

Learning from Earthquakes

Western Sumatra Earthquakes of March 6, 2007

EERI received two reports on the Western Sumatra earthquakes of March 6, 2007 — one on geotechnical effects and the other on building damage. Their publication is supported by the National Science Foundation through EERI's Learning from Earthquakes Program, Grant # CMMI-0650182.

Report #1

Geotechnical Effects

This reconnaissance report was prepared by Danny Hilman Natawidjaja, Adrin Tohari, Eko Subowo, and Mudrik R. Daryono, Research Center for Geotechnology, Indonesia Institute of Sciences (LIPI), Bandung, Indonesia.

Introduction

On the morning of March 6, 2007, two earthquakes ruptured two major segments of the Sumatran fault near Singkarak Lake in western Sumatra. The first event occurred 10:50 a.m. local time, and the second occurred at about 12:45 p.m. The NEIC-United States Geological Survey, moment magnitudes and locations of the first and the second earthquakes are M_w 6.4 at 0.512°S , 100.524°E and M_w 6.3 at 0.49°S , 100.52°E . The two quakes destroyed structures on or near the fault, killing more than 70 inhabitants. The epicenters were approximately 50 km from Padang, the capital city of west Sumatra.

Field investigations of surface fault ruptures and earthquake effects were conducted a week after the events. The surface ruptures of the first event were observed south of Singkarak Lake, with a total length up to 15 km. The observed fault offsets varied from a few centimeters to 24 cm right lateral. The fault slip

also had significant dip-slip component: the west side slipped down up to 24 cm. The rupture for the second event was found north of the lake, with a length estimated at 22 km. The fault offsets of this rupture were only up to 12 cm.

Seismotectonic Background

As depicted in Figure 1, the island of Sumatra sits atop the Southeast Asian plate, which overrides the subducting Indian and Australian oceanic plates that converge obliquely at about 50 to 60 mm/yr (Prawirodirdjo et al.,

2000). The oblique convergence is partitioned into two components: the dip slip is accommodated on the subduction interface, and the strike-slip component is accommodated largely by the Sumatran fault (McCaffrey, 1992; Sieh and Natawidjaja, 2000). Other strike-slip faults that occur in similar settings include the left-lateral Philippine fault (which is parallel to the Luzon and Philippine trenches), the right-lateral Median Tectonic Line (which is parallel to the Nankai trough, Japan), and the Atacama fault

