BEHAVIOR OF NON-ENGINEERED HOUSES DURING PISCO EARTHQUAKE 15/8/2007

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ABSTRACT:

On August 15th 2007, an Earthquake of Intensity 8.0 MM, struck the south shore of Peru. Strong damage on adobe houses was registered on cities like Ica, Pisco, Chincha, and Cañete. Even the quake affected old non engineering houses in downtown of Lima. This report summarizes the kind of damage which appeared on non engineering houses built with two materials: adobe and brick clay masonry. Statistics of the damage and damage survey is presented for three cities: Pisco, San Luis and Huaytara. Classification of the damage by levels and most likely damage patterns are presented in order to avoid errors and produce recommendations for non engineering houses. Also a proposal of wall reinforcement is presented for two cases: adobe case, base on the use of a fiber disposable plastic bag, and masonry case, using electro welded mesh of reinforce. Full scale test on walls using the describe techniques were performed on the structural lab of our institute. Results on both cases increase the capacity of the walls elements and also avoid collapse probability under big deformations.

KEYWORDS: Pisco, Earthquake, Peru, Adobe, House

1. THE PISCO QUAKE

On August 15th 2007 at 18 hrs., 40 minutes local time, an earthquake of magnitude 8.0 Mw, struck the south coast of Peru with epicenter at Latitude -13.49° and Longitude : -76.85° with depth of 26 km located at 74 km west of Pisco city. INDECI (Peruvian Civil Defense) reported that the quake killed 593 persons, with 1,291 injured, and 48,208 collapse houses, and near 90,000 affected houses. Also 14 health services were destroyed and 112 health services were affected. This paper will describe the damage on non engineering houses in three cities: Pisco in Ica Region, San Luis de Cañete in Lima Region and Huaytara in Ayacucho Region.

2. TYPE OF DAMAGE

The damage on one structure is related with the seismic demand and the site where the structure is located. According with the Peruvian National Seismic Standards (NTE-030), the standards of adobe design (NTE-080) and the standards for masonry buildings (NTE-070), the structures must resist a severe quake without collapse and moderate quake with acceptable damage among limits of resistance and displacements. A severe quake will demand accelerations in the order of 0.40g, 0.48g and 0.56g on rigid, middle and soft soils respectively. In other words the seismic demand is associated with the soil type and the acceleration of the ground. Better soil less demand and bad soil more demand. Therefore, a structure of a building with more demand has a high probability to be damaged instead of the same structure under low demand.

During the quake there were different kinds of damage on adobe constructions. Especially these damage experienced difference from zone to zone. Then, light damage was presented by small cracks (less than 0.5 mm) on the finishing of the walls, and also small pieces of mortar that fall down from the wall. Moderate damage is presented when small cracks (between 1 mm to 2 mm) on walls, big pieces of finishing fall down from the walls, cracks on lintels and windows vicinities with diagonal cracks. Severe damage, appears as big cracks on the wall, partial destruction of walls, cracking on part or sections of the structure; collapse of walls and roof in parts or total.

3. DAMAGE ON ADOBE HOUSING

The houses built on soft soils experienced collapse due to the big displacements on soil, the increment of the soil demand due to site conditions, and due to non reinforcement on walls that were used on non engineering constructions. Non engineering house don't use any cane, wood, confine elements on the ends of the walls, therefore, opening of the corners, lost of alignment of walls and overturning on walls (See Photo1 to 4), classifies the damage as severe. As a result of the big displacements, after the damage of walls and the opening of corners appear, the roof collapse and structural system became unstable and total collapse may occur.


Photo 1: Overturning of walls


Photo 2: Collapse


Photo 3: Collapse of roof


Photo 4: Collapse of wood roof

A characteristic of the collapse of walls starts with diagonal cracks on the surrounding area of windows then the area of the wall between the opening and the door is small and very weak, therefore the collapse of the walls occurs. Other characteristic of the adobe walls is lintel beam without enough penetration of the wall, just because this beams don't have enough support on the walls, then horizontal cracks appears and collapse of surrounding adobe blocks. If there are not collar beam, strong vertical cracks appears on the corners of walls between walls then the collapse and overturning of walls and collapse of roof occurs.

