The September 14, 1995, Ometepec, Mexico, Earthquake

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GIIS organized a team to study the effects of the September 14, 1995, earthquake in the southeastern portion of the state of Guerrero, México. The team included Emilio Sordo, Alonso Gómez and Hugo Jáuregui of UAM; Andrés Gama, Esteban R. Gutiérrez and Robert A. Whitney of UAG; Raúl Vera and Edgar Mendoza of UAEM; and Guillermo Alonso of UNACH. Severiano Álvarez, Timoteo Barrios and Juan S. Sugia of the Instituto Tecnológico Superior de la Costa Chica in Ometepec, Guerrero, gave invaluable assistance to the group in their visit.

Introduction

On Thursday, September 14, 1995, at 8:05 A.M. local time (2:05 PM GMT), an earthquake with an epicenter located at 16.8°N and 98.6°W with a surface-wave magnitude $M_s=7.2$ (USGS), struck the area near the town of Ometepec in the southeastern part of Guerrero State, Mexico. Over 800 owner-constructed houses were either collapsed or heavily damaged within a 25 km epicentral radius, affecting more than 5,000 people. However, only four people were killed and few were injured according to early local reports, as local residents are usually out of their houses at that time of the day, working in their farming and agricultural activities.

Ometepec is the most important town in the epicentral area, with about 50,000 inhabitants. It is surrounded by small villages of less than 2,000 inhabitants with rural economies.

This earthquake was also strongly felt in the cities of Chilpancingo, Guerrero, and Mexico City; it was described by their residents as the strongest earthquake felt since September 1985.

Seismic history

Seismic activity in southern Mexico, between longitudes 94°W and 104°W, mostly results from subduction zone events along the Mexican Trench, where the Cocos Plate is being consumed under the southernmost parts of the North American Plate. Collisional velocities range from about 5.5 cm/yr at 104°W to about 7.7 cm/yr at 94°W. The subduction zone is apparently well segmented, with some segments deforming with numerous small events with short recurrence intervals, while others have great earthquakes with recurrence time in excess of 75 years. A reasonable rupture history is known for the Mexican trench for the last 125 years. Within this historical framework, some of the segments have endured less than two seismic cycles, e.g., the Michoacan segment, which previous to the great earthquake of September 19, 1985, had only experienced one other event in 1911. The Guerrero seismic gap, roughly between the cities of Acapulco and Petatlan, both in the state of Guerrero, has only experienced one event, in 1911, in this 125-year time frame. A great earthquake is expected along this segment of the subduction zone in the near future.

The September 14, 1995, event occurred on the Ometepec segment of the subduction zone. This segment behaves differently than those which produce the great seismic events in Mexico, in that it ruptures with events of about Richter magnitude 7.0 to 7.5, with a recurrence interval which averages about 12 years. The previous events on this segment were on June 7, 1982, when the segment ruptured with two magnitude 7.0 events. Reported depths of the events on the Ometepec segment range from 18 to 65 km and focal mechanisms are both normal and thrust. It has been proposed that the

<table>
<thead>
<tr>
<th>DATE OF EVENT</th>
<th>MAGNITUDE</th>
<th>DEPTH (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 19, 1882*</td>
<td>7.5</td>
<td>60</td>
</tr>
<tr>
<td>Dec. 02, 1890</td>
<td>7.2</td>
<td>30</td>
</tr>
<tr>
<td>Feb. 10, 1928*</td>
<td>6.5</td>
<td>65</td>
</tr>
<tr>
<td>Dec. 23, 1937</td>
<td>7.5</td>
<td>18</td>
</tr>
<tr>
<td>Oct. 11, 1945*</td>
<td>6.5</td>
<td>65</td>
</tr>
<tr>
<td>Jan 6, 1948 (double event)</td>
<td>Combined</td>
<td>6.7</td>
</tr>
<tr>
<td>Dec. 14, 1950</td>
<td>7.3</td>
<td>18</td>
</tr>
<tr>
<td>Jul. 28, 1957</td>
<td>7.5</td>
<td>18</td>
</tr>
<tr>
<td>Oct. 24, 1980*</td>
<td>7.0</td>
<td>65</td>
</tr>
<tr>
<td>June 7, 1982 (double event)</td>
<td>7.0 ; 7.0</td>
<td>18 ; 19</td>
</tr>
<tr>
<td>Sep. 14, 1995(??)</td>
<td>7.2</td>
<td>50</td>
</tr>
</tbody>
</table>

*Normal Mechanism

The segment undergoes a deep normal mechanism event followed several years later by a shallow subduction thrust event. Table 1 lists the major events (M=6.5 or greater) which have affected this segment since 1882. Normal mechanism earthquakes are marked with an asterisk. Although the mechanism of the 1995 event has not been determined, if the event follows these seismic pattern for this segment, the mechanism will be normal.

