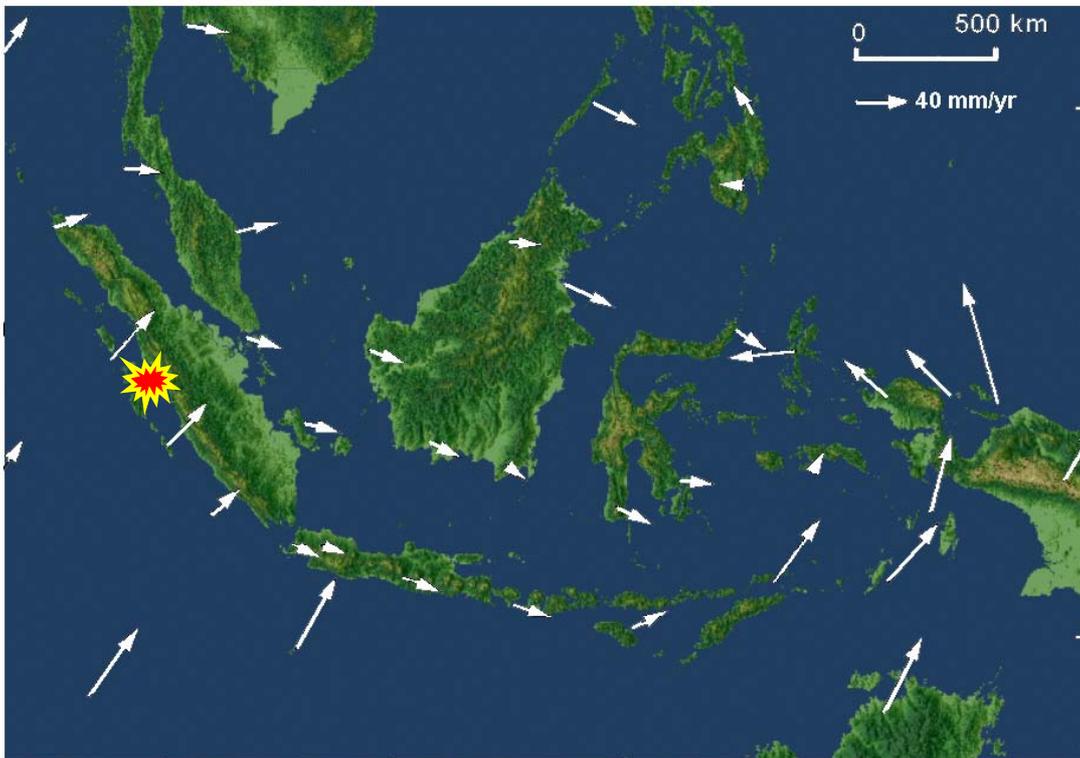


A RECONNAISSANCE REPORT
ON
THE PARIAMAN-PADANG EARTHQUAKE OF SEPTEMBER 30, 2009*



2009 Pariaman-Padang Earthquake Reconnaissance Team

by

Japan Society of Civil Engineers,

Japan Association for Earthquake Engineering

Engineers Without Borders - Japan

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* This report has been compiled and edited by Ömer Aydan (Tokai University)

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1 INTRODUCTION

A deep slab earthquake struck West Sumatra Provinces of Indonesia on September 30, 2009, killing more than 1000 people and caused heavy damage in Pariaman and Padang of West Sumatra Province along the western shore of Sumatra Island. Two large events with a moment magnitude of 5.5 and 6.8 occurred after the main shock. The earthquake with a magnitude of 6.8 in the early morning (6:49 AM on IST) was on the Sumatra fault.

Following the 2004, 2005 and 2007 great off-Sumatra earthquakes, it was pointed out the West Sumatra as well as Sumatra Fault Zone may be subjected to large earthquake in near future (Aydan 2007; Sieh 2007). Within this respect, the earthquake of March 6, 2007 occurred in Singkarak Lake along the Sumatra Fault Zone might have significant implications on the near future seismic activities along this fault zone. The 2009 Pariaman-Padang earthquake took place in 450 km long and 60-70km wide area seismic gap along the subduction zone (Figure 1.1). Nevertheless, the strike of this earthquake is perpendicular to that of the subduction zone.

Japan Society of Civil Engineers (JSCE), Japan Association for Earthquake Engineering (JAEE) and Engineers Without Borders-Japan organized two survey teams (Team leader: Prof. Dr. Masanori HAMADA, Waseda University) (see Tables 1.1 and 1.2 for the members of the teams) immediately after the event. The teams were dispatched to Indonesia, and conducted damage assessment in the damaged area. The teams collaborated with Indonesian Counter-parts

The first team visited the epicentral area along Western Shore of Sumatra Island between during the period between 2009 October 15 and October 19. The investigation was concentrated on structural and geotechnical damage induced by ground shaking. Although no damage was induced by the tsunami, the response of people against tsunami was investigated. The second team also visited the same areas between December 13 and 23 with an emphasis on the rehabilitation and reconstruction of damaged highways and landslide areas.

Roadways running along the shores of sea and rivers line were damaged by the ruptures and settlement due to landslides. The landslides occurred in Longsor vilage in Padang Alai region was of great scale. Furthermore, rockfalls occurred along the steep rock slopes. The loosened rock slopes caused further rockfalls killing two people and injuring 13 people.

The damage to reinforced concrete (RC) buildings was extensive in Padang city. The collapse of RC buildings damaged during 2007 Bengkulu earthquake and repaired by re-plastering was particularly remarkable to note.

Bridges generally performed well in the epicentral area. Nevertheless, some damage was observed in the strongly shaken and/or liquefied areas.

Table 1.1: Members of the first dispatched team by JSCE and EWBJ together Indonesian collaborating members

Member	Affiliation
Masanori HAMADA	Waseda University
Ömer AYDAN	Tokai University
Shigeru MIWA	Tobishima Corporation
Tomoji Suzuki	EWBJ-JSCE
Muneyoshi Numada	Tokyo University
Rusnardi Rahmat Pura	Kyoto University
Abdul Hakam	Andalas University
Ismail Febrin	Andalas University

Table 1.2: Members of the second dispatched team by JSCE and EWBJ together Indonesian collaborating members

Member	Affiliation
Masanori Hamada	Waseda University
Ömer Aydan	Tokai University
Tomoji Suzuki	EWBJ-JSCE
Akira Sezaki	Nihon Koei
Masahiro Yoshimura	NEXCO
Masaru Takemoto	NEXCO
Rusnardi Rahmat Pura	Kyoto University
Abdul Hakam	Andalas University
Ismail Febrin	Andalas University



Figure 1.1 Location of the earthquake and investigation routes

2 REGIONAL GEOLOGY, TECTONICS AND SEISMICITY

2.1 Regional Geology

The oldest rocks of Sumatra Island are gneiss, schist and quartzite and the schists often contain gold. They probably belong to several geological periods, but all were folded and denuded before the Carboniferous beds were deposited. They form the backbone of the island, and crop out on the surface at intervals along the mountain chain, which runs parallel to the west coast. They are penetrated by granitic plutons at several locations, which are also Pre-Carboniferous.

A Pre-Tertiary basement is exposed extensively in the Barisan Mountains (Fig. 2.2) and in the Tin Islands of Bangka and Billiton. The oldest rocks, which have been reliably dated, are sediments of Carboniferous-Permian age, and undated gneissic rocks in the Barisan Mountains may represent a Pre-Carboniferous continental crystalline basement. All the older rocks, which lie mainly to the NE of the Sumatran Fault System, show some degree of metamorphism, mainly to low-grade slates and phyllites, but younger Permo-Triassic sediments and volcanics are less metamorphosed.

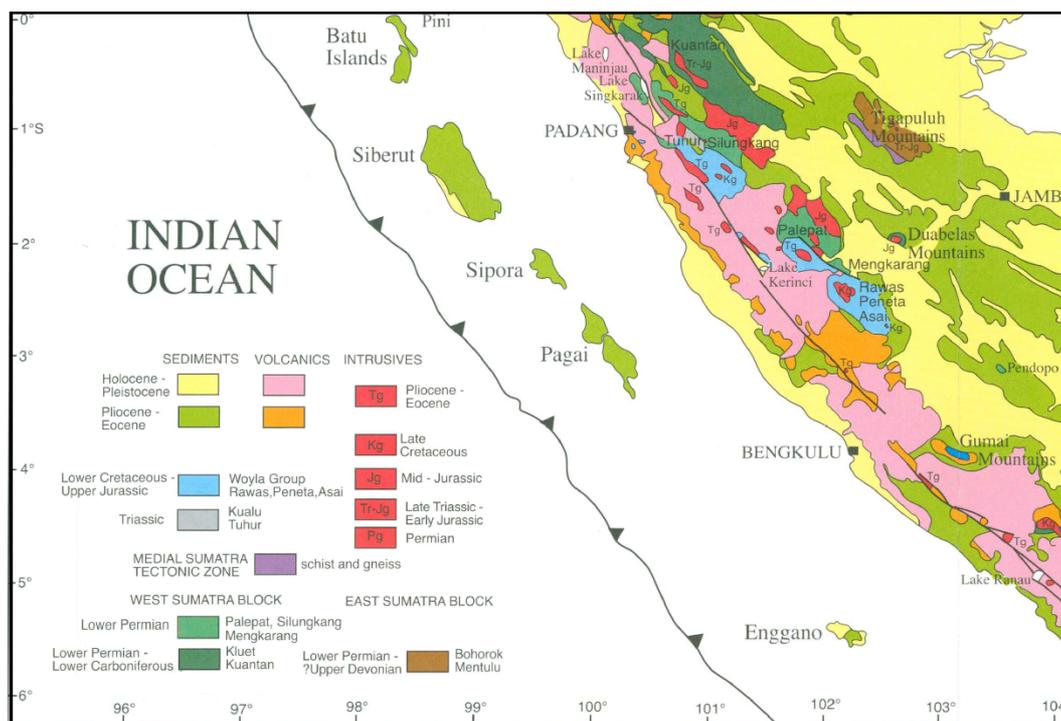


Figure 2.2 Simplified geology of the earthquake affected area (modified from Crow and Barber, 2005)

The area to the SW of the fault is composed largely of variably metamorphosed Jurassic-Cretaceous rocks. The Pre-Tertiary basement is cut by granite plutons that range in age from Permian to Late Cretaceous. Locally within the Barisans the basement is intruded by Tertiary igneous rocks and is overlain to the NE and SW by volcanoclastic and siliciclastic sediments in hydrocarbon- (oil and gas) and coal-bearing Tertiary sedimentary basins. These basins have backarc, forearc and interarc relationships to the Quaternary to Recent volcanic arc. Lavas and tufts from these young volcanoes overlie the older rocks throughout the Barisans Mountains.

