in 1946 called *Compañía Nacional de Cemento Portland Pacasmayo.*

[ix] University involved in this initiative were te Pontificia Universidad Católica del Perú (PUCP) and the Universidad Nacional de Ingenieria (UNI).

[x] See Ministerio de Vivienda, Construcción y Saneamiento. http://www.vivienda.gob.pe/. and Servicio Nacional de Capacitación para la Industria de la Construcción (SENCICO). http://www.sencico.gob.pe.