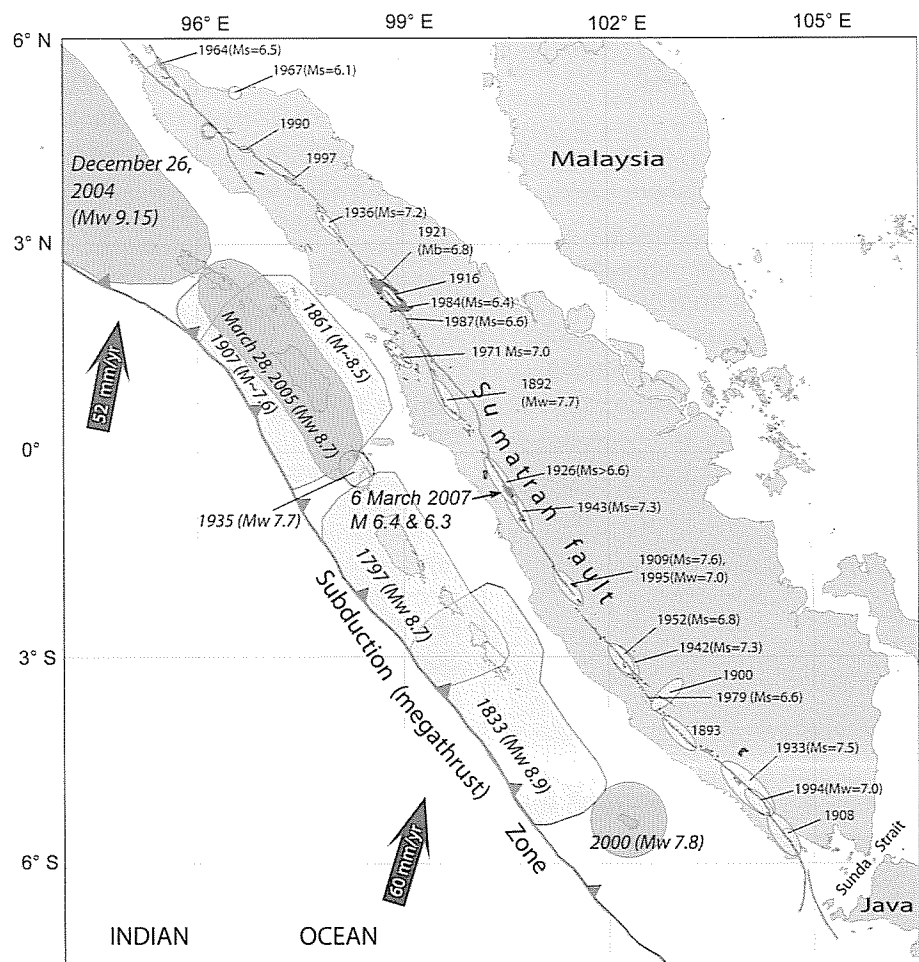


Figure 1. Historical major earthquakes along the Sumatran fault zone (SFZ) since 1892, including the 6 March 2007 event. The ellipsoid shapes indicate fault segments that were ruptured. The large ellipsoids west of Sumatra indicate recent and historical megathrust events in the Sumatra subduction zone.

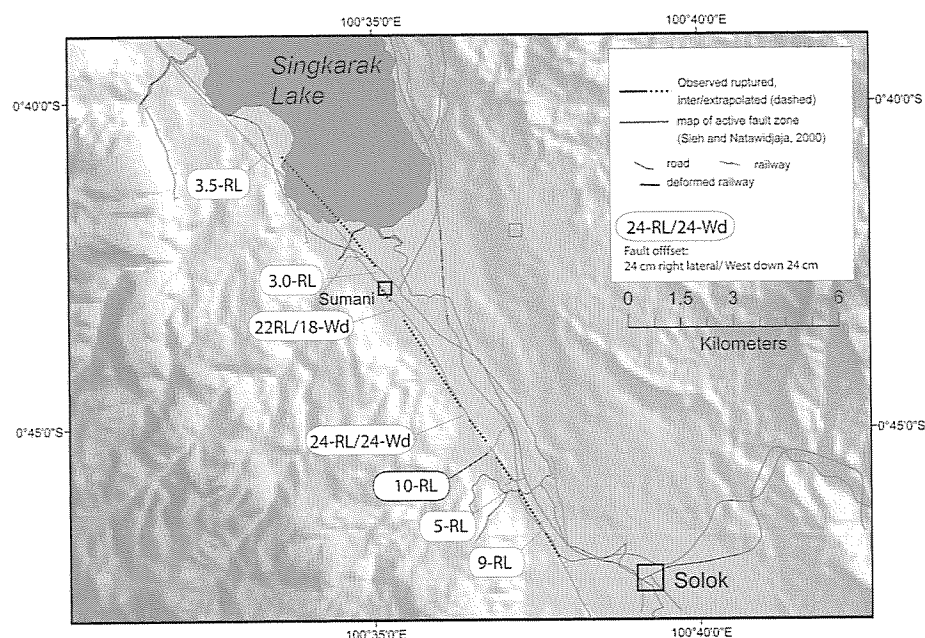


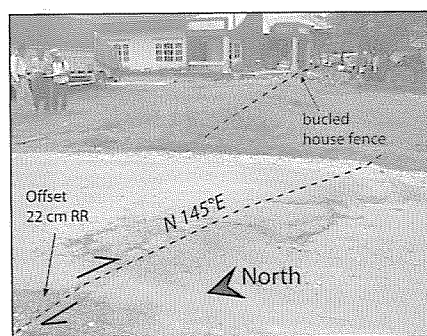
Figure 2. Surface fault ruptures and measured fault offsets of the first main-shock. The length of the rupture zone is up to 15 km. The offsets vary from a few up to 24 cm displacement (west side down) of right-lateral movements. The largest slip occurred on the central part of the rupture. The dip-slip movements are also observed.

(which lies parallel to the South American trench, offshore Chile).