Tertiary deposits are very widely spread over the plains and low-lying regions. They consist of breccias, conglomerates, sandstones, marls, and limestones, with seams of coal and lignite. The most valuable coal occurs in the Eocene beds.

Recent alluvial sediments occupy small grabens within the Barisan Mountains, developed along the line of the Sumatran Fault and cover lower ground throughout Sumatra. These alluvial sediments are of fluvial origin immediately adjacent to the Barisans, but pass into swamp, lacustrine and coastal deposits towards the northeastern and southwestern margins of the island. The geological age of soil is mostly Tertiary Pleistocene

2.2 Tectonics of Sumatra

In the region of Sumatra Island, the Indo-Australia plate moves toward the northeast at a rate of about 6 cm/year relative to the Euro-Asian plate (Figure 2.3). This results in oblique convergence at the Sunda trench. The oblique motion is partitioned into thrust-faulting, which occurs on the plate-interface and involves slip directed perpendicular to the trench, and strike-slip faulting. Strike-slip faulting occurs several hundred kilometers to the east of the trench and involves slip directed parallel to the trench. This fault is named Sumatra fault, which passes through the entire island. The fault is divided into three sections, namely, southern, central and northern sections. The fault is thrust type with a dextral sense. Sumatra Fault System (SFS) probably dates from the Middle Miocene and the opening of the Andaman Sea, although the relative motions of the major plates have changed little since the Middle Eocene. The SFS runs the length of the Barisan Mountains, a range of uplifted basement blocks, granitic intrusions, and Tertiary sediments, topped by Tertiary-Recent volcanics. Studies of Mesozoic outcrops in central Sumatra suggest that the SFS has a displacement of approximately 150km in this area. It is however noted that strike slip deformation is distributed over a geographically wide area outside the present active trace of the SFS.

Most of the fault plane solutions indicate the dominant faulting mode is thrust type with a slight dextral or sinistral lateral strike-slip sense in the subduction zone (Figure 2.4(a)) Nevertheless, dominant strike-slip faulting is observed within the Euro-Asian plate between the southern tip of Sumatra Island and Nicobar Island. The fault plane solutions indicate dextral strike-slip sense of deformation for faults trending NW-SE.

Figure 2.4(b) shows the annual crustal deformation rate in/around Sumatra Island. As noted from the figure, the direction of deformation rate vectors differs in the west side and east side of Sumatra fault. While deformation vectors are oriented towards NE in the western side of the fault while they are eastward in the eastern side. In view of Figure 2.2, it seems that Sumatra Island tends to rotate clock wise in conjunction with Euro-Asian plate.

Sieh and Natawidjaja (2000) presented a detailed description of tectonics of 1900km long Sumatra Fault. They identified 19 segments, which are named by names of rivers or sea, and indicated the possibility of sub-segments for each major segment. The longest and shortest segments are 220km and 35km long. As noted from Figure 2.3, there are many unbroken parts along the Sumatra fault, According to the segmentation of Sieh and Natawidjaja (2000) and seismic gap concept, the segments with high possibility of future earthquakes are Sunda (150km), Kumering (150km), Dikit

(60km), Sumpur (35km), Burumun (115km), Tripa (180km), Aceh(200km) and Seulimeum (120km). Although it is pointed out that data is lacking for the last three segments, the expected moment magnitudes of earthquakes for these three segments would range between 7.4 and 7.8. The largest earthquake with a surface magnitude of 7.7 occurred on Angkola segment south of the 2007 Solok earthquake (Sieh and Natawidjaja, 2000)). In view of this observational fact, the estimated magnitudes are quite reasonable. Nevertheless, the intra-plate earthquakes are more destructive than the offshore earthquakes due to differences in ground shaking characteristics, distance as well as permanent continuous or discontinuous ground deformations.

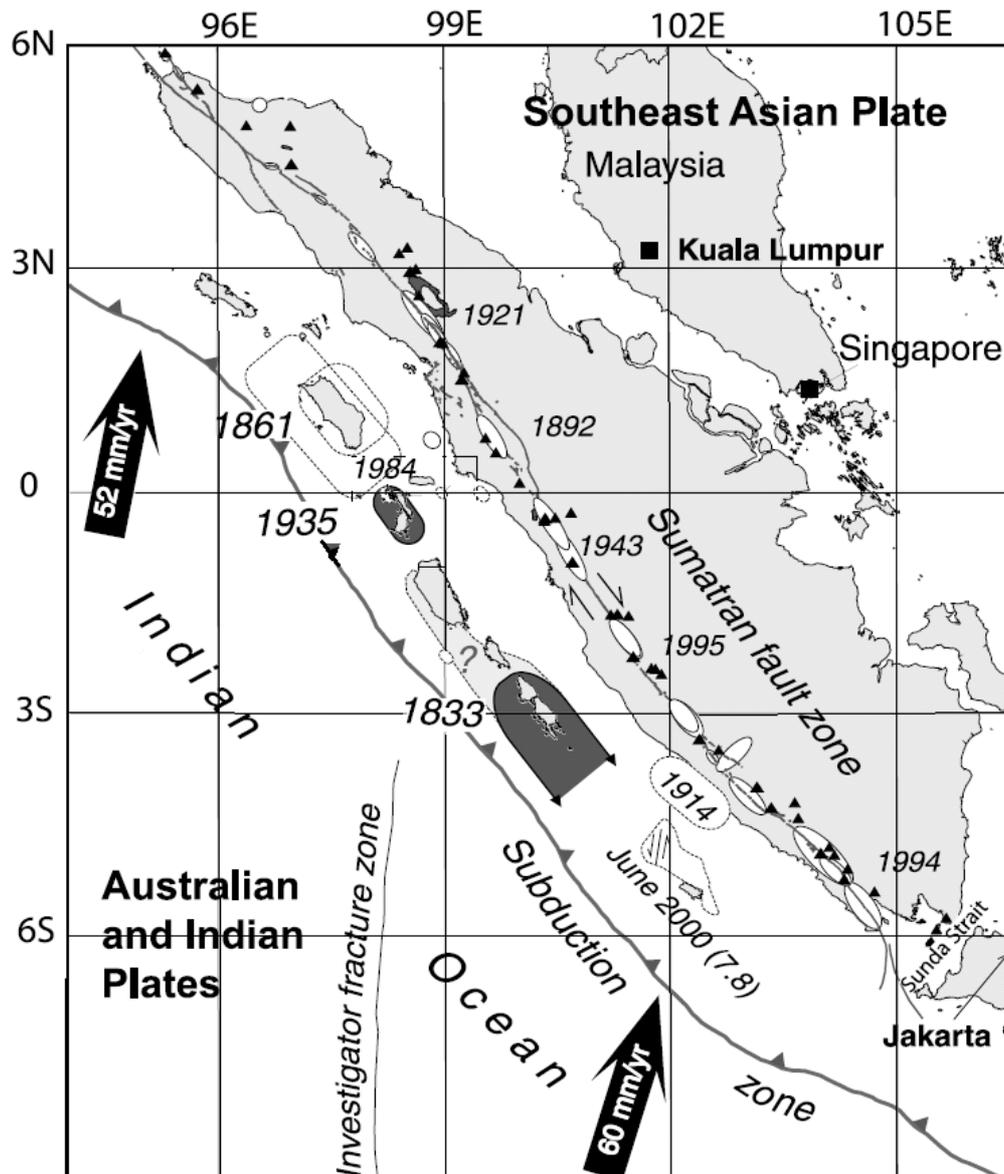
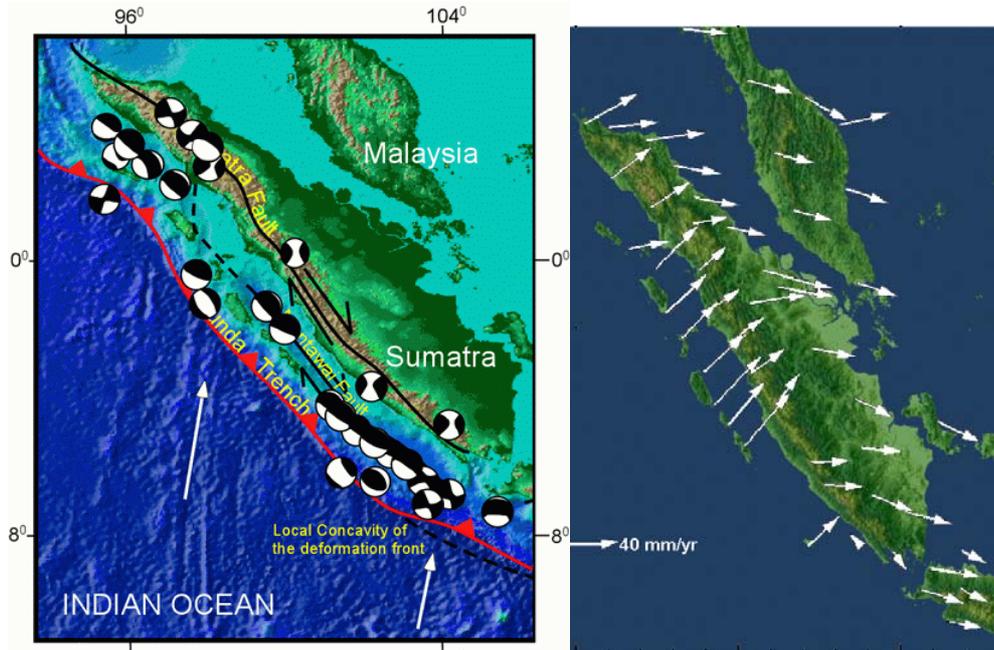


Figure 2.3: Seismo-tectonics of Sumatra Island (from Natawidjaja et al. 2004)



(a) Faulting mechanisms (b) Inter-seismic crustal deformation rates
 Figure 2.4 Faulting mechanism and inter-seismic crustal deformation rates in Sumatra Island and its close vicinity

