The challenges of protect historical adobe constructions in Peru

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ABSTRACT:
This paper attempts to describe the general structural conditions of historical adobe buildings which are mainly located in the coast of Peru that is a zone of high seismic activity. The seismicity of the zone is discussed through an earthquake hazard analysis and the importance of action towards the protection of heritage architecture in Peru is emphasized. It is noted that the state of general disrepair and the intrinsic weakness of the earthen constructions add to the seismic vulnerability of this kind of heritage architecture. Besides, the repair after actual damage or destruction from earthquakes, even when timely undertaken, may lead to alteration of valuable originality of heritage structures, owing to the unavailability of materials or skill from the time of the original constructions. The need for initiatives towards preventive actions for protection from damages and prevention of collapse due to earthquake disasters appears quite evident.

Keywords: adobe constructions, earthquake hazard, seismic vulnerability, Peru, world heritage

1. INTRODUCTION

The coast of Peru is affected by frequent earthquakes that are originated mainly by the tectonic interaction between the Nasca plate and the South American plate. Protection of life and property from earthquakes disasters has been a subject of major emphasis in engineering research and practice in this region. However, this seems to be little effort made to evaluation of the vulnerability of heritage architecture to earthquake disasters and in general to natural disasters.

In the coast of Peru that presents high seismic hazard level, many historical sites are located, and the constructions are mainly made of adobe or sun-dry bricks. In the case of Lima, the capital of Peru, the historical centre has been declared as UNESCO world heritage and many adobe buildings exist together with another earthen system called quincha. Walls made of quincha consist of a wooden frame with a mesh of cane that receives a mud plaster. This wall system is always used in combination with adobe walls and it is common to observe two stories or three stories buildings where the first story is made of adobe walls and the upper stories are made of quincha. It is well known that earthen constructions are in general weak structures to resist earthquake actions. Recent earthquakes like Pisco earthquake of the year 2007 occurred in Peru illustrate this situation. Moreover, the local economy makes it impossible to pay attention to cultural heritage in the aftermath. Therefore, the constant disrepair of the heritage architecture and the luck of research on hazard, resistance and strength of historical building make critical the vulnerability of these constructions.

Earthquake disaster is not the only hazard that affects the vulnerability of historical adobe buildings located in the coast of Peru; there are also other kind of natural disasters like rarely rains, floods, sand storm, etc. On the other hand, in the urban areas, these historical buildings are affected by the invasion of people that constructs houses in reserved zones or people that uses part of the structure or materials to construct their houses.

This paper attempts to describe the structural conditions of historical adobe buildings which are located in the coast of Peru that is a zone of high seismic activity. The seismicity of the zone is discussed through an earthquake hazard analysis and the importance of action towards the protection of heritage architecture in emphasized. It is noted that the state of general disrepair and the intrinsic weakness of the earthen constructions add to the seismic vulnerability of this kind of heritage architecture. Besides, the repair after actual damage or destruction from earthquakes, even when timely undertaken, may lead to alteration of valuable originality of heritage structures, owing to the unavailability of materials or skill from the time of the original constructions. The need for initiatives towards preventive actions for protection from damages and prevention of collapse due to earthquake disasters appears quite evident.

2. SEISMIC HAZARD OF THE COAST OF PERU

The west coast of South America is affected by frequent earthquakes originating mainly from tectonic interaction between Nasca plate and South American plate. The Peruvian Institute of Geophysics (IGP) has published the catalogue of historical earthquakes in this region, consisting of information from year 1471. Old records of this earthquake catalogue have information of probable magnitude and estimated location inferred from historical reports on damages in affected zones. Moreover, earlier records prior to instrumental measurement can not be expected to be representative of the actual distribution of hazard since at earlier times only earthquakes occurring around populated areas seem to have been reported. If only records with complete information of location, magnitude, depth, etc are selected, the distribution of these instrumental recorded earthquakes appears as can be observed in Figure 1. It can be noted that there is a concentration of epicentres along the coast line. Also it can be observed that the Southern part of Peru presents more activity that the North and Central part. To analyze the nature of the earthquake of the Northern zone, the Central zone and the Sothern zone, sections that show the earthquake distribution in elevation were constructed. The location of this sections are indicated in the Figure 1 as section A-A for the North part, section B-B for the Central part and section C-C for the South part of Peru. In all cases earthquakes located inside a band of 200 km with centre at the correspondent section line were considered.

