Learning from Earthquakes

The March 20, 2012, Ometepec, Mexico, Earthquake

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Unless otherwise indicated, photos in this report were taken by team members. This report was edited by Sarah Nathe, EERI Newsletter Insert Editor.

Introduction

On Tuesday, March 20th, 2012, at 12:02 p.m. local time (18:02 GMT), an M_w = 7.4 earthquake struck the area near the towns of San Juan Cacachuatepec, Oaxaca, and Ometepec, Guerrero, in the southeastern region of Mexico (Figure 1). Table 1 shows the most important parameters of the main shock and the greatest aftershock.

According to state and federal government agencies, 19 municipalities in Guerrero and 28 in Oaxaca had heavy damage, and federal funds were deployed to help recover infrastructure and to support the affected population (*Diario Oficial de la Federación*, 2012a and 2012b).

Almost 2,000 houses collapsed or were judged to be total losses, over 3,000 houses sustained heavy damage, and over 3,000 were reported with minor damage. Also damaged to some extent were 22 schools, 42 government offices, and 24 historical buildings (Oaxaca, 2012). However, only two people were killed and few were injured, according to early local reports. Local residents are usually out of their houses at that time of day, working in the farming and agricultural activities.

Ometepec (55,000+ inhabitants), Cuajinicuilapa (25,000+ inhabitants), and San Juan Cacahuatepec (8,500+ inhabitants) are the towns in the epicentral area; the epicentral region is largely comprised of small villages of fewer than 2,000 inhabitants, some of them lacking basic services (INEGI, 2005). This earthquake was also strongly felt in the cities of Chilpancingo, Guerrero, and Mexico City.

Seismic History

Seismic activity in southern Mexico (between longitudes -94° W and -104° W) results primarily from subduction 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 having numerous small events

Figure 1. *Epicenters of the March 2012 and the September 1995 Ometepec earthquakes (Sordo et al., 1995 and USGS, 1995).*

Table 1. Major parameters of the Ometepec earthquake of March 20th, 2012, and the aftershock of April 2nd, 2012.

Source (main shock)	**Lat**	**Long**	**Depth (km)**	**Mw**	**Fault type**
SSN	16.42	-98.36	15	7.4	-
Harvard, CMT solutions	16.41	-98.43	19.8	7.4	Reverse
USGS WPhase Moment Solution	16.662	-98.187	15	7.4	Reverse
Source (main aftershock)	**Lat**	**Long**	**Depth (km)**	**Mw**	**Fault type**
SSN	16.27	-98.47	10	6.0	-
Harvard CMT Solutions	16.62	-98.30	12	6.0	Normal
USGS (WPhase Moment Solution)	16.476	-98.286	11	6.0	Normal

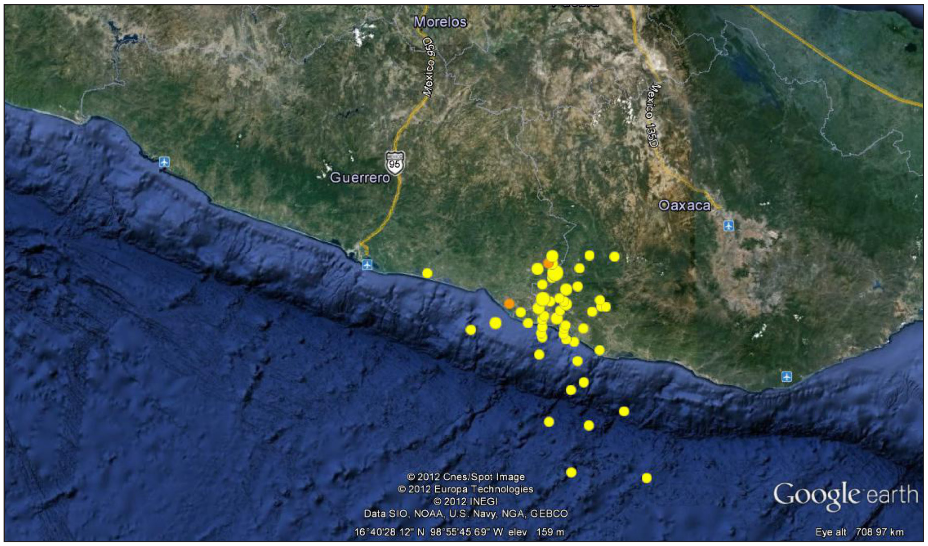

***Figure 2.** Main shock and aftershocks of the March 20th, 2012, Ometepec, Guerrero, earthquake.*

with short recurrence intervals, and others having great earthquakes with recurrence times of over 75 years. A reasonable rupture history is known for the Mexican Trench for the last 140 years. Within this time period, some of the segments have endured less than two seismic cycles, e.g., the Michoacan segment with one previous event in 1911, before the great earthquake of September 19th, 1985. The Guerrero seismic gap, roughly between the cities of Acapulco and Petatlán, had only one event in this time period. A great earthquake is expected along this segment of the subduction zone in the near future (Sordo et al., 1995).