The SFZ is highly segmented and consists of 19 major segments, ranging in length from 35 km to 200 km. These fault segments are separated by more than a dozen

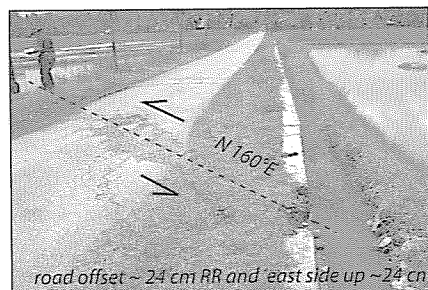
discontinuities, ranging in width from less than 4 km to 12 km, mostly dilatational step-overs (Sieh and Natawidjaja, 2000). The SFZ poses major hazards to people living on and near the active fault trace.

Figure 3. Examples of expressions of the surface ruptures. (a) Left-stepping moletracks are observed near Sumani. The rupture cut the asphalt road and right laterally offset it about 22 cm. (b) Surface rupture/moletracks crossing the asphalt road in village west of the main road, halfway between Sumani and Solok. The road is right laterally offset about 24 cm. The west side is also down about the same amount. (c) Same feature viewed from the south.



(a)▲

▼(b)



road offset ~ 24 cm RR and east side up ~ 24 cm



(c)▼

Since 1890, there have been about 21 major earthquakes with magnitudes ranging from 6.5 to 7.7 (Figure 1). Thus, on average, there have been roughly two earthquakes every decade. In the past decade, two major earthquakes occurred in Liwa, south Sumatra in 1994 ($M_w 7.0$) and in the western flank of the Kerinci Volcano in 1995 ($M_w 7.1$). In the region of the recent March 6, 2007, earthquake, the historical earthquakes occurred in 1926 and 1943. Despite the frequency of large earthquakes, until now the threat has not been taken seriously in land use planning and building code practices.

Fault Ruptures

We interviewed many local people who were affected by the quakes. They all agreed that they felt two strong earthquakes at about 10:50 a.m. and 12:50 p.m., but people who live on opposite sides of Singkarak Lake give different accounts about which one was the stronger earthquake. People in the south felt that the strongest shock was at about 10:50 a.m.; people in the north felt that the second earthquake was the strongest one. These eyewitness accounts support the physical evidence: that the sources of the first ($M 6.4$) and the second events ($M 6.3$) were different, with locations separated by the 25-km-long Singkarak Lake. We found clear evidence of two separated fault rupture zones; one north of the lake along the southern part of the Sianok segment, and the other south of the lake on the northern half of Sumani segment.

First event ($M 6.4$). Figure 2 shows that the total length of the surface rupture zone is up to 15 km. The southern extent of the rupture zone seems to end about 3 km west of Solok town. The surface fault ruptures were clearly marked by their moletracks, which were easy to see in a few locations cutting the asphalt roads (Figure 3). Generally, the surface ruptures were oriented

