Learning from Earthquakes

Preliminary Observations on the December 22, 2003, San Simeon Earthquake

Following the earthquake, EERI initiated a reconnaissance effort composed of teams from various California universities, agencies and engineering professionals. The team was composed of Graham Archer, Craig Baltimore, Charles Chadwell, Rakesh Goel, and Abe Lynn from California Polytechnic State University; Lew Rosenberg, San Luis Obispo County geologist; Robb Eric S. Moss, Fugro West, Inc.; Fred Turner, California Seismic Safety Commission; Chris Poland, Jay Love and Jason Horwedel, Degenkolb Engineers; and Joshua Marrow, Simpson, Gumpertz and Heger. The Earthquake Investigation Committee of the ASCE Technical Council on Lifeline Earthquake Engineering (TCLEE) was represented by LeVal Lund, civil engineer and TCLEE team leader; Mark Yashinsky, Caltrans; John Eidinger, G&E Engineering Systems Inc.; Anshel Schiff, Precision Measurements; Teresa Elliot, Portland Water Bureau; Al Guerrero, Southern California Edison, retired; and Tom Cooper, TW Cooper Inc.

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Introduction

An earthquake of moment magnitude M_W 6.5 struck the central coast of California at 11:15:56 a.m. PST (19:15:56 UTC) on Monday, December 22, 2003. The epicenter was 11 km NE of San Simeon, at a depth of 7.6 km (35.706N 121.102W). The earthquake was felt as far north as the San Francisco Bay area, as far south as the Los Angeles area, and east into the San Joaquin Valley (see Figure 1).

The earthquake struck in San Luis Obispo County, which has a population of 246,681 (from the year 2000 census). Two people were killed and 47 people were reported injured. Countywide, 290 homes and 190 commercial structures were damaged. One building collapsed and 20 buildings were severely damaged in Paso Robles, which is located 39 km from the epicenter. Structural damage was also noted in the city of Atascadero and in unincorporated areas of the county. Local, state and federal disasters were declared.

Seismological and Geotechnical Aspects

The seismicity along the coast of central California is dominated by the northwestward motion of the Pacific plate with respect to the North American plate. The largest historical earthquake in the vicinity was the magnitude 6.2 Bryson earthquake of November 1952.

The hospital in Templeton had the largest recorded ground motion of 0.48g, indicating rupture directivity to the SE from this earthquake (Figure 2). Unfortunately, there were few near-field recorded motions. Almost all the recordings were from