The March 20th event struck on the Ometepec segment of the subduction zone. There were more than 50 aftershocks greater than magnitude 4.1 in the following month (Figure 2). This segment behaves differently from those that produce great seismic events in Mexico: it ruptures with events of about 7.0 to 7.5 magnitude and with a recurrence interval of about 12 years. The previous event was on September 14th, 1995, with a magnitude of M_w = 7.3. With a depth of 21.8 km; it was given an MMI = 7 (Sordo et al., 1995). Reported depths of the events on the Ometepec segment range from 10-70 km, and focal mechanisms are both normal and thrust. Table 2 lists the major events on this segment since 1882 (Sordo et al., 1995).

Seven asperities were identified on this segment; the segments are associated with earthquake events in Table 2 with a (*), (Núñez-Cornú, 1996). The epicenter location of the March 20th, 2012, earthquake is located in the same region as the doublets in 1982. We concluded that the earthquake event of March 20th, 2012, and the subsequent aftershocks (including one of M_w = 6.0) are associated with the two asperities and the doublets of 1982, thus indicating that the double events might occur every 30 years.

Geology and Soil Conditions

Bedrock geology in the area with highest intensities 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 considerable clays overlaid by thick laterite deposits where the terrain is gentle. Construction generally follows the existing topography, but where fills are used, compaction or material suitability is not controlled (Sordo et al., 1995). There were some cases where fill softened due to ground motion and produced partial collapses of house foundations on steep hill slopes.

Topography in the epicentral area is gentle to moderate, with elevations ranging from about 300m in Ometepec and San Juan Cacahuatepec, to over 800m 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

Table 2. Largest Earthquakes in the Ometepec region since 1882, (González-Ruíz and McNally, 1988; Sordo et al., 1995; and Núñez-Cornú, 1996)

Date of event	Magnitude	Depth (km)
July 19th, 1882	7.5	60
December 2nd, 1890	7.2	30
February 10th, 1928	7.7	65
October 9th, 1928 (*)	7.8	30
December 23rd, 1937 (*)	7.5	18
October 11th, 1945	6.5	65
January 6th, 1948 (double event)	Combined 6.7	18
December 14th, 1950 (*)	7.3	18
July 28th, 1957	7.5	18
August 2nd, 1968 (*)	7.4	36
October 24th, 1980	7.0	65
June 7th, 1982 (double event) (*)	7.0 and 7.0	18 and 19
September 14th, 1995 (*)	7.3	21.8
March 20th, 2012	7.4	15

Figure 3. *Small debris fall on Ometepec-Huanjintepec Road.*

Figure 4 shows the isoseismal map for the March 20th quake. Through travel to damaged sites and analysis of media and technical websites (USGS and SSN), we developed this map. It displays with a solid line the locations we visited, and with a dotted line those locations for which we gathered data electronically. The most important accelerographic data was captured by Centro de Instrumentación y Registro Sísmico (CIRES) in Mexico City. CIRES has recorded ground motions since 1988. In this event, 14 stations recorded the acceleration time histories in Mexico City: two in firm soil (zone I: TP13 and UI21); one

some indications that topographic focusing occurred in some of the villages (Sordo et al, 1995).

North and east of the epicentral area, the terrain is steep to very steep, and to the south are flood plains and the coastal plain, filled with young soft sediments (Sordo et al., 1995). No liquefaction or subsidence-related phenomena were reported or encountered.

On the road between Copala and Ometepec, approximately 10 km southwest of Ometepec, we observed minor landslides. On the roads around the epicenter area there were no slides (rotational or translational), lateral spreads, or in roads, but very small debris falls or debris topples were detected in short and large road cuts (Figure 3).

Ground Motion

Maximum intensities were reported in Ometepec, Huixtepec, Huajintepec in Guerrero; and Buenavista and San Juan Cacahuatepec in Oaxaca, with values ranging from VII-VIII (see Table 3).