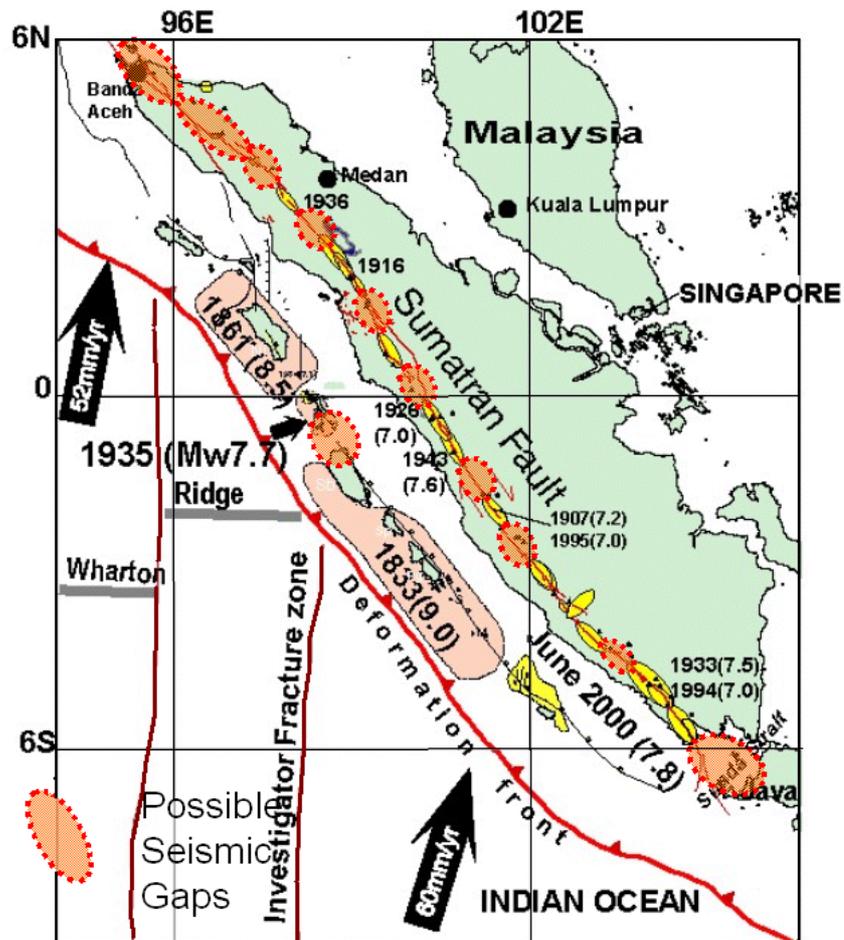


Figure 2.6. Possible seismic gaps along Sumatra Fault Zone (SFZ)

Another important issue is the return period of earthquakes. Since many faults exhibit a stick-slip behaviour, it may be possible to estimate their return period on the basis of mechanical models for stick-slip phenomenon. The return period depends upon the rigidity of continental plate, frictional properties and subduction or relative sliding velocity. The experimental data indicate that the return periods may not always be the same even for the same fault. Nevertheless, if the rigidity of the overriding plate is low and relative slip is slow, the return periods become longer. The slip data during the earthquakes along Sumatra fault is also scarce. Sieh and Natawidjaja (2000) report a 450cm relative sliding for the 1892 earthquake with a surface magnitude of 7.7 on Angkola segment, which was initially reported to be 200cm. The slip rate at various segments of the Sumatra fault ranges between 11 mm/yr to 27mm/yr. If the slip rate is assumed to be constant in time, the earthquakes for a 450cm relative slip may range between about 160 to 400 years. The data on the past seismicity of Sumatra fault is also still lacking and this aspect of the region still needs further investigations and studies.



Figure 2.7 Location of the anticipated mega-thrust earthquake off Sumatra Island

2.3 Regional Seismicity

The subduction zone along the west coast of Sumatra Island is activated in June 2000 and it is known as Bengkulu earthquake. Following this earthquake, three mega-thrust earthquakes occurred. The Aceh earthquake in December 26, 2004 had a magnitude of 9.3 (it may vary depending upon the institute) and resulted a huge tsunami in Indian ocean and killed more than 200000 people. The great Nias earthquake of March 28, 2005 ruptured another segment next to the Aceh earthquake segment. The South Sumatra earthquake occurred on September 12, 2007 and had a magnitude of 8.4. The estimated rupture length is about 270-300 km long. Now there is an unbroken segment facing Padang City of West Sumatra Province of Indonesia (Figure 2.7). The unbroken part is more than 400km and it may result in mega-thrust earthquake with a magnitude greater than 8.7.

Figure 2.8 shows the seismicity prior the 2007 event. As noted from this figure, there are two areas of high seismicity. One of them is associated with 2004 Bengkulu earthquake while the other one is located in the east of Siberut island. The area between these two locations looks like a seismic gap.

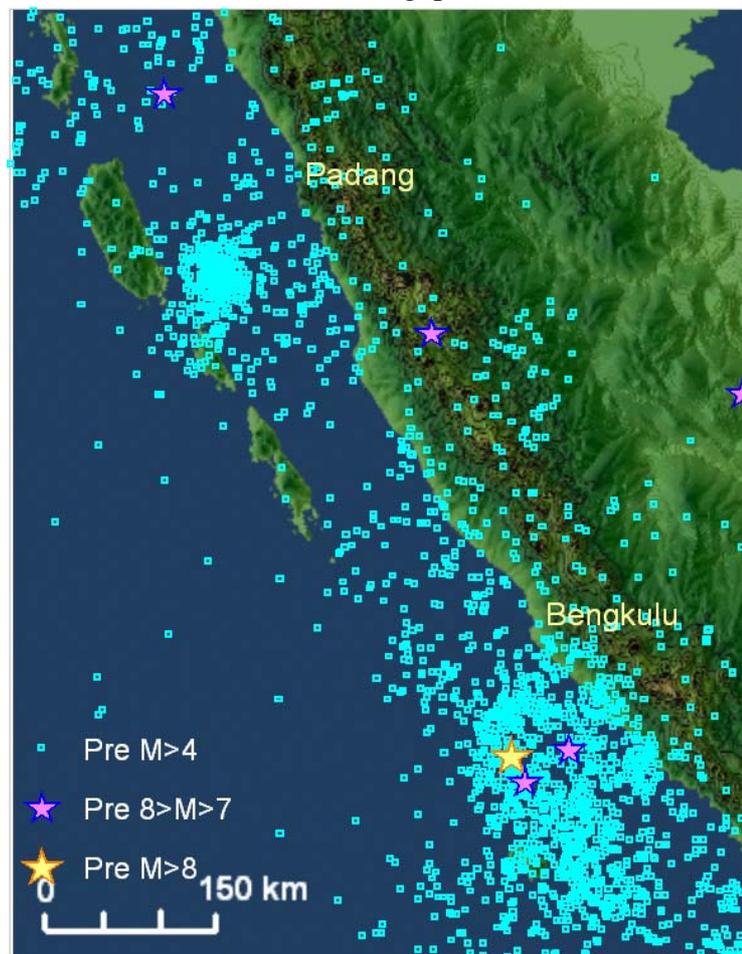


Figure 2.8 Distributions of epicenters of the earthquakes in the region bounded by Latitudes 0-6S and Longitudes 98-104E.

Figure 2.9 shows the cumulative magnitude variation since 1973 in the region bounded by Latitudes 0-6S and Longitudes 98-104E. As noted from the figure, the

2000 Bengkulu earthquake drastically changed the rate of seismic energy release. The second disturbance took place on March 28, 2005. It seems that the time interval between the large disturbances is becoming shorter. This might have some important implications on the timing of the potential West Sumatra Earthquake off Padang City.

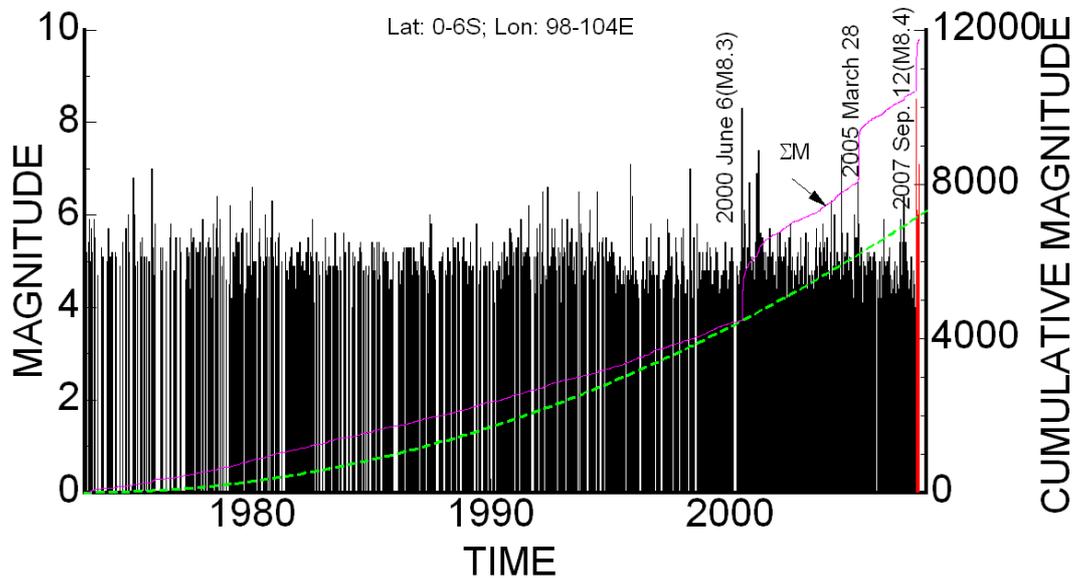


Figure 2.9 Variation of cumulative magnitude of earthquakes in the region bounded by Latitudes 0-6S and Longitudes 98-104E.