4. DAMAGE ON MASONRY HOUSING

On soft soils areas, the houses built with clay masonry walls, but following engineering procedures, experienced moderate damage, represented by collapse of balconies and non structural walls (see Photos 5, 6 and 7)
Also the collapse of non structural walls due to irregularity is presented on Photo 8. In the process of auto construction, many owners used non regulated brick units generating failure on non structural walls or producing collapse on buildings when these walls were used as structural units.


Photo 5: Overturning wall


Photo 6: Damage on wall

Photo 7: Facade collapse


Photo 8: Collapse cantilever

The masonry structures built by auto construction or with irregular configuration or built with non regulated bricks (not permitted by the standards) suffered severe damage and in some cases impossible to be repaired (see Photo 9, Photo 10 and Photo 11). Some old buildings build by blocks without reinforcement like Hospital San Juan de Dios (see Photo 12) presents failure on walls with severe damage, without possibility to be repaired after the event. In this case this hospital was an essential structure same as other hospitals in the area (see Photo 12) and don't comply the criteria of safe hospitals defined by WHO-PAHO. Therefore, after the quake Pisco city hasn't hospital for attention, just because all the hospitals on the city collapsed.

Many buildings in the city with severe damage or collapse were mix structures with first floor of adobe and second floor of masonry (see Photo 13), this type of buildings is not regulated and is considered a non engineering structure.


Photo 9: Collapse due to cut on belt beam


Photo 10: Collapse due to irregularity


Photo 11: Collapse due to soft story


Photo 11: Failure because non reinforce


Photo 12: Damage ESSALUD Hospital


Photo 13: Mix structure – Failure on adobe

5. FIELD SURVEY

The authors with the support of professors and students of the Civil Engineering Faculty carried out a field survey on the three cities involved in the present report with the financial aid of IDB and PCM. Two of the cities are located on the coast and one city is located on the highland. However the damage characterization depends of the demand and also the site conditions where different kinds of soil profiles were found. The City of Pisco has areas of soft soil represented by a mix of sand with gravel with high level of humidity and also a middle soil with gravel and compact sand. The City of San Luis has two types of soils: soft soil represented by sand and rock on a hill at one side of the town. The city of Huaytara is a typical Andes town surrounding by mountains with small part of the downtown with rock in a hill and most part of the town with a mix of lime and sand soil.

5.1. Field Survey on Pisco City

Figure 1 shows the results of field survey of Pisco City, by damage for each type of material used in the city.

From the total of adobe dwellings 82% collapsed, following by quincha buildings with 65% collapsed. Masonry buildings suffered less damage from the strike of the quake (slight damage and non damage) with 70% of them without high demand.

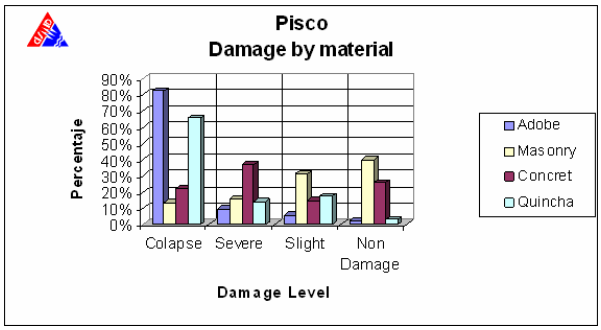

Figure 1: Damage by material in Pisco City

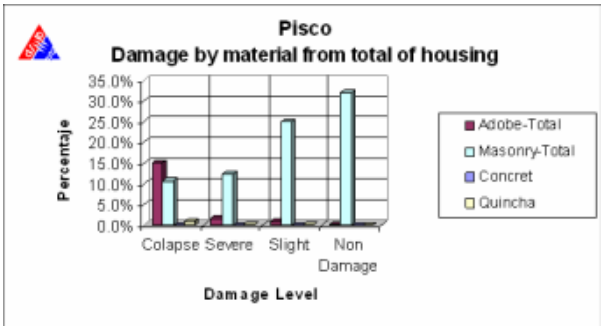

Figure 2: Damage related with total of buildings-Pisco

Figure 2 shows the percentage considering the total of the buildings of Pisco city. The adobe buildings that collapse in the city represents 15% of the total and the masonry buildings that collapse represents 10.7% of the total of housing.

