SEISMIC BEHAVIOUR OF MASONRY CONSTRUCTIONS IN 2007 PISCO, PERU EARTHQUAKE

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ABSTRACT :

The Pisco, Peru earthquake of August 15, 2007 (Mw8.0) produced many damage in several masonry constructions. The objective of this paper is to indicate several defects observed in these constructions, ranging from mild to total collapse. The seismic behavior is examined under the recent Peruvian Masonry Code provisions. Comments are given regarding the soil conditions, the type of foundations, the masonry units (clay bricks and concrete blocks), the construction system and sequence, the architectural configurations, and the structural detailing. Also, a wide amount of failures occurred in non structural masonry, such as parapets, perimeter walls and infill walls, in several cities along the Coast. Conclusions are drawn regarding the failures described and the Masonry Code recommendations.

KEYWORDS: Masonry, constructions, code, walls, Pisco, earthquake

1. INTRODUCTION

In August 15, 2007, a strong earthquake hit the central coast of Peru. The magnitude of the shock has been reported by the Peruvian Geophysical Institute (IGP) and the National Earthquake Information Center (NEIC) as ML=7.0, Mw=8.0, respectively (Bernal 2007). The epicenter was located at the Pacific Ocean, 60 km west of the provinces of Chincha and Pisco, with a depth of 40 km (Tavera et.al. 2007). The earthquakes in this area are caused by the subduction of the Nazca plate under the South American Plate. Lima, Peru's capital city, with more than 8 million people, is 200 km north of this epicenter.

One month after the shock, the report from the National Institute for Civil Defense of Peru, informed of 519 deaths, more than 70000 houses collapsed and more than 33000 houses with some damage. The affected area included provinces in the regions of Ica, Lima, Huancavelica, Ayacucho and Junin (INDECI 2007).

Acceleration records of the shock were produced in 2 stations in Ica, 138 km southeast from the epicenter, and 14 stations in Lima, with more than 2 minutes duration. The higher values were obtained at the Parcona (PCN) record in Ica, which reached 0.49g of peak ground acceleration, while the Rinconada (RIN) record in Lima reached 0.11g. Figure 1 (Tavera et. al. 2007) displays a map of the affected area and stations locations.

Several damages were seen in different sorts of constructions, mainly those of adobe, masonry, and some reinforced concrete ones. This paper deals only with the damages observed in masonry buildings, pointing out the series of defects observed, with the objective to learn the lessons provided by this earthquake.

Many buildings had damage in the structural masonry walls, featuring cracking to total collapse. Also, heavy damage occurred in many non structural walls such as poorly braced parapets and perimeter walls; infill masonry walls cracks were observed in low buildings in cities near the epicenter, as well as multistory (10 to 20-story) buildings in Lima. These failures mainly were due to: 1) poor soil quality, 2) improper foundations, 3) low quality of construction materials, 4) deficient construction techniques, and 5) poor structural configuration and design.

It can be said that this earthquake can be considered a moderate one, because other well done structures did not suffer any damage. Previously to this earthquake, a new Masonry Building Code was enforced in Peru

(SENCICO 2006). Therefore, this is a unique opportunity to point out a series of Code requirements that were not followed in the damaged constructions.

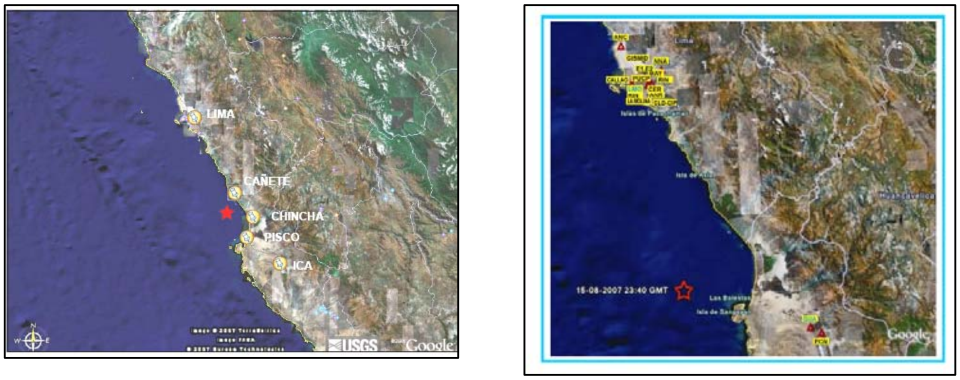


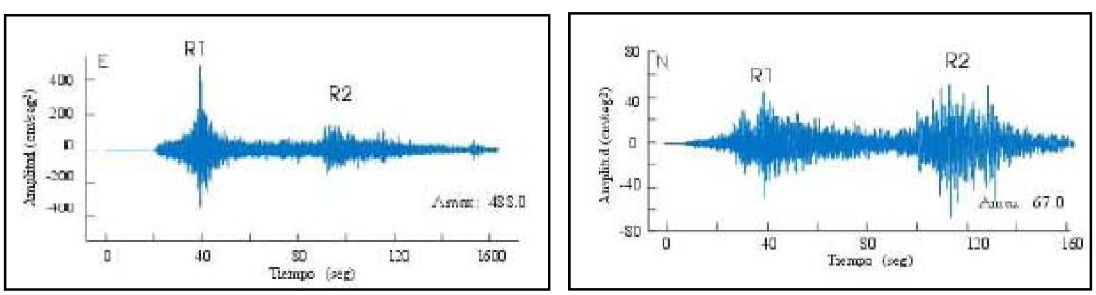
Figure 1. Affected area of the Pisco, Peru 2007 earthquake and stations location (Tavera et. al, 2007).