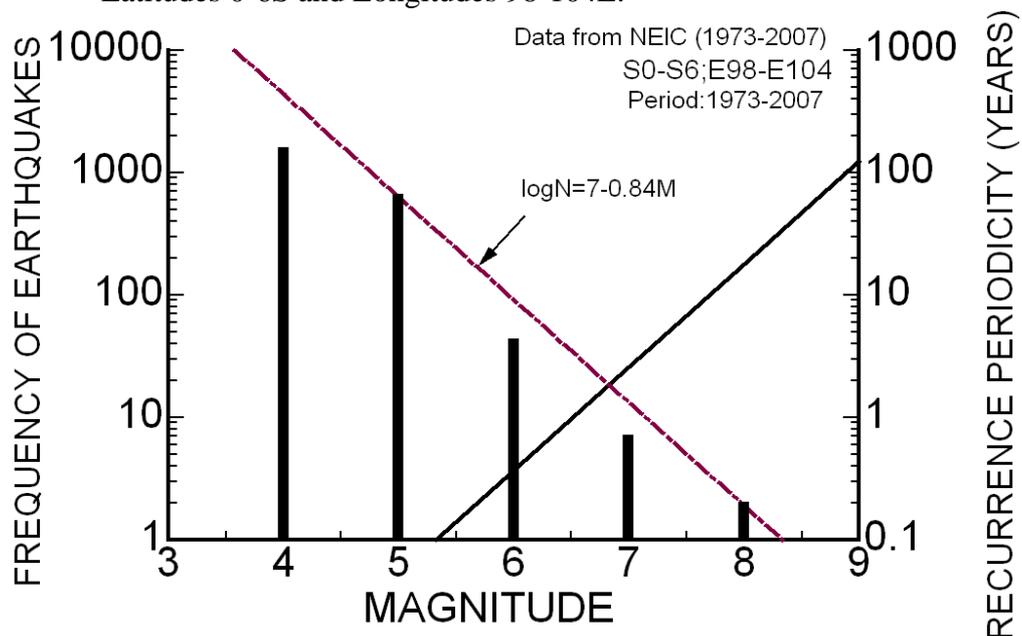


Figure 2.10 Gutenberg-Richter relation between magnitude and frequency of earthquakes in the region bounded by Latitudes 0-6S and Longitudes 98-104E.

Figure 2.10 shows the magnitude frequency relation for the region bounded by Latitudes 0-6S and Longitudes 98-104E. The observational data between 1973 and 2007 prior this earthquake sequence can be fitted to the following equation.

$$\log N = 7 - 0.84M$$

This equation roughly implies that an earthquake with a magnitude of 8.3 can take place at a time interval of 33 years in the region considered.

3 LOCAL GEOLOGY, TECTONICS AND SEISMICITY

West Sumatra Province is a mountainous district nearly 3,000 meters in elevation made of Paleozoic sedimentary rock and igneous rock that extends from the active row of volcanoes to the east. The Great Sumatran Fault divides the center of the province. The central mountain range and the shore is made of volcanic and pyroclastic flow sediments with a narrow coastal plain distributed along the seacoast. Towering above the eastern side (i.e. the mountain side) of Padang Pariaman are two large volcanoes; Gunung Tandikat (2,347m) and Gunung Singalang (2,877m) are twin volcanoes to the east of Padang Pariaman. Lake Maninjau is a caldera lake of 20 kilometers long in north-south and 8 kilometers wide in east-west and it formed after a large volcanic burst 52,000 years ago. The volcanic material from this giant eruption are scattered over a wide area in the north-central area of Padang Pariaman.

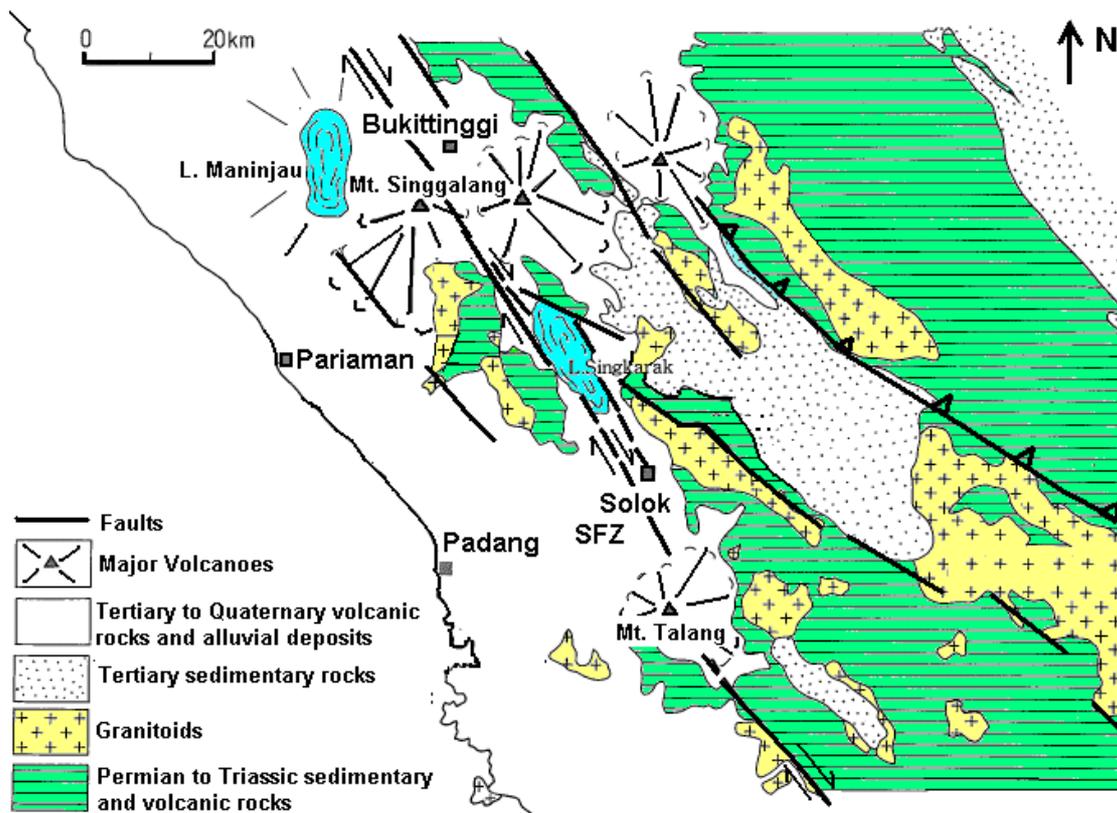


Figure 3.1 Geology and tectonic features of Padang-Pariaman (modified from Sato, 1991).

Figure 3.2 shows a more detailed close-up geology of the earthquake affected area. Padang and Pariaman are mainly situated on river alluvial (Qal) deposits. According to the Geology Map of Padang (Kastowo et al. 1996), the surficial deposits consists of silt, sand, and gravel and may locally include remnants of pumice-tuff (Qhpt or Qpt). Most of Padang and Pariaman is very low lying and flat and thus has a very low velocity. The shear wave velocity of the river alluvial (Qal) deposits is estimated to be in the range from 180 m/s to 360 m/s near the coast, and increase in the hills.

Mountainous areas where surficial landslides occurred are generally covered with intercalated sandy to gravelly and clayey layers of volcanic origin (Figure 3.3). The sandy to gravelly layers are very porous and abundant with ground water.

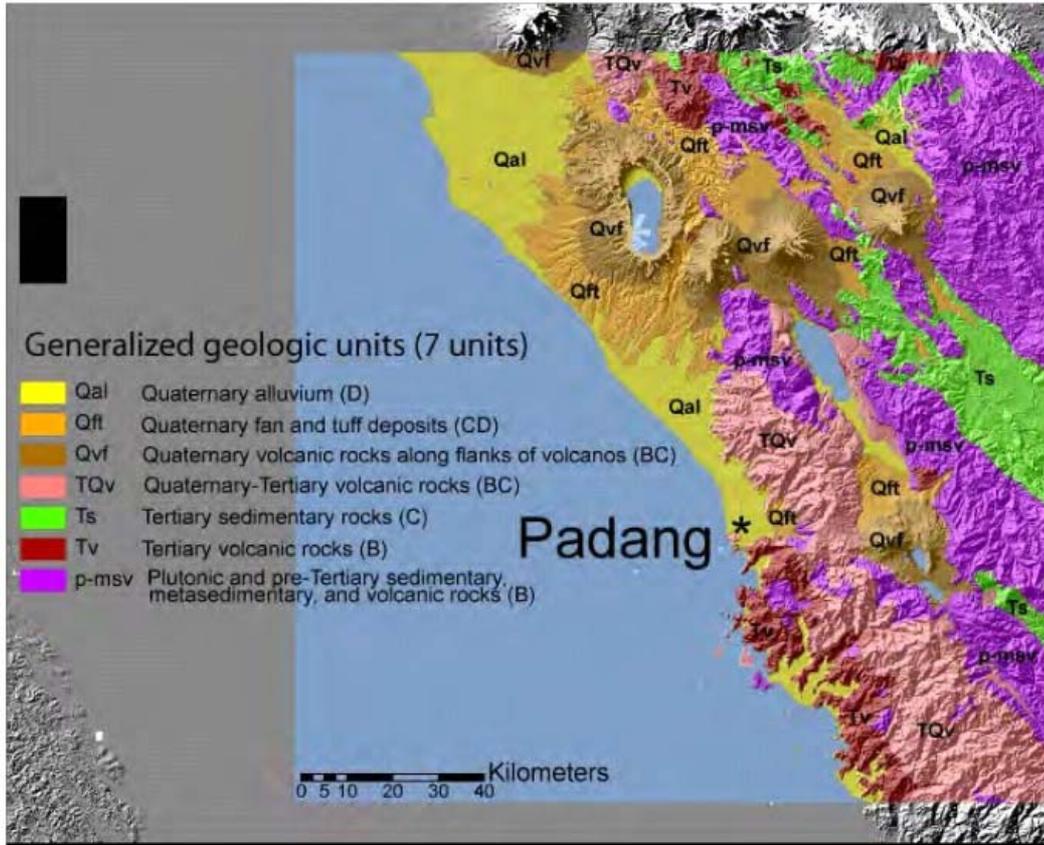


Figure 3.2: A more detailed geological map of Padan and Pariaman (from Kastowo et al. 1996)

