Learning from Earthquakes

Preliminary Observations on the Tecomán, Colima, Mexico, Earthquake of January 21, 2003

This report is based on data collected after the earthquake by a number of teams and individuals. Four separate reconnaissance groups collaborated in this effort, under the recently signed cooperative agreement between EERI and the Sociedad Mexicana de Ingenieria Sísmica (SMIS). (See Acknowledgments for a complete listing of team members.) The Earthquake Engineering Research Institute (EERI) team was headed by Richard E. Klingner of the University of Texas at Austin.

The joint National Center for Disaster Prevention (CENAPRED)/Mexican Society for Earthquake Engineering (SMIS) team was headed by Sergio Alcocer of CENAPRED. The joint Inter-University Seismic Research Group (GISS)/SMIS team was headed by Hugón Juárez García of Universidad Autónoma Metropolitana – Azcapotzalco.

The National Science Foundation (NSF)-sponsored geotechnical reconnaissance team was headed by Joseph Wartman of Drexel University, Philadelphia, PA, and Adrian Rodriguez-Marek of Washington State University, Pullman, WA.

The EERI team arrived in Manzanillo on January 23 and collaborated closely with the CENAPRED/SMIS team, which initiated reconnaissance activities on January 22. The GIIS/SMIS team arrived in Colima on January 23 and visited damaged sites in the state of Colima as well as in the neighboring states of Jalisco and Michoacán. The NSF team arrived on January 25 and coordinated with the EERI team already on the ground.

Financial support for the NSF geotechnical reconnaissance team was provided by the National Science Foundation under Grant 0321781. Financial support for the EERI team and for the publication and distribution of this report was provided by the National Science Foundation grant #CMS-0131895 to EERI's Learning from Earthquakes Program.

Introduction

On Tuesday January 21, at 8:06 p.m. local time, a strong earthquake shook the coastal region of the state of Colima, Mexico. The earthquake was strongly felt in the states of Colima, Jalisco and Michoacán. The effects of the earthquake were also felt in Mexico City. The reported magnitude varies from M_w 7.4 (Harvard CMT) to M_w 7.6 (USGS). The reconnaissance teams carried out a basic evaluation of the effects of the earthquake, concentrating on the response of structures and soils, and also on the functioning of response organizations in different levels of the Mexican government. The teams visited the municipalities of Colima, Manzanillo, Tecomán, Comala, Coquimatlán, Villa de Álvarez, Ixtlahuacan and Armería (shown in Figure 1).

As of February 20, the effects of the earthquake are as follows: 21 confirmed dead; 500+ injured (this is an uncertain figure since there has not been a systematic confirmation of the injured); 13,493 residential structures reported damaged (many of these reports from rapid visual inspections by public teams). Of the 13,493 structures, 11,009 had been inspected with the following official results: 2,728 total damage; 4,150 partial damage; 4,131 safe for occupancy. Six hundred structures housing medium and small businesses also suffered some damage. The military had established 56 disaster assistance centers to provide food, shelter, medical assistance, and public information.

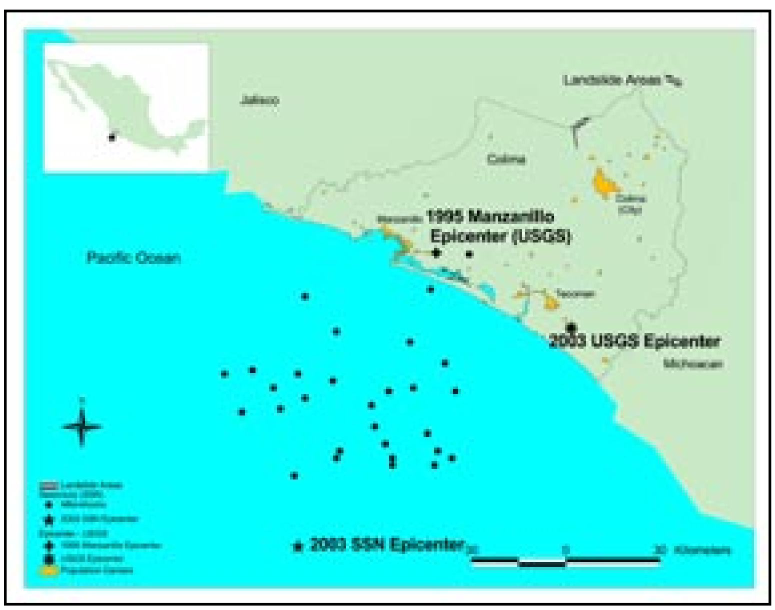

***Figure 1** - Epicentral locations of main shock and aftershocks as reported by the USGS and SSN. Included also is the epicentral location of the M_w 8.0 1995 Manzanillo earthquake.*