2. SEVERITY OF THE PISCO EARTHQUAKE

According to the structural point of view, the peak acceleration at a site is of main interest. The Peruvian Seismic Code (SENCICO 2003) specifies that a maximum acceleration of 0.4 g corresponds to a severe earthquake in a hard soil at the Pacific coastal area. Also, the Peruvian Seismic Code specifies that the base shear force has amplification factors (S) due to local effects caused by the foundation soil (1 for firm soil to 1.4 for soft soil).

The records of the Pisco earthquake acceleration show two ruptures sources of the tectonic plate (called R1 and R2 in Figure 2). The station located at the Catholic University of Peru (PUCP station) in Lima over hard soil, had a peak horizontal acceleration of 0.07g, and associated to rupture R2. This peak value approximately corresponds to the mean value of the 14 stations located in the province of Lima. Therefore, in Lima the earthquake can be considered as mild, in comparison to the severe earthquake considered by the Seismic Code.

The Parcona and Ica2 stations are located on a sedimentary soil; in these stations the peak ground acceleration was 0.49g and 0.33g, respectively, associated to rupture R1, with much reduced values for rupture R2 and the rest of the record. For the most affected area in Pisco and Chincha, several facts evidence that the shock can be considered as a moderate one. The roads and electric poles were severely affected only in soft soils. Also, several structures did not suffer damage although their stability appears to be rather poor (Figure 3).



Parcona, 0.49g in R1 **PUCP, 0.07g in R2**

Figure 2. Horizontal Acceleration records from Parcona, Ica (left) and PUCP, Lima (right) stations (Tavera et. al., 2007).

Figure 3. Evidences that the Pisco earthquake can be qualified as moderate.

3. SOIL LIQUEFACTION, FOUNDZATIONS AND RELATED EFFECTS

In the district of Tambo de Mora, province of Chincha, soil liquefaction produced several collapses of many adobe and masonry houses (1 to 3 stories high). This town has a very shallow water table, which during the earthquake provoked structural settlements (Figure 4). This severe damage demonstrates that in such soil conditions, the foundations should be very strong, economically unaffordable for the common people of the town. The first author of this paper suggested the major of Tambo de Mora to declare that area as an open museum, to show the effects of the soil liquefaction under non prepared structures.

Figure 4. Affected masonry houses in Tambo de Mora.

In Tambo de Mora, a few blocks away from the liquefaction area, a series of school buildings (Fig. 5), rests on a stable soil. The buildings of this school had only some small cracks in the masonry walls. Similar school buildings suffered damage during the earthquake of Nasca 1996 (Mw7.5, Muñoz et.al. 2004). It can be inferred that the accelerations in the stable soil area of Tambo de Mora must correspond to a moderate earthquake

Figure 5. School in Tambo de Mora, Chincha had slight damage.

The masonry walls have brittle seismic behavior, with a drift of 1/800 diagonal cracks appear. So, for soft soil, a rigid foundation must be used. The Pisco hospital (figure 6) had a new block with RC foundation beams and had a good behavior, while old blocks without rigid foundations had heavy damage.

Figure 6. Pisco hospital with rigid foundation in new block (right)

4. MASONRY UNITS

In the provinces of Pisco, Chincha and Ica it was observed that artisan made bricks, industrial tubular bricks and hollow concrete blocks, are popularly used for bearing and infill walls in buildings. According to the Peruvian Masonry Building Code (Norma E.070 in Spanish), in this seismic zone, artisan bricks may only be used for 1 or 2 stories. Also, the use of tubular bricks and hollow concrete blocks is forbidden in bearing walls because they crush at failure (Figure 7), losing drastically the resistance and rigidity of the walls (San Bartolomé 2007).

Figure 7. Inadequate masonry units used in Chincha, Pisco and Ica.

5. WALL CONSTRUCTION

The way in which buildings in the affected area of Pisco and surroundings are constructed is hybrid, lying between confined masonry and framed RC with infill walls. This is a wrong structural conception, caused by informality construction and poor qualified hand labor. In such a hybrid typical wall, firstly the RC columns are cast, then the masonry wall is constructed, and finally, the RC roof slab and beams are cast. For this reason, hybrid masonry walls carry vertical load, but are not integrated with the concrete columns, as if a vertical smooth joint between wall and column existed.

