THE PADANG, SUMATRA - INDONESIA EARTHQUAKE OF 30 SEPTEMBER 2009

A FIELD REPORT BY EEFIT

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1. ACKNOWLEDGEMENTS

The authors would like to express their thanks to the many individuals and organisations that have assisted with the EEFIT mission to Sumatra and in the preparation of this report.

We firstly thank AIR Worldwide for enabling John Alarcon to attend this mission

We would particularly like to thank the Engineering and Physical Sciences Research Council for providing funding for Sean Wilkinson, Rini Mulyani, Jessica Whittle and Darren Chian to join the team. Their continued support in enabling UK academics to witness the aftermath of earthquakes and the effects on structures and the communities they serve is gratefully acknowledged.

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2. INTRODUCTION

On the 30th September 2009, a Moment Magnitude M_w7.6 earthquake occurred off the island of Sumatra, Indonesia, near the city of Padang. This earthquake had a devastating effect on many of the buildings and affected infrastructure and communities there. The epicentre of the event occurred in the same region as the 2004 Sumatra-Andaman earthquake that generated a Tsunami resulting in the deaths of over 200,000 people. The earthquake epicentre was about 54 kilometres west northwest of the low-lying coastal city of Padang (population around 900,000), the capital of Indonesia's West Sumatra province, and the home to many large hotels, some of which were either severely damaged or collapsed. Two hospitals and a large shopping centre were significantly affected as well.

Following the earthquake, the UK-based Earthquake Engineering Field Investigation Team (EEFIT) mounted a reconnaissance mission to the Padang region in Sumatra. This report presents some of the preliminary findings of the team. A number of pictures taken by the EEFIT Team have been uploaded for free views on the Virtual Disaster Viewer (www.virtualdisasterviewer.com).

THE MISSION

On 16th October the EEFIT management committee decided to launch a mission to Padang and the area affected by the 30th September earthquake. With this purpose Dr Sean Wilkinson was selected as team leader for the mission. The other team members were selected to cover a wide range of expertises including engineering seismology, earthquake engineering, structural engineering, seismic risk analysis, risk modelling, lifelines and geotechnical earthquake engineering. The team members are introduced in Figure 1 and Table 1.

Figure 1. Sumatra EEFIT mission members. From left: John E. Alarcon, Sean Wilkinson, Rini Mulyani, Jessica Whittle and Siau Chen (Darren) Chian.

Table 1. The EEFIT Padang team.

Name	Mission Role, Position	Institution	Expertise
Sean Wilkinson	Team Leader, Senior Lecturer	Newcastle University	Structural engineering, Non-linear dynamics
John Alarcon	Deputy Team Leader, Research Associate	AIR Worldwide	Seismic hazard assessment, Risk modelling
Rini Mulyani	PhD Student	The University of Sheffield	Seismic risk analysis
Siau Chen Chian	PhD Student	University of Cambridge	Geotechnical earthquake engineering
Jessica Whittle	PhD Student	University of Oxford	Structural earthquake engineering

The team flew into Padang Airport in the evening of the 7th of November and then spent 5 days surveying Padang City and the surrounding area. A map of the survey sites can be seen in Figure 2, Figure 3 and Figure 4. The mission finished on the 13th November; however, Rini Mulyani stayed in Indonesia to collect more data.

Figure 2. Map of key survey sites in Padang (labels indicate day and sequence of visit).

Figure 3. Map of visited sites in the central region of Padang city.

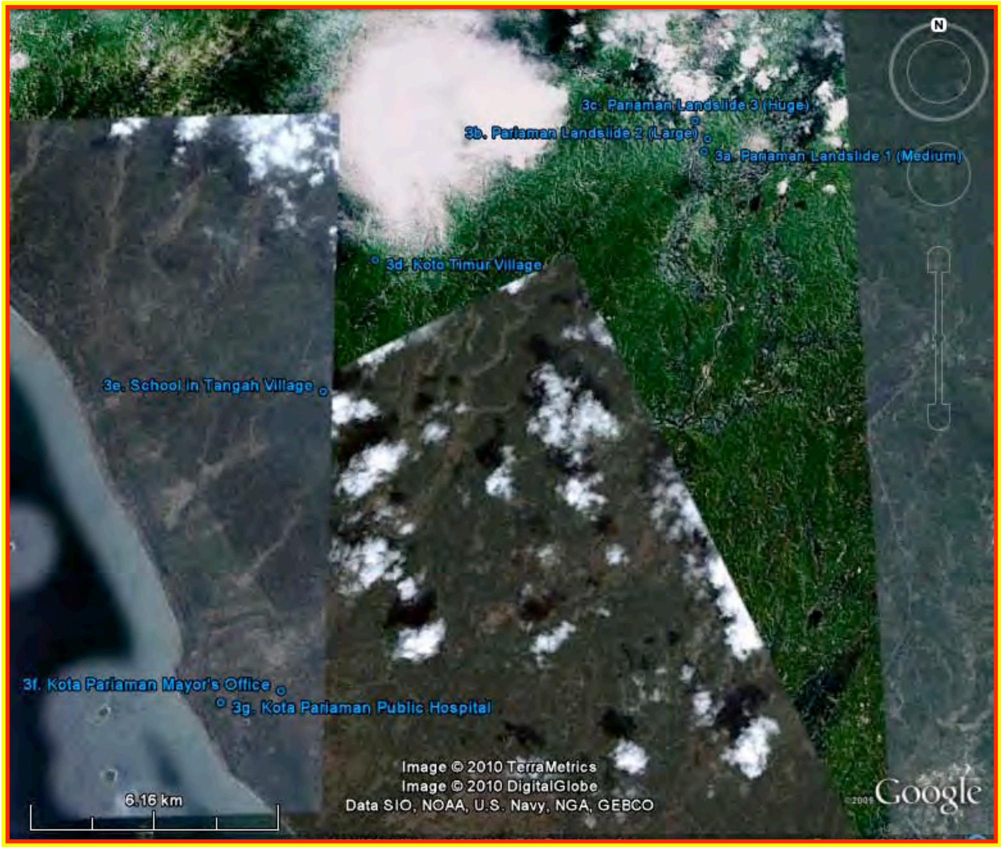


Figure 4. Map of key survey sites in Pariaman.

The mission had two main aims. The first was to carry out a field Investigation to collect data on building and infrastructure performance and geotechnical failures, while the second aim was to collect landslide data to help assessing the feasibility of using satellite data to collect landslide information.

The specific aims and objectives were

I) Field Investigation and Data Collection Objectives:

1. To carry out a detailed technical evaluation of the performance of structures, foundations, civil engineering works, industrial plants and natural geographical features within the affected region.
2. To assess the effectiveness of earthquake protection methods, including repair and retrofit, and to make comparisons of the actual performance of structures with the expectations of designers.
3. To study disaster management and recovery procedures associated with this earthquake, to see how effective these were post-2004, and to develop indicators of resilience.
4. To train new researchers in the techniques of earthquake investigation and data analysis.
5. To observe and review local construction materials and methods.
6. To report on the mission findings.

II) Development of Data Analysis Tools and Data Analysis Objectives:

1. To observe and collect data on landslides and determine their damaging effects on infrastructure.
2. To assess the feasibility of developing a system that can predict the susceptibility of natural slopes to earthquake induced landslides using satellite imagery and expert interpretation.

The mission covered most of Padang, surveying buildings in China Town (Pondok), Jati, Ulak Karang, City Centre and Air Tawar. The outlying district of Pariaman was also visited.

As part of the mission a number of interviews were conducted with the staff from the main hospital in Padang, engineers from the water supply company, engineers from the local university, NGO representatives and local residents.

3. REGIONAL SEISMICITY

The territory covered by Indonesia lies within the Pacific Ring of Fire, where some of the largest recorded earthquakes in the world have taken place. The seismicity in the region is controlled by the subduction of the Australian plate beneath the Eurasian plate. The subduction between these tectonic plates occurs along the western side of Sumatra forming the Sunda trench (Figure 5). The dip angle of the subducting in the uppermost part of the contact between the plates is of about 13°-15° (Irsyam et al., 2008).

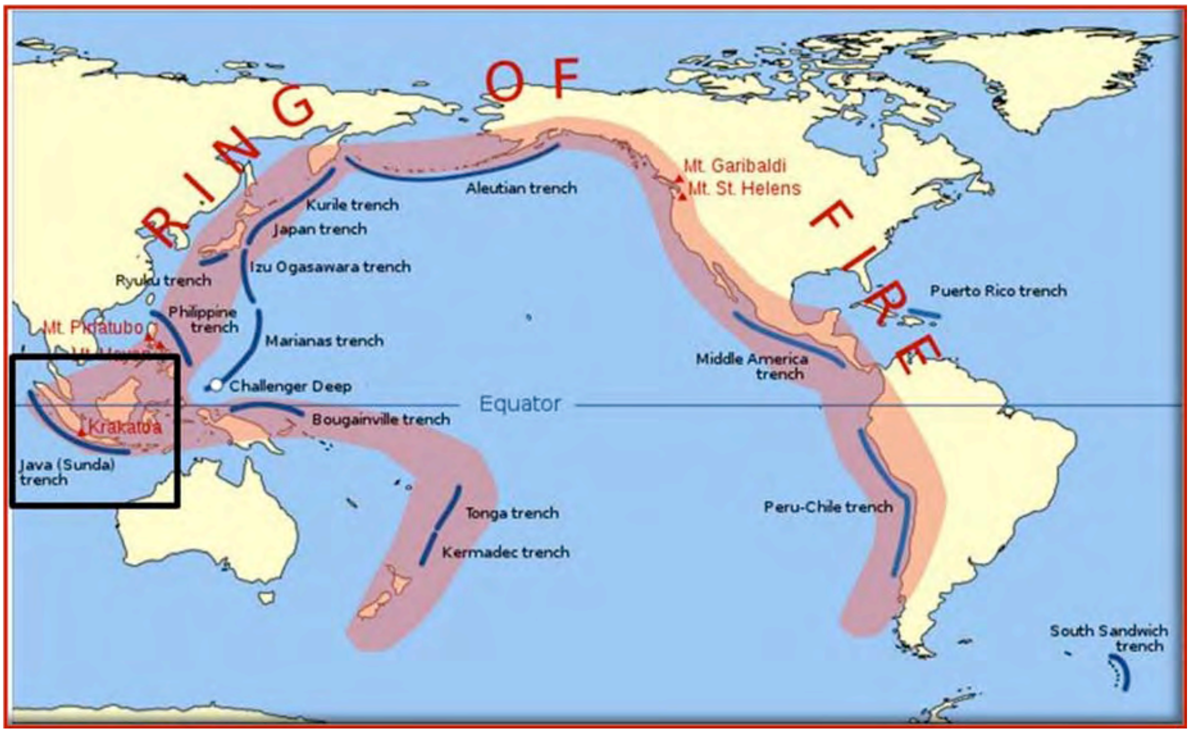


Figure 5. Location of Indonesia within the Pacific ring of fire (black rectangle). The subduction on the Western side of the country corresponds to the Sunda trench.

The velocity of the relative motion between the Australian and Eurasian plates varies according to the area studied; it is calculated at about 52 mm per year at the northern part of Sumatra and at 62 mm per year at the southern part, as illustrated in Figure 6 (Natawidjaja, 2002). At depth, the subduction along Sumatra extends into the Benioff zone to depths of up to 200 km. In the Benioff zone, the Australian plate subducts at a dip angle of about 40°-45°. Considering the hypocentral location of the 30 September 2009 earthquake, being off-shore Padang Pariaman (see details below), the event is estimated to have occurred in the Benioff zone.

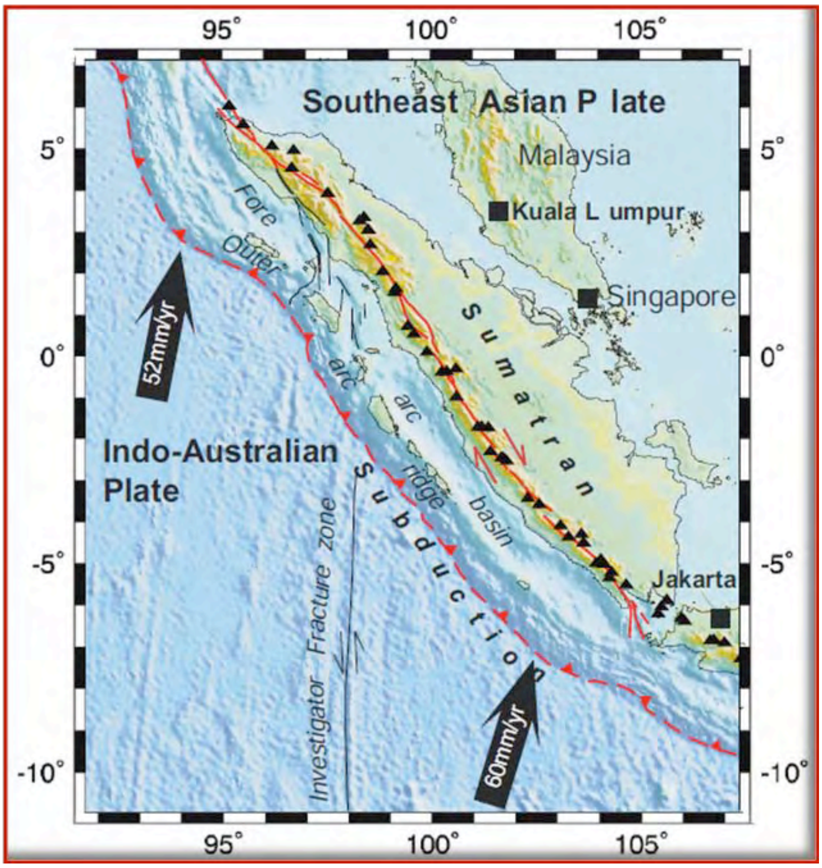


Figure 6. Tectonic setting of Sumatra (Natawidjaja, 2002).

The subduction zone in Sumatra is known for producing mega-thrust earthquakes such as the moment magnitude M_w 8.8-9.2 in 1833, the M_w 8.3-8.5 in 1861, the M_w 9.0-9.3 in December 2004, the M_w 8.7 in March 2005 and the M_w 8.4 in September 2007 (Irsyam et al., 2008). Based on the recent seismic activity, Aydan et al. (2007) identified a segment of the subduction zone facing Padang City that has not ruptured in the last 213 years. This seismic gap has the potential to produce an earthquake with magnitude greater than 8.7. The seismic gap is located in between the 1833 and 1861 fault ruptures, and it is estimated to have an approximate recurrence interval of 230 years (Zachariasen, 1999).

Another important seismic feature in the region is the Sumatra fault (see Figure 6 and Figure 7), that accommodates the oblique convergences of the Australian and the Eurasian plates. Natawidjaja (2002) mapped the Sumatran Fault and found that it is a trench-parallel strike-slip fault system, 1900 km long extending from North to South of Sumatra. The fault is highly segmented, with the majority of these segments being of less than 100 km. As a result, the potential earthquake rupture length in the Sumatra fault is not likely to exceed 100 km, so the maximum magnitude expected from such an event is estimated as M_w 7.5 (Natawidjaja, 2002; McCaffrey, 2009).