Table 1. Seismological Data

Agency	M_w	Hypocenter Coordinates	Hypocenter Depth	Strike/Dip/Slip (fault plane)	Reference
USGS	7.6	18.81N 103.89W	9 km	263°/10°/46°	http://neic.usgs.gov/neis/FM/neic_phac_q.html
Harvard	7.4	18.77N 103.89W	32.6 km	305°/17°/103°	http://www.seismology.harvard.edu
SSN	7.6[1]	18.22N 104.60W	10 km		http://www.ssn.unam.mx/Colima030121/index.html
IISEE[2]	7.4	18.62N 104.12W	20	300°/20°/93°	http://iisee.kenken.go.jp/staff/yagi/eq/colima/colima.html

(1) Energy Magnitude, M_E (See Singh and Pacheco 1994)
(2) Fault plane solution by Yagi, IISEE.

Seismicity

Just as the initial reports on the magnitude of the earthquake vary, so does the reported location of the hypocenter. Table 1 lists the source parameters of the event as reported by various agencies. Figure 1 plots the location of the epicenters as reported by various agencies, along with the locations of aftershock epicenters reported by the Servicio Sismológico Nacional de México (SSN).

The significant discrepancies in moment magnitude and epicenter location obscure any preliminary conclusions about the unusual damage distribution. There was much greater damage to the inland city of Colima than the coastal city of Manzanillo (which is closer to the rupture zone as defined by aftershock hypocenters) while, in contrast, damage from the 1995 M_w 8.0 Manzanillo earthquake was largely focused near the epicentral region.

The earthquake occurred near the juncture of three tectonic plates: the North American Plate to the northeast, the Rivera Plate to the northwest, and the Cocos Plate to the south. Both the Rivera Plate and the Cocos Plate are being subducted beneath the North American Plate. The slower-subducting Rivera Plate is moving northwest at about 20 mm per year relative to the North American Plate, and the faster Cocos plate is moving in a similar direction at a rate of about 45 mm per year (USGS **http://neic.usgs.gov/neis/bulletin/neic_phac.html**). The earthquake was an interplate subduction event at the contact between the North American plate with either the subducting Cocos or Rivera plates.

The event filled a seismic gap located between the rupture zones of the M_w 8.0 1995 Manzanillo earthquake and a M_w 7.6 earthquake in 1973 (Figure 2). A fault plane solution by Yagi (**http://www.iisee.kenken.go.jp**) from the International Institute of Seismology and Earthquake Engineering (IISEE), Tokyo, is shown in Figure 3. The dimensions of the rupture plane are approximately 80 km x 50 km.

Ground Motions

The Manzanillo Power plant record is the only strong-motion record of the earthquake obtained within 100 km of the rupture plane. Various records at distances greater than 120 km were obtained from strong motion arrays in Guadalajara and Mexico City. The Manzanillo Power Plant record registered maximum accelerations of 0.263g in the EW direction, 0.329g in the NS direction, and 0.191g in the vertical direction. Strong shaking lasted approximately 30 seconds. It was reported that earthquake movement ruptured the power plant's main 2.4 m diameter cooling water intake pipe, which caused the plant to operate at a reduced capacity in the days after the main event.

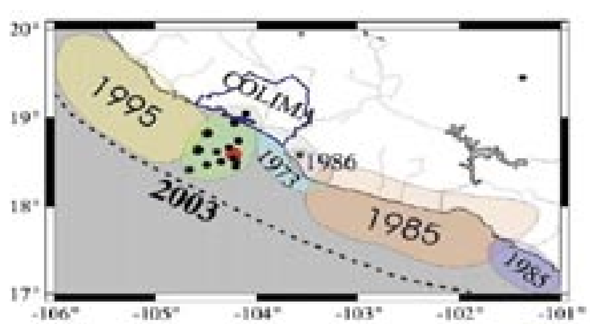

***Figure 2** - Approximate location of rupture planes of subduction zone events since 1973 (http://www.ssn.unam.mx/Colima030121/index.html).*

Site Effects

Damage surveys in the conjoined cities of Colima and Villa de Álvarez indicated locations of damage concentration around the neighborhoods of San Isidro (Villa de Álvarez) and Lomas de Circunvalación (Colima) (see Figure 4). In addition, damage to adobe housing in downtown Colima was extensive. Damage surveys were carried out using PQuake software (Georgia Institute of Technology), which directly integrates digital photography and handheld GPS technology to facilitate documenting, mapping, analyzing, and visualizing damage data. The use of PQuake permitted a digital data set of the earthquake effects to be created in a timely manner. Damage surveys were performed either by assigning an average damage index (D0 = no damage, D5 = collapse) to a whole block (Block Survey), or by assigning damage indices to individual buildings.