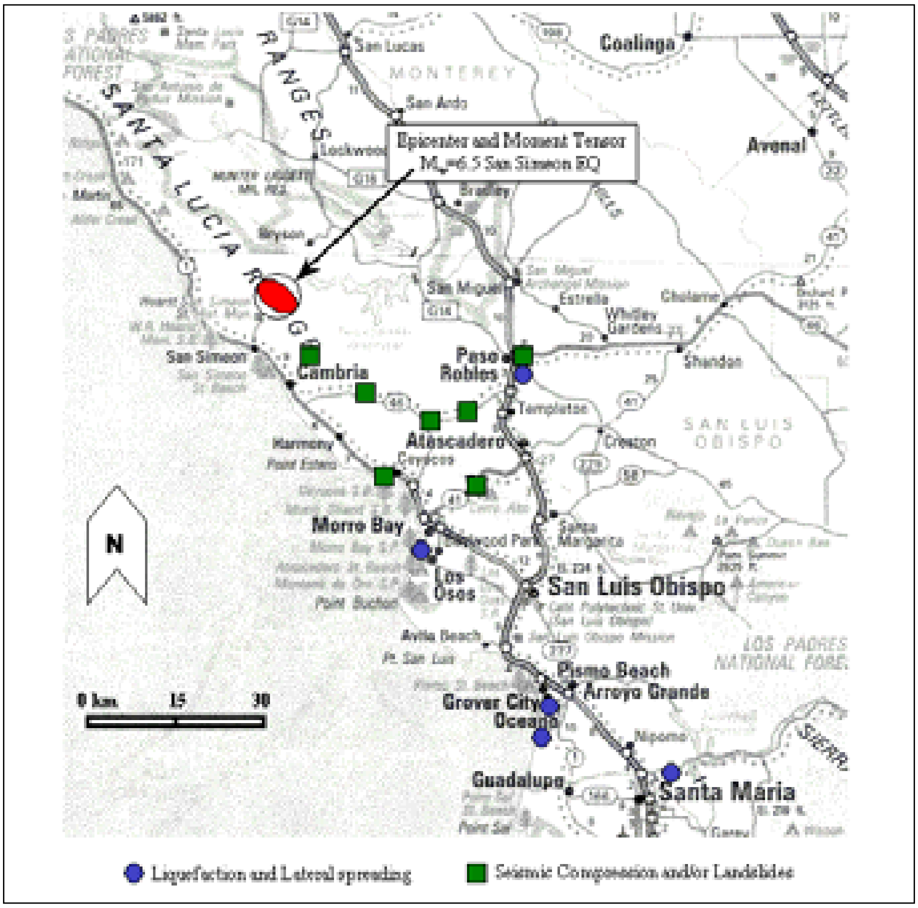

Figure 1. *Regional map showing epicenter and location of ground damage.*

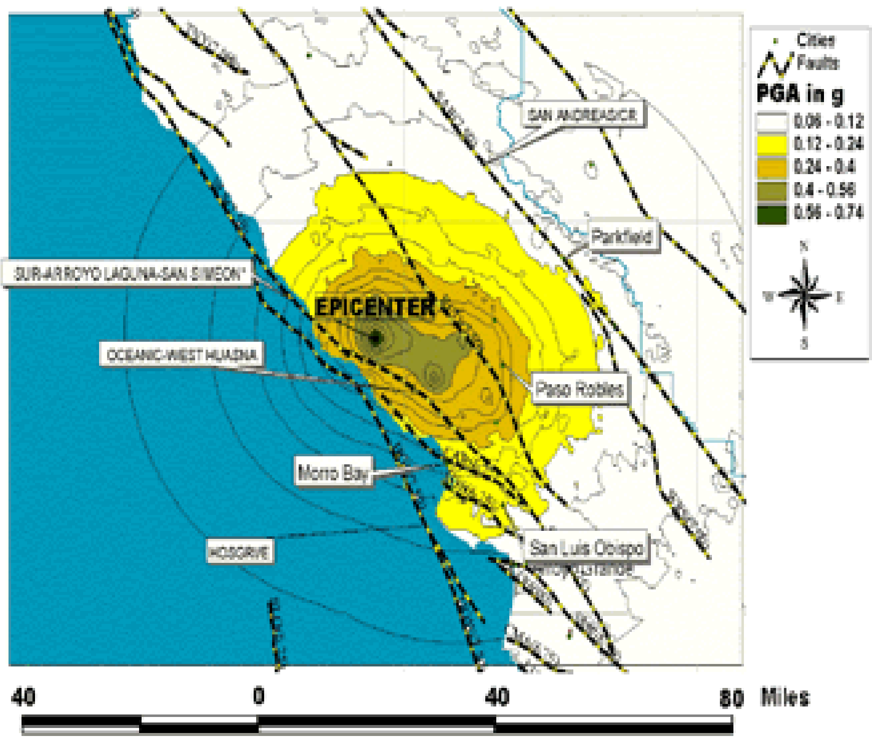

Figure 2. *ShakeMap peak ground accelerations (g).*

the Parkfield array, 50 to 100 km to the east. The closest recording was the free-field station at the San Simeon Creek bridge on State Route (SR) 1, 13 km to the west of the epicenter. Despite the shallow depth, the rupture did not appear to propagate to the surface. At the time of this writing, the causative fault was not known.

There was a surprising amount of liquefaction and related ground damage for what were relatively low levels of ground shaking. A directional preference of ground shaking was evident in the observed ground damage patterns and strong motion recordings. Besides liquefaction, geotechnical effects included lateral spreading, seismic compression, and potential basin effects. Repair costs from ground displacements were related mainly to the damage to highways from seismic compression, and to houses and infrastructure from lateral spreading.