Intensity levels decreased more rapidly along the coast than in the inland direction, as observed in previous earthquakes (Sordo et al., 1995; Juárez García et al., 1996 and 1997). Two small pockets of high intensity appear in Chilpancingo and Mexico City, apparently in response to 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.

Table 3. MMI Intensity values observed in Guerrero and Oaxaca states.

Location	State	MMI	Location	State	MMI
México City		VI-VII	PinotepaNacional		VIII**
Chilpancingo		VI-VII	San Pedro Jicayan		VII*
Tierra Colorada		V	San Andres Huaxpaltepec	Oaxaca	VII*
Las Mesas		V	Sta Ma Huazolotitlan		VII*
San Marcos		V	San Pedro Amuzgos		VII*
LasVigas		V	Cuajinicuilapa		VII*
Cruz Grande		V	Xochistlahuaca		VI*
Copala		V	Sta Ma Zacatepec	Guerrero	VI*
Playa Ventura	Guerrero	V	Azoyu		VI*
Marquelia		V	StaCatarinaMechoacan		VI*
Juchitán		VI	Putla de Guerrero		VI*
San Juan de Llanos		VI	Santiago Jamiltepec	Oaxaca	VI*
Ometepec		VII-VIII	Pinotepa de Don Luis		VI*
Huixtepec		VII-VIII	San Luis Acatlán	Guerrero	VI*
Huajintepec		VII-VIII	Tecoanapa		VI*
Buenavista	Oaxaca	VII-VIII	Sta Ma Asunción Tlaxiaco	Oaxaca	VI*
San Juan Cacahuatepec		VII-VIII	Santiago Juxtlahuaca		V*
Amarillo	Guerrero	V	Acapulco	Guerrero	V**
Petaquillas		V*	El Espinal	Oaxaca	V**
Cuautepec	Oaxaca	V*	Ayutla	Guerrero	V**
Ayutla de los libres	Guerrero	V*	Iguala		V**
Alpoyeca		V*	Tuxtepec	Oaxaca	V**
Cuilapan de Guerrero	Oaxaca	V*	Taxco	Guerrero	V**
Chilapa	Guerrero	VI**			

* http://earthquake.usgs.gov/earthquakes/eventpage/usc0008m6h#pager_cities

** http://earthquake.usgs.gov/earthquakes/dyfi/events/us/c0008m6h/us/index.html

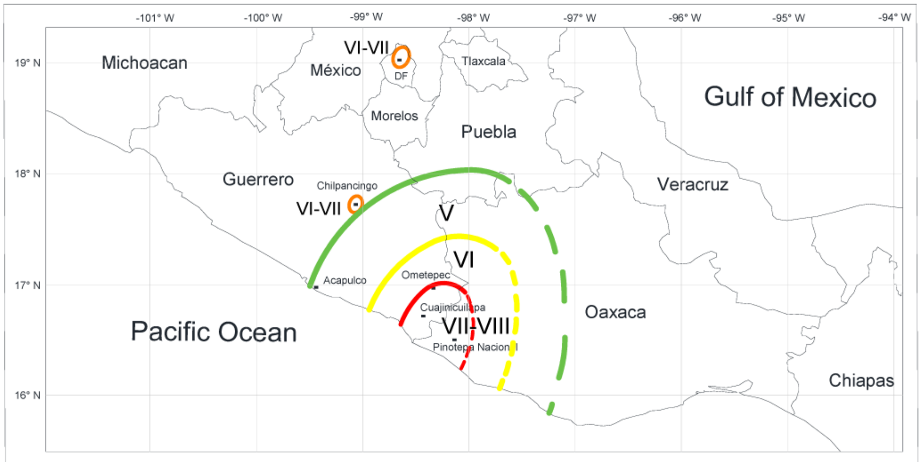

Figure 4. *Isoseismal map of March 20th, 2012, Ometepec earthquake.*

in a transition zone (zone **II**: DX37); and 11 in lakebed zones (zone **III**: 6 stations are located in Colonia Roma CO56, LI58, EX12, CJ03, CJ04 and CI05).

Non-corrected maximum peak ground acceleration (PGA) values recorded are shown in Table 4. These PGA values are compared with two different events: September 14th, 1995 (M_w = 7.3), and April 25th, 1989 (M_w = 6.9). The September 1995 quake was on the Ometepec segment; the April 1989 quake was in a different zone in Guerrero, but it produced the largest PGA values in Mexico City since the 1985 earthquakes. The PGA values, in general, are very similar in the three earthquakes.