The San Isidro neighborhood is located near the Arroyo de Pereira, a small creek running north to south across Colima/Villa de Álvarez. Most of the damaged area overlies highly heterogeneous fill. Evidences of liquefaction were found in areas of high damage concentration. Significant ground settlement was observed at some locations, possibly due to collapse of poorly compacted fills (Figure 5). There were numerous reports of open-pit sand mining earlier in the 1900s at this location. Poor filling of these pits could explain localized zones of large surface settlement. Although construction quality in the San Isidro neighborhood is poor, other neighborhoods with similar construction did not suffer as much damage.

The Lomas de Circunvalación neighborhood is underlain by volcanic debris avalanche deposits that also underlie most of the north-central section of Colima. While this unit is highly heterogeneous, it is reportedly stiff and performs well as a foundation material. Intense damage in the Lomas de Circunvalación neighborhood is limited to a few city blocks. Construction patterns do not vary in this neighborhood, suggesting that damage is due to localized ground-motion amplification, suspected to be associated with fills.

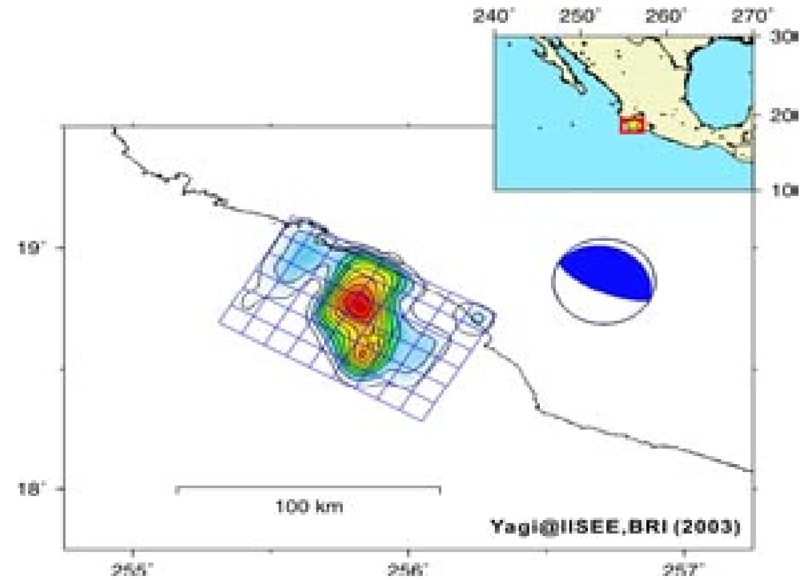

***Figure 3** - Fault plane solution by Dr. Y. Yagi (**http://iisee.kenken.go.jp/staff/yagi/eq/colima/colima.html**).*

Soil Liquefaction

Soil liquefaction caused damage in the coastal city of Manzanillo and in the neighboring cities of Villa de Álvarez and Colima, located approximately 80 km inland.

Liquefaction may have also occurred in the sparsely inhabited region between these two urban centers, though this was not confirmed during the reconnaissance. In Manzanillo, home to one of the largest

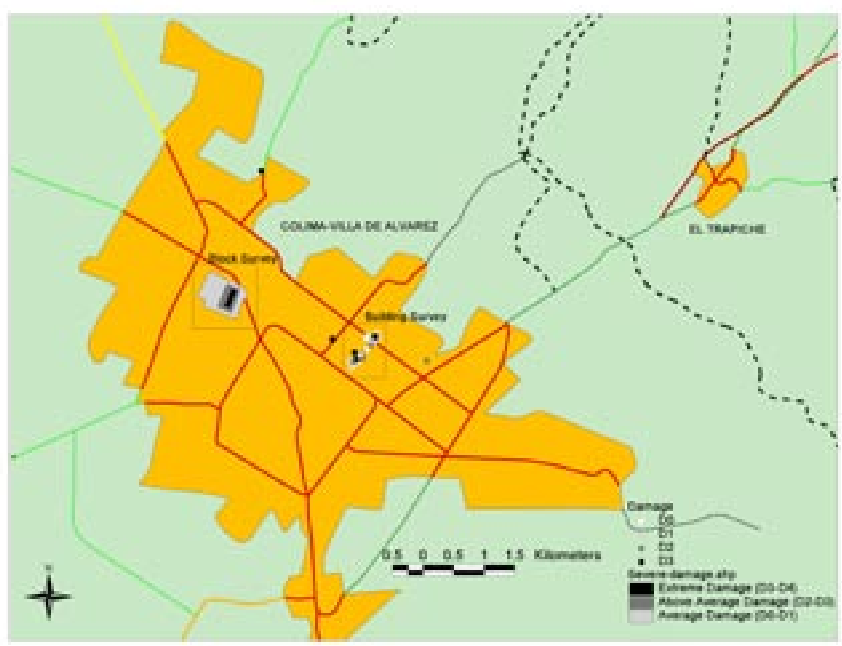

***Figure 4** - Damage survey map of the city of Colima indicating areas of high damage concentration.*

Figure 5 *- Large settlements in a house in the San Isidro neighborhood, possibly due to collapse of poorly consolidated fills.*

ports in Mexico, liquefaction was largely confined to waterfront sites, including multiple locations at the commercial shipping port, a public walk near the center of town, and a promenade located off a major boulevard. Liquefaction-related damage at the port occurred principally at undeveloped or non-critical areas, and port operations were not significantly affected.