Strong Ground Motion: The San Simeon earthquake was a reverse event with, in plan view, a northwest-to-southeast propagation of rupture determined through finite source modeling (California Integrated Seismic Network, 2004). The direction of propagation of the rupture tends to cause stronger ground shaking in the forward region.

The strong motion stations (with SMA accelerographs) that recorded this event are shown in Figure 3 in relation to strong motion attenuation curves from Abrahamson and Silva (1997). Recordings of instruments maintained by the California Integrated Seismic Network (CISN) and the National Strong Motion Program (NSMP) are shown as distance (km) versus geometric mean of the peak ground acceleration (g). Attenuation curves for a reverse type event of M_w=6.5 are shown for the median peak ground acceleration, as well as the median ± 1 standard deviation. Also shown in Figure 3 are approximate distances for SR-46 and nearby towns.

Liquefaction and Lateral Spreading: Most liquefaction and lateral spreading did not affect structures

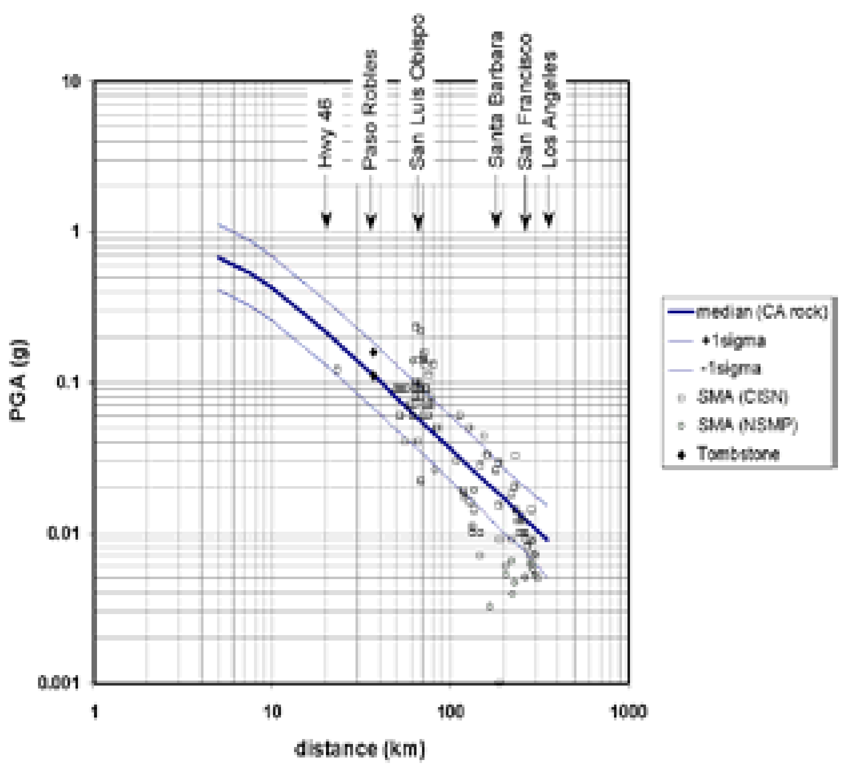

Figure 3. *Peak ground accelerations from M_w 6.5 strong ground motion attenuation curves, strong-motion recordings, and pseudo-static calculations.*

or other facilities (see Figure 1). Liquefaction was observed below the Niblick Road Bridge in Paso Robles just south of downtown. A sand blow in the Salinas River bed below the bridge ejected coarse to fine sand with some fines. The bridge appears to have undergone rocking during the earthquake, resulting in gapping of the soil around the columns, but it is not known if this rocking caused or exacerbated the nearby liquefaction.

Several lateral spreads were observed near Oceano. A group from the reconnaissance team found substantial damage to homes, lifelines, roadways, and a sewage treatment plant there (Knudsen 2004). Spreads up to 180 m wide were observed, with maximum horizontal displacements on the order of 10-20 cm (Figure 4). It is thought that most of the liquefaction and lateral spreading at these Oceano locations is associated with artificial fills. There was also liquefaction and related settlement of the levee along Arroyo Grande Creek.