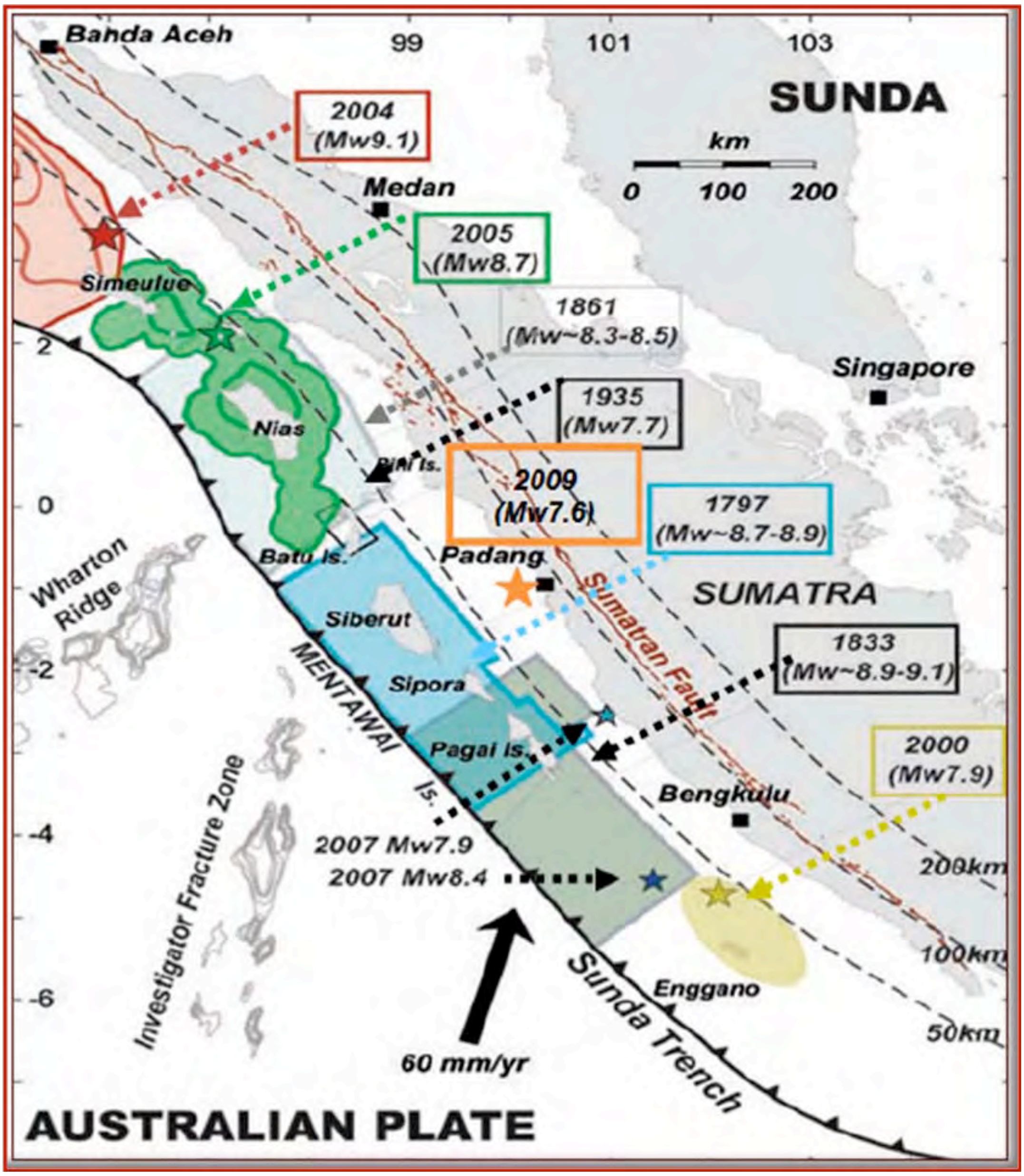
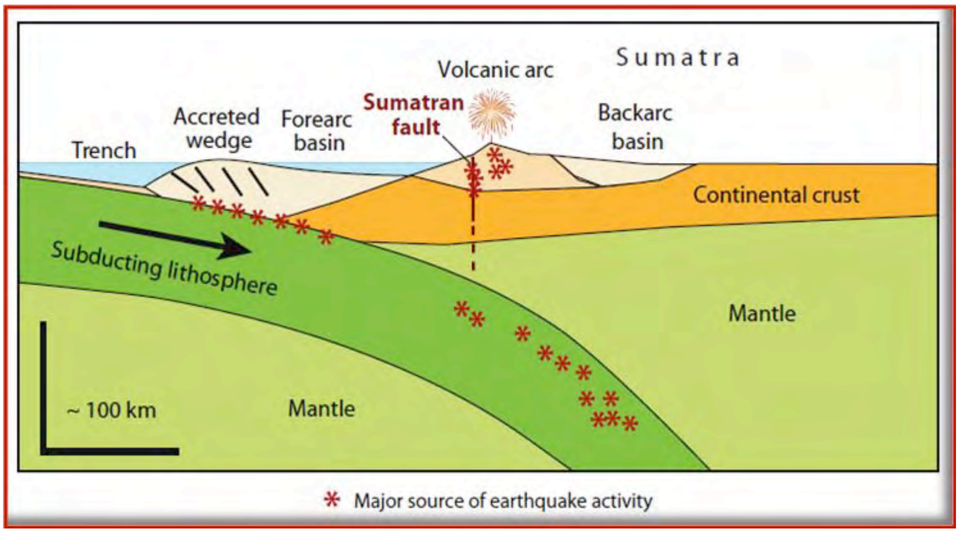


Figure 7. Large events in the Sunda trench along Sumatra and their associated rupture areas (Chlieh et al., 2008). Note a recent seismic gap between the 1833 and 1861 events, on the region where the 1797 event occurred. The star shows the epicentral location of the event.

The convergence between the Australian and Eurasian plates described above has also caused a slip partitioning process that has formed a sliver plate, called as Sunda forearc, as illustrated in Figure 8. The sliver plate is enclosed by the Sumatra subduction zone on the west and the Sumatra fault on the east (McCaffrey, 2009).

(a).



(b).

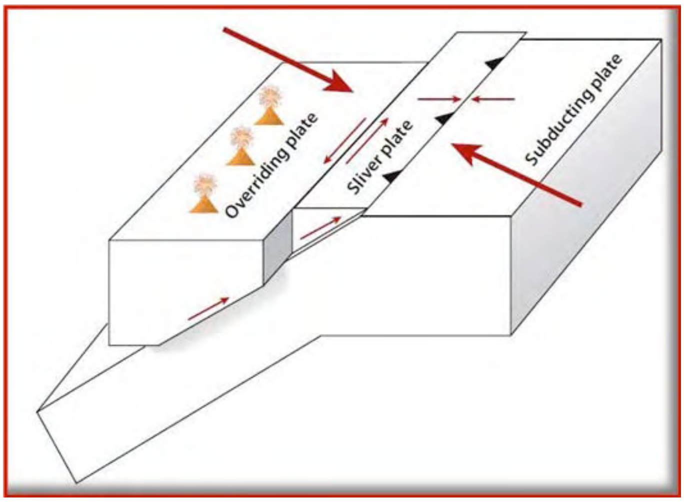


Figure 8. (a). Cross section of Sumatra Plate Boundary; (b). Geometry of sliver plate (McCaffrey, 2009).

THE 30TH SEPTEMBER EVENT

The earthquake occurred at 17hr 16min 09sec local time (10hr 16min GMT) off the coast of Sumatra, in the Benioff zone of the Sunda trench previously described (see location in Figure 7). A summary of the location, depth and magnitudes assigned to this earthquake by the local and four international agencies is shown in Table 2. A fact to mention from the latter table is that the epicentral location assigned by the local Indonesian agency (BMKG) differs from the international agencies by about 22 km. The focal depth also shows a variation between the local seismological service and the other agencies, with the first assigning a focal depth of 71 km while other estimates place the focal depth at around 80 km. Small differences in the magnitude of the event are also appreciated, though these differences are not significant.

Figure 9 presents the fault plane proposed by the French CEA (Commissariat a l'Energie Atomique), and the areas where the slip is concentrated. In the same figure the location and size of a shallow earthquake (10 km) with magnitude Mw 6.8 is also shown. This aftershock occurred on 1st October and had its epicentre about 180 km from Padang.

Table 2. Earthquake parameters.

Agency	Location		Focal depth (km)	Magnitude M_w
	Latitude (S)	Longitude (E)		
BMKG (Local)	0.84	99.65	71	7.6
EMSC	0.76	99.84	80	7.6
GFZ (Germany)	0.78	99.87	80	7.7
CEA (France)	0.79	99.82	80	7.6
USGS (USA)	0.72	99.87	81	7.5

Notes: BMKG – Badan Meteorologi Klimatologi dan Geofisika; EMSC – European-Mediterranean Seismological Centre; GFZ – German Research Centre for Geosciences; CEA – Commissariat a l'Energy Atomique; USGS – United States Geological Survey

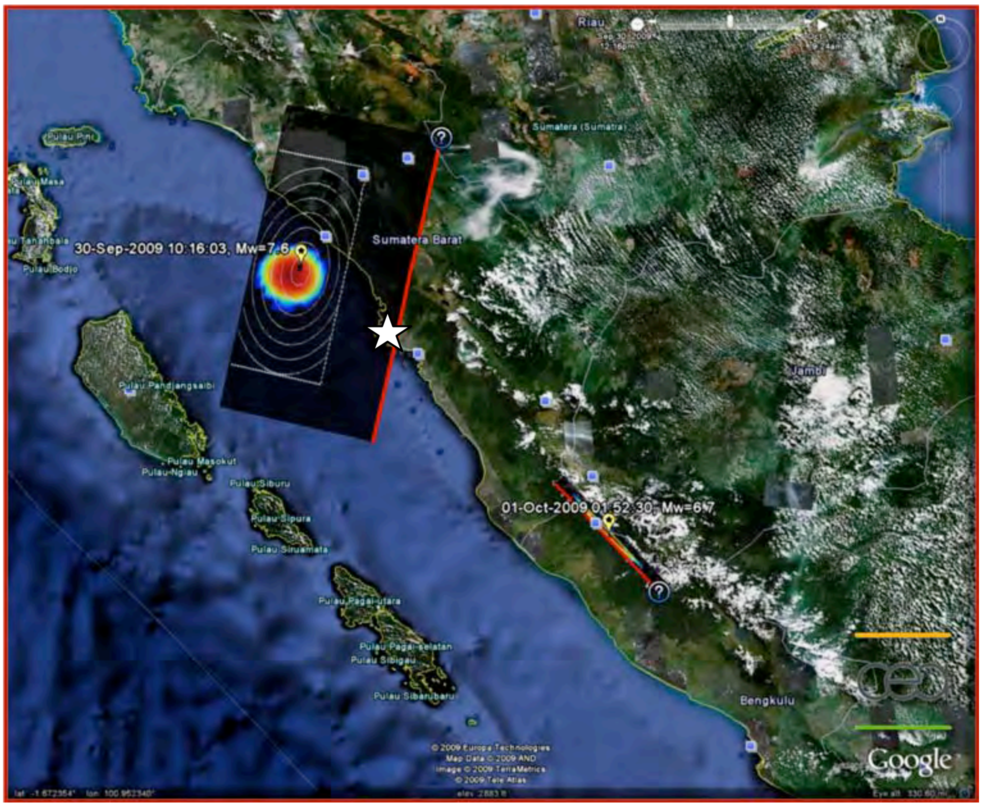
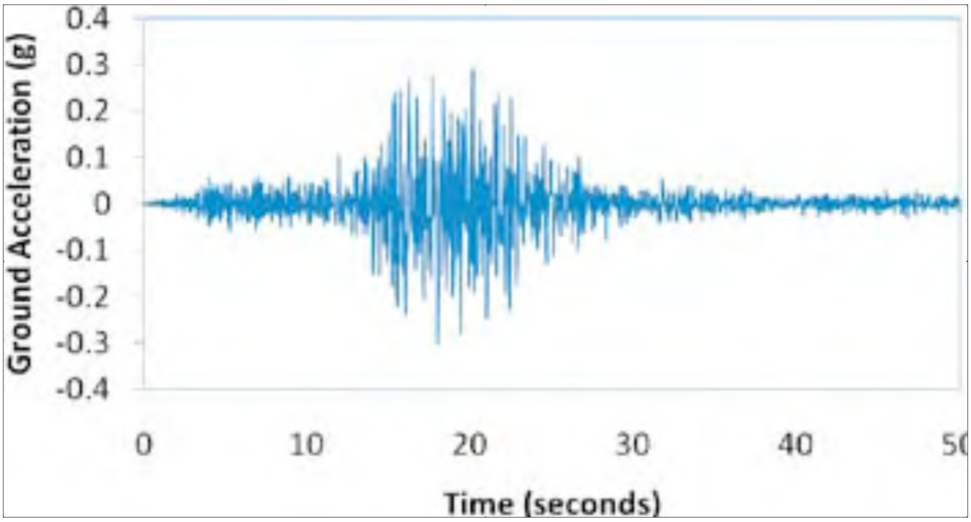


Figure 9. Fault plane proposed by the CEA for the 30th September Mw 7.6 Padang earthquake. The star shows the location of Padang. Note the calculated fault plane of the 1st October Mw 6.8 earthquake to the Southeast of the largest event.

During the earthquake, BMKG and USGS recorded a maximum peak ground acceleration of 0.3g, which lasted about 20 seconds (Figure 10). Considering that the acceleration record was taken from a location with relatively stiff soil, the earthquake ground shaking would have been amplified at Padang city. Padang City lies on relatively thick alluvium deposits as shown in Figure 11 (ESDM 2009). As a result, it was estimated that the earthquake produced PGAs around 0.4g-0.6g across Padang City (EERI, 2009).



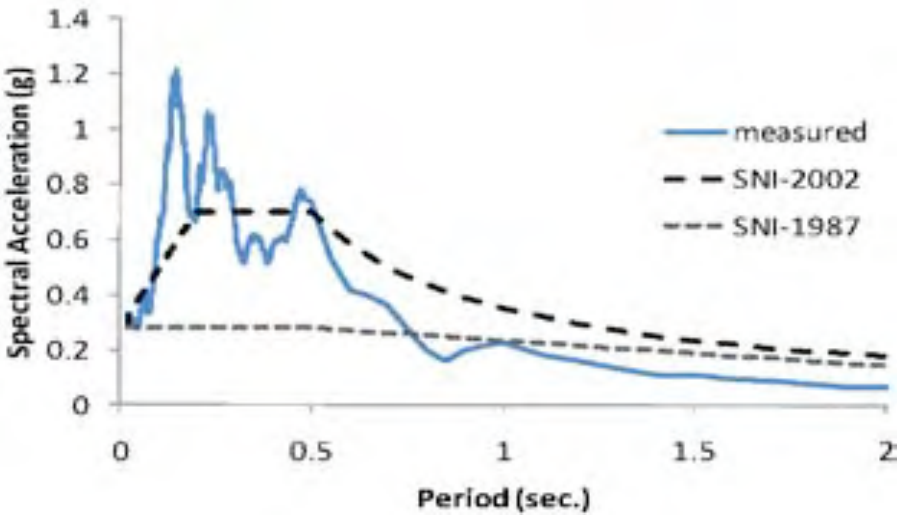


Figure 10. Ground acceleration and response spectra (N-S component) and design earthquake spectra (EERI, 2009).