Figure 2 shows the distribution of earthquakes in elevation for each section described in previous paragraph. Although the distribution pattern presents the same tendency for each zone with shallow earthquakes near the coast and deeper inland earthquakes, the depth distribution and amount of earthquakes for each zone are quite different.

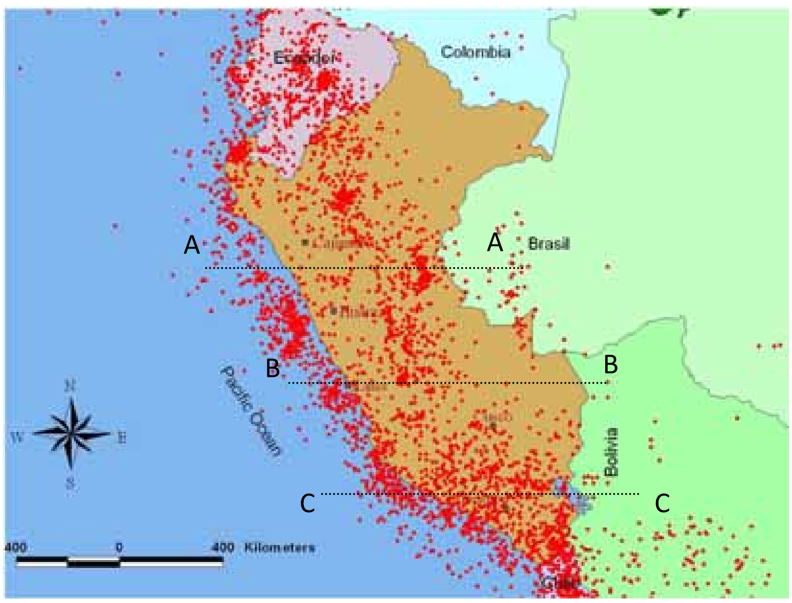

Figure 1: Earthquake distribution near the coast of Peru

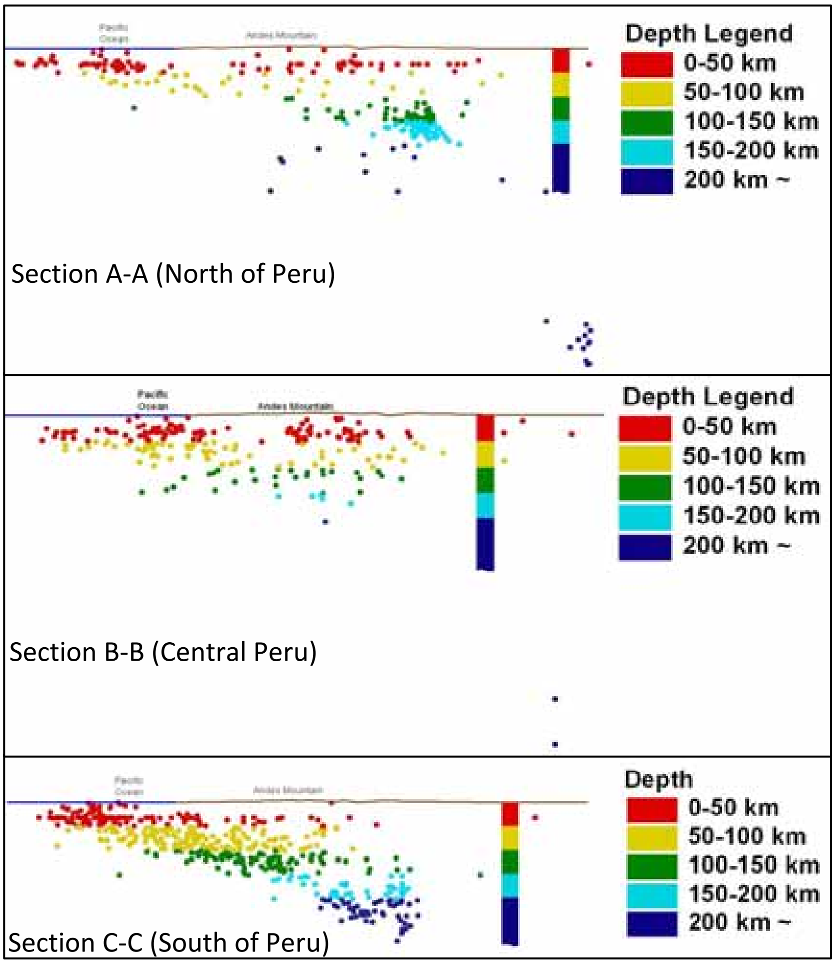

Figure 2: Distribution of earthquakes in elevation

Section A-A shows shallow earthquake distribution near the coast. Concentration of epicentres at focal depth from 100 km to 200 km also can be observed in here. Additionally, concentration of deep epicentres is observed in the zone of the Amazon jungle (east part) with depths of the order of 500 km.

In the section B-B the distribution of the earthquakes shows that in this zone the earthquakes have less that 200 km of depth or even less than that depth. The sallow earthquakes near the coast are closer to the coast line which means that the epicentres are closer to inland cities.

The section C-C shows more clearly the typical earthquake distribution of the subduction action of the marine plate, with deeper inland earthquakes. It can be noted that the number of earthquakes is larger in comparison with the north and central part of Peru.

Seismic hazard analysis for representative sites of the Andean region of Peru (Cusco city), and the coast of Peru (Lima city) was performed by Cuadra et al (2003) and are shown in Figure 3. Hazard curve for Los Angeles city is included for comparison. Results of the probabilistic seismic hazard analysis can also be expressed in terms of the