During the 1995 earthquake, the Port of Manzanillo suffered considerable damage due to liquefaction. Since then, various ground-improvement techniques (for example, stone columns, vibro-compaction) have reportedly been used during repairs or new construction at the port to increase liquefaction resistance of the ground at locations essential for daily operations. It appeared that these improved sites generally performed well, with no obvious liquefaction-related ground-deformation features. Other areas of the port where ground improvement had not been performed apparently suffered seismic densification and lateral spreading. Quantitative assessment of the performance of these improved areas would provide valuable information about the efficacy of the ground improvement techniques.

A majority of the waterfront liquefaction sites in Manzanillo were marked by lateral spreading of the ground toward the free face. The horizontal displacements varied between sites, but were often in the range of 1-3 m. Figure 6 shows lateral spread of a pedestrian promenade located off a major boulevard. The promenade surface consisted of paving blocks, whose positions after the earthquake clearly preserve the deformations caused by lateral spreading. Apparently, a 0.2-0.5 m thick crust of silty sand moved over an unknown thickness of liquefied ground. An overturned concrete railing is visible near the right portion of the photograph. The ground slope was about 3%, and maximum lateral spread displacements at the site were on the order of 2 m.

Observed ground distortions (ground cracking with possible lateral spreading) in a residential district located about 3 km northeast of Manzanillo's city center suggest that liquefaction may have also occurred there, though this was not confirmed. This portion of town was reportedly underlain by miscellaneous fill.

In the city of Villa de Álvarez, just northwest of Colima, liquefaction and consequent loss of strength, ground settlement, and lateral spreading, alone or in combination, are suspected causes of other damage to the San Isidro neighborhood about 3 km northwest of the town center. Damage included uplifted, sunken, or cracked concrete floor slabs; cracked and distorted pavements and sidewalks; and laterally displaced residential structures. Portions of this neighborhood were reportedly built on reclaimed land adjacent to the Arroyo de Pereira, a small creek. Shallow subsurface materials at the site consisted of uncompacted, miscellaneous fill. Local residents reported that immediately after the earthquake, muddy water was ejected from cracks in pavement surfaces and damaged concrete floor slabs.

Figure 7 shows a concrete column supporting a modern three-story residential structure located in the Colima neighborhood damaged by liquefaction. It is typical construction practice in Colima to support columns and load-bearing walls on shallow foundations consisting of spread and wall footings. During the earthquake, the column experienced a loss of bearing capacity and dropped about 30 cm, causing significant structural damage to the building.

Figure 6 - *Liquefaction-induced lateral spread in Manzanillo (for scale, each paving block is 0.20 m square).*

Landslides

The earthquake triggered landslides estimated in the thousands. Classified according to the system of Keefer (1984), the vast majority were rock falls, rock slides, soil falls, and disrupted soil slides. Several liquefaction-induced soil lateral spreads were also observed, as was a single embankment failure that has been classified as a coherent slide.

Two areas of particularly high landslide concentrations were noted. The first is located along the steep walls of the Armería River canyon and along its tributary, the Remate River, north of Colima in the vicinity of the town of Zacualpan. Along each river, a stretch of 6-8 km was subjected to such intense landsliding that material was removed from stretches of slope hundreds of meters to more than a kilometer long in each of several localities (Figure 8). Most or all of these areas were on the outside of meander bends. The vegetated cliffs on which the landslides occurred were typically 150-200 m high and had slope inclinations estimated as ranging from about 70º to vertical. They were composed of very well-graded volcanic debris-avalanche material, reworked by fluvial action and interbedded with fluvial deposits. These materials had little or no matrix cementation.

When this area was inspected on the ground on January 28 and again on January 31, the cliffs were so unstable that they were still producing several falls each minute (Figure 9). On January 31, in fact, 20 falls occurred in 15 minutes along a single section of cliff 1 km long, suggesting that approximately 2,000 falls were occurring there each day. These falls were typically small, ranging from a few cubic meters to perhaps 50 m^3 of material each. The continuing instability of these cliffs, exacerbated by the ongoing removal of material by falls, indicates a possible continuing hazard to villages, dwellings, and other infrastructure in the areas located close to the cliffs.

