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EVALUATION OF HOUSING LOSSES IN RECENT EARTHQUAKES IN LATIN AMERICA

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SUMMARY

Several recent earthquakes in different areas of Latin America have caused an important toll of casualties and injuries, damage in housing construction, and significant losses in the local and national economies. This paper reviews the observed performance of housing construction in the following earthquakes: 1999 Armenia, Colombia; 1985, Michoacan, Mexico; 1997, Caleta de Campos, Mexico; 1999 Oaxaca, Mexico; 2001 San Salvador, El Salvador; 2001; Arequipa, Peru, and 2003 Colima, Mexico.

The study reveals that masonry construction is the most common solution for housing construction in Latin America. Mainly two types of masonry are used: adobe (sun-dried mud blocks) and confined brick masonry (masonry with vertical RC tie-columns to confine brick walls and RC bond beams along walls at floor levels). During the recent earthquakes analyzed, adobe construction and unconfined brick masonry had the highest rate of damage or collapse, and in general good performance was observed in confined brick masonry housing.

The paper also discusses several examples of good and bad housing construction practices. Some events such as the 2001 San Salvador earthquake pointed out the importance of avoiding construction in areas prone to landslides or liquefaction by conducting proper planning in an urban development. Some recommendations are given to reduce seismic vulnerability of housing construction in Latin America.

INTRODUCTION

Several recent earthquakes in different areas of Latin America have caused an important toll of casualties and injured people, damage in housing construction, and significant losses in the local and national economies. Confined brick masonry (masonry with vertical RC tie-columns that confine brick walls and RC bond-beams along walls at floor levels) is the most common types of masonry construction in urban areas. However, unconfined masonry is also used, especially in rural areas. The wide use of masonry dwellings in Latin America suggests that understanding and reducing seismic vulnerability in this type of

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dwelling is an important task for countries in this region. This paper focuses on the observed behavior of masonry dwellings during past seismic events in Latin America and discusses several examples of good and bad housing construction practices. Some recommendations are also given to reduce seismic vulnerability of housing construction in Latin America.

OBSERVED BEHAVIOR OF MASONRY DWELLINGS DURING PAST EARTHQUAKES IN LATIN AMERICA

The 25 January 1999 Colombia Earthquake

The magnitude 6.2 M_L earthquake occurred in an epicentral area near the cities of Armenia and Pereira, with populations of 270,000 and 380,000, respectively. These were the largest cities affected by the earthquake although other smaller cities were also severely damaged. The total number of deaths in Armenia alone was about 1,000, and about 5,000 people were injured in this city (EERI, 2000). Armenia was the city that suffered the highest rate of deaths and damage in dwellings. From a total of 26,456 dwellings reported in an evaluation of observed damage in Armenia (EERI, 2000), about 1,000 dwellings collapsed. A good number of damaged dwellings were in neighborhoods that were severely damaged, with rates that in some cases reached values higher than 50 percent. A strong correlation was observed between the presence of soft soils and severely damaged or completely destroyed areas (EERI, 2000). Poor quality construction and poor detailing were important factors that also contributed to the collapse. Among these factors unconfined masonry and poor quality non ductile reinforced concrete can be mentioned. It was estimated that in Armenia alone the number of displaced people was about 100,000. It is of interest that the urgent need of housing for those affected by the earthquake prompted the owners to repair their houses without technical directions.

It must be mentioned that for low-cost dwelling construction in the affected area bamboo is used for both structural and non-structural elements. No damage was observed in a bamboo housing project in Armenia (EERI, 2000), which suggests a promising use of bamboo for low-cost dwellings in Latin America. However, some improvements in detailing in order to connect the clay tile roofing and walls seem necessary.

Mexico earthquakes in 1985, 1997, 1999 and 2003

The 1985, 1997 and 1999 earthquakes

The 1985 Michoacan earthquake (MI85) was the result of the subduction of the Cocos Plate under the continent and has been classified as of the interplate type. Figure 1 shows the zone of rupture of this event, as well as the location of several towns and villages, and some accelerometers that recorded ground motions. Several reports have been published on observed damage in structures during this earthquake. Most of these reports describe damage in Mexico City. Little information can be found on the behavior of masonry dwellings near the epicentral location of MI85 on the Pacific coast. However, it is accepted that most of the damage occurred in Mexico City, with little or no damage in masonry dwellings in either Mexico City or in the area near the epicenter (Rosenblueth and Ruiz, 1989; NZ Reconnaissance Team, 1988).