return period shown in Figure 3, where peak ground acceleration (PGA) for different return periods with 10% probability of exceedance are plotted. It may be noted that the PGA for 100 year return period is around 0.25 g for the considered Andean region and for Lima (Coast of Peru) the PGA is 0.5 g. This higher level of peak acceleration may produce failure in buildings in general and the situation become critical for weak material like adobe constructions. In addition, the PGA levels in Figure 3 represents rock or stiff soil conditions, while the actual level of shaking depends on local site conditions at specific heritage sites where the local site amplifications and other effects may be important.

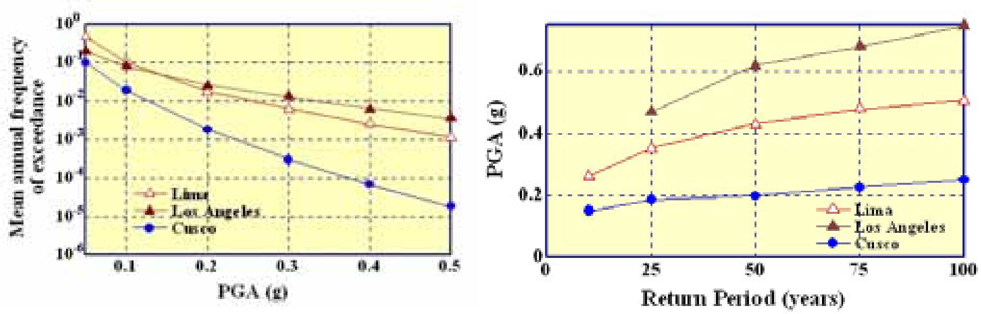

Figure 3: Hazard curve and PGA versus return period for representative sites

3. HISTORICAL SITES IN THE COAST OF PERU

Peru has many sites of cultural and natural heritage reflecting the pre-Inca era, Inca era as well as the subsequent era following Spaniard conquistadors in the 17^{th} century. The distribution of these heritages can be observed in Figure 4 and includes the world heritages declared by UNESCO which are marked by circles. Of the eleven Peruvian heritage sites in the UNESCO world heritage list, seven are considered cultural and two are considered natural. The remaining two are considered mixed category, meaning that the sites reflect the cultural as well as the natural heritage. Additionally to this UNESCO list, other architectural heritages located in the coast of Peru are included in Figure 4 and are marked by triangles. These selected architectural heritages correspond to structures made of adobe and are describe in the following sections.