The other area of high landslide concentration was along a 6-km stretch of the Barranca de Atenquique watershed, a deep, steep-sided canyon cut into the eastern flank of Nevado de Colima, an inactive volcano. At this location, rock falls, soil falls, rock slides, and debris

Figure 7 - *Bearing-capacity failure in Colima. The column dropped through the floor of the structure, ultimately settling about 0.3 m.*

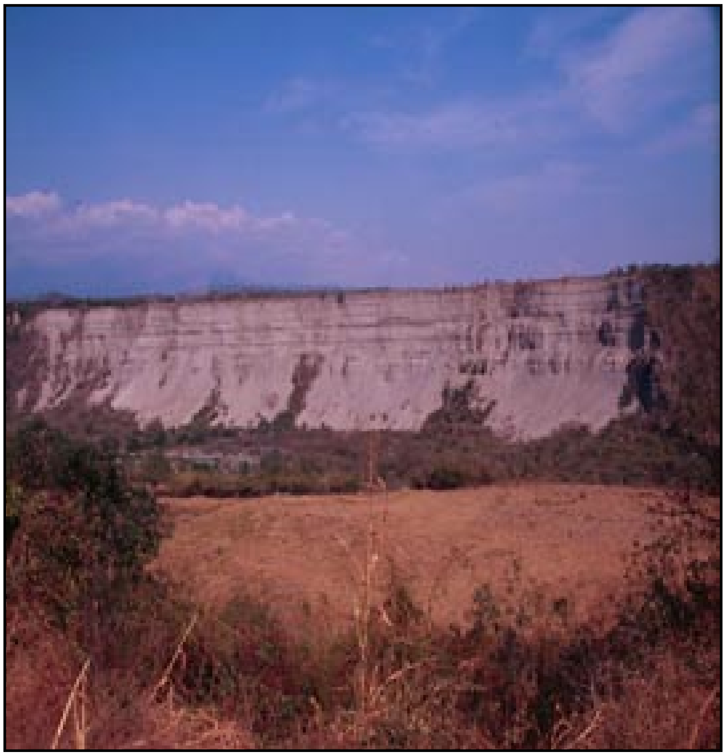

***Figure 8** - Stretch of cliff along Rio Armería northwest of Colima denuded by landslides during the earthquake. Before the earthquake, this stretch of slope was reportedly vegetated in a manner similar to the intact stretch of slope at the extreme right of the photograph.*

***Figure 9** - One of the larger falls observed from the Rio Armería cliffs on the afternoon of January 28, 2003, which had an estimated volume of 20 m^3.*

slides occurred in volcanic materials exposed on canyon walls, typically consisting of an upper fine-grained pyroclastic deposit, a middle unit consisting of well-indurated lava, and a lower unit consisting of a pyroclastic block-and-ash flow deposit (Figure 10). Volumes of the individual landslides typically ranged from a few m^3 to a few hundreds of m^3 each, and the highest landslide concentrations were about 40 landslides per linear kilometer of canyon wall. Slopes were near vertical and ranged up to about 500 m high. The landslides in this area damaged some irrigation systems.

Three smaller areas with moderate landslide concentrations were also observed. Two of these, on the south flank of Volcán de Fuego and along several smaller canyons south of the Barranca de Atenquique, evidently involved similar materials to those along the Barranca de Atenquique. The third area, along the lower valley of the Armería River near the coast, produced a moderate number of landslides along highway and railroad cuts and along the bedrock valley walls. Outside of the areas discussed above, nearly all of the disrupted landslides were along artificial cuts. Fewer than 20 landslides from natural, unaltered slopes were observed outside those areas during either aerial or ground-based reconnaissance. The largest cut-slopes failures were along the Colima to

***Figure 10** - Landslides along one stretch of canyon wall in the Barranca de Atenquique, on the east flank of Nevado de Colima volcano.*

Minatitlán road, between the Armería River and the village of Platanarillos. Cut-slope failures had reportedly blocked the main highway from Colima to Manzanillo and the road from Colima to Minatitlán, but these blockages had been removed by the time these areas were observed during the reconnaissance.

Structural Performance

Damage to structures has been categorized according to construction materials: steel; reinforced concrete; confined masonry; unreinforced masonry; and adobe. Generally, structural steel and reinforced concrete structures suffered little damage, but had the earthquake accelerations been greater, damage to such structures could also have been greater.

Confined masonry structures suffered mostly minor damage, but again, had the earthquake accelerations been greater, damage to such structures could also have been greater. Damage decreased as the number and size of confining elements increased, and also as the buildings' configurations improved (configuration issues are discussed below).

While damage to unreinforced masonry structures varied by location, in those areas of relatively heavy damage, it was concentrated in structures of unreinforced masonry and adobe. Damage was largely due to inadequate connections between walls and horizontal diaphragms and between intersecting walls, and to collapse of walls under combined in- and out-of-plane loads.

Steel Structures: Only one steel structure was observed in Colima: a large storage area, half of which was covered by a roof supported by rolled steel shapes, and the other half, by large timber trusses. Due to an electrical short circuit after the earthquake, the timber half of the roof caught fire and collapsed. The portion supported by steel shapes appeared undamaged.