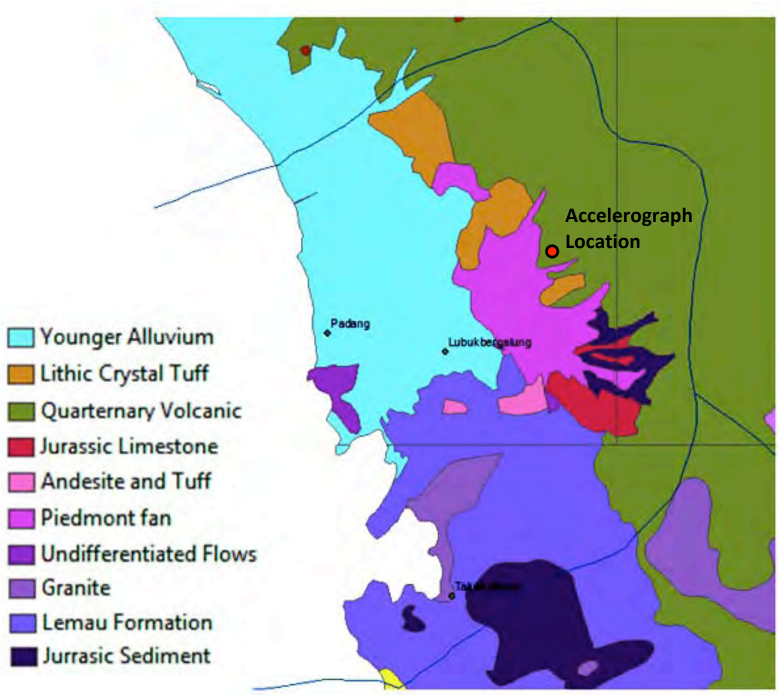
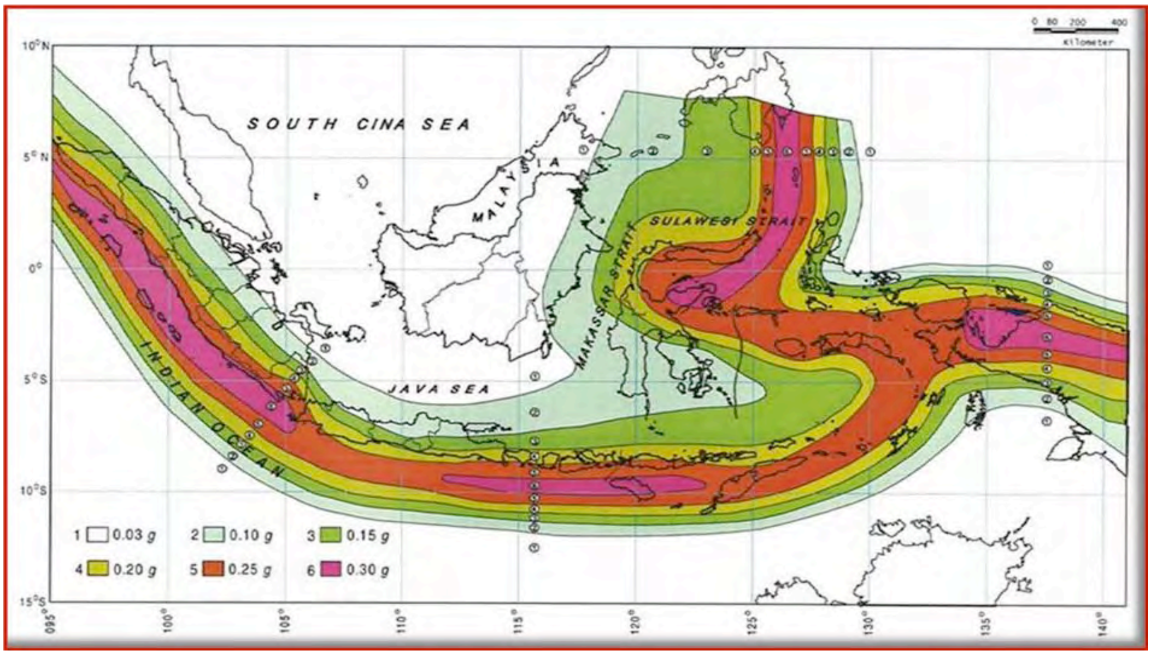


Figure 11. Geological Map of Padang City (Geological Agency-Department of Energy and Mineral Resources of Republic of Indonesia, ESDM 2009)

Figure 12 presents the results of two seismic hazard analyses for Indonesia and Sumatra. The first corresponds to the hazard map included in the Indonesian design code, for which ground motions on rock with a return period of 475 years is of 0.25g for Padang. On the other hand, the hazard assessment of Petersen et al. (2004) presents acceleration values of up to 0.4g for the same return period, which represents a significant difference in the hazard results.



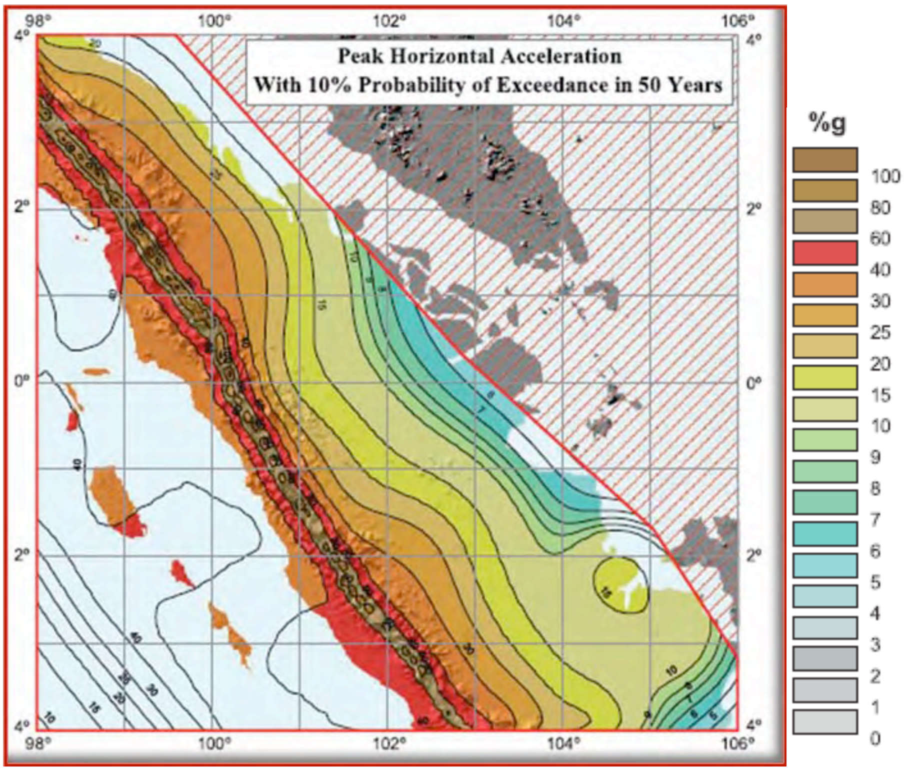


Figure 12. Seismic hazard maps for Indonesia and Sumatra. *Top*: the Indonesian design code (SNI-1726-2002). *Bottom*: Petersen et al. (2004).

4. FIELD SURVEY RESULTS

Structural Performance

Structural typology,

The structures in Padang are primarily made of either unreinforced masonry or reinforced concrete frames with masonry infill. The confinement to the masonry is usually provided by the structural framing of reinforced concrete buildings The planning regulations limited building heights to six storeys prior to the relocation of the airport in 2005; however the vast majority of structures are one or two storey residential or two storey commercial. There are virtually no steel buildings in the city; however one was observed. The build quality was typical for a region at this stage of development with the majority of small structures being very poorly constructed with poor quality building materials and little or no planning permission. Of the larger engineered structures the quality of construction was often reasonable, but poor build quality was also observed. Typical structural typologies can be seen In Table 3.

Table 3 Structural Typologies

Structural Typology	***Typical Occupancy***	***Number of Stories***	***Example***
Timber or Bamboo	Residential	1-2	
Stone or Stone & Brick	Residential	1-2	

Unreinforced Masonry	Residential / Schools/ Commercial	1-2	
Reinforced Concrete with Brick Masonry Infill (typically unreinforced)	Residential / Schools/ Commercial	1-2	
Reinforced Concrete with Brick Masonry Infill (typically unreinforced)	Commercial / Industrial/ Hospitals /Government	2 +	
Steel	Commercial / Industrial	2 +	

The Principal issues

The first issue is associated with the lack of a single design code for the entire country before 1983 and the latest code dating from 2002. From 2002, engineered structures are obliged to meet the requirements of the national seismic code SNI-1726-2002, which can be described as a modern code similar to either American or European equivalents; however, before this date, engineered structures were often designed following local building design practices. This is due to Indonesia being administratively divided as a unitary state where each province has its own legislature. From the 320 municipalities in Indonesia, only about 210 (70% of the total) had local building regulations. From these 210 municipalities, only about 45 regulated the technical parameters of design while the rest only regulated the building permit process and its permit fees (Budiono, 2004). This may explain the seemingly inadequate supervision of either the designs or the construction process. During the field EEFIT survey, very large spacing between confining links, particularly at the beam/column unions, was commonly observed in collapsed reinforced concrete buildings. The use of plain bars for links and main reinforcement instead of ribbed bars was another common feature observed in collapsed buildings. Soft storey collapse was probably the major contributor to the collapse of major engineered structures.

Impact on occupants

The impact of the earthquake on occupants can be roughly assessed by the number of casualties, the damage to structures, the impact on the livelihoods and effect on education, the loss of data and equipment, the current state of critical facilities, and finally, the psychological response of the residents.

As a result of the Western Sumatra earthquake there were approximately 1,117 fatalities, 2,902 injuries (1,214 people with major injuries and 1,688 slightly injured), and 186 people missing, according to National Disaster Management Agency (BNPB, 2009).

Figure 13 indicates the distribution of fatalities in the region. Sixty percent of the fatalities occurred in Padang Pariaman County, where at least 321 deaths due to the landslides were reported by the Pariaman government. Three villages were completely destroyed by the landslides (please refer to the geotechnical section of this report for additional details). Twenty-eight percent of the fatalities (313 deaths) occurred in Padang City and seven percent of the fatalities (80 deaths) occurred in Agam County (BNPB, 2009). Figure 76 indicates the location of these counties.

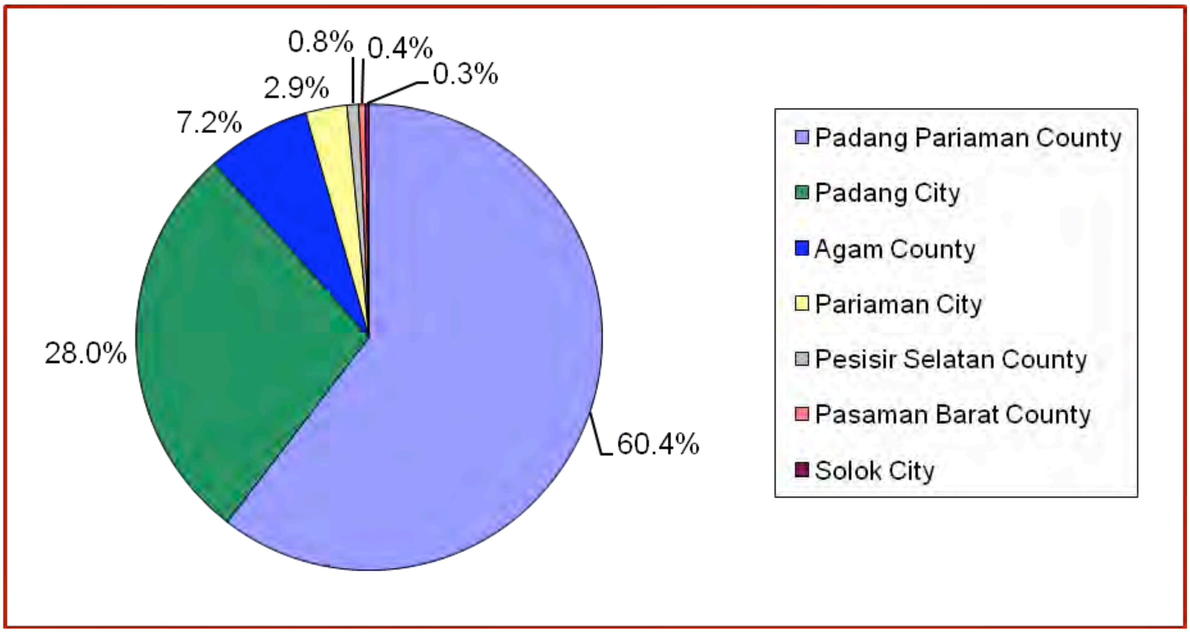


Figure 13. Distribution of Fatalities (total 1117 fatalities)
(BNPB, 2009).

There was also extensive damage to residential buildings, resulting in 135,000 severely damaged buildings, 65,000 moderately damaged buildings, and 78,000 lightly damaged buildings (BNPB, 2009). Refer to the Disaster Management section for more details about the post-earthquake assessment of damaged buildings and identification of temporary shelter needs. Because of the close family network in Sumatra, it would be very common for a family that had lost their home in the earthquake to move in with other relatives. This family support system and the lapse in time after the earthquake may explain why there were few temporary residential shelters and no major refugee problems in the area when the team visited. In the village of Cumanak in the Padang Pariaman county, there were still residents clearing the debris and collecting timber from the landslide rubble for rebuilding of their homes (Figure 14). In the town of Siteba Perumdam, severe residential building damage had been caused by the earthquake and resulting liquefaction. This had not necessarily displaced many of the residents, but instead, rendered the damaged room or part of the house unusable (Figure 15).

Figure 14. Residents Removing Timber for the Cumanak village landslide area.

Figure 15. Siteba Perumdam Village Home with Foundation Failures, Still Occupied.

With the closure of many hotels and extensive damage to numerous commercial buildings and shopping centres, the loss of livelihood was another detrimental impact of the earthquake on Sumatran residents. However, with the increased need for labourers to help with demolition work and reconstruction, labour and construction jobs have increased (Figure 16). As is often the case with a disaster such as this, the need for rebuilding inflates material and labour costs in the regions. Academics and engineers from the University of Bung Hatta confirmed that this was indeed the case for this event with inflation in both materials and labour. The most dramatic inflation has been in the cost of labour which was quoted to have inflated 300%.

Despite the high degree of government building damage, it is expected that the government employees' jobs will be only marginally affected. There has been an inconvenience to the employees of many businesses as they have had to move to temporary facilities. In some cases, such as many small retail shops in some areas of China town, there was little or no damage to the buildings and the impact on the occupants was no greater than concerns over small hairlines cracks.

Figure 16. Labourers Rebuilding the Walls
of the Ramayana Shopping Centre, Padang.

The educational system in Western Sumatra had a two-week hiatus as a result of the earthquake. Volunteers from a local activity company (GALAPAGOS) informed us, it was the government's initiative for the schools to reopen after two weeks. Replacement school buildings were erected around Western Padang, and these buildings were seen in counties surrounding Pariaman and Padang. The University of Bung Hatta had a few buildings with non-structural damage, but had achieved quick recovery and relocation of educational facilities and classrooms by the time of survey.

Loss of documents, essential data, and equipment failure was another impact on the residents on Western Sumatra. Businesses and commercial establishments that relied on paper documentation were greatly affected as lost information had to be collected from the building rubble. In addition, sensitive equipment was also damaged as a result of the earthquake; for example, mechanical equipment at Pt Semen Padang (cement factory) was initially damaged but has since been repaired.

Temporary facilities were initially crucial for the operation of the essential facilities, and the impact of the earthquake on Western Sumatra's essential facilities is still apparent. Extensive details about the operation and response of lifelines will be discussed in further detail later in the report but a summary of how the response of critical facilities have affected the residents is presented here.

The poly-clinic (outpatient general clinic) of the main Padang hospital (Dr. M. Djamil) was severely damaged by the earthquake, and immediately after the earthquake, the hospital employees moved current patients and redirected new patients to temporary facilities set-up in outside tents. Currently, due to the severe damage to the poly-clinic, the hospital has redistributed the prospective poly-clinic patients to the corresponding departments in the main hospital, and the temporary clinics are no longer necessary.

Directly after the earthquake, residents went 10 days without electricity, one month without the complete restoration of the main water supply (but with well access), and about 5 days without mobile phone reception. Today, some of the temporary water tanks that the water company distributed around Western Sumatra are still present (Figure 17). Due to the damage caused to the water company's main building, the water company has set up temporary marquees outside the main building as administrative offices. In addition, small phone towers with generators were set-up throughout Padang (Figure 17).