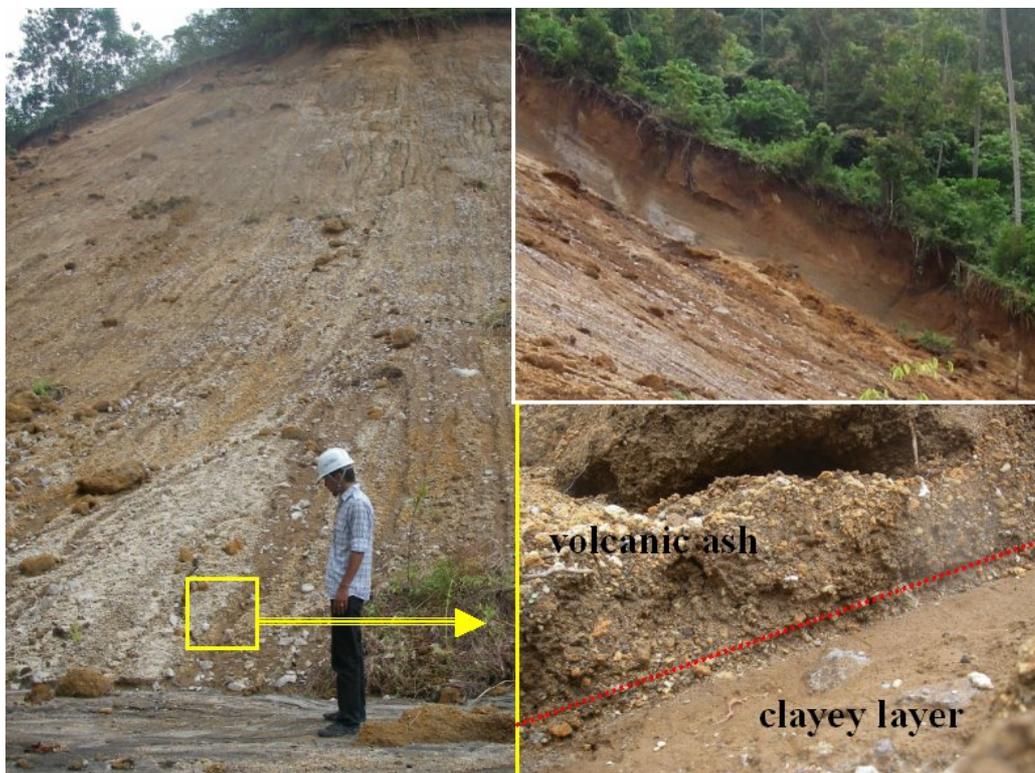


Figure 3.3: Intercalated layering at surfacial landslides area (Padang Alai)

The local tectonics are also governed by the subduction zone thrust faulting and the Sumatra fault. The most recent event in the area took place on March 6, 2007 with a magnitude of 6.4. Figure 3.4 shows the pre-post seismic activity of the region bound by Latitudes 0-3S and Longitudes 98-102E. Although a very high seismic activity is recognized in the area between Sipura and Siberut Islands, no seismic activity occurred in the area of the September 30, 2009 earthquake. The seismic activity projected on the cross-section along line A-A' indicates that the earthquake occurred in the subducting Indo-Australian plate. In other-words, it is an subducting slab-earthquake. Furthermore, one may also infer three asperities from the figure.

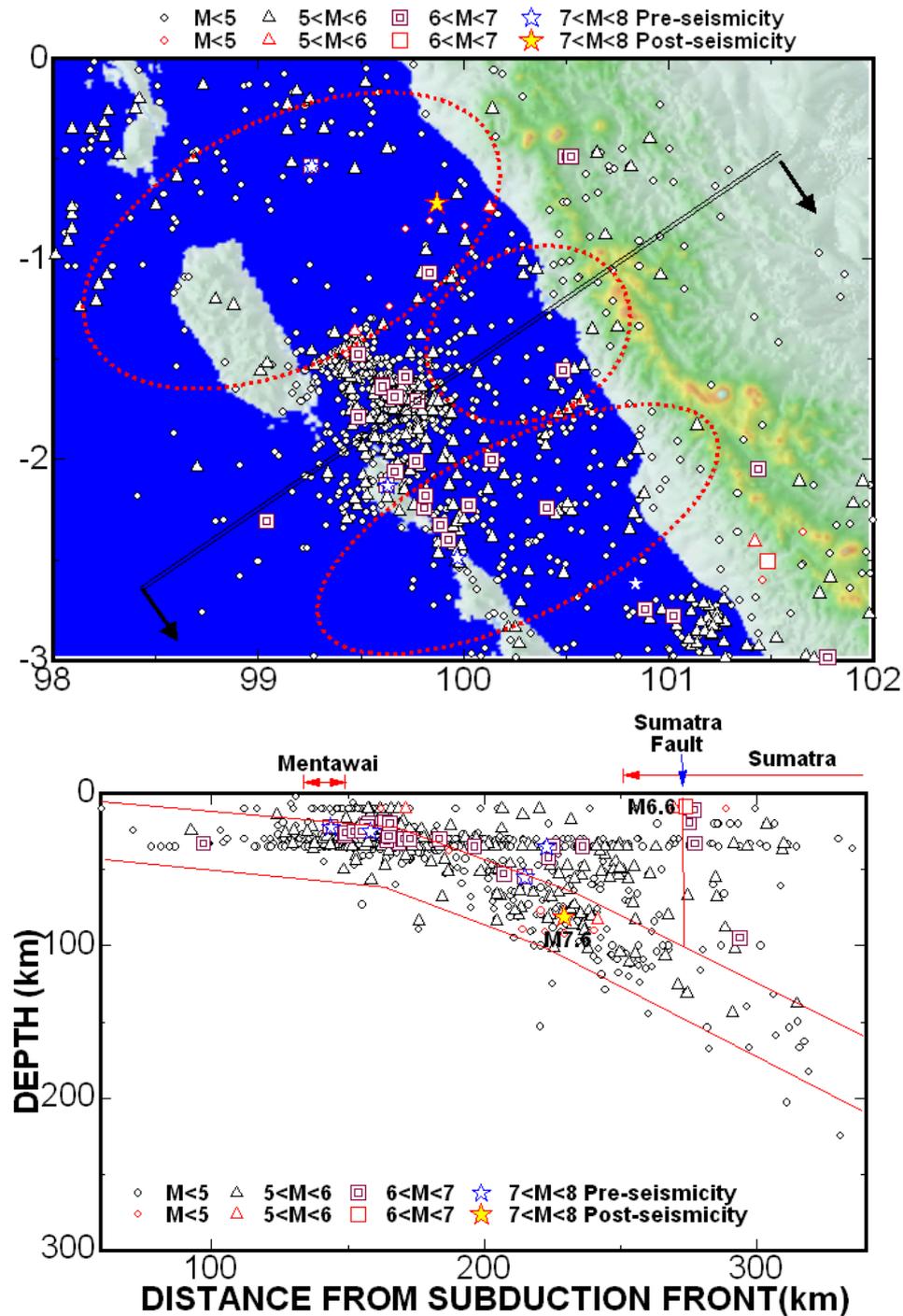


Figure 3.4 Pre-post seismic activity in the epicentral area (data from USGS)

Figure 3.5 shows the seismic activity in time space. As noted from the figure, the seismic activity initiated by the 2004 Aceh earthquake and it continues at an alarming rate. It is further interesting to note that the seismicity of the region increased before the 2007 Bengkulu earthquake. Therefore, the preparedness for the anticipated M8.7 earthquake is very important for the region so that many lives can be saved.

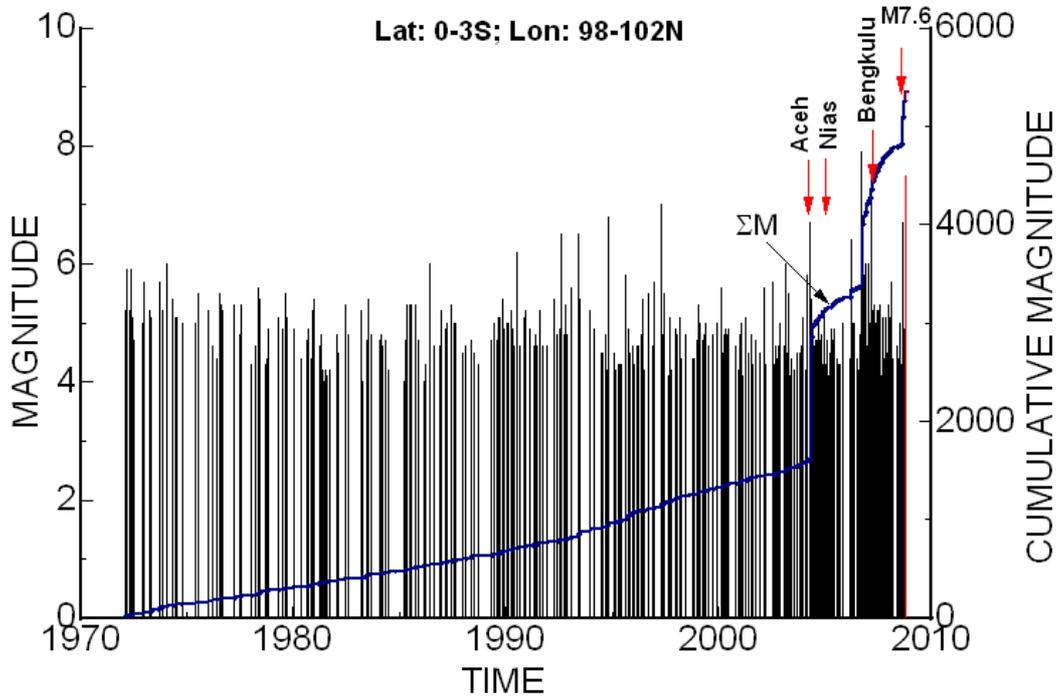


Figure 3.5: The seismic activity variation in time space (data from USGS)

An earthquake with a magnitude of 6.6 occurred on the Sumatra fault on October 1, 2009. However, this earthquake should be regarded as another earthquake due to stress-redistribution rather than as an aftershock.

4 CHARACTERISTICS OF THE EARTHQUAKE

The Pariaman-Padang earthquake of September 30, 2009 occurred as the result of thrust faulting in the subducting Indo-Australian plate. The earthquake is a slab earthquake. Some fundamental characteristics of the 2009 Pariaman-Padang earthquake, strong motions and causalities are described in this section.

4.1 Fundamental Characteristics

The earthquake took place as a large shock on September 30, 2009. The event was at 17:16 (10:16 UTC) with a moment magnitude of 7.5 (USGS, 2009). The fundamental source parameters of the main shock are given in Table 4.1. Another earthquake with a magnitude of 6.6 occurred on Sumatra fault at a depth of 15 km on the next day. Figure 4.1 shows the focal plane solutions by several worldwide institutes worldwide together with the anticipated mega-earthquake. The M7.6 event was due to thrust faulting with slight dextral lateral slip. If the first plane NP1 is taken the causative fault, the first shock will coincide with the general trend of the Sumatra Subduction Zone. However, the second shock with a shallow depth of 10km (USGS)

is far away from subduction zone and it may be viewed as an intra-plate earthquake triggered by the first shock. It has a strike-slip faulting mechanism. The estimated fault length ranges between 25-60 km. The slip analysis by Yagi (2009), Yamanaka (2009) and USGS (2009) estimates the slip between 2.6 to 18 m.