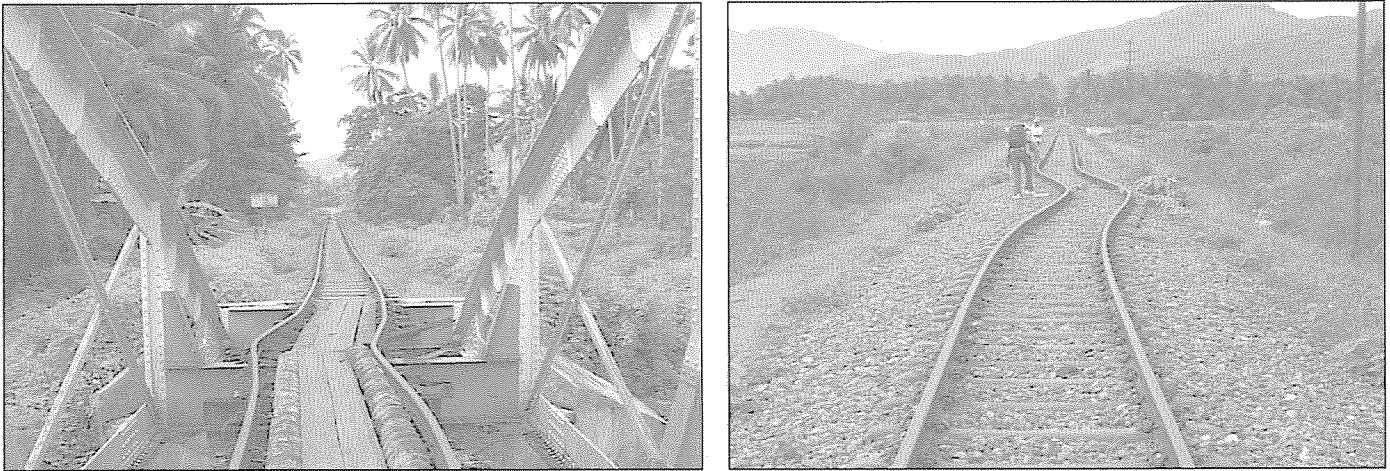


Figure 4. The N-S trending railway tracks on the east side of Sumani that were deformed during the earthquake.

NW to NNW – similar to the Sumatran fault trend.

We measured the geological fault offsets from the displaced road's asphalt edges, house fences and water canals in the rice fields. The observed offset ranged from 3-24 cm, with a sense of a right-lateral movement. The maximum offset was about 22-24 cm, in the central part of the ruptured segment. The fault slips or offsets seemed to get smaller toward both ends. Our measurements also indicated they also showed a significant compo-

nent of vertical movement, or dip slip, with the western side moving down up to 24 cm.

Evidence of another interesting surface deformation phenomena was found in the railway tracks that run along the east side of the main rupture zone: they deformed or buckled in several places, especially along 3.5 km of the N-S trending train track on the east side of Sumani (Figure 4). Local people reported that, during the earthquake, the railway was swinging sideways back and forth.

Second event (M6.3). In the region north of the Singkarak Lake, we observed evidence of surface rupture between the northern tip of the lake and the city of Bukit Tinggi; i.e., along the southern half of the Sianok fault segment. Our mapping shows that the total length of the rupture zone is about 22 km. We found that the maximum fault offsets were about 8-12 cm along the southern half of the rupture zone (Figure 5). The fault slips seem to diminish toward both ends.

The 8-12 cm right-lateral offsets were observed near Jambak village, Batipuh regency. The fault trace cuts the main road and runs through the collapsed or heavily damaged houses (Figure 6). This rupture zone with maximum offset coincides with the most damaged village (i.e., Jambak) in the region.

Near the northern termination of the rupture zone, we found possible expressions of moletracks in Sungai Landai village, about 5 km south of Bukit Tinggi, where we measured a fault offset of only about 2.5 cm. We traveled along the main road between Bukit Tinggi and Maninjau Lake, but we did not find evidence of surface rupture. This suggests that the rupture zone terminates between Sungai Landai village and this road. In addition, no significant damage was reported from the areas north of this road.

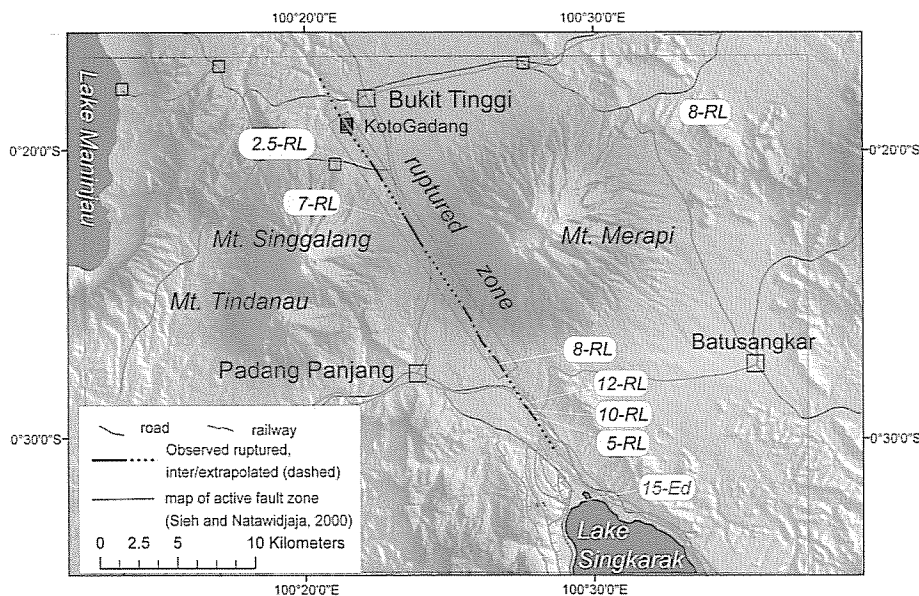


Figure 5. Surface fault ruptures and fault offsets of the second mainshock. The length of the rupture zone is up to 22 km. The largest slip, up to 12 cm, occurred on the central part of the rupture.