Figure 3 shows the summary of the collapsed and severe damaged in comparison with the slight damage buildings and non damaged buildings. It is possible to read that 41.1% of the housing was more affected originated collapse and 58.9% were less affected by the quake. From the severe affected buildings most of them were non engineering structures.

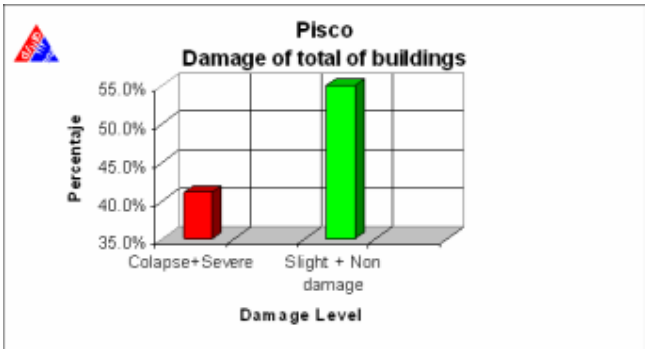

Figure 3: Damage of buildings in Pisco

5.2. Field Survey in San Luis de Cañete

There are two predominant materials in San Luis de Cañete housing: adobe and masonry. Adobe buildings are traditional non structural structures and represent the 62% of the total. They are distributed among the two types of soil in the city. The adobe houses built over soft soil collapsed total or partially, where a particular construction was used: the front build with masonry and the rest of the house with adobe. So adobe part collapsed but the facade of the house, made of masonry, appeared stand or partially stand as shown in Photo 15. Here the internal adobe walls collapsed completely and it is possible to observe a tent inside. On the other side Photo 14 shows the complete collapse of an adobe house in the main street of the city over soft soil.

The behavior of the houses was completely different on the rock hill at one side of the city. Photo 16 shows an example of adobe house without any damage and Photo 17 present the slope road with adobe houses without any damage on the San Luis's hill. However from Photo 17 it is possible to see the flat area of the town with green fields were the soil is soft and adobe houses collapsed.

Photo 14: Total collapse on adobe house

Photo 15: Internal collapse of adobe house

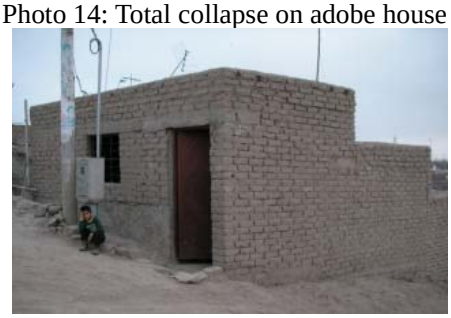

Photo 16: Adobe house on a hill of San Luis

Photo 17: Slope road with adobe houses

Figure 4 presents the survey on this city by material type where 37.8% of adobe houses collapsed and 85% of masonry houses didn't have damage. Figure 5 presents the results by material considering the total buildings, where 23% of affected houses were built by adobe which is the representative of the city with 62% of the total.

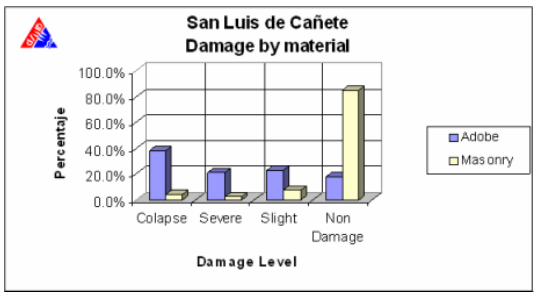

Figure 4: Damage by Material – San Luis

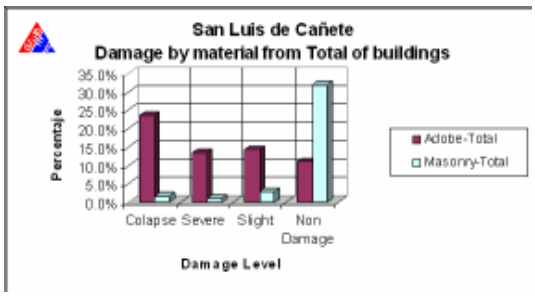

Figure 5: Damage by material from total

Figure 6 presents the addition of the collapse and severe damage in comparison with the addition of slight damage buildings and non damage buildings. We found that 39.8% of the buildings were more affected with collapse and severe damage mainly in adobe buildings. The 60.2% of buildings were less affected by the quake represented by the houses on the hill and masonry buildings.