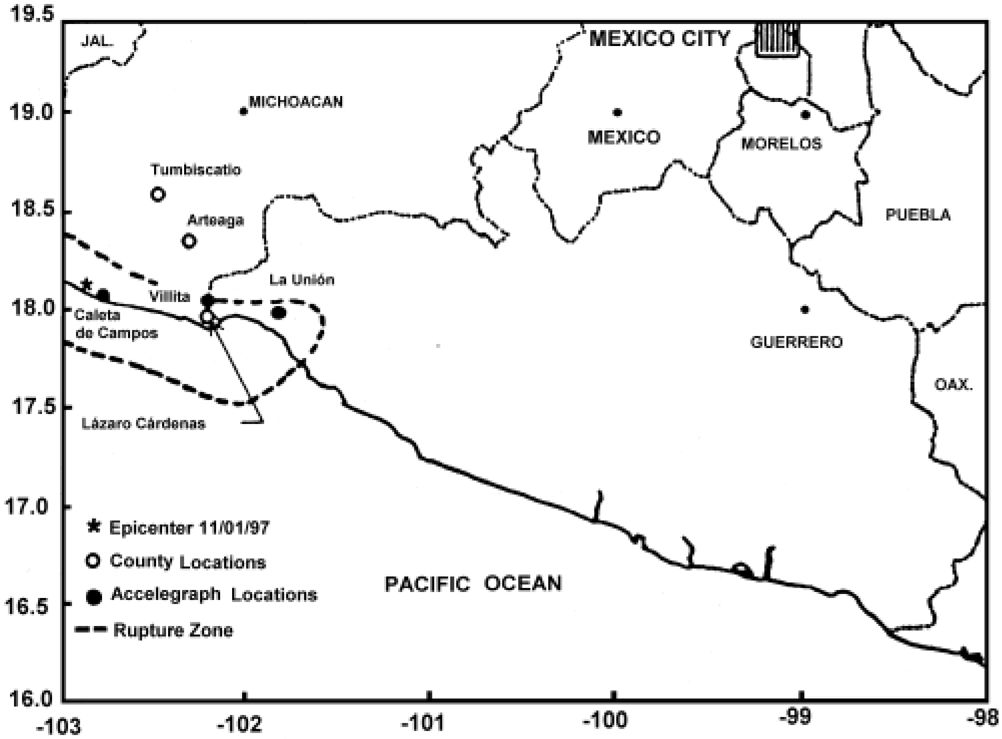

Figure 1. Epicenter and station locations in the 1985 Michoacan and 1997 Caleta de Campos Earthquakes

The epicenter of the 1997 Caleta de Campos earthquake (CC97) was located within the zone of rupture of the MI85 (Figure 1). Interestingly, this earthquake has been reported as a normal-faulting intraplate event, which is interpreted as a result of internal deformation of the subducted slab (Anderson et al., 1997; Singh et al., 2000), which did not necessarily occur immediately below or near the edge of the coupled interface (Singh et al., 2000).

Rodriguez et al. (1998) have analyzed the peak ground accelerations and Arias intensities (Arias, 1970) from a set of accelerograms recorded in several stations (Caleta de Campos, La Union, and Villita, Figure 1) during both MI85 and CC97. The Arias intensity is considered a measure of the potential seismic destructiveness associated with an earthquake. The analysis of ground motions recorded in the Caleta de Campos station, located near the CC97 epicenter, is of particular interest since the amount of damage in masonry dwellings in the area near this station during CC97 was much higher than that observed during MI85. In this station, both accelerations and Arias intensities were smaller for MI85 than for CC97 event. For the records obtained in the La Union and Villita stations, the same parameters were higher for MI85 than for CC97.

Rodriguez et al. (1998) have also studied the statistics of observed damage during the CC97 in masonry dwellings the towns of Arteaga, Lazaro Cardenas and Tumbiscatio, located in the Michoacan area, near the epicenter of the earthquake (Figure 1). Unconfined masonry dwellings suffered considerable damage, much higher than that observed during MI85 in the same area, particularly with a high rate of damage in adobe dwellings. These results are surprising because the 1985 event has a magnitude $M_S = 8.1$, much higher than that of the 1997 event, $M_S = 7.1$. This suggests that intraplate earthquakes are more damaging to masonry structures than interplate events with higher magnitudes.

