PERFORMANCE OF REINFORCED ADOBE HOUSES IN PISCO, PERU EARTHQUAKE

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ABSTRACT :

The Pisco, Peru earthquake of August 15, 2007 (Mw8.0) produced large destruction of adobe constructions in cities and rural towns located in the central coast of Peru. Other buildings of reinforced concrete and masonry were also severely affected or collapsed. However, no damage occurred in five existing adobe houses in the province of Ica that were reinforced in 1998, while neighbor houses without reinforcement, had massive collapses of entire walls and roofs. This successful seismic resistance of reinforced adobe houses was also observed in the June 2001 earthquake (Mw8.4) in southern Peru. The seismic reinforcement used in all the cases described above, consists on strips of wire mesh nailed externally to the adobe walls, in vertical and horizontal directions, simulating columns and beams; these strips are later covered with cement mortar. The dissemination of this reinforcement technique should be done in seismic areas of the world in order to avoid damage to millions of existing adobe houses, protecting the life of people with less economic resources.

KEYWORDS: Adobe, Pisco, earthquake, constructions, reinforcement, wire

1. THE 2007 PISCO EARTHQUAKE

On 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, Ms=7.9, and Mw=8.0, respectively (Bernal 2007). The earthquakes in this area are caused by the subduction of the Nazca plate under the South American Plate. 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 province of Ica where the five adobe houses were reinforced in 1998 is 130 km south east of this epicenter (fig. 1).

Figure 1 Pisco earthquake epicenter in circle and location of the reinforced adobe houses in Ica

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

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 seismic behavior observed in adobe constructions, in which the traditional houses had massive collapses, while a few reinforced houses from demonstration projects exhibited excellent behavior without damage.

The traditional houses are vulnerable due to: 1) high mass, 2) weak material, 3) lack of reinforcement, 4) poor workmanship, 5) null maintenance, among other reasons. The obvious lesson again after this earthquake is that in moderate or severe earthquakes, the traditional adobe houses may have significant damage like thick cracks and collapse of walls and roofs. Therefore, incorporation of reinforcements is a must to provide enough resistance to avoid damage in moderate earthquakes and resist severe earthquakes with allowable damages.

2. THE GTZ-CERESIS-PUCP RESEARCH PROJECT FOR EXISTING ADOBE HOUSES

The project was developed between 1994-1999 under the agreement between the Regional Seismological Center for South America (CERESIS), the Pontifical Catholic University of Peru (PUCP) and the financial support of German Technical Agency GTZ. The main objective of the project was to find ways to protect lives of millions of inhabitants of the Andean Countries that live in adobe houses, when a severe earthquake occurs. The project had three stages: 1) laboratory tests, including seismic simulations in shaking table to establish a reinforcement technique; 2) application of the selected technique in several houses in seismic areas in Peru and other Andean countries as pilot projects; and 3) evaluation of seismic performance after an earthquake.

The laboratory tests were performed at the Structures Laboratory of PUCP (Zegarra et. al, 1996). After several trials, the technique for reinforcing existing adobe houses that showed better performance was to put strips of wire mesh nailed externally to the adobe walls, at the most vulnerable zones, which later should be covered with mortar. The zones for vertical strips were located were the corners at the intersection of orthogonal walls, the intermediate area of long walls and at free ends; at the upper part of the walls, a horizontal strip must connect the vertical ones. This mesh is composed by 1 mm diameter wires, with 19mm (¾") spacing.

3. THE REINFORCED HOUSES IN ICA

In Peru, 20 houses in 6 towns were selected for the pilot projects (San Bartolome et. al., 2004) but some more were partly reinforced for demonstration purposes. In the province of Ica, the pilot project included 2 houses, in the towns of Guadalupe (km 293 Pan American Highway) and Pachacutec (km 314 Pan American Highway). The demonstration houses were 3, in Ica Central, Parcona and La Tinguiña (CERESIS, 2000). All 5 houses were retrofitted in 1998.