Mexico City Early Warning System

CIRES organizes and manages the information and logistics of the Earthquake Warning System (Sistema de Alerta Sísmica — SAS).

Table 4. Maximum non-corrected PGA values for three different earthquakes.

Station	**20/04/2012**			**14/09/1995**			**25/04/1989**		
	NS	**EW**	**V**	**NS**	**EW**	**V**	**NS**	**EW**	**V**
TP13	17.37	11.12	5.89	13.77	10.16	4.08	17.72	12.42	6.98
UI21	15.82	18.60	7.57	13.02	15.16	6.44	SR	SR	SR
DX37	27.64	30.24	7.06	23.87	15.55	7.16	33.78	31.28	7.15
LV17	32.99	40.73	8.36	29.53	30.69	8.18	32.02	32.10	9.70
BO39	21.16	31.84	8.92	30.71	43.99	6.72	33.52	37.46	12.02
VM29	41.46	44.12	7.87	27.73	28.95	6.70	49.14	52.02	12.71
VG09	33.92	33.85	7.53	39.57	24.41	6.07	38.21	47.41	8.88
LI58	41.53	34.54	15.36	SR	SR	SR	40.94	40.34	23.44
EX12	46.00	41.22	14.20	33.05	41.59	10.06	SR	SR	SR
CJ04	42.55	30.47	10.40	24.52	27.08	11.29	SR	SR	SR
CI05	**49.21**	**57.93**	12.36	37.40	41.96	12.20	54.34	45.82	14.52
CJ03	41.43	37.57	10.90	24.90	26.1	10.54	40.73	37.68	10.14
CO56	34.62	40.55	16.14	44.31	45.42	20.65	73.00	39.10	30.64
TH35	**49.57**	**79.08**	14.18	72.72	61.71	16.62	54.77	72.09	18.09

Figure 5. *Data acquisition zones for SAS and approximate distance from Mexico City (source: CIRES web page).*

The SAS project started in 1986 and was fully operational in 1991. The objective is to issue early warning reports to Mexico City, as most of the great earthquakes will strike on the Guerrero coast, 320 km away. The early warning system announces the oncoming earthquake 60 seconds before the arrival of the first seismic waves. A similar system has also been implemented on the Oaxaca coast (SASO) (CIRES, 2012a).

The SAS system is comprised of 12 seismic-sonar stations along the Guerrero coast, which monitor the local seismic activity and issue a warning radio signal to Mexico City receiver stations (Figure 5).

In 18 years the SAS system has recorded over 2,000 earthquakes, with magnitudes ranging from 4-7.4; 53 have been classified as moderate, and 13 have been rated as strong events. For the moderate 53, a “preventive warning” code was issued; only government and emergency agencies (Protección Civil) received the warning, as the earthquake effects were estimated to be moderate; for the strong 13, “public warning code” were issued to the general public through local media. For both Ometepec events, the SAS issued warning signals: in 1995 a “public warning,” and in the 2012 main shock and aftershock a “preventive warning.” For the March 2012 quake, 7 out of 12 stations detected seismic activity forecast moderate effects (Table 5).

Table 5. Data acquisition station status for SAS, March 20, 2012 (source: CIRES web page).

No	Station	Report	No	Station	Report	No	Station	Report
1	Papanoa	NA	5	Pénjamo	NA	9	Las vigas	Detected
2	El veinte	NA	6	El jardín	Detected	10	El Carrizo	Detected
3	Tetitlán	NA	7	San Pedro	NA	11	Marquelia	Detected
4	Cacalutla	Detected	8	El cortés	Detected	12	Huhuetán	Detected
No	**Station**	**Report**	**No**	**Station**	**Report**	**No**	**Station**	**Report**
1	Papanoa	NA	5	Pénjamo	NA	9	Las vigas	Detected
2	El veinte	NA	6	El jardín	Detected	10	El Carrizo	Detected
3	Tetitlán	NA	7	San Pedro	NA	11	Marquelia	Detected
4	Cacalutla	Detected	8	El cortés	Detected	12	Huhuetán	Detected
No	**Station**	**Report**	**No**	**Station**	**Report**	**No**	**Station**	**Report**
1	Papanoa	NA	5	Pénjamo	NA	9	Las vigas	Detected
2	El veinte	NA	6	El jardín	Detected	10	El Carrizo	Detected
3	Tetitlán	NA	7	San Pedro	NA	11	Marquelia	Detected
4	Cacalutla	Detected	8	El cortés	Detected	12	Huhuetán	Detected

Due to the SAS notice, the Metro system and public buildings had 60 seconds to stop operations and evacuate the facilities. Emergency agencies have improved their evacuation procedures, and every worker is accounted for; however, there are still some issues for emergency agencies and local authorities to resolve, for example, as people evacuated buildings, they filled streets and avenues that might have been needed for emergency response vehicles.