Table 4.1: Main characteristics of the earthquake on Sept. 12, 2007(M7.6)

Institute	Mw	LAT (S)	LON (E)	DEP (km)	NP1 strike/dip/rake	NP2 strike/dip/rake	T _d sec
USGS-HARVARD	7.5	0.714	99.917	80.0	194/55/49	70/52/132	
HARVARD	7.5	0.740	99.690	80.0	193/58/90	72/51/90	29

Table 4.2: Slip and rupture characteristics of the earthquake on Sept. 12, 2007(M8.4)

Institute	Mw	DEP (km)	Earthquake Fault			T _d sec	Vr (km/s)	Slip (m)
			strike/dip/rake	Length (km)	Width (km)			
USGS	7.5	80.0	71/54/125	32	20	11	2.91	9.0
Yamanaka	7.5	80.0	201/49/56	25	25	10		18
Yagi	7.6	80.0	71/55/135	60	60	15	4.5	2.6

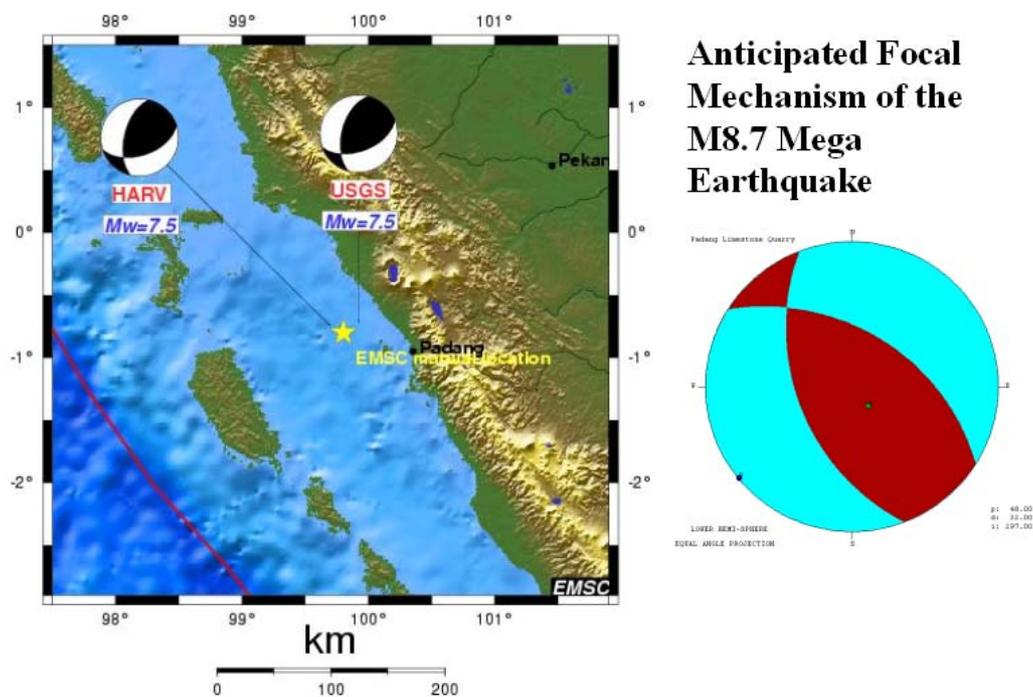


Figure 4.1: Focal mechanism solutions of the main shock by various institutes together with the estimated focal mechanism of the anticipated mega-thrust earthquake (figure arranged partly from EMSC)

4.2 Strong Motions

The EWBJ installed four accelerometers in the West Sumatra Province. Three of these accelerometers installed in Padang City while the other one installed in Bukittinggi City. Because of some technical problems associated with the power supply of the equipments, no strong motion records were obtained by the network of EWBJ. The accelerometer installed by the NIED in Andalas University and Padang Panjang had also some technical problems associated with their installation. So far,

there are two accelerations records (Table 4.3). One of them recorded in Padang City by USGS and operated by BMKG. The another acceleration was recorded in the underground powerhouse of Singkarak hydroelectric power plant (Mangkoesobroto, 2009). The site conditions at both sites correspond to firm ground. As the strong motions is higher at ground surface, at least, twice, the base acceleration should be greater than 0.2g, most probably, 0.3g. Figure 4.2 shows the empirical attenuation relations for maximum ground acceleration and velocity by Aydan and Ohta (2006) with measured and inferred results. Some simple structures were used to infer the maximum ground acceleration and ground velocity (Aydan, 2007). Furthermore, the contours of maximum ground acceleration and ground velocity were obtained using the empirical relations proposed by Aydan and Ohta (2006) and compared in Figure 4.4. As noted from the figure, the estimations are consistent with measurements.

Table 4.3: Measured acceleration values

Station	Re (km)	Ro (km)	NS (gal)	EW (gal)	UD (gal)
UNAND-USGS	60	100	294	-	-
Singkarak HEPP	50	94	90	96	5

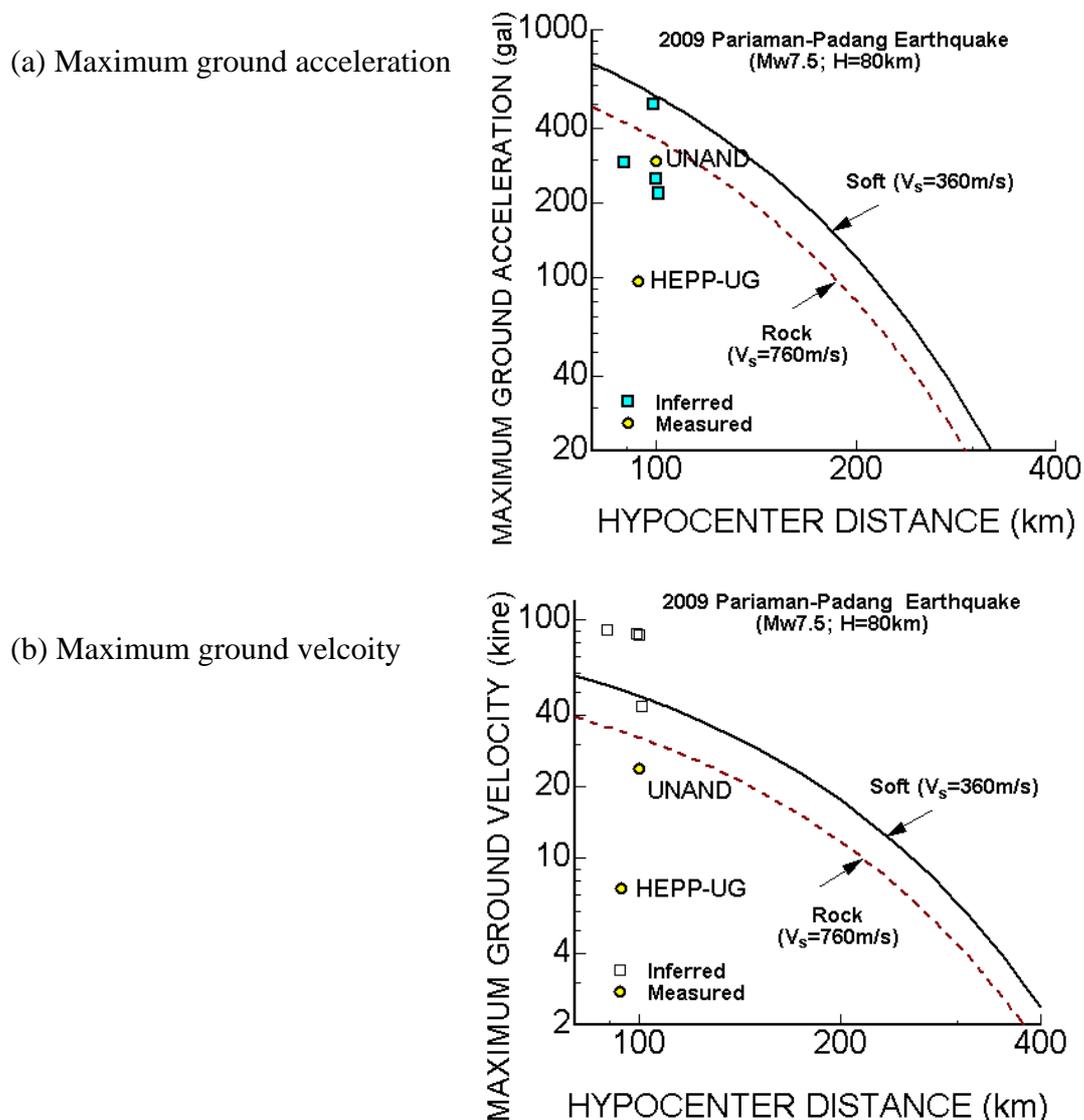
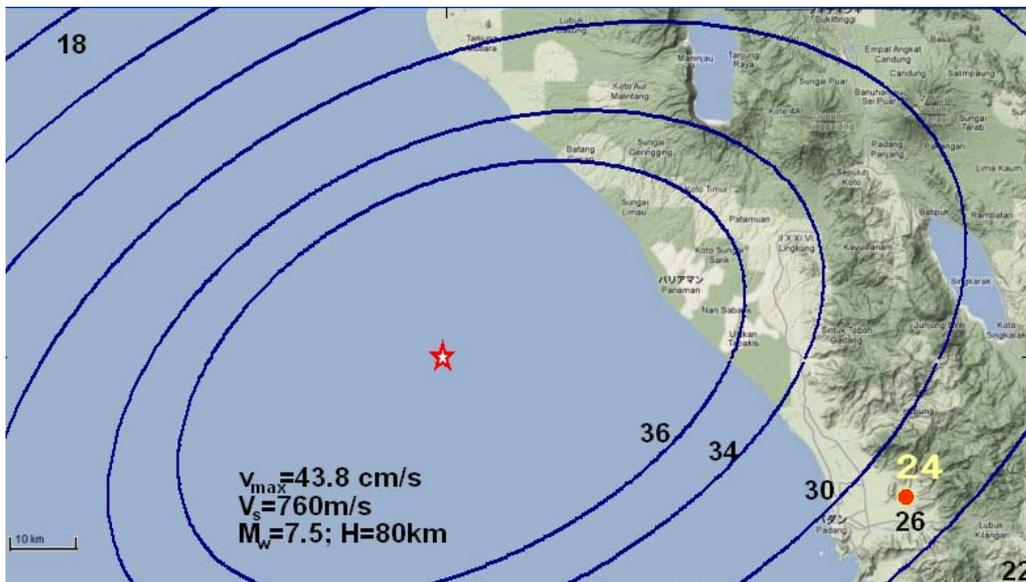


Figure 4.3: Comparison of empirical attenuation relations for strong ground motions with measured and inferred results



(a) Maximum ground acceleration contours



(a) Maximum ground velocity contours

Figure 4.4: Estimated contours maximum ground acceleration and ground velocity

The authors report the records of two earthquakes occurred in 2009, which may give further information on the ground motions in Padang city as well as in Bukittinggi. An earthquake with a magnitude of 6.7 occurred on August 16, 2009 while the earthquake on July 2, 2009 was very close to the Padang City. Figure 4.5 shows the attenuation of maximum ground acceleration for M6.7 earthquake. The comparison of the empirical attenuation relations of Aydan and Ohta (2006) is consistent with measured results. Figure 4.6 shows the acceleration spectra for M6.7 and M4.6 earthquakes. Gubernur station is closest to the sea-shore and Kuranji station is between the Andalas University station and Gubernur station. Bukittinggi station is situated in underground shelter. The spectral amplification of the Andalas University station is high for short periods while Gubernur and Kuranji stations indicate several peaks at longer periods as expected from their ground conditions. The amplification of ground acceleration at Gubernur is almost twice that of the Kuranji station.