The house in Guadalupe belongs to the Espinoza-Trillo family; it is located at the corner of streets Rimac and Callao, just two blocks away from the Pan American highway. The house in Pachacutec belongs to the Legua-Rupay family; it is located in the middle of other properties, a 1-story adobe house to the right and a 3-story masonry house to the left. The front room is made of brick masonry and the back rooms are of adobe, where the reinforcement was applied. In figures 2 and 3 a plan of these houses is shown, with the location of the vertical mesh strips. When it was possible, the reinforcement was applied to both sides of the walls. In the case of walls adjacent to the neighbor houses, only the side of the pilot house was reinforced.

The reinforcement was applied with the following steps (San Bartolomé 2007): 1) marking on the walls the place where the strips of wire will go; 2) cleaning of the surface of the strips, if a previous covering existed (Pachacutec house) it was removed; 3) drilling holes in the zone of vertical strips every 0.5m; 4) preparing the connecting bars and cutting of the wire meshes; 5) filling the holes with mortar with connecting bars embedded; 6) locating the vertical strips of wire meshes, fixing the mesh to the wall with nails and small metal caps or

sheets, and bending the connecting bars; 7) locating and fixing the horizontal strips; 8) covering the strips with mortar of cement: sand. In figures 4 and 5 different parts of such reinforcement process are displayed.

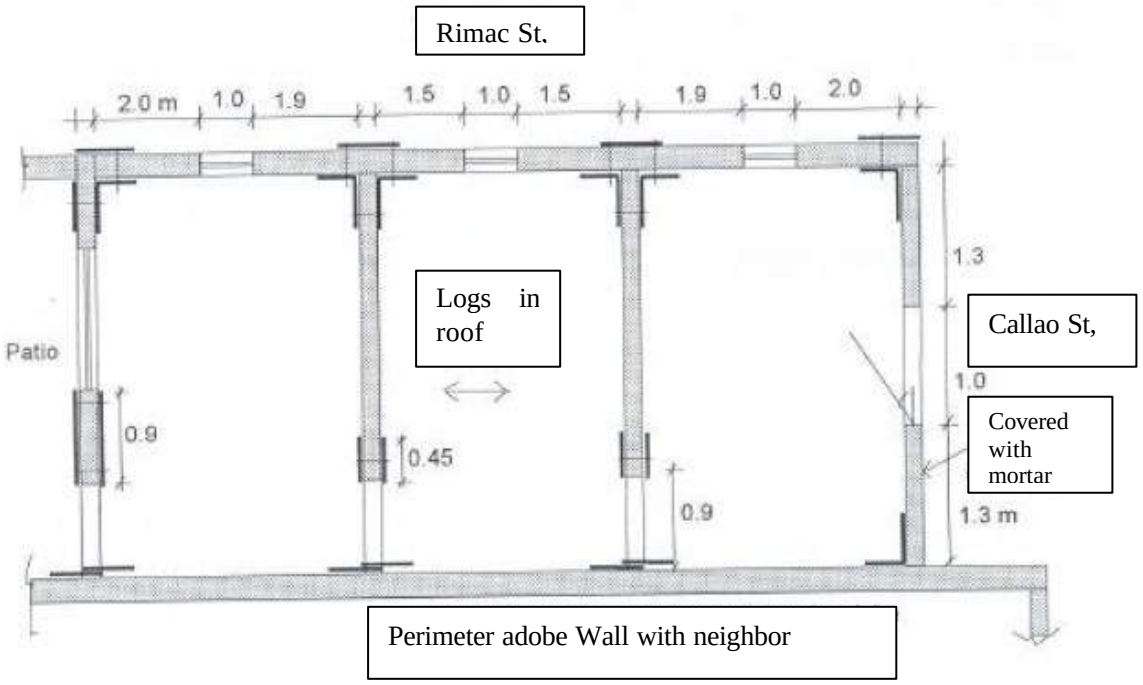


Figure 2. Adobe house in Guadalupe with location of vertical strips.