Figure 17. Water Storage Tank at a Kudu Ganting School (left) and Temporary Mobile Phone Tower at the Inna Maura Hotel (right).

Minimal information was gathered on the psychological impact and health of those not physically injured by the earthquake. The GALAPAGOS volunteers reported that there was no outbreak of disease or illnesses in Padang as a result of the lull in water supply; however, cases of diarrhoea were common in residents in the counties near Pariaman. The main Padang hospital specifically noted in their interview that they were counselling people for any psychological distress prompted by the earthquake. Various conversations with local residents confirmed that most people would not be persuaded to move from Padang as a result of the recent earthquake.

Residential

Residential buildings in the cities of Padang and Pariaman mainly correspond to one- to two-storey high buildings constructed of confined masonry (Figure 18). Due to the predominant high temperatures in the region, with a yearly average of 27^{O} C, houses usually have high ceilings for ventilation purposes; the roofs are typically composed of wood frames on top of which corrugated galvanised iron sheets are fixed (Figure 18, right). In low-income areas or in small villages unreinforced masonry and wooden houses, or a mixed of masonry and wood, were also observed (Figure 19). In contrast, wealthy sectors of Padang and Pariaman have a number of houses constructed of moment resistant frames with infill walls (Figure 19).

Figure 18. Left: Typical one storey house made of confined masonry (photo taken in Padang). Right: typical configuration of residential roofs.

Figure 19. Left: two storey house made of masonry and wood (Pariaman county). Right: House in an affluent area of Padang.

In spite of the large number of residential buildings affected at different degrees (see previous section), severe damage or collapse of residential houses was not widespread in either Padang or Pariaman cities. A detailed survey of residential buildings in the region was carried out by MapAction, an NGO specialised in gathering and mapping information around zones hit by a natural disaster. The results of a survey conducted by MapAction in various areas of Padang City (Figure 20) show that widespread damage (i.e. where 80% to 100% of households were damaged, represented in the map by dark blue areas) is concentrated in specific parts of the city. However, even in these areas the proportion of houses heavily damaged is in general not extensive; this fact is shown by the pie charts at each surveyed area where red colour denotes heavy damage.

A spurious effect of the map in Figure 20 is that the areas in the Southern part of the city, identified with 40% to 70% of households being damaged (i.e., areas in blue colour tones), correspond to mountain areas not densely populated and where houses are mostly constructed along the shore and up to the skirts of the hills. Therefore even though the map proportionally shows a significant percentage of the city having widespread damage, most of these areas in the South do not have a large number of houses.

The area of Padang city with higher concentration of households affected, as shown in Figure 20, is also shown using Google Map in Figure 22. As observed in the latter figure, the area corresponds to a portion of the city surrounded by mountains where potential “basin” effects may have occurred. This hypothesis needs to be corroborated with a soil map of the city though.

Figure 21 shows the distribution of the intensity of the earthquake effects felt at the surface, reported using the Modified Mercalli Intensity scale and data from BMKG. Both Padang City and Pariaman City (Kota Padang and Kota Pariaman) reported a level 7 intensity or greater, described as greater than “very strong intensity.” The BMKG intensity map is comparable to intensity results produced by MapAction (based on data from the Indonesian Department of Energy and Mineral Resources). The correlation between the damage scales of Figure 20 and Figure 76 and the intensities in Figure 21 are not explicitly expressed, but comparing the figures confirms the expected conclusion that a large percentage of what Map action and BNMP has described as severe damage corresponds to VII MMI. Similarly, very little severe damage to homes is seen in areas corresponding to V MMI.

Some examples of damage on residential buildings are presented in Figure 23.

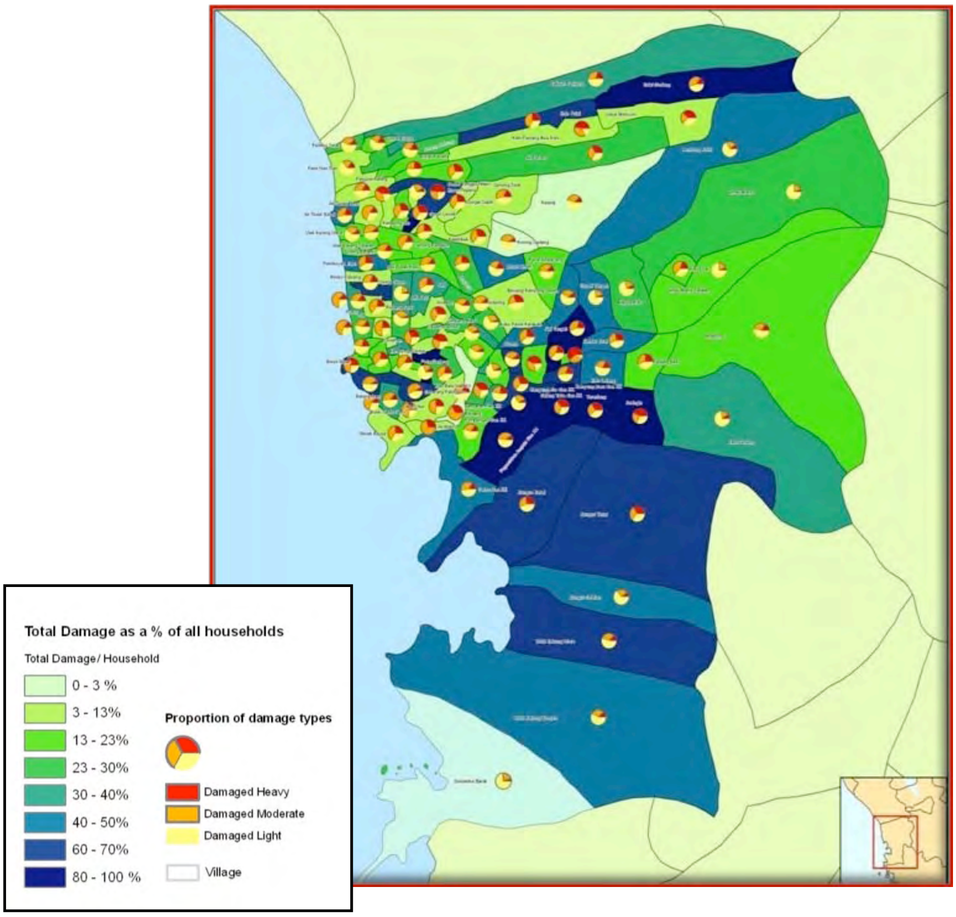


Figure 20. Household damage distribution in areas of Padang City (by MapAction, based on data collected before 21 October). The area with extensive damage, shown in the middle of the map, is presented in Figure 22.

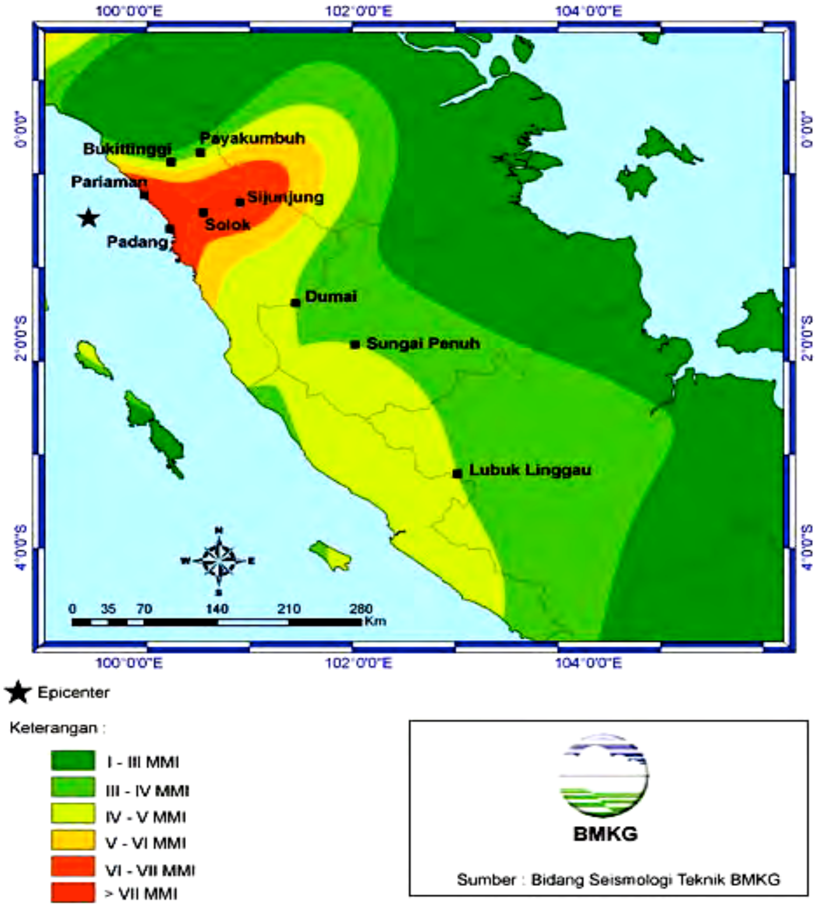


Figure 21. Isoseismal map for west sumatra earthquake (BMKG, 2009).

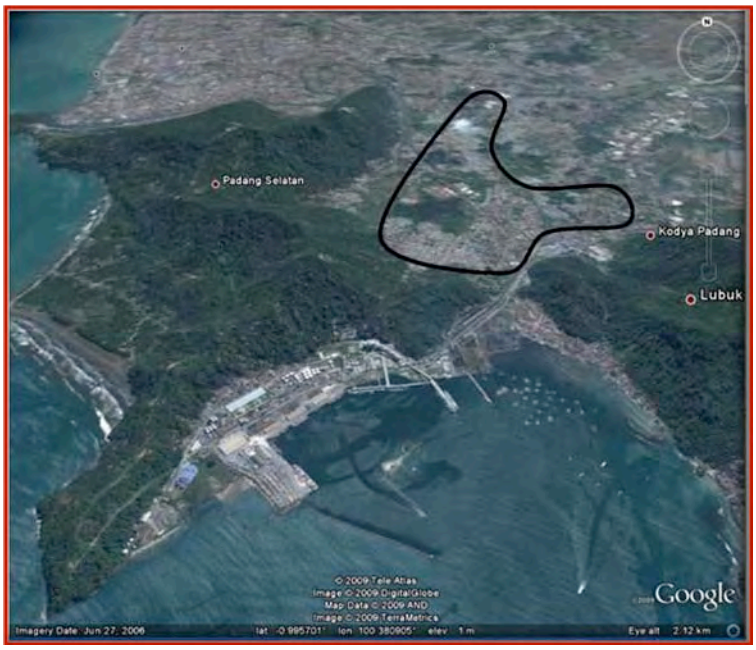


Figure 22. Google Earth 3D visual of the area mapped by MapAction with 80% to 100% of households having a degree of damage.

Figure 23. Damage to residential buildings. Top: households in Padang.
Bottom: structures in Pariaman county.

Commercial

Commercial buildings mainly consisted of one to two storey structures. Most businesses were either small or family businesses and led to the structure being of mixed commercial and residential use (i.e. the ground floor was used for commerce, while the upper floor was residential).

Larger companies, head offices, and hotels ranged from 2-6 storeys and were usually reinforced concrete frames with masonry infill.

China Town. The region shaded in blue in Figure 24 is the China Town in Padang. The construction in this region was particularly poor and many small buildings were badly damaged. This is the main market for Padang and food supplies were disrupted due to a high proportion of the buildings failing. The building typology often consisted of unreinforced masonry (without reinforced concrete frames). The major failure mode of these buildings was collapse of external walls. In the case of buildings that did have reinforced concrete frames, the columns were often 150mm x 150mm. These generally fared better; however the columns were often insufficient.

Figure 24. The China Town (shaded in blue) and Central Region (shaded in yellow) in the city of Padang.

Central region. The majority of buildings in this region (shaded in yellow in Figure 24) were greater than two storeys and were reinforced concrete frames with masonry infill. The performance of the buildings was very variable, with damage ranging from minor cracking of masonry infill to total collapse. The majority of buildings suffered at least significant cracking in the masonry infill panels. Few structures had either no cracking or minor cracking. The masonry infill was often observed to have fallen out of the frame. The majority of failures in the structural system of the buildings were the development of plastic hinges in the tops and bottoms of the columns (soft storey failure) as shown in Figure 25. Minor crushing of concrete was often observed in the tops of the columns often without signs of distress in the bottom of the columns. Strong beam- weak column designs were also observed in various commercial buildings, as well as hospitals. According to the University of Bung Hatta engineers, the principle of strong column and weak beam has yet to be fully adopted by designers in the region. Partial or total collapse of engineered structures was evident in many locations. Often these were government buildings.

Figure 25. Plastic hinging at column ends of reinforced structure.

Hotels. There were many multi-story hotels in Padang, with a high variability of damage ranging from complete structural collapse to only secondary elements damaged. Most of the hotels were constructed within the last 30 years. Shear cracking and failure of the masonry infill was also typical in the damaged hotel buildings, similar to the damage noted in the smaller commercial buildings. Soft-storey failures were common, as seen in Hotel Hayam Wuruk, a small hotel in central Padang, a beach hotel, and the Inna Maura Hotel, a high-class hotel in central Padang (Figure 26 and Figure 27). The failure of the Inna Maura hotel was unique, as the majority of the hotel had only minor structural damage, but one wing suffered extreme damage. A lack of transverse reinforcement at the beam-column joints was observed (Figure 28)

Figure 26. Examples of Soft-storey Hotel Failures.
Top: Hotel Hayam Wuruk. Bottom: Beach Front Hotel.

Figure 27. Soft-storey failure of the Inna Maura Hotel.

Figure 28. Evidence of soft-storey failure, light-fixture and chair at ground level (left) and lack of transverse reinforcement in beam-column connection (right).

Damage to the hotels did not seem to correlate to the age of the building or client affluence. For example, the Ambacang hotel and Inna Maura hotel, both multi-story, expensive hotels, suffered major damage. The Ambacang hotel was the most severely damaged hotel observed during the survey (Figure 29). There were also accounts that proper evacuation plans of the Ambacang hotel were not available when the earthquake occurred, resulting in numerous fatalities. The Ambacang hotel was unusual as it was primarily a steel framed building with the concrete floors being constructed with profiled steel sheeting (this was the only significant steel framed building observed by the team). It appears that there was failure of the steel beams and reinforced concrete columns; however, a complete survey of the building was not permitted due to the negative publicity the hotel received because of its poor performance during the earthquake.

Figure 29. Ambacang Hotel Damage.

In some cases, there was little to no structural damage of the multi-storey hotels. The Bumiminang hotel experienced masonry damage but no obvious primary structural failure. False masonry "columns" (two adjacent masonry walls) were also damaged, but the reinforced concrete columns appeared undamaged (Figure 30). The extension of the beams past the exterior of the columns depicted in Figure 30 is likely to be a seismic rather than an architectural detail and indicates that this building is likely to have been constructed with good seismic practice in mind. The strong ground shaking (evidenced by the failed masonry infills) and the lack of obvious structural damage suggests that this building and the seismic practices employed have worked well. However, the team was informed that the hotel would be demolished and not repaired. It is likely that the decision to not repair is due to damage to architectural elements inside the building as well as the obvious external damage, but this could not be confirmed as access was restricted. The Basko Grand Mall, recently constructed and owned by the Western hotel chain – Best Western, had no apparent structural damage from an exterior survey. The on site guards would not permit an interior survey, but it was confirmed by a hotel associate that the hotel had closed due to damage to architectural elements.

Figure 30. Bumiminang Hotel, shear cracking and damage to false masonry columns.