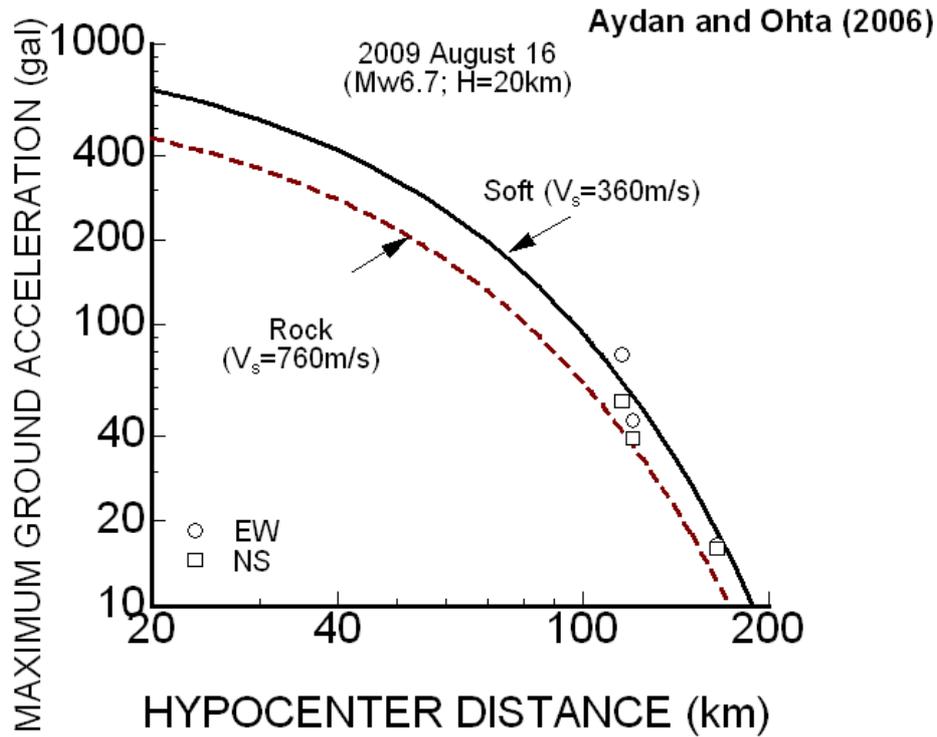


Figure 4.5: Comparison of the empirical attenuation with observations of M6.7 earthquake on 2009 Aug. 16

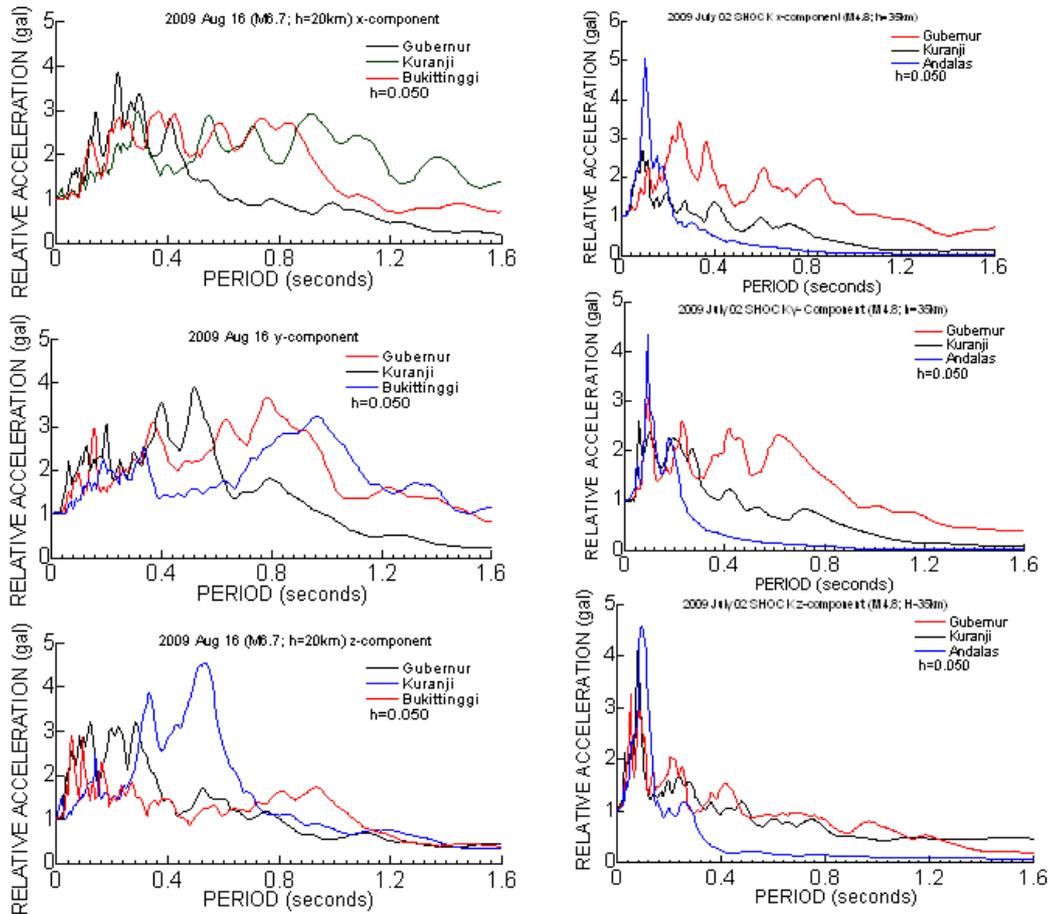


Figure 4.6: Spectral accelerations for M6.7 and M4.6 earthquakes in 2009

5 STRUCTURAL DAMAGE

5.1 Buildings

Buildings in Padang City consists of timber-framed, masonry or reinforced concrete framed structures and the infill walls are generally of brick type and the roof is generally corrugated tin sheets. Timber-framed or masonry structures are quite common in the rural areas, while reinforced concrete framed buildings are common in Padang City and Pariaman City. The unreinforced masonry buildings are found in the China town and buildings from Colonial period of Indonesia by Holland.

If there was no foundation failure due to landslides or shaking, timber framed structures performed well even in liquefied areas and areas close to the epicenter of the earthquake. Those with timbers as infill walls performed much better than those having brick infill walls (Figure 5.1).



(a) Damaged due to foundation failure

(b) Non-damaged

Figure 5.1 Views of damaged and undamaged residential houses in Koto Timur

The low rise masonry buildings with or without thin column performed very badly during the earthquake. Most of these buildings collapsed or heavily damaged due to mainly out-of plane failure of masonry walls as seen in Figure 5.2.



Figure 5.2: Collapsed or heavily damage masonry buildings

Buildings of any type in the areas of landslides collapsed or were heavily damaged by the earthquake. Particularly timber buildings were much weaker to the foundation failure due to landslides as compared with those with reinforced concrete frame buildings (Figure 5.3).



Figure 5.3: Collapsed or heavily damaged buildings due to foundation failure by landslides

This earthquake heavily damaged reinforced concrete (RC) structures. The causes of damage are well known and they are simply the existence of weak floor, poor detailing of column-beam connections, collision of adjacent structures, poor integration of in-fill walls with the RC frame and top-heavy roofs. Many RC buildings are governmental buildings or hospitals. The concrete buildings with two or more stories either collapsed or were heavily-damaged.



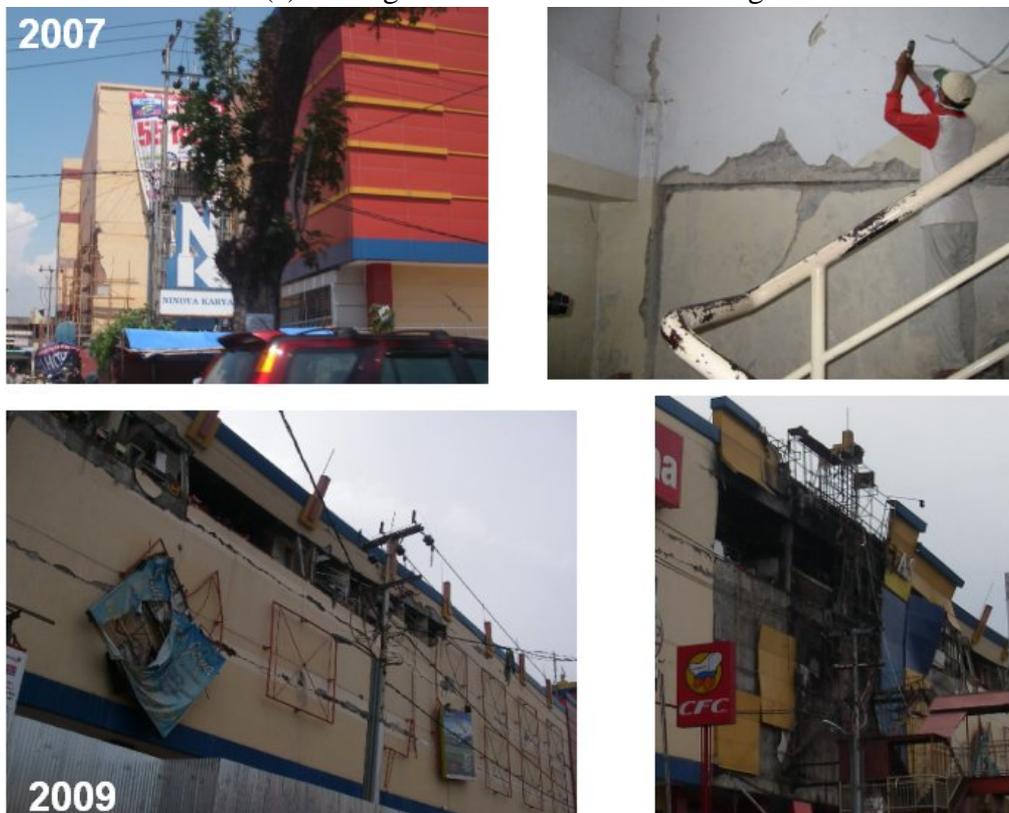
Figure 5.4: Collapsed or heavily damaged RC buildings

It was also interesting to note that some buildings damaged by the 2007 Bengkulu

earthquake and repaired by just plastering cracks were extensively damage by this earthquake. The examples of such buildings were the five star hotel Bumiminang and Ramayana Department store (Figure 5.5). Another important observation was the location of fire at the Ramayana Department Store. The fire was also caused at the same place in the 2009 earthquake as that in the 2007 earthquake.