Seismic Compression and Landslides: The strong ground shaking resulted in numerous small landslides, particularly noticeable along State Routes 46 and 41. Surficial slides were observed along River Road in Paso Robles. Some larger surficial slides were observed in the Franciscan Formation along SR 46.

Seismic compression was prevalent along SR 46 and, to a lesser extent, along SR 41. Disruption of the asphalt produced large cracks with both horizontal and vertical offsets over significant lengths of these two highways. The strong ground shaking caused settlement of the road fills, resulting in sway-backed roads and large cracks in the asphalt pavement with vertical offsets on the order of 10 cm. Deep rotational slope instabilities in the road fills caused the scallop-shaped asphalt cracks shown in Figure 5. Settlement of bridge approaches and embankments also resulted in disruption of the pavement. Overall, the road damage occurred close to the southeast projection of the fault rupture.

Settlement of beach fills caused asphalt and dike cracking at a parking lot along an estuary in Cayucos, although no evidence of liquefaction was observed.

Figure 4. *Lateral spread in Oceano (photo Knudsen).*

Hot Springs: Two hot sulfur springs in Paso Robles began to flow following the earthquake. One spring erupted beneath the surface parking lot at the Paso Robles City Hall. Hot water and sediment were spouting at a rate of approximately 82 liters per second (1300 gpm) at a temperature of 43°c (110°f), making the capping procedure difficult for the emergency construction crew. The spring is said to be at the site of an old bathhouse where an earlier spring was capped when the bathhouse closed down. A second hot spring also began to flow from the side of the U.S. Highway 101 embankment at the Paso Robles Road exit.

Lifelines

Most lifeline facilities performed well. There were no fire ignitions in Paso Robles, and three in Atascadero, located about 16 km south of Paso Robles.

Power Systems: About 60,000 customer services lost power for four or five hours in the areas affected by the earthquake. The power outage in Oceano was reported to have lasted over 24 hours. Many heavily shaken areas retained power. Local outages were associated with feeder-line burn-down, blown fuses, pole damage, or other distribution system damage. Notwithstanding the significant magnitude of this earthquake, there was relatively little damage to power system facilities.

Gas and Liquid Fuel Systems: Natural gas system damage was minor, with only a few mains in need of repairs. Most damage was downstream of the customer's meters. About 500 customers suffered one to two-day outages, some of which were due to customers unnecessarily turning off the gas, even though

***Figure 5.** Seismic compression and slope instability along SR 46 (photo Chadwell).*

they had no damage.

There are oil and gas fields and oil transmission pipelines in the area. The California Division of Oil and Gas reported no damage to oil and gas production and transmission facilities.

Highways and Bridges: The most significant road damage was to SR 41 and SR 46 between U.S. Highway 101 and SR 1 (see Figure 1). As discussed above, rock falls closed SR 41, and landslides and lateral spread closed SR 46. Villa Creek Bridge, north of San Luis Obispo on SR 1, was the only Caltrans structure that was damaged during the earthquake. This is a five simple-span, precast girder structure with a deck supported on tall single-column bents. The bridge was recently retrofitted, but that did not protect it from a rockslide that put a hole in the northeast girder web. The damage did not reduce the girder's ability to carry traffic and the bridge remained open following the earthquake.

The Templeton Road Bridge, which spans over the Union Pacific Railroad and the Salinas River, had its approaches settle about 13 cm (see Figure 6). The barrier rail and utility lines were damaged. The western two spans are cast-in-place girders and the eastern five spans are reinforced concrete box girders. The superstructure is on flared single-column bents with piles, and on seat and end diaphragm abutments on spread footings. Most of the damage was due to liquefaction, settlement, and shaking of the superstructure. The bridge was not retrofitted. Soil borings were taken before a chip seal was placed at the approaches.

A few roads were closed by structures falling onto them. Twelfth Street in Paso Robles and SR 1 in Cambria were closed until debris could be removed.