Figure 6. Surface ruptures in Batipuh area. The ruptures cut and right-laterally displaced the roads 5–12 cm.

In Kotogadang a big mosque collapsed during the second shock at 12:50. This mosque has ground ruptures trending about NNW running through it. We surmise that these ground ruptures are actually the fault rupture, since they are oriented NNW and are plausibly caused by nontectonic ground instability. A committee of the elders of the town plans to move the mosque at least 20 m away from the rupture zone. They will also build a historical monument on the current location to indicate the active fault line and show the next generation the potential for earthquakes.

Near the northern tip of Singkarak Lake, instead of the major NNW-trending rupture, we found ground ruptures trending NE with a pure dip slip motion, SE side down up to 30 cm (Figure 7a). Many houses were deformed due this rupture (Figure 7b). We could not be sure whether this is tectonic normal faulting or a head scarp of a landslide. We favor the former, however, since this mechanism is consistent with the interpretation that the Singkarak Lake basin has formed by a tectonic pull-apart mechanism between the movements of the two major fault strands (i.e., Sianok and Sumani segments) (Sieh and Natawidjaja, 2000).

Rupture Zones and Damage

We did not conduct a comprehensive investigation of damage, but it seemed to us that most damage to houses and other structures coincided with the observed rupture zone. Many collapses were caused by the ruptures, not the shaking. In many cases we saw houses only 10–20 m away from the rupture zone with little or no damage.

It is obvious that only applying building codes will not be enough to prevent future damage. The active fault line in mainland Sumatra should be mapped appropriately and taken into account in land use planning. Applying a regulation like Califor-

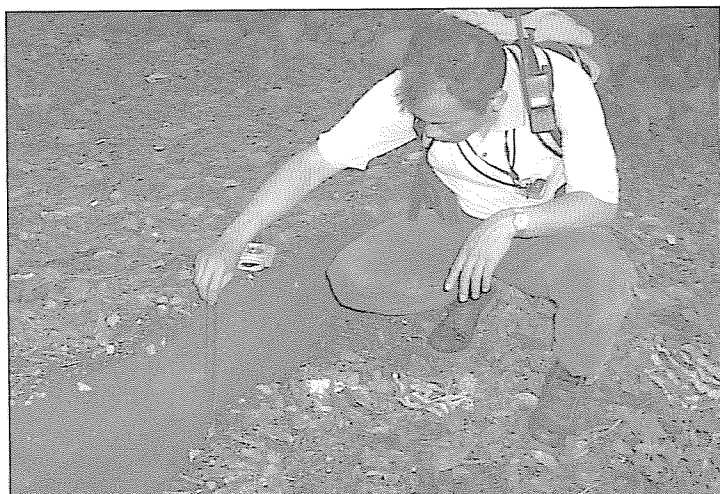


Figure 7. (a) (left) Dip slip near the northern tip of Singkarak Lake. The vertical movement was up to 30 cm, south-east side down. (b) (right) It damaged the houses that sit right on the ground rupture.

nia's Alquist-Priolo Earthquake Fault Zone Act could prohibit building in the area 20 m from the active fault line.

Other houses were damaged due to lateral spreading and landslides triggered by the strong shaking. Most were located on or near steep slopes where the ground is unstable. See the Boen report (below) for more information on damage.

Acknowledgments

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Report #2

Building Damage

This reconnaissance report was provided by Teddy Boen, Senior Advisor, World Seismic Safety Initiative.

Introduction

The impact of these earthquakes was not as big as claimed by newspapers and electronic media. There were fewer casualties than during the Yogyakarta May 27, 2006, earthquake.

No towns and villages were heavily damaged. The health care facilities in Solok did not experience an influx of injured people. The hastily built tents outside the hospital were not utilized.

Buildings that were damaged or collapsed were mostly masonry non-engineered structures consisting of one or two stories: houses, shop houses, religious and school buildings. The main causes of the damage to buildings are poor quality of construction materials and poor workmanship.