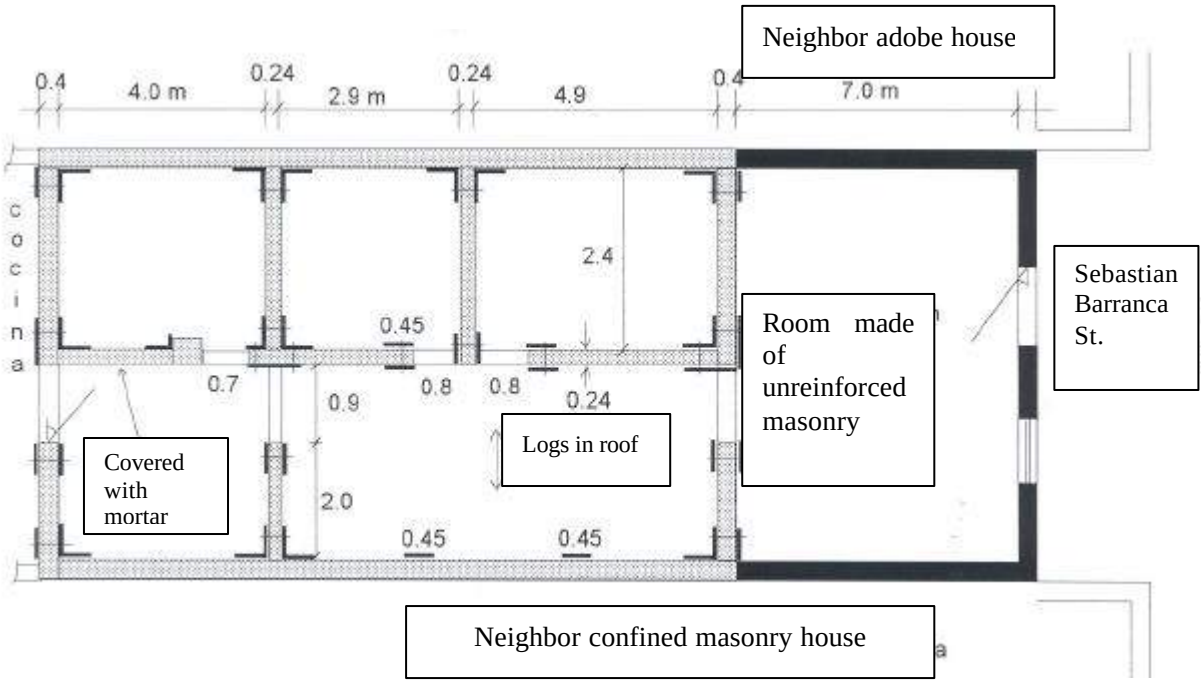


Figure 3. Adobe house in Pachacutec with location of vertical strips.

Figure 4. Adobe house in Guadalupe retrofitted in 1998 (left to right): marking horizontal strip at outside wall, nailing horizontal strip in inner side of wall.

Figure 5. Adobe house in Pachacutec retrofitted in 1998 (left to right): marking vertical strip, removing existing covering, and marking horizontal strip.

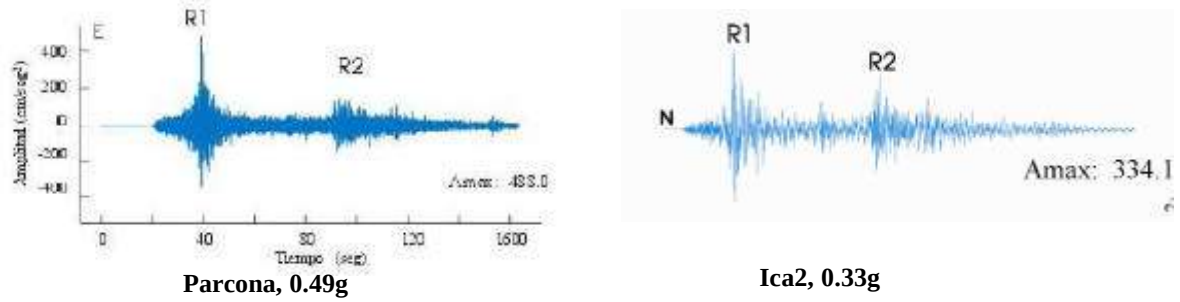
In the three demonstration houses in Ica, part of the wire mesh was left without covering while the other had the mortar covering. This part of the project was performed using the labor men that learned about the reinforcement technique in the two houses of the pilot project in Guadalupe and Pachacutec (figure 6).