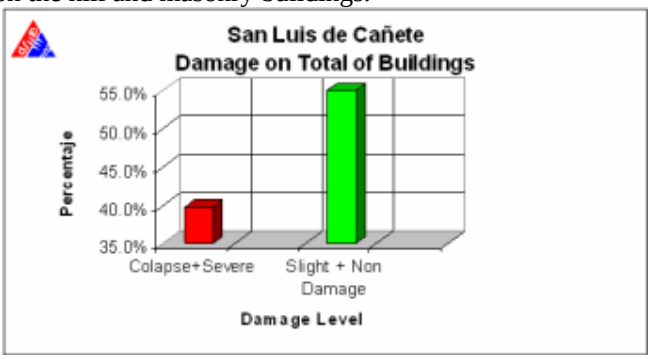

Figure 6: Damage on San Luis Buildings

5.3. Field Survey in Huaytara

The city of Huaytara is a typical Andes city with heavy slopes with two types of soil as was mentioned before. The old adobe houses suffered the strike of the quake with the collapse of walls and roof (Photo 18), or the big cracks on walls of one and two story buildings (Photo 19). However new constructions has no damage (Photo 20) because they are following the standards.

Photo 18: Collapse in Huaytara

Photo 19: Severe Damage

Photo 20: Non damage

Figure 7, presents the distribution of damage by type of material in Huaytara city. The 41.1 % of adobe houses were affected with collapse, and 25.7 % de present heavy damage. The 92.6 % of masonry buildings didn't have damage. Figure 8 shows the damage considering the total of buildings in Huaytara city. Here the 34.8 % of the adobe houses had collapse and the 21.7 % present's heavy severe damage.

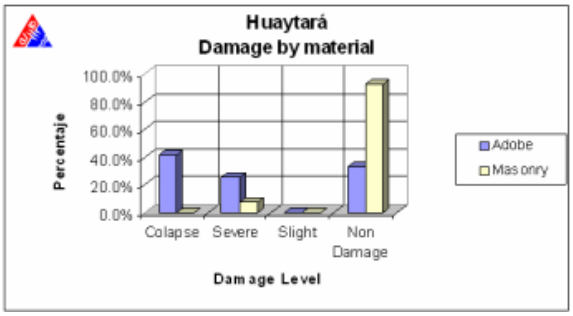

Figure 7: Damage by material – Huaytara

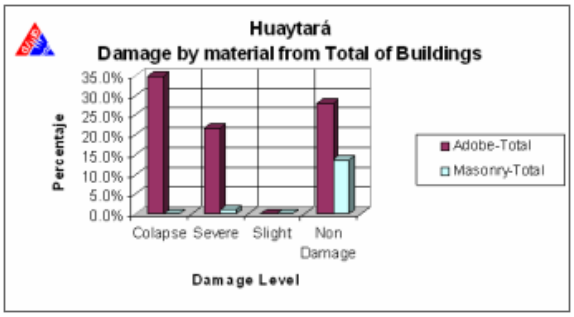

Figure 8: Damage by material from total

Considering the addition of the collapse and severe damage and comparing with the addition of slight damage and non damage, Figure 9 shows the results of this comparison. It was found that 57.6 % of the houses were affected with collapse or severe damage and 42.4% of the buildings were less affected.

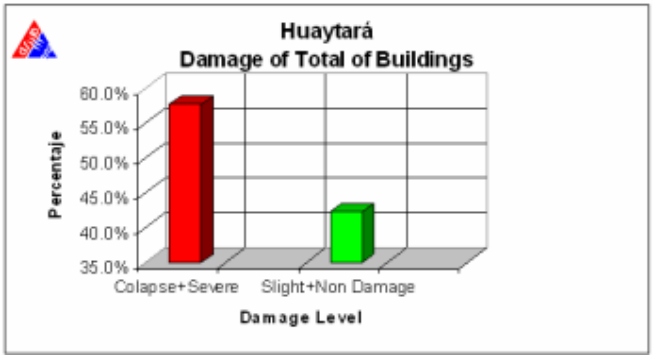

Figure 9: Damage on Huaytara buildings

6. PROPOSAL OF WALL REINFORCEMENT

Most of adobe and masonry walls were damage due to non reinforcement exists and non collar beam was used in their configuration. In order to reinforce the existing walls a proposal of reinforcement is presented.