Landslides and Settlements

Several landslides and ground settlements could be seen in a few places. The most serious landslides occurred at Ngarai Sianok and Bukit Tinggi (Figure 1a). However,

several of the landslides had occurred prior to the March 6 earthquake in periods of heavy rainfall. The soil types at Ngarai Sianok mostly consist of silt and sand, with a slope of almost 90°. One house in Sumani Village, Solok, located at the edge of a river was damaged and moved because of ground settlement.

Engineered Buildings

In the earthquake-stricken areas, there are very few "engineered" buildings beyond hospitals and some other government buildings. Engineered buildings consist mostly of reinforced concrete combined with masonry walls. The engineered buildings were damaged because they were not designed to withstand the seismicity of West Sumatra (see Figure 2). Even though Indonesia has a seismic

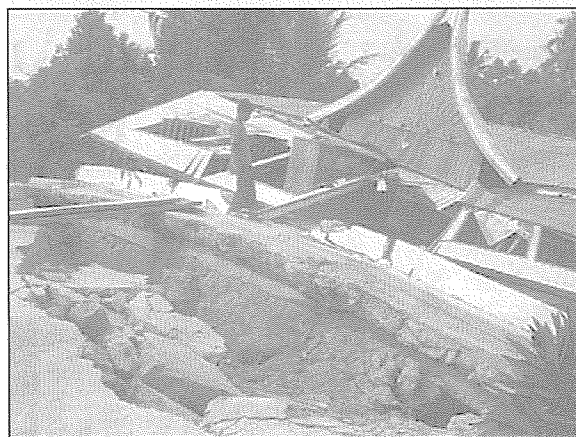
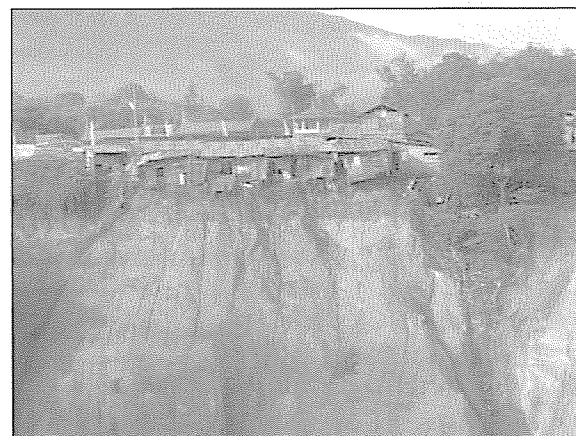


Figure 1. (a) (top) Landslide at Ngarai Sianok, Bukit Tinggi. (b) (bottom) Settlement at Sumani Village (source: Indo Pos, 7 March 2007).



Figure 2. Engineered multipurpose building — Arsyandi Hall, Sumani Village.

code, it was not enforced in the affected areas. The building permit system was also not strictly followed. The poor quality of concrete and detailing contributed to the collapse of the buildings.

Non-Engineered Buildings

Generally, non-engineered buildings in West Sumatra can be divided in three main categories:

- Traditional buildings: indigenous buildings and those in the architectural style introduced by the Dutch.
- The “new culture” confined masonry buildings
- Timber buildings

Traditional buildings: Indigenous buildings built over 150 years ago and those constructed during the Dutch occupation 150 years ago comprise the traditional category. Some of the early indigenous buildings still exist in West Sumatra and those that were maintained withstood the March 6, 2007, shaking. The buildings were constructed with timber, with appropriate connections. When some of these buildings were damaged or collapsed, the main cause was lack of maintenance. The second type of traditional buildings followed the architecture introduced by the Dutch some 150 years ago. The buildings consisted of half-brick thick masonry

walls at the lower part, and the upper part of the wall was made from timber or bamboo mat plastered on both sides. This type of building is also earthquake-resistant. But like the first type, some buildings were damaged because of deterioration due to lack of maintenance (see Figure 3).

The “new culture” half-brick thick confined masonry buildings: Almost 95% of the buildings in the earthquake-stricken areas consist of half-brick thick confined masonry walls. The confinement consists of reinforced concrete framing utilizing the so-called “practical columns and



Figure 3. The traditional buildings based on architecture introduced by the Dutch were slightly damaged due to lack of maintenance.