Shopping Centres. Similarly, the same variability of damage was noted in shopping centres, which were also reinforced concrete frames with masonry infill. Two large shopping centres, the Ramayana Shopping Centre and the Basko Grand Shopping Centre (adjacent to the hotel), and a handful of smaller shopping centres were surveyed. Soft-storey failure was observed in one of the smaller shopping centres, the Nelayan Rest and Café Centre. This structure was adjacent to the Samudera Jaya shopping centre, which had little to no damage (Figure 31).

Figure 31. Small Shopping Centres; Left: soft-storey failure, Right: Minimal damage.

The Basko Grand Shopping Centre had no noticeable structural damage from the exterior, and it is also a very recent construction (Figure 32). However, similar to the Basko Grand Hotel next door, the shopping centre was closed immediately after the earthquake.

The Ramayana shopping centre was a large four-storey structure. Damage caused by fire was noticeable along a section near the roof, and construction workers were beginning the reconstruction of the masonry walls. It appeared that the masonry infill walls had completely failed, although the primary reinforced concrete columns were robust and suffered no obvious damage. Narrow columns supporting the roof cantilever failed.

Different construction techniques were being implemented for the reconstruction of the masonry infill. The concrete confining columns were placed more frequently, likely in an attempt to provide additional support for the masonry walls. See Figure 33 and Figure 34.

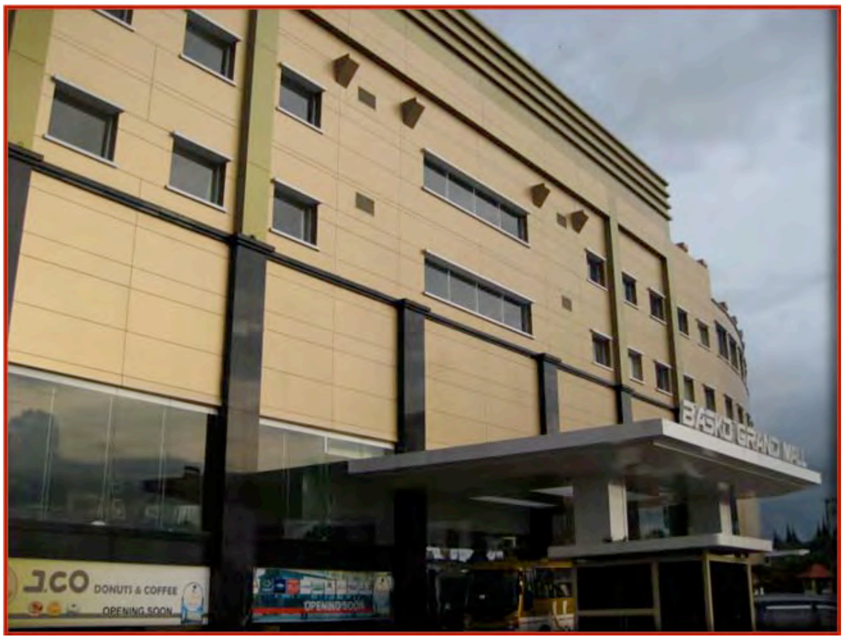


Figure 32. Shopping centre with little to no structural damage.

Figure 33. Ramayana Shopping Centre (left) and roof column failures (right).

Figure 34. Ramayana Shopping Centre:
fire damage (left) and new masonry construction (right).

The extensive damage to hotels and shopping centres, which were usually insured, is the likely explanation for the relatively large ratio between insured and total (ground-up) losses for this event. This is particularly true considering that the earthquake was not devastating for the residential buildings or smaller commercial buildings (usually uninsured buildings).

Government Buildings

According to senior members of the Bung Hatta University, about 80% of all governmental buildings in Padang were severely damaged or collapsed. One of the reasons for this behaviour was explained as the age of most governmental buildings, meant they had been designed and constructed to the old design code. In the latter code, the ground motions for design correspond to 200 years return period, in contrast to the ground motions for design from the new design code (SNI-1726-2002) that are set at a return period of 475 years.

The number of buildings in West Sumatra that were designed according to the 2002 or the former earthquake standard could not be clearly identified. The reasons for this is that even though the latest code was initially released in 2002, it took a few years before the code was adopted by the local engineers. As a result, there is no guarantee that the structures built after 2002 were designed according to the new earthquake code. Secondly, lack of code enforcement by either the Indonesian government or relevant building authorities has contributed to the inappropriate application of the seismic and building standards in construction practices.

The observed Governmental buildings in Padang are constructed of reinforced concrete with moment resistant frames and infill walls. Most of the damage observed in these buildings was caused by soft storey failures. A typical example is presented in Figure 35 where the differences in rigidity between the ground floor and the floors above are severe. Other examples of structural failures of governmental buildings are shown in Figure 36. The roofs of the buildings in the latter figure reproduce the shape of typical constructions in West Sumatra; initially thought to be very heavy roofs and thus a contributing factor to the damage observed, they are actually less heavy than the concrete slabs observed in other buildings.

Even though the construction of governmental buildings requires the supervision of the correct implementation of the design specifications, some quality faults (such as lack of enough reinforcement and the use of plain reinforcement bars contrary to ribbed bars) were observed during the survey.

The use of inappropriate design codes and poor quality of construction may be the major causes of damage to governmental buildings in Padang. A governmental building in Pariaman (closer to the fault rupture) that had a very good structural behaviour is presented in Figure 37.

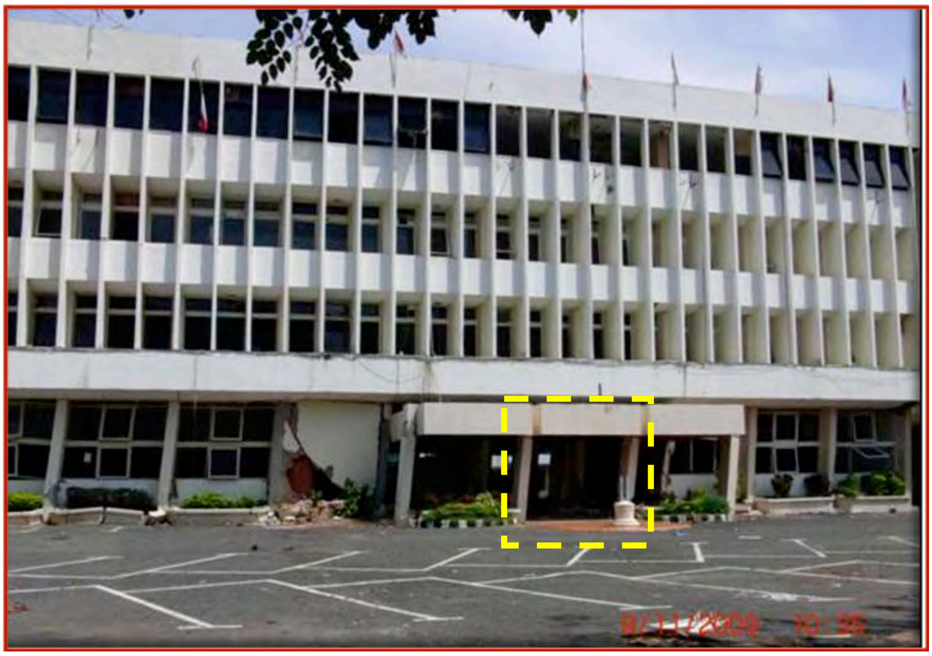


Figure 35. Soft storey failure of a governmental building in Padang, with the bottom photograph showing the failure of the column in the area indicated in the upper photograph.

Figure 36. Examples of soft storey failures in governmental buildings in Padang.

Figure 37. Governmental building in Pariaman city. In spite of the irregular geometry of the building, the observed damage was limited to the two infill walls.

Industrial Buildings

Industrial facilities in Padang are primarily concentrated in the South-eastern part of the city and the area close to the Port, in the South of Padang.

The EEFIT team visited the local cement plant (Figure 38) that, according to its managing director, provides 90% of the cement to the province of Western Sumatra and about 50% to all of Sumatra. They also export cement to Malaysia and Singapore. It is the oldest cement factory in Indonesia (founded in 1910) and directly employs about 2,000 people plus a significant number of people indirectly.

From the structural point of view, the only problem in the factory was a very minor issue with a reinforced concrete column that lost part of the exterior concrete (Figure 39). The most severe structural damage in the complex occurred to a one storey high building made of confined masonry that was used for administrative purposes. This building suffered the collapse of a couple of infill walls, though most of the building only sustained slight damage.

In spite of the practically nonexistent level of structural damage in the factory, the production of cement stopped completely for seven days. The principal reason for this corresponds to the lack of electrical supply from the main network; the plant has its own power generator, though it was not fully functional at the time (personal communication). Additionally, some equipment had to be stopped for reparation since some mechanical problems occurred. The plant personnel were back to work four days after the earthquake, and production was resumed at normal levels a month after the event.

Figure 38. Two areas of the production line of the cement factory (from a total of five lines of production). No structural problems were observed during the visit.

Figure 39. A minor problem with a RC column in the cement factory where part of the face concrete was damaged and then repaired. This did not represent a structural problem.

The cement produced in the factory is distributed and exported through Padang port. Since one of the cranes dedicated to upload the cement collapsed (there were exclusive cranes at the port for loading the cement), the distribution of cement was further reduced. Another factor that reduced the production corresponds to machinery in the mines (located at about two kilometres southward from the plant) having some degree of mechanical damage caused by the earthquake.

All in all, it can be stated that the cement factory stopped production completely and then had a reduced capacity not because of structural damage resulting from the earthquake ground motions but because of the interruption of the electrical supply and machinery problems.

A second industry visited during the survey was a rubber plant that exports materials to some neighbouring countries and the United Arab Emirates (Figure 40). The plant was constructed around 1982 and is a reinforced concrete and steel structure. The plant halted production for ten days because of damage to the reservoir that filters out the poisonous by-product of rubber production (Figure 41). After the tank was repaired, they resumed the rubber production.

Other installations that were affected during the event were the warehouse, the laboratory, the staff housing and the electrical generator, all of them having light to moderate damage. Machinery in the plant had to be recalibrated but was not damaged during the event.

Figure 40. Rubber plant in Padang.

Figure 41. Damage to the reservoir where poisonous materials are removed before disposal of residual waters (photos provided by the plant manager).

Even though the EEFIT team visited a limited number of industries in Padang, it seems that none of the industrial facilities suffered significant structural damage. However, industrial activities in the city were severely disrupted during the first 7 to 10 days due to failures in the electrical power supply, and then afterward due to repairs and recalibration of machinery.

Port facilities

Padang has an international port which is the most important in the West Sumatran province. Access to the port was restricted and security was under the control of the Indonesian navy. Access was finally granted and an assessment of the facilities conducted.

No structural problems were observed in any of the port elements (Figure 42), including a light steel structure and the warehouse made of reinforced concrete moment resisting frames with infill walls. The exception was the collapse of a crane whose principal function was the uploading of cement from the plant (all elements have been removed at the time of the visit, thus no pictures were taken), and the settlement of about 60mm of the access to the dock structure (Figure 43).

Figure 42. No structural damage was observed in any of the port facilities. Left: light steel structure. Right: warehouse of RC moment resistant frames with infill walls.

Figure 43. Settlement of the access to the dock.
Maximum measured settlements were 60mm.

Schools

Schools were among the most affected facilities after the West Sumatra Earthquake. According to National Disaster Mitigation Agency Republic of Indonesia (BNPB 2009), there are 2,164 schools severely damaged, 1,447 moderately damaged and 1,137 lightly damaged in West Sumatra, concentrated in Padang City, Padang Pariaman and Agam County (Table 4).

Table 4. Summary of Damaged Schools After 30 September 2009 Earthquake (BNPB 2009).

No.	REGION	Damaged Level		
		Severe	Moderate	Light
1	Padang City	1,606	1,038	903
2	Pariaman City	92	101	22
3	Padang Pariaman County	257	87	31
4	Agam County	114	77	65
5	Padang Panjang City	23	41	26
6	Solok County	3	36	28
7	Pasaman County	1	-	13
8	Pasaman Barat County	27	16	1
9	Pesisir Selatan County	29	43	34
10	Bukit Tinggi City	-	6	8
11	Solok City	3	-	2
12	Tanah Datar County	5	-	4
13	Mentawai Island County	4	2	-
	TOTAL	2,164	1,447	1,137

The EEFIT team surveyed various schools in Padang and in the district of Pariaman. Most of the schools surveyed were government schools, which typically imply less funding for construction. The primary mode of failure of these buildings was poor construction detailing. Roof failures were common due to inadequate connection details. In some cases, the collapse or tilting of the entire walls was observed. The construction typology of most of the schools was improperly confined masonry with timber framing and roofs. Most of the schools were comprised of numerous, rectangular-plan, single-storey buildings with concrete slab foundations. Some of the school buildings had very narrow concrete columns, while others had not. In either case, it is expected that insufficient support was provided for the masonry. The Indonesian code requires reinforced concrete columns at 3m spacing to confine masonry walls (maximum area of each sequence of masonry wall suggested 12 m^2). This level of confinement was rarely noted in the school buildings. Engineers at the Bung Hatta University in Padang attributed the school building failures to the lack of construction supervision.

According to the volunteer coordinator at GALAPAGOS, numerous schools in Padang were damaged, and seventy-percent of the schools in the Pariaman district were destroyed. Pariaman is only 31 km from the earthquake epicentre. The Indonesian government had an initiative for schools to reopen two weeks after the earthquake, and this was successfully implemented. Temporary school buildings were constructed outside with timber framing and a steel corrugated room, and these temporary school buildings are currently being used.

Of the two school buildings comprising the SDN 24 Ujung Gurun elementary school in Padang, one building completely collapsed and the other suffered shear-cracking. See Figure 44 and Figure 45, respectively. The structural typology was masonry with very narrow reinforced concrete columns at the wall joints. The roof was timber with corrugated sheet metal. The collapse of the building may be attributed to a lack of masonry confinement in the walls, poor or no connection between adjacent walls, an extremely shallow footing, and insufficient concrete reinforcement. It seemed that the collapsed building had a long segment of wall that was not supported by the cross wall (only 500 mm high) or the timber roof trusses. As a result, the outer wall had no support and therefore the inertia force from the wall caused out of its plane toppling (i.e. its weak direction). The masonry walls are constructed as separate panels but not properly tied together at the wall joints, making the walls susceptible to tilting and collapse (Figure 46).

Figure 44. SDN 24 Ujung Gurun Elementary School in Padang – collapsed building.

Figure 45. SDN 24 Ujung Gurun Elementary School in Padang – less-damaged building.

It is unclear why only one of the SDN 24 Ujung Gurun school buildings collapsed, as the mode of construction and age of the buildings appeared identical. However, many factors may have contributed to the survival of the lone building, including increased support for the cantilevered roof as provided by the timber columns (not present in the collapsed building) or more attention given to construction details.

The Yayasan Payoga SD Agnes elementary school, a private school in Padang, was also surveyed. In contrast to the SDN 24 Ujung Gurun elementary school, the masonry walls in this building were well confined and the walls suffered only shear cracking. The school did suffer a roof collapse however, possibly caused by the heavy roof tiles (Figure 47).

Additional schools were surveyed in the district of Pariaman, including a school in the small village of Kudu Ganting, two schools in Pariaman, and the remains of a school foundation were found in the landslide rubble of Kapolo Koto. Refer to the geotechnical section for more details about the Kapolo Koto School.

Figure 46. Location of wall to wall joint – no connection between orthogonal walls.

Figure 47. Heavy clay roof tiles from the Yayasan Payoga SD Agnes school.