Reinforced Concrete Structures: In and around Colima, typical reinforced concrete structures are at most four stories high, probably because of requirements for installation of elevators in buildings with more floors. The level of ductile detailing is unknown. Stucco and tile facades are most common, and are bonded to the underlying structure by mortar without mechanical anchorage. The common practice is to place unreinforced masonry infills within bays of frames. Typically, the infills are neither reinforced nor connected mechanically to the surrounding frame. Overall damage to reinforced concrete structures was minor. The most commonly observed damage consisted of minor shear cracks in walls and columns and spalling at beam-column connections. Most of these buildings were public facilities and therefore had possibly been built with a higher level of design and construction oversight. Most of these buildings appeared to be repairable.

Masonry Structures: Most masonry structures had solid units of fired clay, although a few used solid concrete units (tabicón). Typical masonry structures were constructed with walls one to two wythes thick, with 20-100 mm (1-4 in.) of mortar between courses. Walls are plastered with approximately 30 mm (1 in.) of stucco on both faces, applied directly to the masonry without mesh or mechanical anchorage. Masonry is typically laid in running bond with no interlocking units between wythes. Bond beams are generally not present at the level of the horizontal diaphragms, though wood members were occasionally used for this purpose. Lintels over openings are usually of wood, though sometimes masonry arches are used. For single story houses, roofs are generally constructed of tree trunks and small limbs. Additional wooden limbs are used to support clay tiles or corrugated metal or cardboard sheets. Roof members are generally not attached to bond beams or the supporting walls. In larger houses, solid or prefabricated reinforced concrete slabs are used. The foundation is typically a continuous footing, with its base about 0.4 m below grade, narrower at the top than the bottom, consisting of large rocks interspersed with small rocks and cement-sand mortar.

Confined Masonry — As commonly used in Latin America, confined masonry consists of unreinforced masonry panels, typically measuring 1-2 m in each direction, and joined by horizontal and vertical reinforced concrete elements that are poured in place after the masonry is laid (figure 11). Such confining elements generally are roughly square in

Figure 11 *- A typical confined masonry structure, which performed well in the Tecomán earthquake.*

Figure 12 *- Typical damage to unreinforced masonry structures.*

cross-section, with a cross-sectional dimension equal to the thickness of the masonry. They are generally reinforced with four #3 (9 mm) bars and transverse ties of heavy-gage wire. Structural continuity between masonry and confining elements is generally obtained by mechanical interlock between the running-bond masonry and the cast-in-place concrete. Structures of confined masonry performed better than those of unconfined masonry or adobe. Cracks often formed between the masonry and the confining elements, the latter which sometimes failed, but this was the case solely when the number and arrangement of confining elements was inadequate. In most instances, confined masonry structures remained unscathed.

Unreinforced Masonry — Unreinforced masonry structures are constructed without horizontal or vertical confining elements. They may have lintels of cast-in-place reinforced concrete, but wood is more commonly used. Their strength and initial stiffness may be increased by stucco. These structures failed in two ways: walls failed out-of-plane due to lack of mechanical connection between the top of the wall and the roof or floor diaphragm, combined with inadequate out-of-plane strength due to a lack of reinforcement; and in-plane shear failures occurred separately or in combination with out-of-plane failure. Increases in in-plane stiffness and strength due to stucco were lost as the stucco spalled off due to lack of mechanical anchorage. Due to the absence of reinforcement, combined in- and out-of-plane failure often led to collapse of walls and structures (Figure 12).

Adobe Structures: Typical adobe construction is very similar to that of unreinforced masonry. The foundation is typically constructed about 0.5 m below grade, and consists of large rocks interspersed with smaller rocks and mortar. Instead of a reinforced concrete grade beam (as with unreinforced masonry), the adobe units are laid directly on top of a layer of mortar with no reinforcement or other fastening method. Adobe structures commonly have wooden lintels, and may have wooden horizontal and vertical confining elements.

In some locations, such as Villa de Álvarez, damage to adobe structures was severe. As with unreinforced masonry, it took the form of separation of walls from roof and floor diaphragms, and in-plane shear cracking combined with failure out-of-plane. Due to the absence of reinforcement, such combined failure often led to collapse of walls and structures. Out-of-plane overturning of cantilever adobe walls was common. It is important to mention that the adobe and unreinforced masonry houses located in urban areas, damaged or with partial or total collapses, are quite old, perhaps several decades.

Historical Monuments: The historical monuments visited, mostly churches, exhibited light damage, such as spalling of stuccos and plasters, and damage to nonstructural elements. Fine cracks were observed in walls, but such damage does not compromise the stability of the structure. One exception was the church of San Pedro in Coquimatlán, which suffered severe damage in the main part of the building, as well as failure of the south bell tower, which collapsed onto the yard of the municipal building. The other tower showed damage in the columns and permanent rotation over one of the columns. The main building showed severe shear damage in all walls and cupolas. The main cupola partially collapsed. Though the damage is severe, the structure is considered repairable.

