LESSONS LEARNED FROM THE 2007 PISCO EARTHQUAKE (PERU) AND RECOMMENDATIONS FOR DISASTER MITIGATION

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ABSTRACT :

In August 15th, 2007, the central coast of Peru was struck by an earthquake of magnitude 7.9, which epicenter was located 60 km west of Pisco city and 150 km south of Lima (capital of Peru). Failures in most buildings made of adobe were observed. As in past earthquakes occurred in other regions of Peru, these earthen constructions showed poor structural performance and their collapse was the main cause of deaths and injuries of people. However, failures and even collapse were also evidenced in reinforced concrete structures and confined masonry structures even though they were expected to have better seismic behavior. No much attention has been paid to the failures of these structures due to the generalized failures of adobe constructions. Therefore, it is necessary to analyze the causes of failure of this kind of structures. The causes of failures are not limited only to the structural design. Other reasons such as the lack of control or verification by the local government officers, the lack of preparation or actualization of professionals working in provinces of Peru, the poor quality of local labor work, bad technical advice or guidance, inappropriate materials, etc., should be considered too. In this paper, the occurrence of these failures and their causes are analyzed. From the results of these analyses, some recommendations are proposed to reduce damages on this kind of structures during future earthquakes in Peru. The conclusion and recommendation can be listed as follows: 1) To limit the height of confined masonry buildings to a maximum of four stories. In case of using hand made clay brick the height must be limited to three stories. For practical reasons 4 stories must be the maximum number of stories for hotels without elevators, even if the structure is reinforced concrete. 2) The traditional constructions like adobe building must be prohibited in seismic zone 3. For zones 1 and 2 adobe buildings of only one floor must be allowed. In general the system must not be employed to for public facilities like school, medical post, etc. 3) The transfer of technology it is not a problem of how to transmit this knowledge to the owners or people in general, the problem is how to increase the professional level of engineers that work at rural areas or far from the big cities where the actualization opportunities are few. 4) Even for engineers working at great urban areas there is a problem in the qualification level to take care of structural design. May be a system of accreditation must be implemented. In the actual system young engineers just finishing their university studies are in the same position or equally qualify than experienced engineers to assume design projects.

KEYWORDS: 2007 Pisco earthquake, masonry building, adobe, seismic zonation, earthquake damages, disaster mitigation

1. INTRODUCTION

Peru is located at a zone of great seismic activity originated mainly by the tectonic activity of the Nasca plate under the west coast of continental South American plate. Earthquakes like Chimbote earthquake (Ancash 1970), Cañete earthquake (Lima 1974), Nasca earthquake (Ica 1996), Arequipa earthquake (Arequipa 2001) and the most recent Pisco earthquake (Ica 2007) have produced severe damages on buildings, specially on those so called non-engineered structures. After the earthquake of 1970 (Ancash), efforts to improve the traditional adobe building have been done. Special attention was dedicated to this kind of buildings since at that time the earthen structures were sometime the only available material for construction in rural areas. Also the economical situation did not permit to accede to earthquake resistant systems like reinforced concrete structures and confined masonry. After more than 30 years of research and efforts to improve the behavior of earthen constructions the results of those efforts are not reflected extensively in the practice. As was demonstrated in the recent earthquakes of Moquegua (2001) and Pisco (2007), where generalized collapse of adobe buildings were observed.

On the other hand, buildings that were constructed using reinforced concrete elements and confined masonry systems also failed, although these types of structures are supposed to possess better resistance than adobe.

In this paper, a discussion of the causes of failures is presented. The failures are explained from the structural behavior itself, calling attention the low tension capacity and the low shear resistance of masonry walls and concrete elements, among other factors. However, the causes of damages can be understand or identified as the result of non appriopriate engineering design, poor workmanship and low quality control. After evaluating damages on this kind of construction material, recommendations for disaster reduction are presented, taking into account the seismic activity of the zone and the construction characteristics in Peru.

2. SEISMICITY AND SEISMIC ZONATION OF PERU

As it is well known, the seismicty of the west coast of South America is caused by the movement of the tectonic plates, where the Nasca plate subducts beneath the continental South American plate. The amount of this movement is estimated between 7 and 8 cm per year approximately. Based on the characteristics of Peruvian earthquakes and the seismic attenuation, the seismic zonation of Peru was divided into three zones (Figure 1).