The SDN 01 Lima Kota Timur elementary school, a government school in Pariaman, had a similar structural typology to the Padang schools, without reinforced concrete corner columns. The unconfined masonry walls seemed insufficiently joined, and it appeared that the roof and walls collapsed. There was no anchorage found at the connection between the bearing wall and the roof truss structure, indicating that the roof construction was not appropriately supported in the horizontal direction (Figure 48). As a result the lateral force of the earthquake likely caused the roof construction to displace and fail.

Reconstruction on this school building had already begun, and the replacement bricks were either bricks salvaged from the earthquake, or new bricks of the same exceptionally poor quality (the bricks could be easily crumbled by hand). The local residents showed the team the temporary, timber school building further down the road (

Figure 49). Other schools in Pariaman had initiated demolition of the severely damaged buildings and started on reconstruction. It may be more difficult to differentiate between the earthquake-induced school damage and the building demolition due to the time elapsed since the earthquake (1 month).

Figure 48. SDN 01 Lima Koto Timur, an elementary school in Padang Pariaman County.

Figure 49. SDN 01 Lima Koto Timur temporary school buildings.

Hospitals

The team surveyed three hospitals. The first was The Bunda Medical Centre a private hospital in the centre of Padang, The Dr. M. Djamil General Hospital, which is the main hospital in Padang and therefore the main hospital in Western Sumatra, and the third was the local hospital for Pariaman. All three hospitals were concrete framed structures with masonry infill.

The Bunda Medical Centre had suffered serious damage, with major structural failures in many columns (Figure 50) as well as extensive damage to masonry infill panels and windows (Figure 51). The failed columns were constructed of round smooth bars, with 8mm* smooth confining reinforcement at approximately 150 centres (*lack of access prevented accurate assessment). At the time of the survey the hospital was out of action and repair had started.

Figure 50. Bunda Medical Centre.

Figure 51. Bunda Medical Centre showing extensive cracking of non-structural masonry.

The Dr. M. Djamil General Hospital is a reasonably modern facility dealing with all medical complaints. It has an 800 bed capacity and an outpatient unit that can deal with 1200 patients per day. The structure of the hospital consists of many medical units housed in a number of buildings. These structures are typically reinforced concrete frames with masonry infill. Of these buildings only one, the Polyclinic (outpatient ward) collapsed (see Figure 52). Of the other buildings, none suffered major structural failure; however there was some non-structural damage and widespread failure of the mechanical and electrical services. Some of these services were terminated because of external influences (e.g. water and electricity supply to the hospital was cut) while other services failed due to damage to the mechanical and electrical components of the system.

a) Polyclinic

b) failed Connection detail in Polyclinic

Figure 52. Dr. M. Djamil General Hospital Polyclinic

The team interviewed representatives of the hospital consisting of public relations staff, administration staff and medical staff.

At the time of the earthquake the hospital had 430 patients, which was well below the average bed occupancy of 600 beds. Many patients panicked in response to the earthquake and tried to leave. The hospital has evacuation procedures and an evacuation route and patients were evacuated using these routes. Critical patients were also evacuated with the assistance of hospital staff.

One hour after the earthquake, 14 tents with a capacity of 25 people/tent and 2 surgery tents were erected using the help of the staff of the hospital, the Department of Health, Red Cross Padang, the Social Department and the Armed forces

On the first day 70 people with injuries ranging from minor to severe were treated in these tents; 40 patients with minor injuries were untreated due to lack of capacity. Some patients with minor ailments already being treated at the hospital were sent home early. The vast majority of injuries were head injuries, crushing injuries and fractures.

Although there was some damage to the hospital, the hospital could still treat 800 patients (the usual capacity of the hospital). The only major structural failure in the hospital was the outpatient building which had completely collapsed. This building had a capacity of 1200 patients/day. The patients that were usually treated by this unit were either treated in the tents or in the appropriate inpatient unit of the hospital. At the time of survey, the polyclinic was still out of action and so outpatients were treated by the relevant inpatient units.

Most of the dedicated hospital mechanical services were broken. For example the piped oxygen was broken and so mobile oxygen units were used. These proved to be adequate for the demand.

The hospital was without power for 3 days, and therefore relied on diesel generators. The total capacity of the generators is 25 MW. The usual requirement for the hospital is approximately 100 MW. The diesel generated electricity proved adequate to supply electricity for critical services.

The earthquake left the hospital with no mains supplied water. This resulted in insufficient water for the patients and for critical hospital procedures. The onsite reserves that were available were carried to the patients in the tents and rationed.

After the second day water arrived by truck and this was pumped to where it was needed. This helped to relieve the water shortage, but water supply was still critical.

About 20% of the staff were directly affected by the earthquake (either loss their homes or injuries to relatives) but none of the staff were actually injured. The main director of the hospital directed existing staff to stay at the hospital to treat patients. The hospital has a staff of 200 doctors and 800 supporting staff and all made themselves available. This resulted in no issues due to staff shortages.

The deceased that were brought to the hospital were treated using Disaster Victim Investigation (DVI). This is a basically an identification and autopsy procedure. Once this process was completed, families would collect the cadavers for burial. The capacity of the morgue is 12 x 3 bodies. 36 bodies were processed on the first day with a total of 135 being identified. Body identification was conducted by the DVI team, the police and the North Sumatra Provincial Government.

Several other hospitals were severely affected by the earthquake, some of which were either badly damaged, did not have the capacity to cope or the specialist units to deal with the casualties. All hospitals coordinated and patients were stabilised and then transferred from outlying hospitals to this hospital.

The total number of casualties treated in the temporary hospital was 366, with 200 of these requiring surgery and 1983 casualties were treated as outpatients. Patients were also offered psychological treatments to help deal with the trauma of the event

Outside aid started to arrive on the second day. Initially aid from other parts of the province arrived on the second day, with the first NGOs and other overseas aid organisations arriving on day 4 and the majority having arrived by day 5.

Hospital staff reported that all aid was very helpful and relieved a lot of the extra pressure that had been put on the hospital, but it had mainly relieved the pressure and allowed a better of standard of care to noncritical and critical patients, rather than being essential for critical patients.

People were returned from the temporary hospital setup (tents) in the grounds of the hospital after third day. By the fourth day all patients had returned to the main hospital buildings.

The hospital in Pariaman, although much closer to the fault, sustained virtually no damage. The only visible damage was minor cracking to non-structural masonry. The hospital and cracking on the masonry walls can be seen in Figure 53

Figure 53 Pariaman Hospital

LIFELINES

Water Supply

Padang is serviced by only one water company called *Perusahaan Daerah Air Minum* (PDAM) which supplies 64,000 customers in the city. The Team visited the local water Company and interviewed the engineers and the technical director of PDAM Padang.

The PDAM has three main reservoirs and associated trunk mains and a number of boreholes. The three reservoirs are Lubuk Minturun, supplying the North zone with 290 l/s capacity; Ulu Gadut, supplying the South zone with 220 l/s capacity; and Gunung Pangilun, supplying the central zone, which has a capacity of 500 l/s. The capacity of the boreholes is approximately 90 l/s. All trunk mains were 600 mm in diameter.

Immediately after the event, the main trunk for the central Padang region was severed in two places, resulting in total loss of its 500 l/s supply. The distribution network of the water was also disrupted due to the pipe damages. As the pumps for the boreholes were powered by electricity, this supply was also terminated. This caused the loss of 85% of the borehole service and effectively left the central region with no water. The damages to the water facilities immediately after the earthquake are summarized In Table 5:

Table 5. Damage to water supply facilities.

No.	Damaged Facilities	Damaged Details	Direct Impact
1.	Ground settlement (20-30cm) at water treatment facility in Gunung Pangilun	- Tilted 2 unit of accelerator - Broke effluent accelerator pipes and effluent filtration unit	- Water Treatment Facility was shut down
2.	Supporting Facilities/ Buildings	- Power House - Chemical and water control building - Head Office and The North Branch Office	- No back-up power/electricity for pumping the water - Unsettling administration system
3.	Leak of Pipes	- Transmitting Pipes (DN 500 mm) - Primary Distribution Pipes (DN 400 mm and 600 mm) - Secondary, tertiary and service Pipes	- Water supply had been disrupted 30%, but not affected the water productivity
4.	Water Intake in Sikayan and Ulu Gadut	- Loss of 220 l/s water supply	- Failed to serve ±20,000 customers

Chronology of the situation aftermath was described as follows:

Day 1: The first day after the earthquake, water from the other two reservoirs was diverted to the central region and in particular the hospital; however network failure meant little water got through. The water company had two, 4m^3 water trucks which were immediately mobilised to supply water to the M. Djamil Hospital (the main hospital in Padang). Re-establishing mains water to the hospital was set as the highest priority.

Day 2: On the second day after the earthquake, the water company had started the emergency response program. It obtained another three, 5m^3 water trucks from The Department of Civil Works of West Sumatra. In addition to the extra water trucks, 108 units of 2m^3 water storage tanks were provided which allowed distribution to other areas of central Padang (see Figure 17).

Day 3: Day 3 saw the arrival of another 9 trucks (5 m^3) from neighbouring regions such as Jambi, Solok and others. Other witness reports stated that the hospital was severely short of water until this day.

Day 4 and 5: OS and NGO's arrived on these days bringing a further 49 trucks. These trucks were supplied by ship and by air, the Australian army also provided 2 reverse osmosis units, for the desalination of seawater.

Day 5 and 6: Local residents rioted, attacking the main headquarters of the water company and the departing water trucks. This was in response to having no water for 5 days. The interviewee stated that progress was hampered by many staff having to help their families in the aftermath of the earthquake.

Day 10: The repair of the trunk main occurred on this day. This coincided with the resumption of the electrical supply and therefore the pumping station could operate. The water company had two diesel generators; however these had insufficient capacity, therefore if the trunk main had been repaired earlier it would not have resulted in a significant increase in supply. The other reservoirs were gravity fed and therefore loss of electricity had not resulted in loss of supply.

To mitigate the water problems, the company suggested the following actions:

- Carry out inventory of damaged assets/facilities.
- Build temporary shelters on parking area at the head office to accommodate administration activities since the main office buildings had been severely damaged.
- Establish Water Supplies Emergency Post in collaboration with the local government to supply water to the public by using trucks and hydrants. The allocation of water trucks and hydrants was based on priority in conjunction with the Department of Civil Work (PU Cipta Karya) and UNICEF.
- Launch Emergency Response Team to deal with the repair of water distribution network and asset/infrastructures. The number of repair teams before the earthquake was 4 and had been increased into 14 afterwards. Additional external supporting teams contributed by national and local contractors were also involved to speed up the recovery process.
- Give assistance to the community including getting feedback from the customers and collecting information to better distribute water using the water trucks.

By November 8, 2009, the water company had repaired 2300 broken connections in the distribution network, but still had not returned supply to everyone. The distribution network consists of ductile cast iron, asbestos cement and PVC. It was reported that the vast majority of the failures were in the connections. The technical director suggested that more fire hydrants would have been useful, as it would have improved post disaster supply. Resuming services was being hampered by difficulty in finding leaks. Leak detection was conducted by flushing pipes with water, which was difficult to justify in an already overstretched water supply system.

All reservoirs had been undamaged; however the water treatment works suffered damage due to settlement resulting in an intermittent ability to treat the water that was still an issue at the time of survey.

Transport Networks

In Padang city, transportation networks received little damage from the earthquake. No vehicular bridges were reported as unfit for passage and few roads were closed. No significant signs of damage to bridge decks, displacement of spans at the joints, nor spalling of concrete were observed. Failure was however observed at a minor road by the coast. Figure 54 shows the settlement of road due to the loose soil condition at the subgrade under the earthquake's cyclic loading. The tension cracks parallel to the coastline in Figure 55 may suggest the possibility of lateral spreading arising from the effects of liquefaction. These cracks were particularly found at the edges and midway of the asphalt pavement. The former was likely due to the change in stiffness due to the discontinuity of material, while the latter may have been caused by the presence of construction sequence of the wearing course. The settlements measured were up to half a metre deep and the crack widths of 150mm wide stretching for more than 10 metres long.

Figure 54. Settlement and cracks on road parallel to the coastline.

Figure 55. Tension cracks propagating parallel to the longitudinal axis of the road.

Severe failure was also observed at the crest of a sloping road as shown in Figure 56. This may have been due to settlement of loose soil beneath the road. Heaving was not observed at the toe which ruled out the likelihood of a slip failure.

Cracks parallel to the plane of fault rupture were also sighted in an open car park near a stadium as shown in Figure 57.

Figure 56. Severe failure of road at the crest of the embankment.

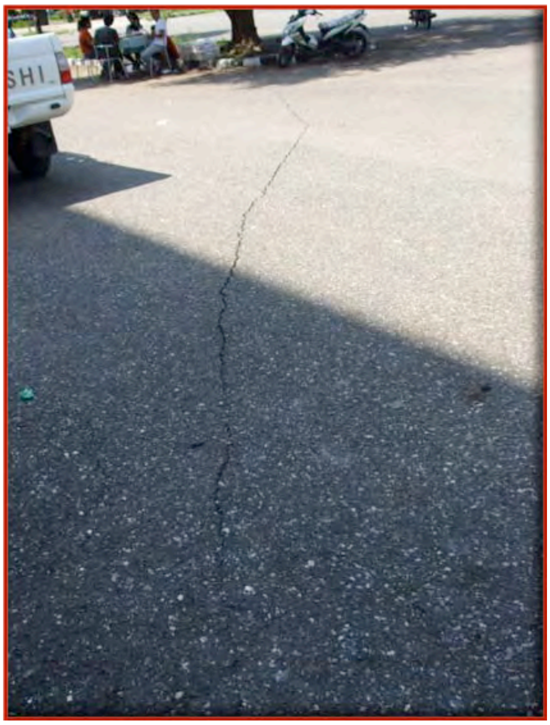


Figure 57. Road cracks parallel to the plane of fault rupture.

In the district of Pariaman, landsides and slope failures did cause disruption to roads and a pedestrian bridge, with a number of roads becoming impassable. Although these roads could be considered to be minor in terms of their construction, in a number of cases they were the only vehicular access to villages and this caused difficulties in providing aid to local people (see Landslide and Disaster management section for further details).

Telecommunication

There was only minor loss of service in landlines; however the majority of mobile phones were out for 10 days. This was due to 80% of mobile phone provision being made by one telecoms company. This company had no (or a small amount) of generators for their mobile phone masts. Connection was re-established using transportable masts with their own diesel generated power supply.

GEOTECHNICAL ASPECTS

Foundation Failures

Foundation failures were minimal in Padang. The foundations of buildings are mostly intact with some minor settlement. One of the university buildings in Universitas Negeri Padang founded on piles had suffered slight differential settlements. This led to substantial cracks and settlements in one of the adjoining classrooms as shown in Figure 58.

Figure 58. Crack on floor tiles of classroom due to differential settlement.

The foundations, however, may have been located on stiffer soil, which therefore resulted in minimal structural damage. Figure 59 illustrates the settlement of the surrounding soil of approximately 100mm relative to the pile foundation. Coarse sand deposits were found in this area as shown in Figure 60.

Figure 59. Settlement of soil around a column of a university building.

Figure 60. Coarse sand grains found within the proximity of the university building.

Elsewhere, an elementary school had suffered a total collapse of a segment of its one-storey classroom building. One of the factors leading to the collapse was the insufficient embedment of the wall into the strip foundation as illustrated in Figure 61.

Figure 61. Wall collapse due to insufficient embedment of strip foundation.

Landslides

The team visited the district of Pariaman, about 50 km north of Padang, to investigate the numerous landslides that were reported in Pariaman's surrounding villages. Table 6 shows the fatalities due to landslides which occurred as a direct result of the September 30 earthquake.

Table 6. Landslide Fatalities in Pariaman (Source: Government of Pariaman).