Figure 6. Demonstration adobe houses in (left to right) Ica Central, Parcona and La Tinguiña, during reinforcement in 1998.

4. THE PERFORMANCE EVALUATION AFTER THE 2007 EARTHQUAKE

Previously, on June 23 2001, a strong earthquake hit southern Peru (Mw8.4). Six houses of the pilot project in the affected area had an excellent behavior, without any crack (San Bartolome et. al., 2004). The German Agency GTZ took this into account to aid reconstruction in the affected area, having supported the construction of more than 400 new adobe houses, 10 demonstration houses, 2 office sites, and more (Quiun et. al., 2005).

On the August 15, 2007 earthquake, two strong motion records were produced in Ica, in the stations called Parcona and Ica2, about 138 km from the epicenter (Figure 7, Tavera et.al. 2007).



Parcona, 0.49g **Ica2, 0.33g**

Figure 7. Horizontal acceleration records in Parcona and Ica2 stations (Tavera et.al. 2007)

All 5 existing adobe houses retrofitted with strips of wire mesh in the affected area of Ica had an excellent seismic behavior without damage, while neighbor traditional constructions had massive failures, wall cracks and collapses. In figures 8 and 9 the reinforced adobe house of Guadalupe and unreinforced neighbor houses of traditional adobe, respectively, may be seen a few days after the event. Only the unreinforced wall of the patio, next to the reinforced area, collapsed by overturning; it was not reinforced due to lack of funds of the owner.

Figure 8. Guadalupe retrofitted adobe house without damage (except unreinforced patio wall)

Figure 9. Other adobe houses with severe damage in Guadalupe

In figures 10 and 11 the reinforced adobe house of Pachacutec without damage and some unreinforced neighbor houses with damage, respectively, are shown a few days after the event.

The Parcona house was partly reinforced, leaving a part of the outside mesh without covering and had no damage (fig. 12). This house is used as the station for the accelerograph, in which the foundation soil is sand lime (Tavera et. al., 2007). Other neighbor adobe houses had severe cracks and had to be demolished (fig.13).

Figure 10. Pachacutec retrofitted adobe house without damage

Figure 11. Traditional adobe houses with damage in Pachacutec

Figure 12. Partly retrofitted Parcona house without damage

Figure 13. Demolished adobe walls in neighbor houses in Parcona

In La Tinguiña, the demonstration adobe house was partly reinforced only in the front room (fig. 14). To the left side in fig. 14 it is observed that the wire mesh has not mortar covering. The back room without any reinforcement had important cracks (fig.15). Similarly, the house in Ica Central was not affected by the earthquake (fig. 16), while other neighbor adobe houses had severe cracks.

Figure 14. Partly retrofitted house in La Tinguiña had no damage.

Figure 15. Non reinforced back room of the house in La Tinguiña had cracks.

Figure 16. Partly retrofitted house in Ica Central had no damage

In the town of Pacaran, province of Cañete, Lima, some new houses were built by a demonstrative project of JICA with internal cane reinforcement and wooden collar beam. These houses also withstood the earthquake without damage, and other houses in the same town had important cracks. This fact also shows the importance of good construction practices and the need of reinforcement in adobe houses.

5. CONCLUSIONS

The project of reinforcing existing adobe houses has had two important tests in real earthquakes in 2001 (south Peru) and in 2007 (central Peru). Six retrofitted houses in 2001 and five retrofitted houses in 2007 have resisted the earthquakes without any damage, while neighbor constructions of traditional adobe houses without reinforcements have had heavy damage or complete collapses.

The applied reinforcement consisting of strips of wire meshes nailed externally to the adobe walls, covered with mortar simulating columns and beams has shown excellent seismic behavior. Even partially reinforced walls (with wire mesh but without the mortar covering) have shown adequate seismic behavior. The technique is easy to apply by labor men with very little training. This reinforcement does not need to enter the foundation neither the roof, therefore it is suitable for millions of existing adobe houses in seismic areas worldwide, especially applicable to the traditional houses in which many people of less economic resources live. Other proposed reinforcement techniques still cannot exhibit similar results in real houses in strong earthquakes. Therefore, dissemination of successful techniques as the one shown here for adobe houses is required.

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