Figure 4: Peruvian world heritages distribution

3.1 Chan Chan archaeological zone

Chan Chan is considered the largest old city of South America that was made of adobe. Chan Chan was the capital of a pre-Inca kingdom of Chimu. The remains of the city can be found in nine parts that are considered separated units or palaces because only around these places can be appreciated remarkable constructions. In Figure 5 some views of adobe constructions can be observed.

Figure 5: Some views of Chan Chan adobe city

The adobe constructions are quickly damaged by natural erosion due to the air, salt, humidity and rain and they require continuous conservation efforts. This zone is also subjected to the impact of El Nino current which affects climate world-wide. Some years like 1983 and 1998 this phenomenon was unusually strong, leading to torrential rain and flooding. As was shown previously the seismic activity in this north part of Peru are smaller in comparison to the southern and central parts. However, historical earthquakes distribution and hazard analysis shown that this area is not free of earthquakes and on the contrary occurrence of rarely earthquakes could strike and damage earthen structures like Chan Chan.

In this study some preliminary microtremor measurements were carried out to estimate the characteristics of the ground in Chan Chan. Results of the data analysis shows that the ground has a predominant frequency of the order of 1 Hz that could indicate that the city is located on a soft soil layer. To obtain this dynamic characteristic of the ground, the H/V spectrum ratio was calculated that is the ratio between the Fourier spectrum of the horizontal wave and the Fourier spectrum of the vertical wave. This H/V spectral ratio is shown in Figure 6.

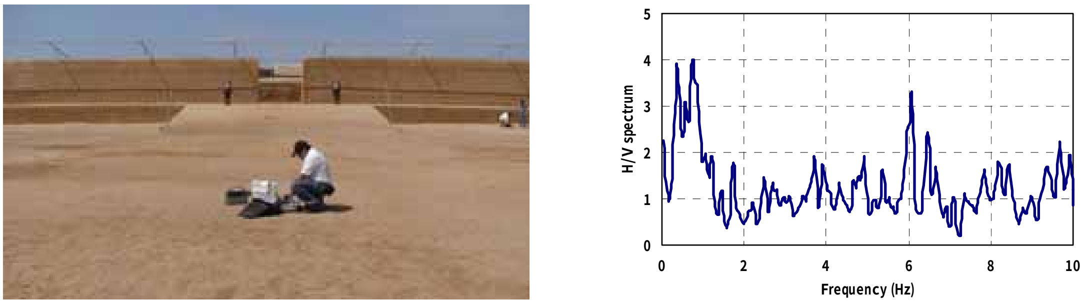

Figure 6: Microtremor measurement and H/V spectrum for Chan Chan ground

3.2 Archaeological complex of Pachacamac

This complex was one of the main centers of religious cult, an oracle center of ancient civilization in the central coast of Peru. It is a pre-Inca heritage which origins date from 200 a. c. It is believed that one of the deities of this temple was the god of earthquakes. Their constructions are made of adobe which present condition shows the fragility of this kind of material to the action of natural hazards. Figure 7 shows some view of the Pachacamac complex. The buildings in general are affected by the erosion due to the sand and also by the movement of the sand dunes that in some cases has destroyed and cover completely the buildings. It is difficult to infer the action of past earthquakes because the damage condition of the building could be the result of the action of earthquakes and the lack of appropriate maintenance. Another hazard to this complex becomes the rapidly development of the urban area near the complex that affect not only the landscape of the zone but the architecture heritage itself since construction materials are obtained from the historical place.

Figure 7: Some views of Pachacamac archaeological complex

3.3 Tambo Colorado

It is believed that Tambo Colorado was one of the administrative centres of the Inca Empire. It is strategically located at the entrance to the Pisco valley, just 35 km inland from the port city of Pisco on the southern coast of Peru, and dominates access to the Inca road leading to the highlands and eventually to Cusco. All constructions are made of adobe and some of them have a coloured plaster with horizontal, alternating, ribbons of white, red and yellow. During the recent earthquake of Pisco of July 2007 many walls were affected and some of them fall down producing not only the failure of the structure itself but also the destruction of the coloured plaster. Some of these damages can be appreciated in Figure 8. In this case, together with the seismic vulnerability analysis it is necessary to analyze the plaster material to try to reconstruct the painted walls. It is obvious that it also has suffered considerable deterioration and damage during the years and urgent conservation measures are required to preserve this monument.