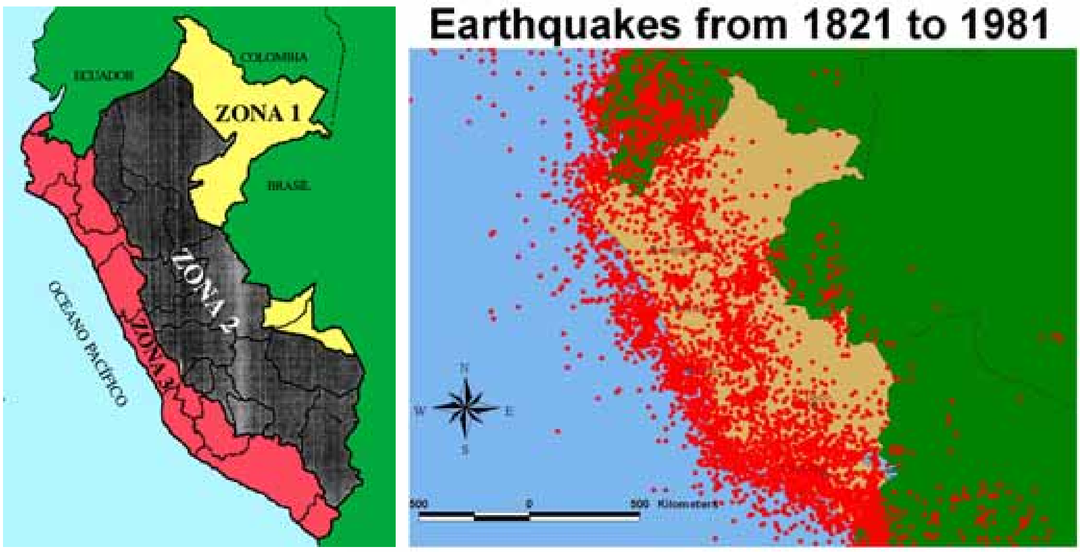

Figure 1 Seismic Zonation of Peru and distribution of earthquakes

In Figure 1, it is also plotted the distribution of earthquakes occurred in the region from year 1821 to year 1981. According to the seismic zonation for Peru, the maximum ground accelerations expected for the Zone 1 is 150 Gal, for the Zone 2 is 300 Gal, and for the Zone 3 is 400 Gal.
The last big earthquake that hit the central coast of Peru (August 15th, 2007 at 18:41 local time), was located near Pisco city and had a magnitude of 7.9. This earthquake caused severe damages in cities of Ica Region (Pisco, Chincha, Ica, among others) and in Lima Region (Cañete city). It was estimated that the earthquake caused more than 500 deaths, more than 1000 injured and more than 600,000 affected people. It was also estimated that about 180,000 dwelling and buildings were damaged in the affected zone.

3. DAMAGES IN EARTHEN BUILDINGS

In the area affected by the Pisco earthquake, as well as, in many rural areas of Peru, the traditional construction system consists of sun-dried bricks laid with mud mortar. This system known as adobe is used mainly for houses. Also, old public buildings like churches use this system. Definitely, this kind of buildings collapsed completely or partially, as can be observed in Figures 2, 3, 4 and 5. Even in the case of no collapse, the cracking and failure pattern show that the building is not longer safer as dwelling. No doubt, the adobe system shows low seismic performance and this generalized failure of adobe buildings overlook the failure of confined masonry buildings and even failures of reinforced concrete buildings.

Figure 2 Collapse of adobe house

Figure 3 Damage in a group of adobe houses

Figure 4 Damage in an abobe church

Figure 5 Typical failure of adobe construction

In Peru exists the national code or norm for adobe constructions (NE 060). However, this norm is not used in common adobe houses due to that the adobe constructions are not controlled by any official government. Only very few public buildings, like small schools and medical post, are constructed with adobe according to the above mentioned norm. Also, some pilot programs that try to demonstrate the applicability of the adobe use the correspondent norm. On the other hand, in the practice, engineers are not interested in this kind of design due to its low seismic performance and its low security factors for design. Therefore, it is very difficult to insure a high seismic performance.