Configuration: Independent of

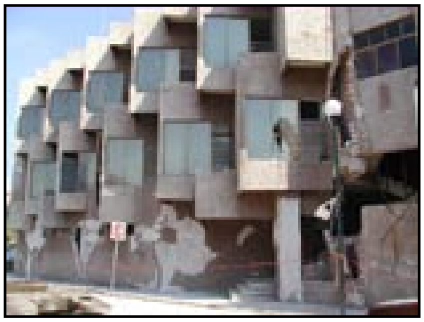

Figure 13 *- Example of lack of structural continuity of vertical and horizontal elements.*

Figure 14 *- Typical damage to adobe structure at the corner of a block.*

material, structural performance was clearly enhanced by aspects of building configuration: presence and symmetrical location of shear walls; absence of large openings in street level walls; and continuity of vertical and horizontal elements (figure 13). Location within a block was also important. Corner buildings appeared to suffer relatively heavy damage, due to a combination of the effects of openings in walls, and the plan eccentricity between the center of mass (generally located near the plan center of the building) and the center of rigidity (generally located near the interior corner of the building plan). This plan eccentricity led to heavy damage in the shear-resisting elements on the corner façade of the building, and sometimes to collapse of the exterior walls near the corner (Figure 14).

Emergency Response

The organizational relationships among the different groups participating in the emergency response are presented graphically in Figure 15. One of the primary purposes of the National System of Civil Protection (NSCP) is to coordinate the governmental and volunteer emergency response and recovery operations during disasters. The Secretary of Government is responsible for the NSCP. At the national level, the system is composed of three main elements: Emergency Operations (General Direction of Civil Protection); Scientific and Technical Support provided by the National Center for Disaster Prevention (CENAPRED); and the National Fund for Natural Disasters (FONDEN), which provides the funds required to finance emergency response and recovery operations. The system relies heavily on the resources of all levels of government, academic institutions, nongovernmental organizations such as the Mexican Red Cross, and a wide range of volunteers such as those from the Colleges of Architects and Engineers, the Construction Industry Chamber, and search and rescue groups. After the earthquake, those groups met almost daily to coordinate their efforts (Figure 16).

The emergency response to the January 21 earthquake was apparently rapid and well-managed by the State of Colima's Civil Protection System. The M_w 7.6 event did not cause the level of damage that could have been expected. It killed 21 people, mainly in adobe structures, including 14 who died in Colima from the collapse of their houses. Four others died in hospitals from

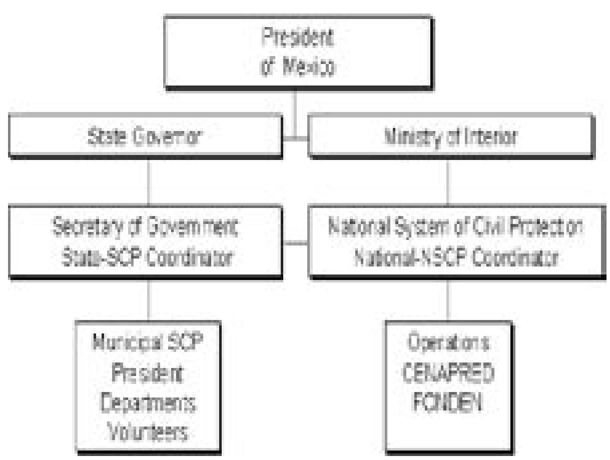

Figure 15 *- Approximate organizational relationship among groups involved in disaster recovery.*

Figure 16 *- Representatives of the government, academic institutions, and non-governmental organizations met almost daily to coordinate their efforts.*

injuries in Colima, and three from injuries elsewhere, a relatively low mortality rate for such a large earthquake.

While the earthquake damaged unreinforced masonry structures and some low-quality concrete frame buildings, it caused no major collapses of engineered buildings, and only slight-to-moderate damage to roads, potable water, electrical power, and communication systems. The demand for search and rescue resources was minimal, and the medical system was able to treat the injured within hours after the strong shaking ceased.

The readiness and competency of responders can be attributed to a number of factors. The Colima Volcano has been active for many years, and the State Civil Protection has often had to evacuate towns located in the most hazardous areas. The frequent activation of the system has provided the agencies and their personnel with practical emergency response experience. Furthermore, the State Civil Protection System has been active in forming and training specialized teams to respond to multiple hazards including floods and hurricanes. Colima has also experienced several large-magnitude earthquakes in the past century. According to Civil Protection authorities, much has been learned from these events, and significant progress has been made in improving building codes and practices.