Figure 8: Some views of Tambo Colorado effected by earthquake motion

3.3 Lima historic centre

The city of Lima, the capital of Peru, was founded by Spanish conquistador Francisco Pizarro on January 18, 1535 and given the name City of the Kings. Lima played a leading role in the history of the New World from 1542, when Carlos V establish the vice royalty of Peru, until the middle of the 18th century. In 1988, UNESCO declared the historic center of Lima a World Heritage Site for its originality and high concentration of historic monuments constructed in the time of Spanish presence and at the beginning of the Republican era. The architecture of the buildings corresponds in general to typical Hispano-American baroque of the 17th and 18th centuries. Since its foundation the city has suffered the action of many earthquakes that have severely affected historical buildings and reconstruction works have been done keeping the originality of the buildings. However due to the age of buildings studies for retrofitting or strengthening are necessary. In this study a preliminary evaluation of structural condition of buildings is presented. As example a building that correspond to an old hotel is presented where ambient vibration measurements were performed to estimate the period of vibration. This building can be observed in Figure 9. Walls are made of quincha that consists of a wooden frame with a mesh of cane that receives a mud plaster. The first story is made of adobe walls and the upper two stories are made of quincha. The building presents some partial collapse of interior walls and serious deterioration of the quincha walls. Results of ambient vibration show a predominant frequency of the order of 3.3 Hz. Figure 10 shows the predominant frequencies for NS and EW directions respectively. The NS direction was taken as the direction parallel to the façade and the predominant frequency is 3.37 Hz. In the EW direction that is perpendicular to the façade the predominant frequency is 3.21 Hz. These frequencies represent reasonable values for a building of 12 m of height however more detailed measurement are necessary to detect the local vibration of portions of the building that could indicate the condition of deterioration.

Figure 9: Some views of a historical building at historic centre of Lima

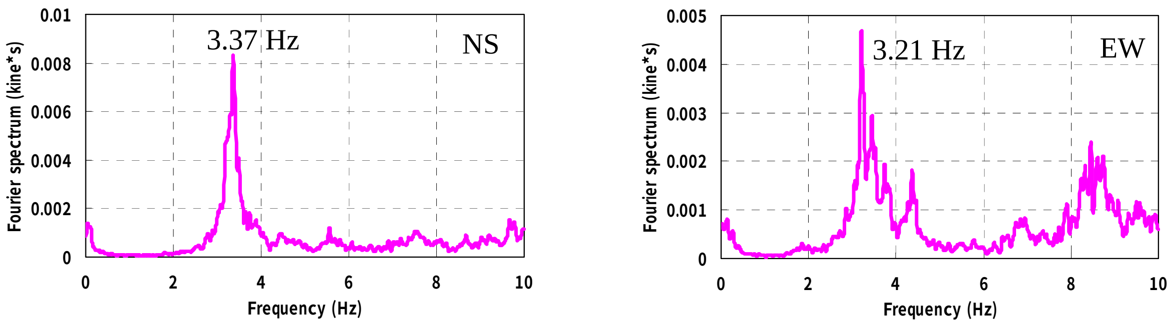

Figure 10: Predominant frequency of selected historical building of centre of Lima

6. CONCLUSIONS

Vulnerability of heritage architecture made of adobe and located in the coast of Peru was discussed. The heritage architecture is exposed to the action of earthquakes as well as another kind of natural hazards and risk emanating from human activity. The adobe heritage architecture is mostly in a state of disrepair and therefore the seismic risk and other kind of risks are particularly acute. The discussion of earthquake hazard to which heritage architecture in the coast of Peru are subjected and the description of the state or structural condition of the buildings, provides and overview of the challenges involved in protecting the heritage architecture made of adobe.

AKCNOWLEDGEMENT

This report is the result of the preliminary field survey conducted by authors under the general research for Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru supported by JST/JICA, SATREPS. Authors would like to thank also to the National Institute of Culture of Peru (INC) in the person of Architect Maria del Carmen Corrales for permit the measurements in historic building at centre of Lima.

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