Evaluation of seismic performance of retrofitted houses

One of the houses retrofitted in the above mentioned project was located in Guadalupe, Callao Street #304, Panamerican Highway, Km. 193 (S 13° 59.179’ W 75° 46.458’). The house is located in a flat area in the vicinity of a small canal and surrounded by several adobe houses and two unpaved streets as shown in Fig. 4.66.

The fairly symmetric house is a one story building with a shared wall, two façade walls aligned with Callao Street and Rimac Street, respectively, and three internal walls. The roof is made of straw mat with bamboo joists. There was no evidence of foundation, however, based on an interview survey, it was found that, in this region, it is common to dig a 60cm-deep trench, place thick adobes inside, and then build walls on top of them. It may be possible that this “foundation” was used when the house was originally constructed.

The house was retrofitted based on the guide shown in Fig. 4.65, and the details of the construction for the wire steel mesh are shown in Fig. 4.67. The mesh was set in all house’s corners and in the intersection of internal and external walls. In the internal walls additional mesh was installed beside the doors, the backyard wall was not retrofitted at all due to budget constraint. No mesh was installed on the main entrance wall.

Fig. 4.66. Front and side of Guadalupe retrofitted adobe house.

Fig. 4.67. Layout of Guadalupe adobe retrofitted house.
The inspection of the house showed that it suffered almost no damage due to the earthquake although the damage rate of adobe houses in Guadalupe was over 80%. A few vertical cracks were observed in the mortar cover of the “collar beams” inside the house. It is believed that they just affected the cover and did not pass through the walls. It is important to mention that the backyard wall, which was not retrofitted, collapsed due to the shaking. A small portion of the steel wire mesh, without any corrosion signs, was exposed as shown in Fig. 4.68.

Fig. 4.68. Retrofitted house after the Pisco Earthquake

In order to identify the dynamic properties of the structure, microtremors were measured on the house roof and at the ground as shown in Fig. 4.69. Two 300sec-long measurements, sampled at 100Hz, were taken. The spectral ratios were calculated and they are shown in Fig. 4.69. A clear peak at 0.08sec is observed. This predominant period is similar to those measured in non reinforced adobe structures with similar characteristics suggesting that, as expected, the retrofitting procedure, did not affect the natural period of the structure.

(c) Measurement arrangement

Fig. 4.69. Ratio of Fourier spectra of microtremor measurement in retrofitted adobe house.
4.3.2. Construction of new earthquake resistant adobe houses

The Japanese International Cooperation Agency (JICA), the Peruvian NGO Alternativa and the National Service for Training for the Construction Industry (SENCICO), worked together between 2004 and 2006 in the pilot project “Training and Diffusion of Improved Adobe Technology for the Construction of Healthy and Secure Houses”. The main purposes were to train and motivate local people to construct adobe houses using an improved technology. During the development of the project seven model houses, located in the rural areas of Lunahuana, Pacaran and Vinac in Lima Region, were constructed. All these locations are seismically active.

Fig. 4.70 Vertical and horizontal adobe reinforcement. After E.80 [11]

The construction technique for the model houses followed the adobe standard NTE E.80 for cane reinforcement. It incorporates techniques regarding improvements in adobe fabrication and reinforced construction processes. The cane reinforcement consisted of a grid of vertical and horizontal canes (see Fig. 4.70), tied-up in the crossing points of the walls, foundation and ring beams. This type of reinforcement improved the response of adobe walls against seismic loads. Vertical reinforcement restrains out-of-plane bending and in-plane shear, while horizontal reinforcement transmit the out-of-plane forces in transverse walls to the supporting shear walls and restrain the shear stresses between adjoining walls. An additional reinforcement used in the model houses was the timber ring beam that ties the walls in a box-like structure and supports the roof. A systematical procedure for the construction of this kind of reinforced adobe house is shown in Fig. 4.71.
Step 1. Foundation. No reinforce beam W= 55cm H=80cm. Vertical reinforcement is fixed to the beam.

Step 2. Vertical Reinforcement. Canes are placed on center of wall every 80cm, buried 10cm.