__Figure 6.__ Damage to Metro´s rail system (source: Twitter, user Adan4xinhua?).

The SAS earthquake warnings gave 60 seconds to the Metro system to stop operations, and also gave operators and people time to evacuate. No damage or injuries were accounted for, although Line A of the Metro station sustained damage to the rail structures, probably due to presence of large surface waves (Figure 6). However, 24 hours later, line A was repaired and fully functional.

Structural Response

Unreinforced adobe masonry structures. Typical villages in the epicentral region are small rural communities lacking adequate roads and communication systems. Inhabitants build their own one-room houses with load-bearing walls made of adobe blocks, with no lateral resistant elements. As was the case in 1995 (Sordo et al., 1995), adobe quality again played a key role in structural response: major damage was observed in weathered adobe blocks. Rain and other natural elements degrade the resistance and stiffness of adobe blocks. Three typical failures were detected: (1) inadequate bonding in the adobe wall corners led to out-of-plane failures (Figure 7); (2) transverse wall failure due to inertial forces induced by the main wooden beam of the roof system; and (3) stress concentrations at corners of openings in the walls (windows and doors).

Confined masonry structures. In general, housing and commercial buildings are built with this technique. We found structures that had redundant confined concrete elements (“dalas” and “castillos” — Figure 8). We believe that this is a consequence of moderate earthquakes in the past, local and state seismic provisions, and the intuition of the local construction workers. As the Guerrero area is hot and humid, interstory heights range from 4-5m, and hence they place concrete elements every 1.5m or less, as illustrated in Figure 9. Even though the materials used for the clay bricks and concrete elements might not be of the highest quality, these structures exhibited no damage.

Concrete structures. The two-story reinforced concrete frame

__Figure 7.__ Out-of-plane failure in adobe walls due to inadequate bonding.

Figure 8a and b. *Redundancy of concrete elements in new reinforced masonry structures.*

Figure 9. *Concrete elements every 1.5m or less.*

General Regional Hospital in Ometepec suffered no structural damage, though there was light to moderate nonstructural damage in drywalls and façade elements. The main concrete columns were surrounded by dry wall casings that had cracks, due to the difference in resistance and stiffness of the structural and nonstructural systems, but no damage was observed in beams and columns.

A two-story concrete and masonry hotel in Ometepec has a great wall density ratio, an irregular structural configuration, and inadequate constructive joints, so cracking was visible in several infill masonry walls and in places where the constructive joints were located (Figure 10).

A three-story concrete hotel with masonry infill walls also sustained light to moderate structural damage in the concrete frame. It was evident that the separation from neighboring buildings was inadequate and was filled up with rocks and stones; this led to pounding, causing damage at the joints of the beams and columns (Figure 11).

At the Instituto Tecnologica Superior de las Costa Chice in Ometepec, there are ten reinforced concrete buildings, ranging from one to two stories. We observed light nonstructural damage in two of the buildings and light structural damage in one. In Building C, a two-story façade clay brick wall had an out-of-plane failure. The heavy façade wall was about 90 cm thick, with a height of about 10 m, and was not properly anchored to the main structure. This wall did not cause collapse, but institute authorities decided to demolish it, in order to prevent damage or casualties to the student population,

The one-story reinforced concrete frame Library building had three bays in the longitudinal direction

Figure 10. *Cracking at the constructive joints and in infill masonry walls.*

Figure 11a ▲and b. *Pounding and cracking in beam elements. ►*

Figure 12. *The concrete government building in downtown Chilpancingo was damaged in the December 16th, 2011, earthquake, and the March 20th, 2012, earthquake increased the damage.*

(8.5 m), four bays in the transversal direction (4 m), with RC columns (45 x 30 cm), and an interstory height of about 5 m. It is considered a flexible structure with stiff nonstructural elements (false ceiling and large doors and windows). Nonstructural damage was observed in the false ceiling elements, the aluminum grid holding the false ceiling was not properly anchored at the edges of the building, and the vertical accelerations led to the failure of the aluminum bars that hold the ceramic tiles of the ceiling. The window and door frames were also bent, and some windows were broken.