Airports: Of the five airports in the area affected by the earthquake, only the Oceano Airport, which is for civil aviation, had any damage. Although it is 80 km south of the epicenter, the runway suffered liquefaction, lateral spreading, and settlement. The damage was exacerbated by utility lines (unknown to airport management) under the runway. The soil settled around these utility lines. The airport closed because it also lost power. The generator turned on, but failed after five hours.

Dams: There were ten locally owned and nine federally maintained dams in the area. Owners of dams or their consultants inspected these dams following the earthquake, as did the California Department of Water Resources Division of Safety of Dams. The US Army Corps of Engineers inspected federal dams. Most of the dams were instrumented and recordings of free field and dam motions are available.

The Las Tablas and the Whale Rock dams both had longitudinal cracks

***Figure 6.** Templeton Road Bridge approach settlement (photo Yashinsky)*

along their crests. This type of cracking is due to the stiffer core sloughing off the surrounding material as the core moves back and forth. There was also a rockslide along the right wall of the Las Tablas spillway channel about 60 m downstream from the dam, but it is not large enough to prevent the spillway from passing the design storm.

There was also longitudinal cracking in the upstream face of Atascadero dam. Because these cracks could be exacerbated through erosion, they were immediately covered and will be excavated and sealed with new compacted material.

Water Systems: Several "boil water" notifications were made in the Five Cities area on the coast south of San Luis Obispo Bay because of broken water mains and service connections. The notices were lifted in a few days, and there were no water quality problems reported.

No functional problems were reported with any of the local groundwater wells, except for loss of power. Also, there was no loss of function to the water supply from Santa Margarita Lake (a reservoir), the Whale Rock Reservoir Project, Lopez Lake (a reservoir), or the Coastal Branch Aqueduct of the California State Water Project.

Water storage tanks in Paso Robles and Templeton had damage in the form of tank wall buckling ("elephant's foot"), an example of which is shown in Figure 7. Additionally, pipe connection damage due to tank differential settlement occurred at several locations. There were few water repairs, except in the Oceano area where there was liquefaction.

Wastewater Systems: The California Central Coast Regional Water Quality Control Board indicated there were no sewer spills as a result of the earthquake. There was no reported functional damage to wastewater treatment plants, except for the loss of commercial power. Emergency generators came on line automatically. The Paso Robles Sewer Pumping station emergency generator permitted pumping for 17 hours of its 40-hour design operation. The wastewater treatment plant nearby continued to operate with emergency generators. The vertical plastic baffles were dislodged in one of the two primary clarifiers, possibly due to sloshing, but this did not affect the wintertime operation of the plant.

Structural Performance

The towns of Paso Robles, Templeton, Atascadero, and San Miguel were most affected by the earthquake. Building types in these areas are predominantly residential (single home to low-rise, multi-family dwellings), and low-rise commercial, industrial, and municipal buildings. Most residential structures are of wood frame construction. Most commercial, industrial and municipal structures are wood and light-gage steel-frame construction, unreinforced masonry, or reinforced concrete frame or shear wall.

Figure 7. *Buckle and fence post (photo Eidinger).*

Paso Robles: In Paso Robles, the damage was concentrated in the three-block historic downtown area, with the largest amount of damage observed in a roughly one-block radius about the center of the district. Most buildings are of unreinforced masonry (URM) construction, many of them dating back to more than a century ago. Many were not designed for seismic loads and lacked proper seismic detailing. A few had been retrofitted by tying the floor diaphragm to the walls, and the damage level was lower in those buildings. In fact, none of the buildings with some kind of seismic retrofit collapsed, indicating that even a basic level seismic retrofit may help to prevent collapse and resulting loss of life in a moderate event.

Most buildings in the affected area, especially on the Park and 12th Streets, are constructed without any gap between them. In general, buildings on the street corners performed poorly. The configuration of these corner buildings with windows on the street sides and solid walls on the other two sides created extreme plan asymmetry (i.e., large eccentricity between the floor center of mass and the center of rigidity). The resulting torsional motions during the earthquake shaking imposed much larger demands on these buildings compared to buildings with symmetric plans. Unreinforced masonry buildings without seismic retrofit located mid-block suffered

Figure 8. *The collapsed Acorn building (photo Marrow).*

less damage.