No.	District	Village	Dead
1	Nagari Tandikek at Patamuan	Pulau Air	45 (25 Found, 20 Not Found)
		Cumanak	75 (34 Found, 41 Not Found)
		Lubuk Laweh	132 (48 Found, 84 Not Found)
2	Koto Timur	Padang Alai	54 (19 Found, 35 Not Found)
		Kudu Ganting in Talao	9 (7 Found, 2 Not Found)
3	Padang Sago	Sungai Pua Tanjuang Mutus	5 (3 Found, 2 Not Found)
		Batang Piaman	1 (0 Found, 1 Not Found)
	Total		**321** **(58% not found)**

The majority of rural communities living in West Sumatra are situated in agriculturally-intensive villages near the foot of volcanoes. The reason for locating villages in these regions is due to the fertility of the land. The close proximity to steep slopes consisting of weak, weathered pumice makes them particularly susceptible to landslides. ReliefWeb (2009) reported over 1000 landslides triggered by the earthquake. These landslides were particularly clustered in the Gunung Tigo highlands between the districts of Padang Pariaman and Agam districts in the Pariaman region as well as in Kota Padang and Solok districts in the Padang region as indicated in Figure 62. Despite the lower population and population density in these mountainous regions as compared to the urban city area, there was a high number of casualties (about 1/3 of the total fatalities due to the earthquake). This high number of fatalities could be partly attributed to a large number of villagers attending a wedding ceremony in Cumanak Village (see location in Figure 62), where a major landslide occurred, but mainly due to the very lethal nature of the landslides.

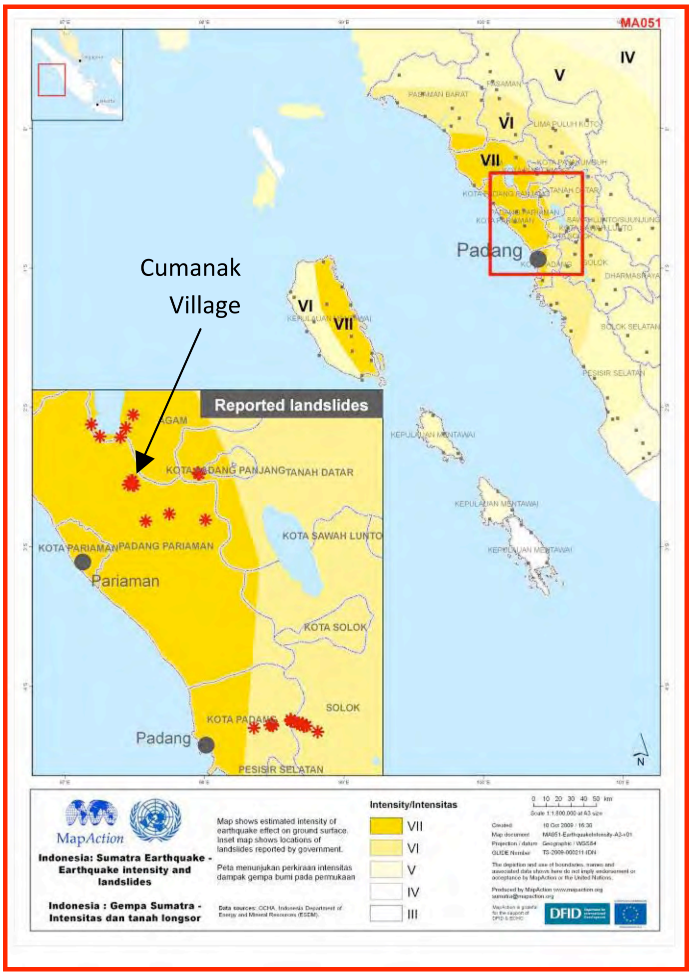


Figure 62. Earthquake intensity and landslides.

Many of the surviving local residents lost most of their family members. Figure 63 shows the three landslide sites visited in the worst-affected district of Nagari Tandikek in Pariaman. Two villages, Pulau Air and Cumanak were virtually destroyed by these landslides.

Figure 63. Relative locations and topography of three landslide sites visited during the survey, superimposed on Google Earth with NUS CRISPS overlay.

Landslide Site 1

The first landslide was accessible via car. The height of the scarp and runoff distance measured were 65 m and 230 m respectively The characteristics of the landslide as measured by a GPS survey are given in Table 7

Table 7. Characteristics of Landslide Site 1.

Characteristics	**Estimated Values**
Elevation of top of scarp	247 m
Elevation of base of scarp	182 m
Landslide length	230 m
Landslide width (max)	120 m
Landslide thickness (average)	5 m
Maximum slope angle	45^o
Landslide volume (assume ellipsoidal shape)	10,210 m^3
Landslide velocity	49 m/s

The estimated landslide velocity was 49 m/s following Slingerland and Voight (1979). As the landslide resembles the quarter ellipsoid-shaped mass with its maximum width coinciding with its toe, the landslide volume was approximated to be 10,210 m^3 based on the formula by Cruden and Varnes (1996). Figure 64 shows the photos of the landslide taken near the summit and the runoff toe.

Figure 64. Views of Landslide Site 1 near the summit (left) and the runoff toe (right).

Landslide Site 2

The 2nd landslide was once Kapalo Koto, a part of the Pulau Air village which has been buried by the landslide. The concrete slab foundation and brick and timber debris of the destroyed Kapalo Koto elementary school were the only remains in the site as shown in Figure 65. The soil collected from the surface of the landslide debris was mainly coarse weathered pumice as illustrated in Figure 66. Such lightweight and porous material typically originates from volcanic rocks which underwent rapid cooling and depressurization when they were violently ejected from a volcano. The height of scarp and distance of runoff were about 100 m and 750 m respectively. The estimated landslide velocity was 88 m/s based on the formula by Slingerland and Voight (1979). Table 8 indicates the characteristics of the landslide as measured by a GPS survey.

Figure 65. Slope failure (left) and the foundation of a destroyed school (right) at Landslide Site 2.

Figure 66. Weathered pumice collected from the landslide debris.

Table 8. Characteristics of Landslide Site 2.

Characteristics	Estimated Values
Elevation from bottom to top of scarp	100 m
Landslide length	750 m
Landslide width (max)	180 m
Maximum slope angle	45^o
Landslide velocity	88 m/s

Landslide Site 3

The third landslide visited was the largest site reported with the most number of causalities. The EEFIT team travelled to the site at Cumanak Village by foot. Figure 67 shows elevated views on a section of the landslide site where the village was sited.

a

b

c

d

e

a) View looking up the valley with the high point of the survey indicated as well as locations for photos (c) and (d)

b) High point of the survey, looking down the valley with the locations for photo (a) and (e)

c) View looking up the valley from the high point of the survey as indicated in Figure (a)

d View looking up the valley from the high point of the survey as indicated in Figure (a)

e) View looking at landslide adjacent to the surveyed landslide. Photo taken looking approximately as shown in Figure (b)

Figure 67. Various views of Cumanak Village landslides.

Residents reported that a number of relatively large landslides had occurred since the earthquake. Residents indicated the location of one of these landslides and this is shown in Figure 68 . At the time of the survey the wet season was in progress and there had been the usual high rainfalls. Locals reported that there had not been a great deal of rain in the weeks preceding the earthquake, although there had been heavy rain the night before and during the day of the earthquake. Rock samples taken from the site, were later identified as pumice and ranged in size from gravel to fist size rock, with the vast majority being less than 10mm in size.

Figure 68. Rain induced landslide.

The locals were actively removing debris from their homes for reuse and rebuilding. Only a handful of small houses survived the landslide. Two houses were positioned just outside the landslide's path, while a small timber house (shown in Figure 69) directly in the landslide path also survived. Local residents said that the soil "flew over the top" of the house. The house did not move and its inhabitant survived the landslide. The trees behind the house may have protected it from the majority of the landslide impact. Apart from the pedestrian suspension bridge and handful of houses, no other surviving structures were visible in this area. Local residents said that earthquakes have been particularly frequent in Cumanak, and they noted that the village was located between two volcanoes, Singgalang, an active volcano northwest of the village, and Tandikek, a dormant volcano northeast of the village.

Figure 69. The extend of the landslide taken from the high point of the survey (left), and showing the location one of the few houses which survived the landslide (right).

The site was difficult to access and search and rescue efforts after the earthquake may have been delayed by the narrow, winding roads and steep hills. After the earthquake, government aid and NGOs took approximately four days to arrive at the village. Matters were made worst by the damaged pedestrian bridge which was the sole passage leading to the site. Figure 70 shows the damaged bridge which was still frequently used by the residents after the occurrence of the landslide.

Figure 70. Damaged pedestrian bridge still frequently used by residents.

The extend of the landslide was about 2 km long and 1.5 km wide measured from the satellite images from Google Earth and NUS CRISP.

Liquefaction

Liquefaction was observed at localised areas in Padang. This is attributed to alluvial deposits composing of loose sediments with high sand content. In addition, Padang is on a low lying coastal strip where a high ground water table is present.

The tension cracks on the road near the coastline as described in the Transport Network section of this report in Figure 55 suggest the possibility of liquefaction. This is supported by the cracks arising from lateral spreading near the beach as portrayed in Figure 71.

Figure 71. Tension cracks arising from lateral spreading.

Landwards into the Padang city core, the Mere Amelie Church suffered effects of liquefaction as well. Sand boils were observed in the school beside the church (Yayasan Prayoga SD Agnes school) as shown in Figure 72. This can be substantiated given that these sand boils were predominantly silty sand which came from the soil depths beneath the topsoil. Teaching staffs in Universitas Negeri Padang, a university near the coast and occupants of shophouses also reported seeing fluidised sand seeping through their cracked floor slabs in their compounds. However, these sand boils were cleared up soon after the earthquake to resume lessons and businesses respectively.

Figure 72. Sand boils in adjoining building of Mere Amelie Church.

In low land regions such as the Siteba and Perumdam Villages, clear signs of liquefaction were also sighted. A well in Siteba Village had been choked by the rising sand due to the build up of pore water pressure during the earthquake. In order to continue providing water to the village, the sand in the well was excavated after the earthquake. The well and excavated soil are as shown in Figure 73. The excavated soil was a uniformly graded fine sand, confirming liquefaction.

Figure 73. The well (left) that was blocked with sand (right) due to liquefaction.

In Perumdam Village, two adjacent single storey houses near the river have suffered from the effects of liquefaction. Excess pore water pressure had built up below the floor slabs. This led to the upheaval of the floor slabs as portrayed in Figure 74. Once the cracks in the floor slabs had opened the water could flow out thus relieving the excess pore pressure and allowing the floor slabs to settle back down.

Figure 74. Upheaval of floor slabs due to liquefaction.

DISASTER MANAGEMENT

Post disaster relief in Indonesia is lead by the National Disaster Management Agency (BNPB) in coordination with the Local Disaster Management Agency (BPBD). This consists of SATKORLAK PBP at province level and SATLAK PBP at municipality/regency level. The SATLAK PBP is responsible for the disaster field coordination unit that is supported by the governor of the region (SATKORLAK PBP). Both of these agencies work under the guidance and supervision of National Disaster Management Agency (BNPB), which reports directly to the president of Indonesia.

The Indonesian government divided the West Sumatra relief operation into 3 phases: emergency, rehabilitation and reconstruction. The emergency response originally was implemented for 2 months from 1 October 2009 to 31 November 2009. However, since the livelihoods in the affected region had already begun to return to normal, the emergency phase was implemented for only 1 month (except for Pariaman and Agam County, which still needed emergency relief).

In general medical services performed very well, with patients from damaged hospitals being transferred to the Dr. M. Djamil General Hospital (main hospital in Padang). This hospital had the capacity to deal with all medical emergencies (see Hospitals Section for further details).

Water supply was a major problem immediately after the earthquake and continued to be a problem at the time of the survey; however critical shortages only lasted approximately ten days.

Rehabilitation and reconstruction activities started on 1 November 2009 (preparation stage) and it is planned that the implementation of the rehabilitation and reconstruction phases will be performed from 2010 to 2011. The aim of the rehabilitation phase is to return livelihoods in the affected area to normal including repair, retrofitting or rebuilding of damage infrastructure. The priorities for the rehabilitation phase are housing, public facilities and inter-sectoral facilities such as governmental buildings. The rehabilitation will be followed by a reconstruction phase to improve infrastructure at all levels and to accelerate the economic growth in the affected region. Indonesian National Development Agency (BAPPENAS, 2009) has said that the rehabilitation and reconstruction cost for West Sumatra will be approximately Rp. 6.4 trillion (~ USD 675 million).

As the Indonesian government quickly affirmed access to international assistance, at least 115 international non-governmental organizations joined the relief process in collaboration with government, military and national volunteers/organizations. More than 21 search and rescue teams from 14 countries helped in the evacuation process. Five days after the earthquake (5 October 2009), the government and search and rescue (SAR) decided that there was little chance of survivors being found and further rescue activity would only be carried out by national SAR. International SAR teams were redirected to humanitarian activity and to support survivors (OCHA, 2009). It was also reported that soon after the earthquake, evacuation was mainly focussed in Padang. This resulted in most of the affected remote areas not receiving any aid for days because their situation had not been identified, and several affected areas could not be reached due to blocked roads caused by landslides and major road damage, see Figure 75.

Figure 75. Blocked road in V Koto Timur District, Padang Pariaman County-West Sumatra.

As many as 288,389 buildings were damaged in West Sumatra as illustrated by Figure 76. OCHA (2009) identified at least 70,000 households in need of temporary shelter. Most of the people who have lost their houses had to live in tents, tarpaulins and plastic sheeting adjacent to the damaged houses. Many of these damaged houses risked the possibility of future collapse. To verify the damaged buildings, rapid assessment had been carried out by the government in collaboration with engineers from several universities in Padang such as Andalas University, Bung Hatta University, Padang State University and Padang Institute of Technology. The main objective of the building verification was to determine the damage level of the buildings/houses for the rehabilitation and reconstruction purposes (severe, moderate and light) and also to categorize the safety of house occupancy (immediate occupancy, life safety and collapse prevention). However, some people ignored the recommendation of the engineers and still occupied the damaged houses, see Figure 77.