Another Mexican earthquake that is interesting form the point of view of the seismic behavior of masonry dwellings is the 1999 Oaxaca earthquake. Figure 2 shows the epicentral location in the Pacific coast and the distribution of Mercalli intensities of this event. The earthquake has been classified as normal-faulting intraplate type (Singh et al., 2000). According to some statistics of the observed damage in the state of Oaxaca, the earthquake affected more than 41,000 dwellings, mostly made of unconfined masonry or adobe. For example, in the town of San Pedro Tututepec in the Pacific coast near the epicenter, 3,000 dwellings collapsed and 3,200 experienced some degree of damage (Singh et al., 2000).

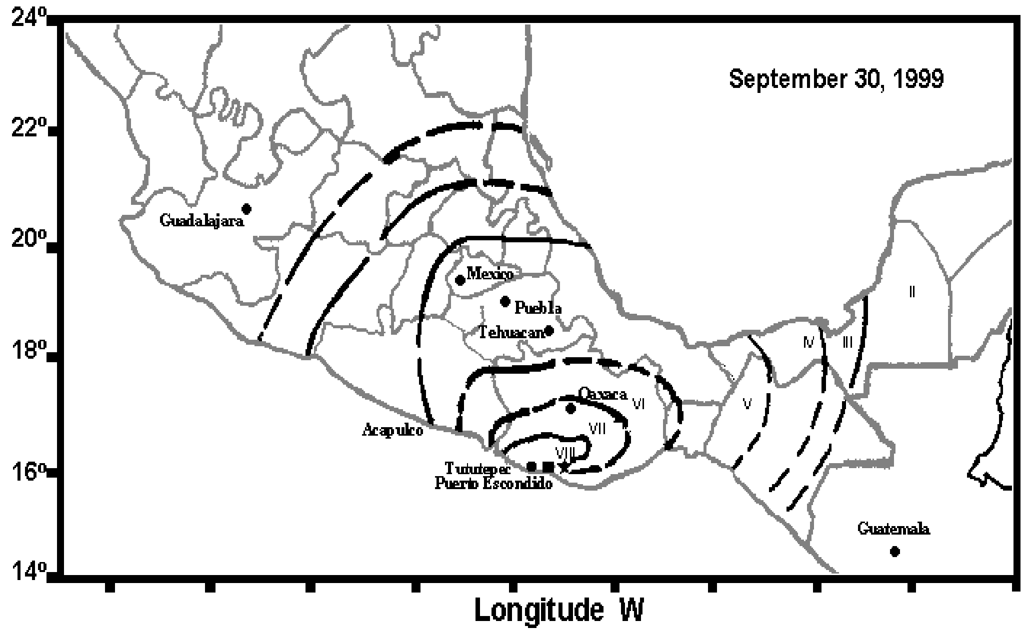

Figure 2. Epicenter and isoseismic maps of the Oaxaca earthquake of 30 September 1999

The observed damage in masonry dwellings in the above mentioned earthquakes in Mexico as well as others Mexican intraplate events, such as the 1931 Oaxaca earthquake (15 January 1931, M_w = 7.8) and the 1999 Tehuacan earthquake (15 June 1999, M_w = 7.0), suggests that intraplate earthquakes are more energetic at higher frequencies than the interplate earthquakes (Singh et al., 2000). This would explain the high rate of damage observed in Mexico in masonry dwellings in the past earthquakes of the intraplate type compared to that in interplate earthquakes. Similar results have been found in the 1997 Punitaqui intraplate earthquake (14 October 1997, M_w =7.1) in the north of Chile, in which a high rate of severe damage in adobe dwellings was observed (Astroza et al., 2002).

The 21 January 2003 Colima, Mexico Earthquake

The earthquake occurred in the coastal region of the state of Colima and had a magnitude of about 7.6 M_w. From 13,500 dwellings reported damaged, about 2,700 collapsed (EERI, 2003). Confined masonry dwellings suffered mostly minor damage and most damage was concentrated in dwellings of unconfined masonry or adobe. No earthquake ground motions were recorded in the affected area, which made the task of carrying out a more comprehensive evaluation of housing damage during the earthquake difficult. This is a lesson to be learned also for future earthquakes.