The damage pattern indicates stronger shaking in the east-west direction, the direction normal to the fault rupture, compared to the north-south direction. This is consistent with the observation in previous earthquakes that the shaking may be strong in the direction normal to the fault compared to the direction parallel to the fault.

The Acorn building, a historic, unreinforced masonry building dating to 1892, collapsed completely, causing the only two fatalities of the earthquake (Figure 8). The lateral-load-carrying system of this two-story building appears to have been unreinforced masonry walls supporting the timber floor and roof trusses. Neither the floor nor the roof seemed to have been even minimally tied to the walls. During the earthquake, the clock tower on the Park and 12th Street corner of the building collapsed and the second story wall on the Park Street side collapsed out-of-plane. The major shear resistance of this building was in the north-south direction, but, as noted previously, the strong shaking was in the east-west direction.

Located across the street from the Acorn building, the building housing Marlow Interiors did not collapse, but it suffered extensive structural and nonstructural damage. Both buildings were subsequently demolished.

Other buildings suffered nonstructural damage to parapets and the external wythes of brick. The building in Figure 9 was reportedly partially retrofit prior to the earthquake. However, the veneer separated from the exterior URM bearing wall and fell to the sidewalk and street.

Atascadero: Built in 1918, the Atascadero City Hall consisted of a reinforced concrete space frame with brick façade. The exterior damage primarily consisted of cracks and severe spalling of the brick façade on the rotunda (Figure 10). Falling bricks from the façade took out a skylight and fell on the tables in a room located at the rotunda office level. The reinforced concrete space frame supporting the dome roof was found to have suffered no damage. The parapet walls and interior dome structure — which were not damaged — had received a seismic retrofit in 1987.

Internal damage consisted of severe cracks in the walls and plaster throughout the building. The damage was more severe in the first story. The rotunda office where the city council meets experienced spalling of plaster from the roof and the ring beam. There were also large amounts of contents damage within the structure in the form of overturned display cases, bookshelves and office furniture.

Residential Damage

The earthquake caused little residential damage. There was scattered chimney damage throughout Paso Robles and the surrounding area, and isolated cases of more serious damage. The most serious damage appears to be associated with a few houses located in the hills west of Atascadero and in the Hidden Valley area. One late-70s house located at the top of the hill

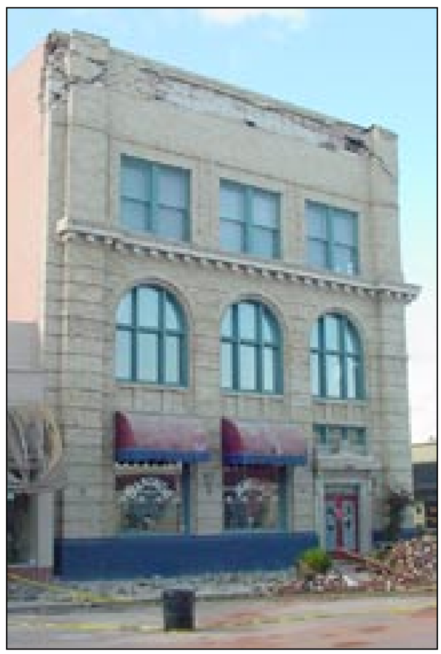

Figure 9. *Nonstructural parapet and veneer brick damage (photo Lynn).*

Figure 10. *Atascadero City Hall facade damage (photo Lynn).*

on San Gregorio Road moved off its foundation, suffered collapse of its cripple walls, loss of its chimney and porch, and separation into several sections (Figure 11). While the house had plywood siding and foundation bolts, in fact most of its damage appears to be caused by poor construction. Many of the nails fastening the plywood to the sill plate actually missed the sill plate, and there were fewer nails than required. There were also a number of severely damaged and collapsed residential structures in the region directly southeast of the epicenter. While there have been some suggestions that this damage is associated with ridge-top shattering, other houses along the same ridge did not appear to have suffered any significant damage.