Figure 4. Walls collapse due to out of plane loading.

beams.” Practical columns (size 120x120 mm with four 10 or 12 mm diameter bars as longitudinal reinforcement and 8 mm stirrups spaced at 150-200 mm) are commonly cast after the construction of the masonry walls is complete, and sometimes the “practical columns” were cast first. Practical beams (size 150 x200 mm with four 10 or 12 mm diameter bars as longitudinal reinforcement and 8 mm stirrups spaced at 150-200 mm) are cast directly on top of the foundation and serve as tie beams. Similar beams (size 120 x200 mm with four 10 or 12 mm diameter bars as longitudinal reinforcement and 8 mm stirrups spaced at 150-200 mm) are cast directly on top of the brick wall and serve as ring beams.

Almost all buildings have timber roof trusses with galvanized iron sheets for roofing. The new culture buildings mostly use saddle type roof trusses, but some use the traditional roof trusses, copying the Minangkabau house.

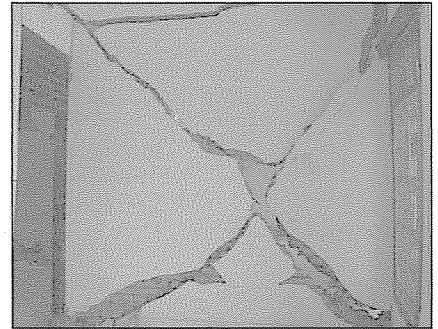
Typical concrete compression strengths range from 12.5 MPa to 15.0 MPa, with rebar having a yield capacity of 240 MPa. The masonry infill wall is made of 50x100x200 mm brick using running bond with mortar thickness ranging from 8 to 15 mm. The mortar mix usually ranges from 1 sand: 3 cement to

1 sand: 4 cement. The walls are plastered on both sides with sand and cement mortar of approximately 10 mm thickness. Past earthquakes have shown that new culture buildings do well in earthquakes, provided they were built with good quality materials and good workmanship. They have survived the most probable strongest earthquake delineated in the Indonesian seismic hazard map.

Problems have arisen when the reinforcement of the practical columns and beams is not in accordance with the code requirements or when the reinforcing bars detailing is not appropriate for earthquake resistance. The damage to two-story buildings was caused by the so-called “soft first story.” Damage includes out-of-plane bending (see Figures 4 and 5), failure



Figure 5. Diagonal cracks in walls due to out of plane loading.



of walls, in-plane shear failure, and failure at corners of walls and corners of openings. Walls tend to shear off diagonally due to twisting or warping in unsymmetrical buildings.



Figure 6. Poor reinforcement detailing and poor workmanship.

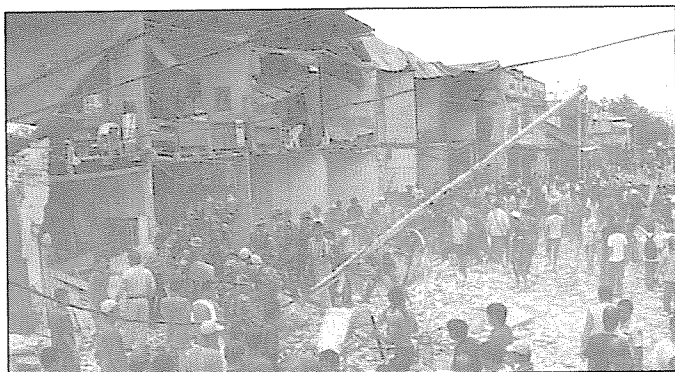


Figure 7. Poorly built shop houses damaged at Payakumbuh (source: *Warta Kota*, 7 March 2007).

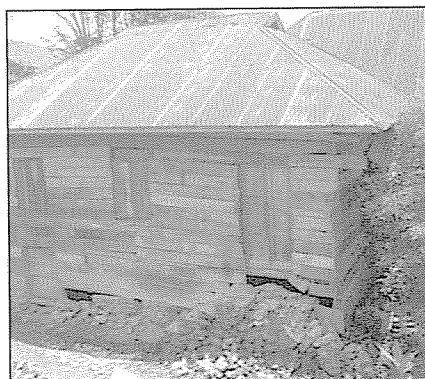
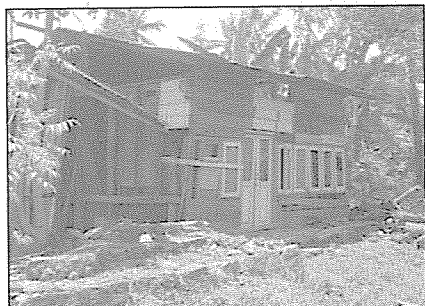


Figure 8. Damaged timber buildings due to deterioration.