The 3 March 1985 Chile earthquake

This was an interplate event in the subducted Nazca plate, with M_S = 7.8. Its epicenter was located 20 km from the Pacific coast of central Chile. This earthquake is considered one of the most important experienced in Chile in the 20th century and has been compared to the great 1906 Valparaiso earthquake (Saragoni et al., 1993). Most of the severe damage occurred in adobe dwellings in rural areas, particularly near Llolleo (Flores, 1993), where an acceleration record had a peak ground acceleration of 0.67g (component N10E).

The 3 January 2001 San Salvador Earthquake

This earthquake had a magnitude of 7.6 and was of the subduction type. The epicenter was southwest of the capital city, San Salvador, at about 35 km off-shore underneath the Pacific Ocean and at a depth of about 35 km. The death toll was estimated at about 800, and more than 4,000 people were injured. About 70,000 homes were destroyed. Most of the damage occurred in adobe and unconfined masonry dwellings in small villages and towns. This earthquake left an important lesson for reducing seismic vulnerability of dwellings in Latin America. The suburb of Santa Tecla, a middle class area in San Salvador, suffered the collapse of about 300 homes due to a flow of mud and debris caused by bad planning in the housing location. More than 50,000 people were evacuated because of the main landslide during the main shock and additional landslides. The government of El Salvador estimated that the earthquake caused about US$1 billion in damage in a US $6 billion-a-year economy (EERI, Newsletter, 2001).

The 23 June 2001 Arequipa, Peru Earthquake

The epicenter of this interplate earthquake (M_S = 7.9) was located on the Pacific coast of southern Peru, off the town of Ocoña, at the interface between the Nazca and the South American plates, at a depth of 38 km. Figure 3 shows the location of the epicenter and some towns, as well as the isoseismic map (MM intensities). The only station that recorded the ground accelerations of this event was located in the city of Moquegua, at about 320 km from the epicenter, see Figure 3. The station is located on coarse gravel alluvial soil (Lermo et al., 2002).

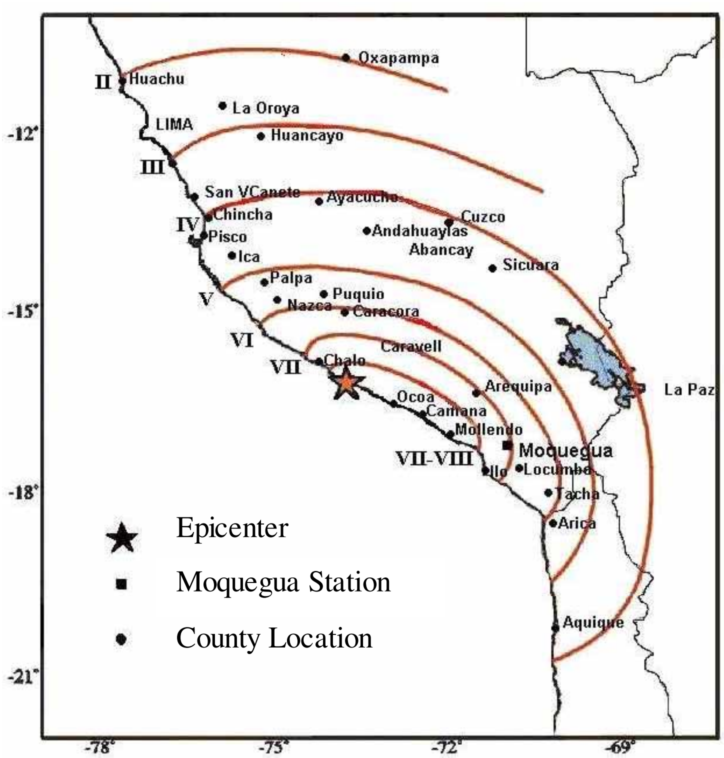

Figure 3. Epicenter and isoseismic map of the Arequipa, Peru earthquake of 23 June 2001

Damage levels in masonry dwellings in towns near the epicenter, such as in Ocoña, were lower than those observed in the city of Moquegua or even in Tacna, a city at the border with Chile, see Figure 3. (PEER, 2002). This paper presents only the observed damage in dwellings in the city of Moquegua, with respect to the ground motion recorded in that city. This city was the most affected by the earthquake (Lermo et al., 2002). There was a high rate of damage and collapse in adobe construction, including colonial buildings over 100 years old. Brick construction without seismic resisting details or built without proper construction procedures also suffered considerable damage (Muñoz and Tinman, 2001; Lermo et al., 2002; PEER, 2002). It has been mentioned that the damage to structures in Moquegua caused by this earthquake was enhanced by site effects, particularly due to recent developments of the city (Lermo et al., 2002).