There is a strong military presence in the city of Colima, with many types of resources that have been deployed to assist the civilian efforts. Thus far, the military has provided shelter and the personnel and equipment for demolition and debris removal. Because the city of Colima is the capital of the state, all of its resources were readily available to assist the affected municipalities.

Disaster Recovery

Only five days after the earthquake, the initial recovery from the disaster was well underway, being supported by the all levels of government, the private sector, and the affected population. At the time of the visit, the most important issue was the need to continue with the safety inspection of damaged structures. In some towns in the outlying areas, practically every adobe structure suffered some kind of damage, and some people were still occupying structures that were severely damaged. This situation caused concern, especially among the owners of homes or businesses that were damaged, since they are unsure about the safety of their structures and whether they could continue to be occupied.

As of February 11, there were only 95 volunteer inspectors in the field, organized and trained by the Colleges (associations) of Architects and Engineers and the Chamber of the Construction Industry. The data they are collecting is being categorized by “total damage,” “partial damage,” and “slight damage.” The rapid visual assessments provide the basis for determining which structures will require a more detailed assessment, be designated for demolition, or be repaired. This is an area where the utilization of GIS, such as that used by the EERI team, could dramatically increase productivity and efficiency.

The Civil Protection System asked the Mexican military to begin the demolition of structures categorized as totally damaged and to remove the debris from streets. The team observed the demolition of damaged adobe structures in the Municipality of Villa de Álvarez, which borders the northwest section of the city of Colima (Figure 17). After the demolition in that area is complete,

Figure 17 *- Demolition by the Mexican military of adobe structures categorized as totally damaged.*

large parcels of adjacent vacant land will be left behind. It is difficult to discern at this time whether the municipality will prohibit rebuilding in that area.

Immediately after the earthquake, the Governor of Colima ordered all schools to close for the rest of the week to allow time for safety inspections. Of the 703 primary and secondary schools in the state of Colima, according to initial reports, 220 suffered some level of damage (figures 18 and 19). All schools were scheduled to open on Monday, January 27, 2003. Students from damaged schools were to continue classroom instruction in temporary safe facilities.

The direct economic impacts of the disaster are beginning to emerge, but remain somewhat murky due to the discrepancies among the estimates being provided by various federal, state and municipal sources. Nevertheless, the federal government has already committed to provide 144.7 million pesos (approximately US$14 million) to be used for funding a variety of recovery programs: 42 million pesos for the repair or rebuilding of damaged housing units; 79.7 million pesos for assistance to the private sector, primarily small businesses; 20 million pesos to assist those unemployed due to the disaster; and 3 million pesos to promote tourism. This is only the initial installment, but it is deemed enough to move the recovery forward and stimulate the recovery of the state's economy. More importantly, these actions are an effort to distribute funds to those in need as quickly as possible.

The financing of this disaster will pose some major challenges to the federal government. The mechanisms used by Mexico to finance disaster recovery are complex and can at times be problematic. For example, in other times, the 144.7 million pesos committed to disaster recovery would have been diverted from the federal fiscal year 2003 budgets of the key agencies involved in promoting socioeconomic development. This diversion of resources would run the risk of retarding progress in this most important national priority. In recognition of this serious problem, the federal government instituted FONDEN (Fund for Natural Disasters) in 1996 and allocates a fixed annual amount (in 2003, FONDEN's budget is approximately US$350 million) to finance the repair or replacement of uninsured public facilities, and to provide disaster assistance to the poorest sectors of the affected population.

In recent disasters, the FONDEN has been able to restore the funds diverted from other federal agencies, but there have been other times when a few major disasters have driven FONDEN into insolvency before the fiscal year was over, and agency funds were not restored.

The FONDEN is a unique approach

Figure 18 *- Damage to a school building.*

Figure 19 *- Inclined cracking in an infill wall of a school building in the village of Ixtlahaucan. The structure of the school is made of light gage steel members.*

to financing disasters. Some aspects of FONDEN are innovative and may be of some interest to the United States. This disaster may provide opportunities for knowledge transfer between the United States and Mexico, and how the FONDEN is applied in this disaster may merit further study.

Reconnaissance Team Members

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In addition to Wartman and Rodriguez-Marek, the NSF team included David Keefer of the United States Geologic Survey, Menlo Park, CA; Scott Deaton of the Georgia Institute of Technology, Atlanta; Pedro Repetto, URS Corporation, Denver, CO; Emir Jose Macari, Louisiana State University, Baton Rouge; and Carlos Navarro Ochoa, Juan de la Cruz Tejeda Jacome, Carlos E. Silva Echartea and José Armando Téllez Alatorre of the Universidad de Colima, Colima, Mexico.

David Frost and Scott Deaton (Georgia Institute of Technology and Dataforensics, Atlanta, GA) provided the software PQUAKE, which was used to record and organize data during the geotechnical reconnaissance.

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