Geology and soil conditions

The region which experienced the highest intensities lies a few kilometers north of the town of Ometepec (Figure 1). Bedrock geology in this area is composed of widespread Jurassic age granitic intrusive rocks, locally intruded with Tertiary age granitic plutons. The older granitics are heavily weathered while the younger are only moderately affected. The older bedrock consists of heavily decomposed granitics with a considerable content of clays overlaid by thick laterite deposits where the terrain is gentle. Locally this is used to form poor to average quality adobe blocks for house construction. Construction generally follows the existing topography, but where fills are used, compaction or material suitability are not controlled. There were some cases where fill softening due to rain, together with the earthquake motion, produced partial collapses of the foundation of houses constructed on steep hill slopes.

Topography in the epicentral area is gentle to moderate, with elevations ranging from about 300 meters in Ometepec to over 800 meters in the mountains just north of the city. Many of the villages are located on the highest portions of the hills, to avoid flooding of the valleys in the rainy season and to leave arable land for agricultural purposes. There are some indications that topographic focusing occurred in some of the villages.

North and east of the epicentral area the terrain is steep to very steep. To the west the terrain is equivalent to the Ometepec area and to the south are flood plains and the coastal plain, filled with young soft sediments. No liquefaction or subsidence related phenomena were reported or encountered.

Ground Motion

A schematic distribution of the reported modified Mercalli intensities is presented in Figure 1. Maximum intensities were reported in Ometepec and surrounding villages, like Igualapa, La Soledad, Santa Maria, Azoyu and Chacalapa, with values ranging from VII to VIII. Intensity level decreases more rapidly along the coast than in the inland direction, as illustrated in Figure 1.

Two small pockets of high intensity appear in Chilpancingo and Mexico City, apparently in response to the particular characteristics of local topography and soil conditions. It is already known that seismic effects in the valley of Mexico City are amplified by soft soil and topography; significant amplifications of accelerations and long duration of ground motions recorded on soft deposits with respect to those on firm soil were detected during the 1985 earthquake, and again during recent events. Likewise, the city of Chilpancingo has suffered in the past severe damage due to subduction earthquakes generated in the Mexican Pacific coast, like during the 1957 and 1985 earthquakes. Moreover, accelerographic information from recent earthquakes indicates amplification effects in some zones of Chilpancingo.

The closest strong motion accelerometer to the epicentral area of the Ometepec earthquake is located in Copala, Guerrero, at a distance of approximately 80 km from the reported epicenter. This station is part of the Guerrero Array installed by the Instituto de Ingeniería de la Universidad Nacional Autónoma de México (UNAM) and the Institute of Geophysics and Planetary Physics of the University of California at San Diego. The peak ground acceleration at this station is reported as 77 gals.

The amplification effects in Chilpancingo and Mexico City are illustrated in Figure 2, where recorded ground accelerograms are indicated for both firm (CA and DA) and valley soft (CC and DX) soil sites at stations of the array installed by the Red Inter-universitaria de Instrumentación Sísmica (RIIS).

The earthquake alarm of Mexico City announced the event 70 seconds prior to the strong motion arrival in the city, allowing enough time for evacuation of some schools and official buildings where the alarm is currently installed.
Structural Response
Unreinforced Adobe Masonry Structures

a) Villages

Typical villages at the epicentral region in southeast Guerrero are small rural communities with lack adequate roads and communications. At these locations, inhabitants build their own one-room houses with load bearing walls made of adobe blocks, with no specific lateral resistant elements to account for seismic induced forces. Adobe quality has been shown to play a key role in the structural response, and major damage has been detected in the small villages where adobe blocks are directly exposed to weather conditions. Intensive rains were reported in the area prior to the earthquake occurrence, degrading the resistance and stiffness characteristics of the adobe blocks.

In these villages, an average of 20% of the adobe houses collapsed, 75% were heavily damaged and only 5% received light, if any, damage. The least damaged houses are relatively new constructions with good adobe quality in terms of maintenance and mixture.

Three typical failure modes can be detected from the severely damaged houses. The first one is the result of inadequate bond in the adobe wall corners, leading to corner cracks and eventually to an outward failure of the walls (Figure 3).

The second failure mode is associated with a particular roof system that is typically utilized in the area. As illustrated in Figure 4, a light wooden net of ceiling joists, resting on the walls, holds the clay roof tiles. At the top vertex of the roof, this net is supported by a main longitudinal wooden beam held by the transverse walls and three or four secondary interior horizontal beams resting directly on the longitudinal walls. Earthquake motions generated inertial forces at the roof which were transmitted through the top longitudinal beam directly to the transverse walls, leading to a critical out of plane flexural failure (Figure 5). Lack of cross-
unreinforced adobe structures were heavily damaged, and about 70% suffered light cracking. In addition to the failure patterns described above, typical diagonal shear cracks in walls were also observed in this city.