Some adobe dwellings, however, had good seismic performance during the 2001 Arequipa earthquake. Several adobe houses were retrofitted before the earthquake with steel wire mesh and mortar forming vertical and horizontal bandages as shown in Figure 4 (Zegarra et al., 2001). These reinforced houses did not suffer any damage, while conventional, unreinforced, adobe dwellings nearby showed structural damage, or collapsed.

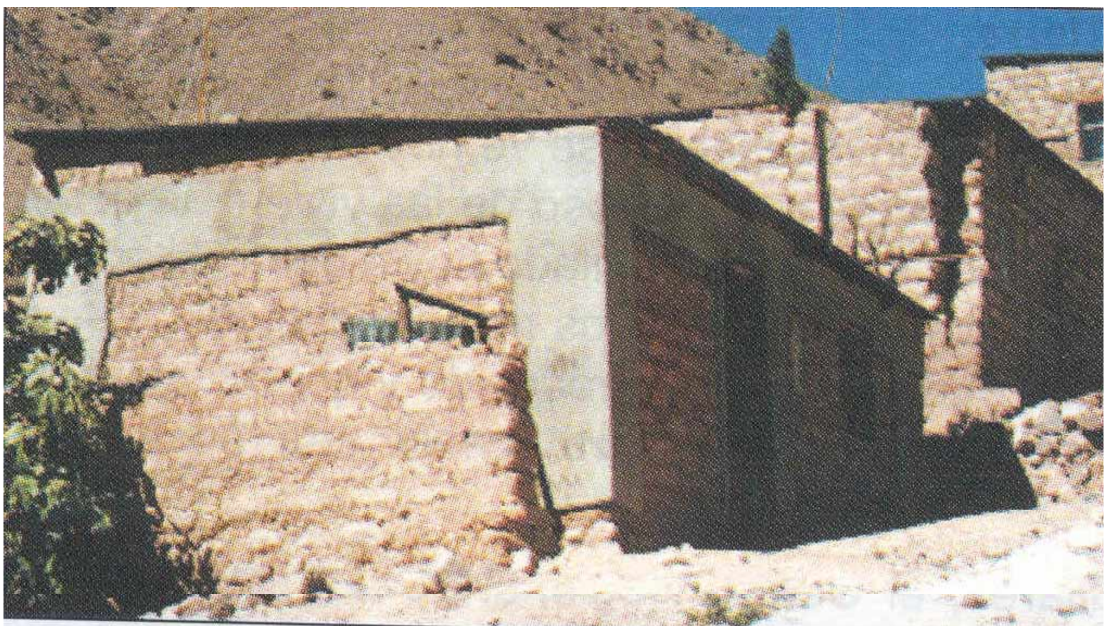

Figure 4. Adobe dwelling rehabilitated before the 2001 Arequipa earthquake with steel mesh and mortar forming bandages which resisted this earthquake without damage (Zegarra et al., 2001)

CONCLUSIONS

An evaluation of observed damage in housing construction during recent past earthquakes in Latin America suggests the following conclusions.

1. Some earthquakes such as the 1999 Colombia and the 2001 San Salvador earthquakes point out the importance of conducting appropriated identification of soft soils for avoiding construction of housing or at least for improving quality construction and detailing in housing construction. Stronger participation and interaction of local engineering communities, government officials and owners seems necessary for achieving these goals.

2. Poor construction quality and poor structural detailing contributed to the collapse or damage of housing in most earthquakes analyzed in this study.

3. Local construction techniques and materials have shown promising results for safe, low cost housing construction in seismic regions of Latin America, as in the case of the use of bamboo in Colombia and retroffited adobe dwellings in Peru. It is important to explore local solutions rather than just trying to adapt housing construction from other local realities.

4. In several Latin American regions, intraplate earthquakes have produced more damage to masonry dwellings than interplate events with higher magnitudes. This fact should be considered in future plans for reducing seismic vulnerability in seismic risk areas in Latin America.

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