BEHAVIOR OF EARTHEN BUILDINGS DURING THE PISCO EARTHQUAKE OF AUGUST 15, 2007

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Introduction

This brief report is based on the visits made to the affected area with Eduardo Fierro, EERI Team leader, on Saturday August 18th and with a PUCP team led by Nicola Tarque, who started the site inspection on Friday August 17th and then joined the EERI team. The cities visited were, from South to North, Ica, Paracas, Pisco, Chincha, and Cañete. Small towns neighboring these cities were also visited.

The earthquake caused enormous damage to all earthen buildings in the affected area. Pisco was the city closer to the epicenter and thus undoubtedly sustained the heaviest toll. Most adobe houses and churches in Pisco collapsed or suffered irreparable damage. The damage observed in Pisco was repeated, to a lesser extent in the neighboring cities and towns.

Traditional adobe houses

Adobe construction is widespread in Peru. Most houses 50 years old or older are made of adobe. Although confined masonry is becoming the preferred construction technique for families who can afford it, adobe construction is still the only viable alternative for many families in Peru.

On the Peruvian coast, most adobe houses are one story high. When the house has two stories, the second story is usually built with *quincha*, a series of wooden frames filled with crushed cane, covered with mud and plastered with mud or gypsum. Since it does not rain on most of the Peruvian coast, roofs are horizontal and flat, and consist of wooden joists supported directly on the adobe walls and covered by wooden planks or a layer of crushed cane, sometimes also covered by straw mats (*esteras*) and then plastered with mud.

Wall thickness and height depend mostly on the age of the dwelling: older houses have thicker, taller walls (up to 0,80 m thick, 4 m high; with slenderness ratios of 5 to 6). Contemporary houses have thinner, shorter walls (typically 0,25 m thick, 2,5 m high, with slenderness ratios between 8 and 10 or higher).

Interior walls and partitions are made of adobe or *quincha*. In neither case the walls were provided with additional reinforcement to withstand seismic forces.

In Pisco, more than 80% of the adobe houses collapsed or sustained heavy damage. This was due to the perverse combination of mechanical characteristics of adobe walls: they are massive, weak and brittle. Since they are massive, they attract large inertia forces during seismic shaking, which they are unable to resist because the masonry is weak, and brittle failure occurs without warning. Furthermore, it seems that the adobe blocks and mortar in the Pisco and surrounding areas were made with sandy soil, which did not have sufficient clay to provide good adhesion between mortar and adobe blocks. Figure 1 shows a view of a street in Pisco, full of debris from collapsed adobe houses.

Fig.1 Street in Pisco three days after the earthquake. Most of the adobe houses suffered total collapse. The light blue house at the far right, undamaged, was made of confined masonry.

The most common type of failure observed in adobe houses was due to the formation of vertical cracks at the corners of the façade walls as a result of out-of-plane shaking, followed by the collapse of the walls onto the street and sometimes the collapse of the roof (especially if the roof joists were supported on the façade wall). A top collar beam joining all walls probably would have been helpful to prevent this type of damage. See Fig. 2 below.

Fig. 2. Two collapsed adobe houses in Pisco. The roof joist of the house on the left are supported on the *quincha* partitions. The roof joists of the house on the right were supported on the façade wall, and thus collapsed with the façade. Notice the undamaged confined masonry house at left, and the collapsed masonry parapet on the house at the back right.

In some adobe houses the walls that did not collapse out-of-plane showed the typical diagonal cracks due to in-plane loading, following the staircase pattern within the mortar-block interface. A few adobe houses did not suffer significant damage because they were confined by neighboring confined masonry houses.

Reinforced adobe houses

In 1999 the Catholic University of Peru (PUCP) reinforced 19 adobe houses in different locations of the country. The reinforcement consisted of bands of welded wire mesh nailed to the walls and covered with a cement-sand mortar. Figure 3 shows the house that was built in Guadalupe, a small town near Ica. It did not suffer any damage during the Pisco earthquake, whereas neighboring unreinforced houses suffered significant damage or collapsed. This reinforcing system should be used with caution because although shaking table tests have shown that the strength of the adobe walls is significantly increased, the mode of failure is brittle.

Fig. 3. This undamaged adobe house was reinforced with bands of wire mesh covered with sand-cement mortar. Vertical bands were placed at each wall intersection, and horizontal bands at roof level. Notice the collapsed unreinforced wall at the right.

Churches

There are many beautiful ancient churches in Peru. Many of them are built with adobe walls and a *quincha* vault covering the nave. Most churches suffered tremendous damage during the earthquake. The most dramatic case was that of the San Clemente church in Pisco, where the vault collapsed suddenly and killed around 160 people who were attending a funeral service. The priest was saved because he was under the dome, which had been repaired with reinforced concrete after a previous earthquake. Figure 4 shows a side view of the church of San Luis, a small town just South of Cañete. It seems that the lateral thrust of the vault pushed the supporting lateral wall, weakened by a door opening.

Fig. 4. San Luis Church. The lateral wall and its heavy abutments were practically torn down, presumably by the dynamic thrust of the collapsing vault. The towers are made of *quincha* and suffered little damage.

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