Reinforced Adobe Masonry Structures
Although traditional construction in southeastern Guerrero is based on unreinforced adobe blocks, it is not uncommon to find adobe houses having rudimentary reinforced concrete elements that somehow improve lateral structural behavior. In many cases, it is clear that these elements were added after the occurrence of earlier earthquakes that caused damage to the construction. Owner’s intuition and experience are usually the main guides for these retrofitting techniques, like the reinforcement illustrated in figure 7, where reinforced concrete elements were supplied because of previous earthquake damage. In general,

Figure 6 Stress concentration failures at corner of door.

A particular type of unreinforced adobe masonry structures in the area are local churches, usually the largest adobe structures in the area. Most of them suffered extensive cracking during the earthquake, but few of them collapsed. From an inspection of these structures, one can easily see damage associated with previous earthquakes that was repaired by simply filling the cracks with some mortar or clay. In many instances, the observed damage from this event was localized at these “repaired” cracks and in the towers and domes of the churches.

b) Ometepec
Since Ometepec is the largest town of the epicentral area, the quality of the adobe houses is generally much better than in the small villages. In general, adobe walls have adequate coating and are not directly exposed to rainy weather conditions. The quality of adobe material is also increased by adding straw to the clay mixture. For this reason, only 15% of the reinforced concrete retrofitting in adobe houses improved substantially the lateral resistance of the structures, resulting in less damage to these structures.

Reinforced Brick Masonry Structures
Typically, brick masonry houses in the area have reinforced concrete elements embedded in the wall, both vertical (castillos) and horizontal (cadenas), adding confinement and resistance to masonry walls, as illustrated in figure 8. The behavior of these types of construction was quite satisfactory. Small diagonal cracks in the walls were observed in most of the structures of this type, but no important damage was reported.

Concrete Structures
The few reinforced concrete structures existing in the area are located in the town of Ometepec city, and severe damage was limited to three buildings. One is a hospital, where damage was due mainly to the inadequate structural configuration, as the detail in Figure 10 illustrates. A five-story hotel in downtown Ometepec also suffered heavy damage in the top stories, due to the presence of partial unreinforced masonry walls leading to short-column behavior in concrete vertical elements. A building for an
auto parts retailer was another case in which short-columns were heavily damaged by shear forces.

Figure 10 Inadequate structural configuration in Ometepec hospital.

Bajareque Structures
Many village houses have an additional room to store agricultural tools or firewood, which can also be used as a barnyard. In some cases, these rudimentary structures are built by the poorest inhabitants to be used as houses. The walls of these cabins are basically formed by two parallel nets of horizontal and vertical bamboo or thin wooden branches, supported by a set of vertical thick wooden branches (Figure 11). The inner space between the two nets is filled with clay, typically mixed with all kind of available materials, like rocks, broken roof tiles, leaves, straw, or even garbage. The roof system consists of a net of ceiling joists supporting the roof tiles. This type of construction, called bajareque, had a very satisfactory seismic behavior, with no damage reports associated with them.

Figure 11 Bajareque structures.

Lifelines
In general, lifelines performed well during the earthquake, although it is worth noting that in the villages near the epicentral area, operation of water and electricity supply is very limited, if any. However, some electricity shut offs

Figure 12 Differential settlement from bearing failure in a bridge near Marquelia.

Social Impacts and Emergency Response
Besides the four deaths reported, it is difficult to obtain reliable records on personal injuries in this area because people do not often go to the scarce medical facilities, as they usually employ traditional medicine in case of injuries. From the 800 houses reportedly heavily damaged or collapsed, it is estimated that more than 5,000 people were affected. However, many of these people still live in the damaged houses or in their backyards with some sort of temporary shelter.

Government emergency response has been focused primarily in Ometepec and in a nearby small village, Igualapa, where news media coverage was most extensive. The Mexican army was, as usual, the first group to help people in these places, and government construction teams were integrated after two or three days. Two weeks after the earthquake, most of the villages in the area were still waiting for effective government aid.

Conclusions
The Ometepec earthquake shows again the importance of good structural configuration and adequate maintenance of buildings. The three types of failure that adobe structures suffered were typically found in small isolated villages where the inhabitants have no economic resources and cannot easily retrofit their structures with reinforced concrete or rebuild new reinforced masonry structures. They tend to utilize clay mixtures or rebuild with questionable quality adobe block, which results in heavier damage during future earthquakes. Thus, structural damage is strongly related to economic situation. The lack of expert advice on how to improve structural configuration utilizing local available materials and minimizing costs leaves many damaged houses with highly inadequate retrofits. The importance of improving construction practice in these areas cannot be sufficiently stressed.

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