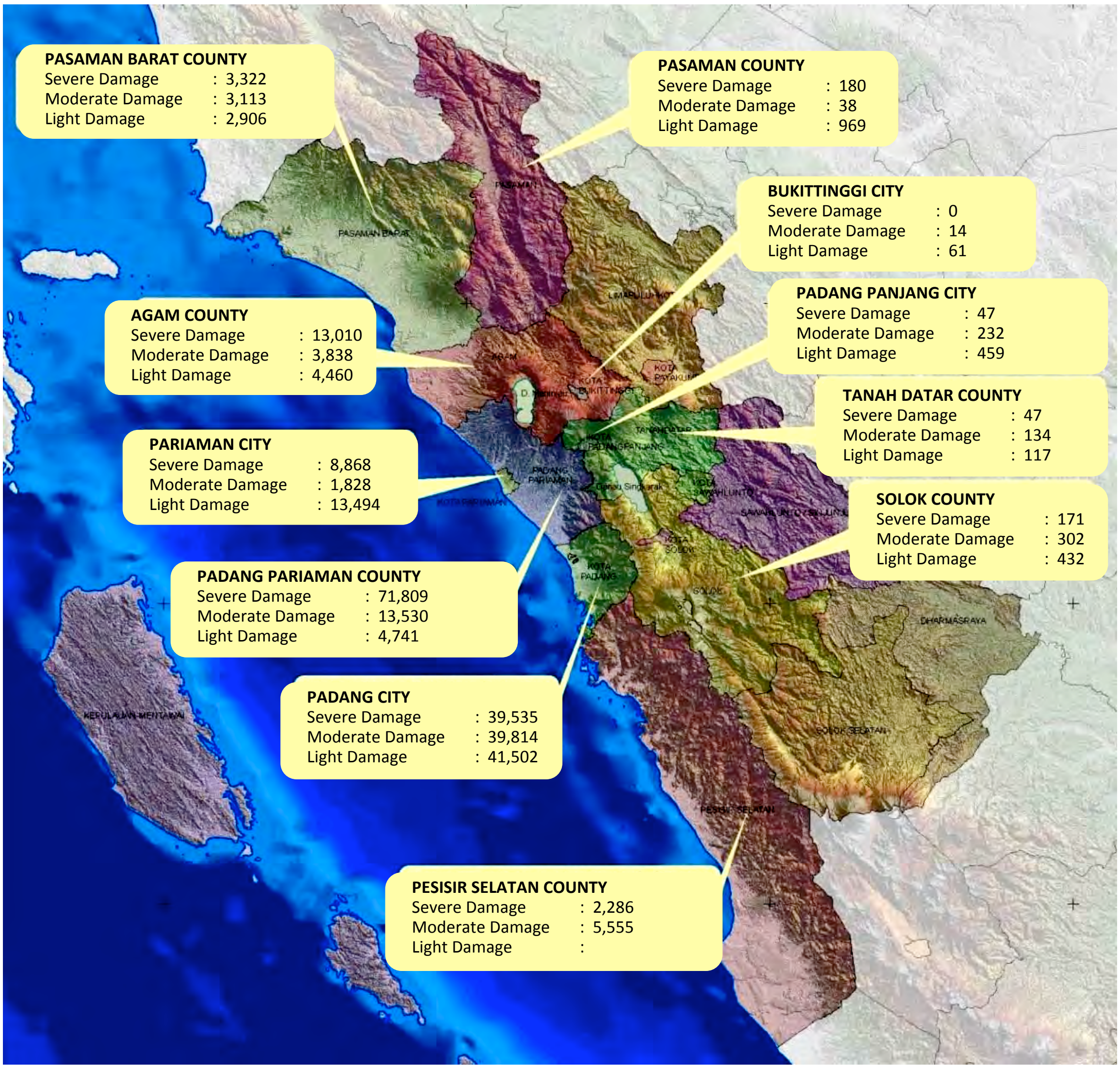
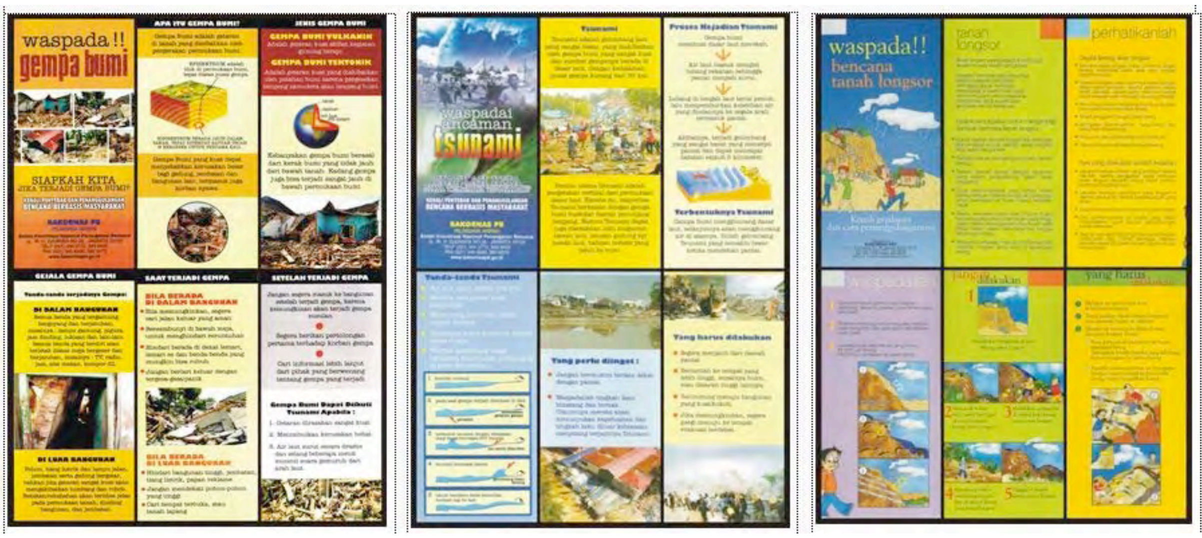


Figure 76. Distribution of Damaged Buildings in West Sumatra Province (map: Bakosurtanal, damaged data: BNPB Daily Report 19 October 2009).

Figure 77. A small shop in V Koto Timur district had lost most of its wall component and immediately opened after clearing the rubble caused by the earthquake.

After being hit by the Great Sumatran Earthquake in 2004, awareness of earthquakes and the associated hazards such as tsunami and landslide in Indonesia has increased significantly. The government has tried to give proper information on how to deal with the potential disasters in the prone areas by using leaflets (Figure 78), electronic media (TV, radio, etc.) and have also conducted earthquake and tsunami evacuation drills. Disaster education programmes have also been given to a great number of schools in vulnerable areas in West Sumatra by local NGOs such as KOGAMI – the Tsunami Preparedness Community (Dewi, 2007).



a). b). c).

Figure 78. Sample of leaflets to build awareness for potential disaster to the society: a). Earthquake; b). Tsunami; c). Landslide (published by BNPB).

Indonesia has developed a tsunami early warning system (Figure 79), but it still needs improvement to avoid false alarms and to give people reliable information immediately after the earthquake. The time for tsunami arrival is predicted using numerical analysis. There is a system run by (meteorological climatology and geophysical agency) for determining whether the earthquake is likely to be tsunamigenic (personal communication with University of Bung Hatta engineers).

When the earthquake occurred, the people in Padang City felt the ground shaking and assumed a tsunami was imminent. This led to wide scale panic and people trying to evacuate to higher ground. There is one major road out of Padang City and to higher ground and this, along with minor tsunami evacuation routes, (Figure 80) soon became jammed with traffic. Meteorology, Climatology and Geophysics Agency of Indonesia (BMKG) made an announced on national television that the earthquake caused no potential tsunami. However, the people could not receive the information because the power had failed during the earthquake. The government in Padang tried to reduce panic by announcing that no tsunami had be generated by the earthquake; This announcement was made through loudspeakers attached to cars driving through the main road in the city. Witnesses reported that this did little to relieve the evacuation.

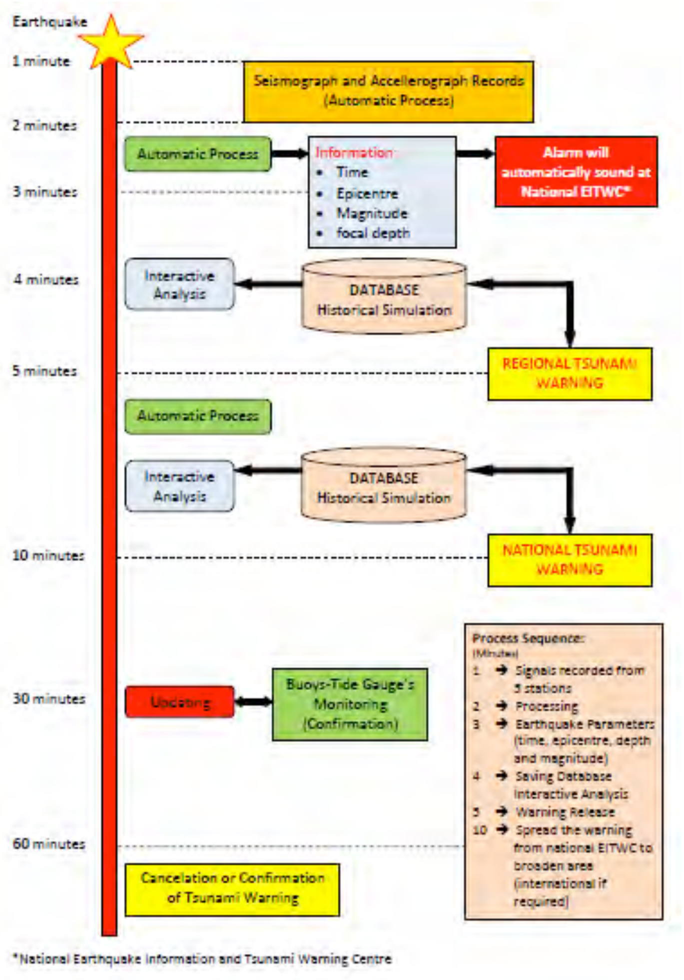


Figure 79. Indonesia Tsunami Early Warning System (redrawn from the picture at BMKG Padang Panjang, 2009).

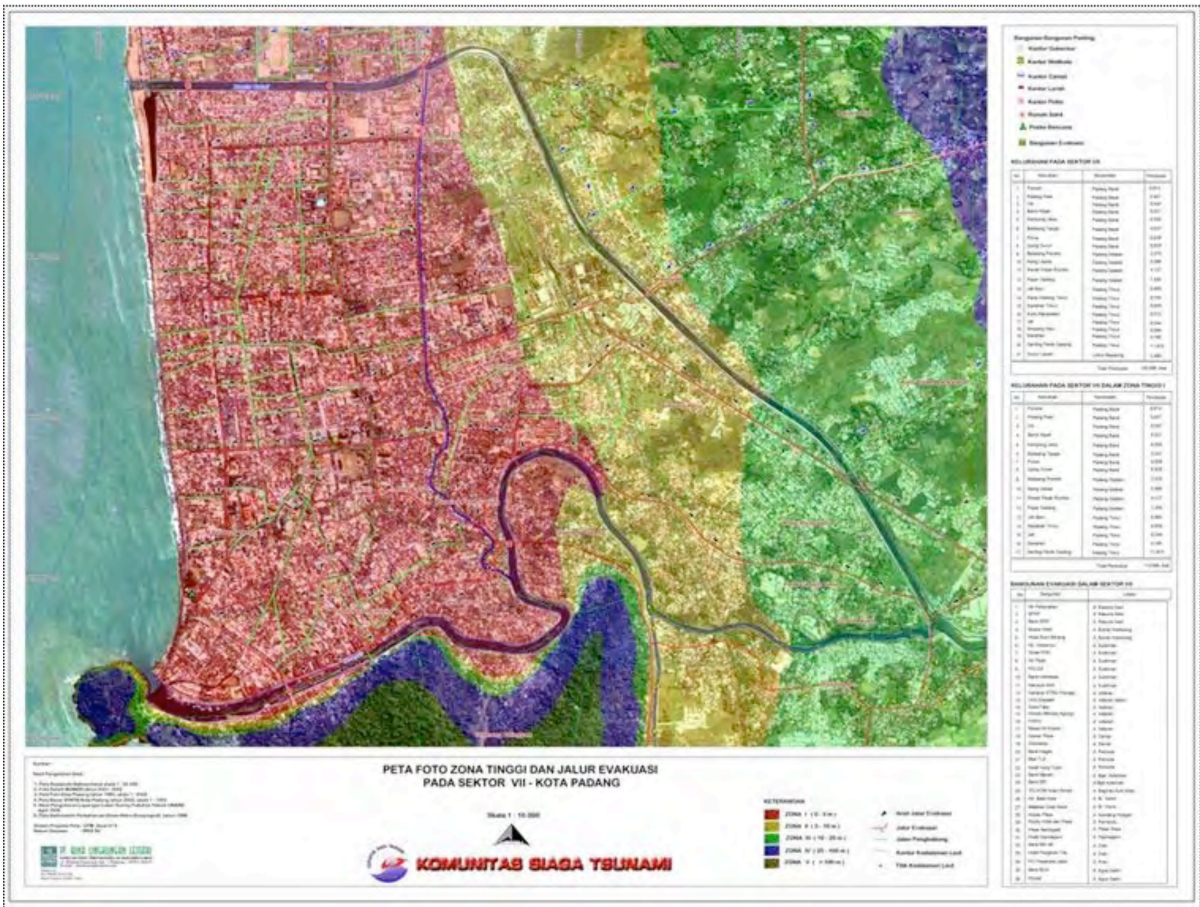


Figure 80. Tsunami Evacuation map for Padang City produced by PT. Bina Lingkungan Lestari & Tsunami Preparedness Community **(**KOGAMI**)**.

5. CONCLUSIONS AND RECOMMENDATIONS

The conclusions made by the team based on their observations and corresponding recommendations are:

The timing of the event (17:16 local time) was very fortuitous. All schools were empty and most businesses located in major structures had no or few workers within. This helped to reduce the casualty figures significantly.

The pattern of observed building collapse was very variable. Many poorer types of construction survived, while seemingly engineered structures collapsed. The distribution of these failures was also very variable, with structures that had collapsed located next to others with little damage. This suggests either very variable soil conditions or very variable construction quality – or a combination of both.

The construction of schools had poor earthquake resistance and as a result, schools suffered very badly. It is recommended that risk assessments be made to all schools in the region.

Larger engineered buildings in Pariaman, although much closer to the epicentre, seemed to fare better than those in Padang. This could be due to either the focus of the earthquake being very deep, the different soil conditions in the two areas or the quality of the supervision of the construction between the two regions.

In Padang, extensive damage was observed in many engineered buildings. Buildings over two storeys seemed to be the most affected. Although these types of buildings would have been engineered, they often performed worse than simple, poorly constructed buildings. Again, this could be due to the depth of the earthquake filtering out the high frequency components and resulting in a longer period spectral content in the ground motions further from the epicenter. This sort of ground motion would be more damaging to the taller buildings in Padang while the ground motions nearer the epicenter may not affect the taller buildings there. Another reason for the failure pattern of these buildings could be due to differences in the supervision of the construction.

Soft storey collapse was by far the major failure mode observed in engineered buildings. It is recommended that a risk assessment be made of all existing major buildings and implementation of strong column/weak beam design philosophy for all new buildings

Industrial and port facilities performed extremely well and only suffered minor mechanical or operational damage.

There were examples of buildings that had received strong ground shaking (evidenced by the major damage to masonry infill) that had suffered little structural damage. This suggests that the latest Indonesian earthquake code, its design practices and construction, is capable of providing the guidelines for designing and constructing buildings that are seismically sufficient for an earthquake of this intensity (structurally, at least).

There was extensive major damage to non-structural masonry infill. This is a major problem with West Sumatran (and possibly Indonesian) construction. It is recommended that research into alternative details be conducted

It is likely that buildings are either not being designed to the code, or what is being designed is not being constructed (although this may only be true for older buildings). Building supervision and approval procedures should be revised.

The response of lifelines was variable, with the major problems resulting from lack of electricity for 10 days, damage to the main water line, and lack of mobile phone coverage. Temporary water tanks, water storage trucks, and transportable, diesel-generate mobile phone masts were used as short-term solutions. The main Padang hospital (Dr. M. Djamil) responded well and effectively gathered its resources to treat all incoming patients from surrounding areas.

Tsunami evacuation plans need to be revisited. The warning time for the tsunami is too long to effectively stop the evacuation response due to non tsunamigenic earthquakes.

Building foundation failures were minimal in Padang which indicates proper foundation design for engineered buildings in general. Settlements were most significant near the coast with continuous cracks on floor slabs of buildings and flexible road pavements.

Evidences of soil liquefaction in the form of sand boil deposition and upheaval of floor slabs have been observed. A water well in a rural village was also blocked with sand due to the increase in pore water pressure. Lateral spreading was seen along the coastline as well.

Landslides are a major threat to this region. The landslides visited by the team can only be described as “enormous and lethal.” The greatest concentration of the deaths from this earthquake was due to landslides and there was very little chance of survival for the residents of the houses in the path of one of these landslides. Considering there is likely to be another event in the not-too-distant future, there is an urgent need to assess the risk posed by earthquake induced landslide in Western Sumatra. The devastating effect that these landslides had on the communities in Pariaman is a very strong argument to perform hazard assessment in other regions of the world.

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