6.1. Proposal for adobe walls

The use of a fiber disposable plastic bag or rice bag can be use as an economic alternative to reinforce an adobe wall and avoid the collapse. This technique could be applied increasing the section of the walls totally or increasing the corner section as confinement. Photo 21 presents the sequence of the reinforcement increasing the corner section.

Photo 21: Four stages of reinforcement an adobe wall

Two walls under monotonic loading were experimented in our laboratory. Two walls were of 2.45 m. length, 2.30 m. height and 0.20 m. thickness was tested without reinforcement. Under monotonic load an average of 1.153 t for a drift 1/250 was registered. The walls were repaired using the proposal and tested again under the same conditions. A maximum load of 1.790 t was reach for this alternative of reinforcement. The load capacity increase in 65% the drift can resist deformations for drift between 1/250 a 1/60 after the reinforcement.

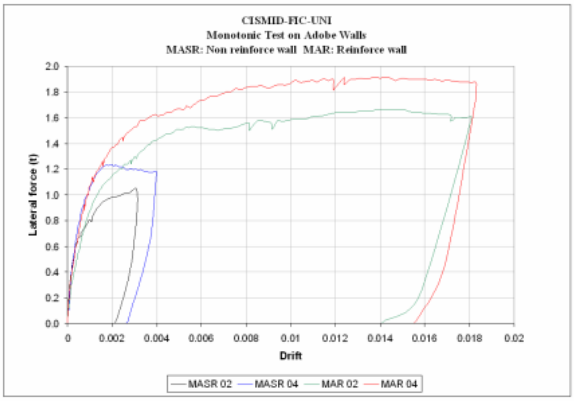

Figure 10: Monotonic Test on adobe walls

6.1. Proposal for masonry walls

Masonry walls of 2.25 m. length, 2.40 m. height and 0.15 m. thickness with vertical reinforcement of #3 bars inside each hollow block, and #4 on the corners and horizontal reinforce of 8 mm bar were tested (original wall). Walls started their cracking at drift of 1/1000. At 1/500 drift walls started the damage of the toe that collapse at 1/100 drift. The wall was reinforced with steel mesh equivalent to 8 mm bar following the procedure presented in Photo 22. Toe was repair and mesh was fixed with anchors. After a mortar 1:4 was sprayed over the mesh and finishing the wall.

Photo 22:Four stages of reinforce a masonry wall with electro welded mesh

Figure 11 presents the comparison of the results of the behavior curve of specimens, where repair wall appears with thick line and original wall with thin line. The stiffness on the repair wall was restored but small ductility was observed. A separation of the mesh started under a drift of 1/333 and it continued until a drift of 1/166 when the toe collapsed.

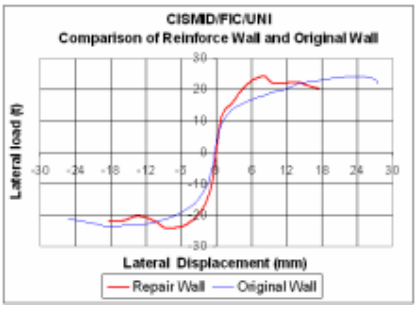

Figure 11: Behavior curve from cyclic loading test

7. CONCLUSIONS

- Field survey of Pisco, San Luis and Huaytara cities was performed house by house. In Pisco city 41.1% of the buildings were affected originated collapse and 58.9% were less affected by the quake. For San Luis 39.8% of the buildings was more affected with collapse and severe damage mainly in adobe buildings. The 60.2% buildings were less affected by the quake represented by the houses on the hill and masonry buildings. In Huaytara city 57.6 % of the housing was affected with collapse or severe damage and 42.4% of the buildings were less affected.
- The collapse depends on the site condition and the quake demand. Special considerations for improving the behavior of the existing adobe houses must be taken. A proposal for reinforce adobe walls is presented and improve the load capacity of the wall in 65%. Also a proposal for masonry walls restores the capacity of the original wall reinforced by a mesh with #3 bars. It will recover the wall resistance and must be used in case of existing buildings.

8. REFERENCES

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