Wineries

Many wineries throughout the region sustained damage to tasting rooms and production facilities. There are approximately 85 wineries in the Paso Robles Wine Region, of which 15 are known to have sustained damage, ranging from broken bottles and glassware in the tasting rooms, to toppled wine barrel stacks (see Figure 12) and ruptured wine tanks. Generally, no major structural damage was reported or observed. The most heavy winery damage was centered along SR 46, southeast of the epicenter.

Wineries reported losses of millions of dollars where barrels toppled and burst. Wine barrels stacked three levels high on two-barrel portable steel wine barrel racks fell when the racks moved. A worker in a barrel room suffered minor injuries after she was buried underneath falling barrels. She was rescued only after other workers spent an hour emptying the barrels and rolling them out of the way.

There was also damage to stainless steel wine tank fittings. One unanchored 8,000-gallon tank shifted during ground shaking, causing the valve to catch on a concrete pedestal and break the manifold. Winery workers said rivers of wine flowed out of barrel rooms. Cleanup and salvage were difficult because of aftershocks.

Public Policy Issues

This earthquake raised a number of public policy issues indicated in the following list, associated with the slow progress in the retrofit of older, unreinforced masonry (URM) buildings. These issues will be explored in more detail in a subsequent report.

1. As noted above, the earthquake caused damage to URM buildings, particularly those that had not been retrofitted. The retrofit and demolition rates in the central coast region for these buildings are considerably lower than the statewide average of 52% and 13%, respectively.

Figure 11. *Residential collapse in Atascadero (photo Lynn).*

Figure 12. *Collapsed wine barrel stacks at Turley Wine Cellars, SR 46 near Paso Robles (photo Marrow).*

Throughout the region, mandatory strengthening ordinances adopted by local governments have either compliance deadlines well into the future (2008, 2017, 2018) or the deadlines are likely not being triggered or enforced, as is the case in SLO County. The last time the Seismic Safety Commission considered this matter in 1995 it recommended mandatory strengthening. The act under consideration at the time would have required an engineering evaluation to be completed within six months to six years and any recommended retrofit completed within three years of the evaluation. Several communities are reconsidering their ordinances and seeking input on reasonable deadlines for retrofitting.

2. One of the rationales for the extended deadlines in the above ordinances is a trough or area of low seismicity in SLO County depicted on a variety of public maps (see, for example: a map prepared by the California Geological Survey **http://www.consrv.ca.gov/cgs/rghm/pshamap/pshamain.html**). Recommendations against adjustments on the basis of this trough were made in the early 1990s after owners and preservationists began to use this as an argument for relaxing retrofit requirements. Given the unknown detailed sources of some earthquakes and uncertainties in map values, is it appropriate for governments to relax recommended minimum practices because of such troughs? Should there be "floors" in design and policy values for the outdated Seismic Zone 4?

3. Many cities have used redevelopment funds for "Main Street Programs" to provide nonstructural enhancements to downtown business districts to help economic revitalization. Unfortunately, these improvements also make attractive perils of collapse-risk buildings, increasing the public's exposure to the risk. At what point should investments in safety be coupled with cosmetic investments? Is this issue adequately addressed in seismic evaluation and retrofit triggers in the International Existing Building Code?

4. As in Northridge and Napa, the collapse of stacked building contents posed significant threats to life and property. Stacked wine barrels collapsed and blocked routes of egress. Recent laws call for shrink-wrap, fencing on racks, and other measures, as well as OSHA oversight. However, public compliance and OSHA enforcement are both lax. Wine caves have somehow escaped regulation from fire and other safety codes, and are hazardous for a number of reasons, not the least of which is egress after an earthquake.

5. A small but significant number of relatively modern wood buildings suffered damage disproportionate to their type, notably because of insufficient nailing and other connections. Thorough plan reviews and code enforcement in some areas of the central coast appear to be in need of improvement.

Acknowledgments

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