The two-story cafeteria building with RC frames and infill walls has a great wall density at the first floor (administrative offices), and the cafeteria is located at the ground floor. Cracks were visible in some of the infill walls at the stairs structure, located at one end of the main structure. At the first floor some infill walls also exhibited cracking, but the structural damage was considered light.

In Chilpancingo, Guerrero, geological conditions have significantly amplified the ground motion in past earthquakes (Gómez-Bernal et al., 1999). The March 2012 Ometepec earthquake caused accumulation of damage in some structures. The government building located downtown, a few meters from the Cathedral, is a four-story concrete building with infill masonry walls, and an irregular structural configuration (soft first floor at one end), had moderate nonstructural damage and light structural damage in the concrete columns (Figure 12).

A preparatory school built in the 1950s reportedly sustained the most structural damage in the March quake. It is a three-story concrete frame structure with masonry infill walls, with a 50 x 15 m plan dimension. The building was restricted on the ground level with a stair entrance, which has two parallel walls in the center (Figure 13). This condition restricted the oscillating movement of the building in the short direction, causing severe structural damage in the ground and first levels.

Many buildings in Mexico City suffered light to moderate nonstructural damage, such as broken glass, collapsed transformers on top of light posts, and parapets fallen on sidewalks.

Lifelines

In general, lifelines performed well in the epicentral area, although in rural villages, nearby water and electricity supplies were interrupted. Some electricity, telephone, and mobile phone service shut-offs were reported in Ometepec, but they were fully re-established within a few hours.

Local roads were damaged, but they lack proper maintenance. Highway and related bridges suffered no damage, and they remained fully operational. Well-maintained highways and bridges retrofitted after previous quakes suffered no damage.

In Mexico City, most damage occurred to the transportation system. Line A of the metro sustained damage to its rails (Figure 6). Damage to the supporting system of a motor

Figure 13a-d. *Structural damage to the first two levels of the building.*

Figure 14a and b. *Left: vehicle bridge. Right: collapsed hand rail of a pedestrian bridge.*

vehicle bridge caused damage to the deck (Figure 14 left). Part of a pedestrian crossing bridge collapsed in a main street of northern Mexico City (Figure 14 right).

The new Deep Eastern Drainage Tunnel System (TEO), currently under construction, and Line 12 of the Metro both cross a variety of soil deposits from soft clay to volcanic tuff layers and sometimes pass through the water table bed. Both underground structures behaved well and were not damaged.

Some public hospitals in Mexico City reported nonstructural and structural damage. One of them, in the northern part of Mexico City, was totally evacuated and remained closed for seven days. In the southern part of the city, 60 m^2 of façade elements of another public hospital collapsed on April 13th, 2012.

Social Impacts and Emergency Response

There were only two people killed by the earthquake; one of them as a consequence of a heart attack. Ometepec's two new hospitals were operational, despite the light nonstructural damage, and treated all casualties. From the 3,000 houses reported as damaged, around 10,000 people were affected. Many of these people still live in the damaged houses or in their backyards with some sort of temporary shelter.

The media did not focus much attention on the epicentral area or the rural communities; rather, they reported on the SAS system and Mexico City. As usual, the Mexican army was the first group to help people in the epicentral region. However, two weeks after the earthquake, most of the rural 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. We observed that the construction practice has improved; the affected population has learned the lessons of having houses with poor adobe blocks or poor structural configuration. People at the epicentral area are substituting confined masonry structures for unreinforced adobe structures.

Emergency agencies have improved their evacuation procedures; however, there are still some problems. For example, as people evacuated public buildings, they invaded streets and avenues, which might be compromised if they are turned into Emergency Response Routes. Local authorities believe that response is based on the way the SAS functions and the organization in public buildings initiating the evacuation process; however, there is no subsequent coordination between local and national authorities.

There are many accelerographic stations installed all over Mexico, but only a few of them are fully operational. Fifteen years ago in Mexico, there was a will to establish acceleration stations, and authorities and institutions were ready to build them and to start recording seismic data, but equipment obsolescence, lack of technical expertise, and human and economic resources have become serious problems in operating these stations. We also found a hesitancy to share earthquake data; some data "owners" are not aware of the importance of having the seismic data available for research.

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