The Peruvian Masonry Code (SENCICO 2006) does not allow the construction type described. This code establishes that for a wall to be confined, the masonry wall has to be firstly built, and then the concrete of the columns can be poured. The connection between RC columns and masonry wall can to be toothed, or vertical with added connecting wires in the horizontal joints anchored in the columns. The construction sequence used in the Pisco buildings does not provide vertical support to the masonry wall under out-of-plane seismic forces. Therefore, after the earthquake, in many cases it could be observed that the masonry walls fell by overturning, especially in the higher stories (Figure 8), in which the acceleration are larger and the gravity load is less. A suggestion for such existing walls is to tie the masonry to the columns by using welded wire mesh.

Figure 8. Overturning of masonry walls in high stories due to out-of-plane seismic forces.

6. ARCHITECTURAL AND STRUCTURAL CONFIGURATION

6.1. Soft story and torsion

The soft story occurs due to a sudden change in rigidity between consecutive stories. In figure 9, along the shorter direction of the building, the first story walls did not continue for the use of parking area in the first floor, expect the perimeter walls. The units of these walls are poor quality bricks, so the wall has low shear resistance. The walls at the building borders (corner) also produced an important torsional effect. Therefore, after the failure of the first floor walls in the short direction, the soft story problem developed and the whole building collapsed.

6.2. Low wall density

In the Peruvian Masonry Code (SENCICO 2006), buildings are required to have a minimum wall density in each direction, and, it must be verified that the provided wall resistance should be at least equal to the seismic shear force in the floor under analysis on a severe earthquake. The buildings shown in figure 10 were not only built with low quality bricks, but also had not enough wall density in the short direction as the Code requirement.

Figure 9. Soft story and torsion.

Figure 10. Low wall density

6.3. Non bearing walls in Façades.

In some building façades, more area is added in the upper stories by cantilever slabs. Quite often, the walls in the room with part in cantilever are built using tubular bricks (called "pandereta" in Peru). Even though a toothed connection may exist with the orthogonal walls, it is not enough to resist the out-of-plane seismic forces, and fail by overturning (Figure 11) in a dangerous way, as they may fall over people getting out by the first floor. Such non bearing walls should be retrofitted, for example, using welded wire meshes.

Figure 11. Failure of cantilever facades by out-of-plane forces

7. STRUCTURAL DETAILING IN MASONRY AND REINFORCED CONCRETE ELEMENTS

Several defects in the structural detailing could be observed in masonry buildings in the affected area. All of the following issues are mentioned in the Peruvian Masonry Code E.070 (SENCICO 2006) and were not complied: absence of diaphragms, missing collar beams, columns without continuity, beam-column joints without ties, and more. Some of the abovementioned situations are shown in figures 12 and 13.

Figure 12. Collapse of roofs and walls in buildings without rigid diaphragm

Figure 13. Walls without collar beam and column without continuity (left); bracing vertical columns too far apart each other (right); in both cases masonry failure is observed.

8. PERIMETER WALLS AND PARAPET WALLS

In Peru, most properties feature a tall perimeter wall (2.40m or higher) for protection purposes. Most of such walls are made of clay masonry and others are earth walls (adobe or tapial). Other shorter walls used at the edge of balconies and buildings are mostly masonry walls called parapets. These walls have to be designed to resist out-of-plane seismic forces. Therefore, bracing RC columns and beams are used to prevent overturning.

After the Pisco earthquake, in cities along the way between Lima and Ica, many perimeter walls and parapet walls collapsed by overturning, mostly due to lack of braces, or even when a rather small masonry wall was used as brace in the orthogonal direction. In several cases, the RC bracing columns collapsed together with the masonry wall due to lack of resistance, see Figures 14 and 15.

Figure 14. Perimeter walls collapsed by overturning. Masonry Piers are not enough.

Figure 15. Parapet wall without bracing collapsed (left) and other adequately braced undamaged, both located on the third floor of their respective buildings, Pisco.

9. CONCLUSIONS

1) The 2007, August 15 earthquake may be classified as mild for Lima, and moderate for Pisco and Chincha. This earthquake put into evidence a series of defects that are present in masonry constructions. It is believed that most of the defects are due to the informality in the constructions, although National Construction Codes are available for Seismic and Masonry design (as well as adobe).
2) In the liquefaction area of Tambo de Mora, Chincha, it is recommended that no buildings should be built. Instead, a site museum is suggested, so that everybody visiting that town can see the destructive effects and understand such phenomena. Other potential areas of liquefaction should be identified and extreme precautions should be observed.
3) The severe damage in the city of Pisco was observed mainly in soft soil conditions (sand with shallow water table). In such situations, it is recommended the use of rigid concrete foundations for any kind of buildings.

4) It is important that the officials that approve the building projects for construction license at the municipalities, have skills and training required to detect some common problems that may occur during future earthquakes, such as soft story, torsion, short column, low wall density, etc. Also, it is necessary that engineering inspectors visit continuously site constructions to verify that the code requirements and the structural aspects to be accomplished.
5) In the affected area it is imperative to train the masons and other construction labor men in the correct way to construct the confined masonry walls. The field observations indicate that the present way of wall construction does not allow the RC columns to work as braces under out-of-plane seismic forces. In the upper stories of existing buildings it is necessary to improve the stability of masonry walls.

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