Factors contributing to such failures are weak connections between wall and wall, wall and roof, and wall and foundation. Poor quality materials and poor workmanship results in poor detailing (Figure 6), poor mortar quality, poor concrete quality, and poor brick laying (Figure 7). It is a common practice that roof trusses are not strongly anchored to the ring beams.

Timber buildings: Timber houses consist of a timber frame, timber plank walls, and usually galvanized iron sheets as a roof. This type of building has gradually been aban-

doned and replaced by the “new culture” type building as soon as the owner manages to secure the funds. Timber buildings in general are earthquake-resistant and survived the March 6 earthquakes. The timber buildings that were damaged had deteriorated due to lack of maintenance (see Figure 8).

Religious Buildings

Several mosques were damaged, due largely to inappropriate design and construction. Usually mosques are built by the community on a self-reliant base and without any engineering intervention. The construction is based on the inadequate local artisan’s knowledge of concrete, concreting, and reinforcing, which is based on observations of past practices when constructing confined masonry houses. Most of the damage, particularly the collapse of the domes, is caused by poor quality of concrete and inappropriate reinforcing bar detailing. One other factor is the heavy weight caused by excessive thickness in the dome — a clear indication of the absence of engineering input (see Figure 9).

Infrastructure

Although some non-engineered masonry buildings were damaged by the

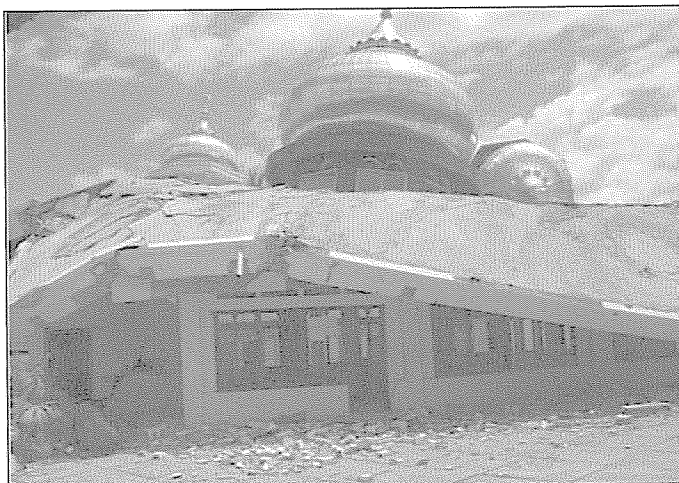
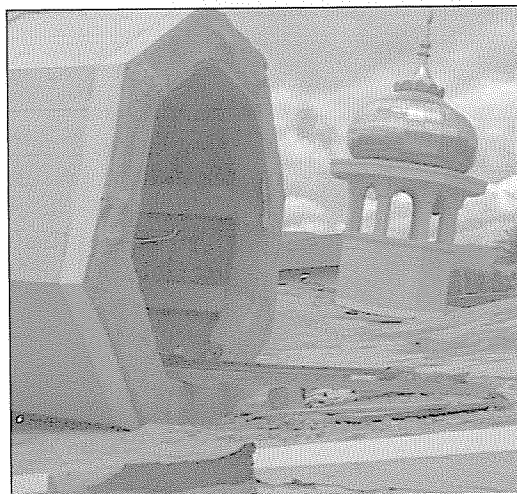


Figure 9. Damage to mosque domes.



March 6 earthquakes, almost all infrastructure was left intact. There was a slight disturbance in electrical power supply in parts of Singkarak Lake; however, it was restored in a relatively short time. Several cracks were observed, particularly at Solok along the road from Solok to Padang Panjang (Km. 6 Tanjung Bikung) and along the shore of Singkarak Lake. Telecommunication towers, bridges, and railways were generally not affected by the earthquake.

Fire after the Earthquake

Right after the earthquake, some buildings caught fire. The gable wall of a primary school in Sumani Village, Solok, fell down on top of an adjacent house. That resulted in the overturning of a gas stove and caused a fire that burned down several houses as well as the school.