Step 3. Horizontal reinforcement. Crushed canes are placed every four layers and connected to vertical canes with nylon strings.

Step 4. Ring beam. Timber beams are fixed the top of adobe wall. (7.5x7.5cm)

Step 5. Roof. Timber beams are placed every 60 cm (5x20cm)

Fig. 4.71. Construction procedure for adobe cane reinforced house. After Narafu [12]

4.3.3. Evaluation of the seismic performance of reinforced houses

Three reinforced adobe houses, 1- and 2-story, inside of the affected area were visited and two of them were evaluated in detail. These are located near Pacaran city, in a flat area with a small hill at the backside (S 12° 51.719’ W 76° 03.271’).
The plan view of both houses is shown in Fig. 4.73. Both of the reinforced houses were constructed following the procedure shown in Fig. 4.71. The roofs are light and well connected and the foundations were made of unreinforced concrete. The 2nd floor of the 2-story house was made of light prefabricated quincha panels.

After the Pisco Earthquake, the houses seemed to be in good condition, although some cracks in the plastering of the quincha panels on the second floor were observed. It is important to mention that the number of damaged houses in Pacaran was not as large as other cities inside of the affected area. However, some nearby public buildings made of adobe collapsed due to the shake.

The dynamic properties of the structure were evaluated using microtremor measurements. The arrangement used for reinforced houses is shown in Fig. 4.74. In this case one sensor was located in open field, another close to house’s foundation, and the other ones on the roof of each floor.
Three measurements were taken at 100Hz during 300 sec. The spectral ratio was calculated and it is shown in Fig. 4.75 for the 1-story house. A clear peak at approximately 0.07 sec is observed in both X- and Y-directions. Compared to the house measured at Guadalupe, Ica, this structure is stiffer. This may be due to the buttresses which are used in this structure and the stiffer roof.

For the 2-story house, spectral ratios 1st Floor Roof / Free field and 2nd Floor Roof / Free field were calculated and are shown in Fig. 4.76. Although the response at the 1st floor roof shows one clear peak at 0.06s in X- and Y- directions, the response at the 2nd Floor roof is more complex and shows multi peaks. The lowest period corresponding to one of these peaks is 0.06s, in both X- and Y-directions, which coincides with the natural period of the 1st floor roof response. This may suggest that it is the effect of the 1st floor on the 2nd. The remaining peaks may indicate additional vibration modes active for the 2nd floor, which are not transmitted to the 1st floor because the mass of the second floor is very small compared to that of the 1st floor. Further analysis is necessary to confirm these interpretations.
Fig. 4.76. Ratio of Fourier spectra of microtremor measurement in reinforced 2-story adobe house

4.4. Final Remarks

Predominant construction systems in the areas affected by the 2007 Pisco Earthquake are adobe and confined masonry combined with light roofs made of either straw mat or light gage steel plates. Although the relatively small death toll during this
The earthquake was mostly due to the time occurrence, 18:41, the predominant light roofs may have also contributed to keep this number low.

The structures that were designed and built according to the construction codes performed well. Design and construction deficiencies caused most of the observed structural damage.

Many public facilities, including schools, hospitals, churches, and hotels, performed badly. More than 30% of the casualties in this earthquake were caused by the collapse of San Clemente Church in Pisco. The main hospital of Pisco City was also heavily damaged as well as large part of the school infrastructure.

A few reinforced adobe houses were located in the affected area and performed well during the event. They demonstrate that adobe can have a good seismic performance if adequately treated. The reinforcement with bamboo is adequate for new constructions as long as there is enough bamboo. The reconstruction experience after the 2001 El Salvador Earthquake showed that in some cases, when the number of houses to be reconstructed is too large, there may not be enough material available and using industrial materials is needed.

For retrofitting existing structures, the steel wire mesh has showed good performance. However, there is controversy among experts who argue that instead of increasing strength, as with this method, it is more important to increase ductility. In addition, this system is still expensive for the majority of the Peruvian population. Other cheaper solutions which address the ductility issue are presently available such as external coatings with polymer meshes and PP-band meshes [18, 19, 20].

REFERENCES

[1] INEI, Population and Housing Census 2005