4. DAMAGES IN CONFINED MASONRY AND RC BUILDINGS

In Peru, confined masonry buildings are considered as suitable type construction to obtain earthquake resistant structures. However, the knowledge of this “noble” material as earthquake proof material has transformed in abuse of this material, leading to vulnerable structures. It was generalized the criterion that the use of this kind of system itself would provide safer structures. The quality control has been ignored not only during the construction process but also during the selection of the primary materials for this kind of buildings. One of the problems is the lack of control by the government officers, and this will worsen due to that recently a new law has been approved by the government in Peru, which permits the beginning of construction work of buildings before the expedition of the respective license. This law presumes that the building design and construction is under the guidance of professional engineers. The main purpose of this law is to incentive the construction, with shorter period of construction to satisfy the housing demand. However, this relaxation of quality control would result in a greater vulnerability of buildings.
The influence of these underlying causes of failure in buildings can be detected by analyzing the damaged buildings during the last Pisco earthquake. In Figure 6, the collapse of the 1st floor of an apartment building of 4 stories is shown. From the structural point of view, it is clear that the building failed due to low stiffness distribution in this level. Unfortunately, it was not possible to confirm with the city officers if the building project was approved or not by the correspondent division. However, the characteristics of the building suggest that it was constructed following an approved project. It can be observed that the building was completed up to the 4th floor following a continuous process of construction, which was apparently supervised by an engineer. This case is different than the previous self construction process where the construction advances with clear identifiable jumps. The collapse of this building was due to the failure of the north side columns, while the south side columns have infilled walls that provided greater stiffness to that north side, as is shown in Figure 7. However, it can be noted in a detail of the failed column in Figures 8 and 9 that the reinforcement of the column corresponds to 4 bars of 12 mm diameter (bar No 4) with stirrup of 6 mm diameter. This kind of reinforcement is usual in confined masonry system where the reinforced concrete elements and their reinforcements are designed to take the tension stresses in case of seismic events. In this structural configuration, the column of the north side corresponds to a portal frame where the columns must resist the axial force in combination with bending moment. Therefore, the provided quantity of reinforcement was not enough to resists the seismic force generated by the Pisco Earthquake. These columns should be designed according to the reinforced concrete code instead of the masonry code. Apparently in this case, there is a misunderstanding between the concept of reinforced concrete system and the confined masonry system. In this case, if the project specifies this design, the structural engineer in charge of the structural project had not clear the right criterion for the design. On the other hand, when the project is presented for revision to obtain the correspondent construction license, the inspector officer (whom is supposed to be an engineer) did not detect this mistake in the structural project. Moreover, the engineer in charge of the construction works did not notice the error in the dimensions and reinforcement amount of the mentioned columns during the construction process.
Other buildings that were supposed to have the correspondent license for construction are the hotel facilities. These buildings are 5 stories, which are apparently the maximum height permitted by the

building code for confined masonry structures. Figures 10, 11, 12 and 13 show some pictures of these buildings which remain stand up but with serious damages in their structures. In the first plane of Figure 13 can be observed also an empty terrain where it was located a hotel of five stories that collapse completely. In this case, the original structure was a house of two stories that was converted into a hotel. These facilities were constructed after participating designer engineers, and surely, after approving by the local government officers. All of them failed in achieve a safe project. It is very difficult to point out that it was the result of administrative corruption, instead of that it is believed that the fail in all steps of the project is due to the lack of qualification of the designer, the inspector officer and the constructor.

Figure 6 Collapse of 1st floor of a masonry building

Figure 7 South view of collapsed building

Figure 8 Failure of north side columns

Figure 9 Column reinforcement detail

Figure 10 Reinforced concrete hotel

Figure 11 Detail of column failure

Figure 12 Six stories hotel

Figure 13 Collapse of five stories hotel

5. CONCLUSIONS AND RECOMENDATIONS

After analyzing the damages produced by the 2007 Pisco Earthquake, the following conclusions and recommendations can be given:

- To limit the height of confined masonry buildings to a maximum of four stories. In case of using hand made clay brick, the height must be limited to three stories. For practical reasons, 4 stories must be the maximum number of stories for hotels without elevators, even though the structure is made of reinforced concrete.
- The traditional constructions like adobe building must be prohibited in the seismic zone 3. For zones 1 and 2, only one floor adobe buildings must be allowed. In general, the adobe system must not be employed in public facilities like school, medical post, etc.
- The transfer of technology it is not a problem of how to transmit this knowledge to the owners or people in general, the problem is how to increase the professional level of engineers that work at rural areas or far away from big cities where the opportunities of transmitting knowledge are few.
- Even for engineers working at big urban areas, qualification level for structural design is needed. A system of accreditation must be implemented.

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