(a) Damage state of hotel Bumiminang



(b) Damage state of Ramayana Department Store

Figure 5.5: Damage state of RC buildings repaired by just plastering cracks in 2007

5.2 Bridges

Miwa and Numada of the first JSCE team carried out a detailed assessment of damage to bridges. 15 bridges in Padang (14 bridges) and Pariaman (1 bridge) were investigated in detail and this earthquake caused no significant damage to bridges (Figure 5.6-5.9). The types of bridges in the epicentral area are mainly truss or simple beam bridges (Table 5.1). The earthquake shaking did not cause any significant damage to the function of bridges. Most of the damage was caused by the settlement of the abutment soil. In some cases, the anchors of the truss bridges were sheared off. In some simple beam bridges girders were displaced and rotated with respect to the adjacent girders due to probably heavy ground shaking as well as slight settlement and movement of piers. Nevertheless, almost all bridges were open to traffic with speed limitation.

Table 5.1: A list of bridges investigated by the first team of JSCE

Bridge Name	Type	Remarks
Sitinurbaya	concrete	Settlement of abutments about 100cm
Purus	truss	Settlement of abutment about 10cm
Mirang Railway	truss	Settlement of concrete piers and tilting
Mirang	concrete	Settlement of abutment about 20 cm
Bungus	truss	Movement of piers about 10cm
Timbalun	truss	No damage
Kuranji	concrete	No damage
Kalawi	truss	Pier abutments displaced
Sungai Sapih	concrete	Settlement of lateral movement of abutments
Lubuk Minturun	concrete	15 cm lateral deformation
Kandis	concrete	Settlement of abutments
Pariaman port	concrete	Cracking and spalling of north piers



Figure 5.6: Damage to Mirang railway bridge in Padang



Figure 5.7: Damage to Mirang roadway bridge in Padang



Figure 5.8: Sitinurbaya Bridge on Batang Arau in Padang downtown (damage due to abutment settlement and movements)



Figure 5.9: Slight damage to piers and railings

5.3 Airports

The airports in the earthquake affected area are Tabing air-force airport and Minangkabau civil airport. Minangkabau airport is newly re-built in 2001 by Shimizu Corporation and PT Adhi Karya through a softloan from Japan International Corporation Bank (JICB) (90%) and APBN (10%). The runway is 2750m long and its elevation is about 5m. The ground condition in the vicinity area is sandy soil. The earthquake did not cause any structural damage to its runway and terminal building although some cracking at the joints of infill walls and frame were observed. Some settlement in the vicinity of airports was noticed. The control tower built as a reinforced concrete structure at the Tabing air-force airport was observed.



(a) Minangkabau airport

(b) Tabing air-force airport

Figure 5.10: Views of damage at Minangkabau and Tabing airports

5.4 Power Houses and Transformer Stations

There are two major electric power plants in the earthquake affected area. One of the power plants is Singkarak hydroelectric power plant, which was completed in 1998. The hydro-electric power plant has involved an underground power house (station), small dam and 16.5 km long head-race tunnel. The Singkarak HEPP is at 50 km east of the earthquake epicenter and it was developed to provide electric power of 175 MW. The supply water from Singkarak Lake is flowed through a head-race tunnel as long as 16.5 km with inner diameter of 5.0 m (excavation diameter 6.2 m). The maximum ground acceleration at the powerhouse was about 0.1g and no damage was reported at this power plant.

The second power plant is located near the Maninjau Crater Lake. The power plant is a hydroelectric power plant. The power plant has four turbines. The earthquake did not cause any damage to the power plant (Figure 5.11). However, some ceramic isolators were broken due to ground shaking at the sub-station of the Maninjau power plant. As the isolators had to be brought from Sweden, it took several days to repair the isolators (Figure 5.12). The sub-station near Pariaman did not suffer any damage due to the earthquake. In the downtown of Padang and Pariaman some transformers mounted on poles were fallen down so that the electricity had to be cut-off in such areas. Although some reinforced concrete poles broken due to either ground shaking or collapsed buildings, nor damage occurred to the pylons of the major transmission lines.



Figure 5.11: Views of Maninjau hydroelectric power plant



Figure 5.12: A view of Maninjau sub-station and broken ceramic isolator.

5.5 Water Supply Plant

The water supply plant was investigated by Prof. Kawamura of Toyohashi Technical University and the information given here is based on his report in Padang. The water is basically pumped from the river to the purification plant on a hill and it was distributed through the gravitational flow after the purification (Figure 5.13). The major damage occurred at the purification plant due to relative settlement and movement of foundation ground, which caused some structural damage to the plant (Figure 5.14). The water was supplied to the network 4 days after the earthquake. However, it took more than 10 days in heavily damage areas.



Water Treatment Plant

Water Intake

Figure 5.13: Water supply system of Padang City



(a) Water intake facility

(b) Purification and supply facility

Figure 5.14: Views of water supply system after the earthquake

5.6 Industrial Facilities

The major industrial plants are located to the south of Padang City. The largest plant in the earthquake affected area is Padang Cement factory. The earthquake did not cause any damage to this plant. The earthquake did not cause any damage to the loading storage facilities of the cement plant and coal plants at Teluk Bayur port.

There are many cylindrical storage tanks at the Teluk Bayur port. Although most of the storage tanks performed well and non-damaged during the earthquake, there were some buckling failures at some of these cylindrical tanks. Furthermore, settlement of soil around some of tanks was observed.



Figure 5.15: Views of buckled tanks at Teluk Bayur port

There are also some petroleum tank yards, which are located near Bungus port. The visual inspection at the petroleum tank yard indicated that there was almost no damage to the tank yard.

6 GEOTECHNICAL DAMAGE

6.1 Roadway Damage due to Slope Failures and Rock falls

There was extensive damage to roadways due to slope failures in the mountainous areas such as Padang Alai and Tandikat. This damage was of great scale when roadways run along the thin ridge of the mountains. The ground was made of loosely packed volcanic ash. The slope failures were initiated due to intense ground shaking combined with high water content and lack of cohesive force and layers dipping towards the slope (Figure 6.1).



Figure 6.1: Roadway damage due to slope failures in Padang Alai

There was also some damage to roadways due to rock falls. These failures were observed along Padang-Bukittinggi Highway and Padang-Bungus. The fallen rock blocks were more than 5m in diameter (Figure 6.2).



Figure 6.2: Roadway damage due to rock falls

6.2 Slope failures and Rockfalls

Extensive slope failures were observed in Padang Alai and Tandikat (6.3). The area is covered very loosely compacted and layered volcanic ash. The grain size of layers varies from the clay size to gravel size. Large fragments are made of pumice and their unit weight is very light. The sandy and gravel sized layers are porous and rich in water content. The site investigation indicated that layers have inclination more than 10 degrees towards to slope side. The failure of slopes took place along the interface of clayey and sandy layers due to intense ground shaking, which is expected to be more than 0.3g and the failed body become fluidized during the motion. More than 200 people were killed in a slope failure at Tandikat.



Figure 6.3: Slope failures in Padang Alai

Furthermore, the hard rocks are andesite or basalt and they are jointed due to cooling joints. There were numerous rockfalls in mountainous regions consisting of hard rocks. The spectacular rock falls and slope failures particularly southern inner rim of Maninjau Crater (Figure 6.4). The debris created some landslide dams and the breach of the landslide dam caused huge debris flow 15 hours after the earthquake and causing some structural damage (Figure 6.5).



Figure 6.4: Rockfalls and slope failure in the inner rim of Maninjau Crater



Figure 6.5: Debris flow induced damage due to the breach of landslide dams

6.3 Embankment Failures

Embankment failures of roadways and rivers were also widespread in the area where the ground motions were high (Figure 6.6). The embankment failures at abutment of the roadway bridges were widespread. One of the major causes of the embankment failures was ground liquefaction induced lateral spreading.



Figure 6.6: Views of some embankment failures in the epicentral area

6.4 Ground Liquefaction and Lateral Spreading

Results of geotechnical drilling and cone penetration tests to the depth 30 m in Padang City indicated that the soil layers consist of mainly loosely to densely-packed sand and soft silty clay layers. The liquefaction susceptibility analyses show that the soil

layer is potentially prone to liquefaction. The loose sandy layers at the depth of less than 5 meters below the ground are considered as the controlling factor for the susceptibility. Ground liquefaction was observed in various parts of Padang City in the areas such as Pecinan, Purus, Air Tawar, Alay, Ampang, Tabing, Linggarjati, Lubuk Buaya, Pariaman City and Bungus port (Figure 6.7-6.9). The settlement of the ground ranged between 5-40 cm. Lateral spreading of ground were greater than 200 cm in some areas. The ground liquefaction caused some structural damage to buildings and port facilities. Figure 6.10 shows the grain size distribution curves curves of samples collected at several sand boiling sites. As it is noted from the figure, the liquefied soil is within the bounds of easily liquefiable ground.



Figure 6.7 Ground liquefaction and its effects in Pariaman



Figure 6.8 Ground liquefaction in Padang



(a) Susidence of wave break at Pariaman



(b) Uplift of petrol tank



(c) Tilted structures



(d) lateral spreading at Padang Port

Figure 6.9: Effect of ground liquefaction on various structures

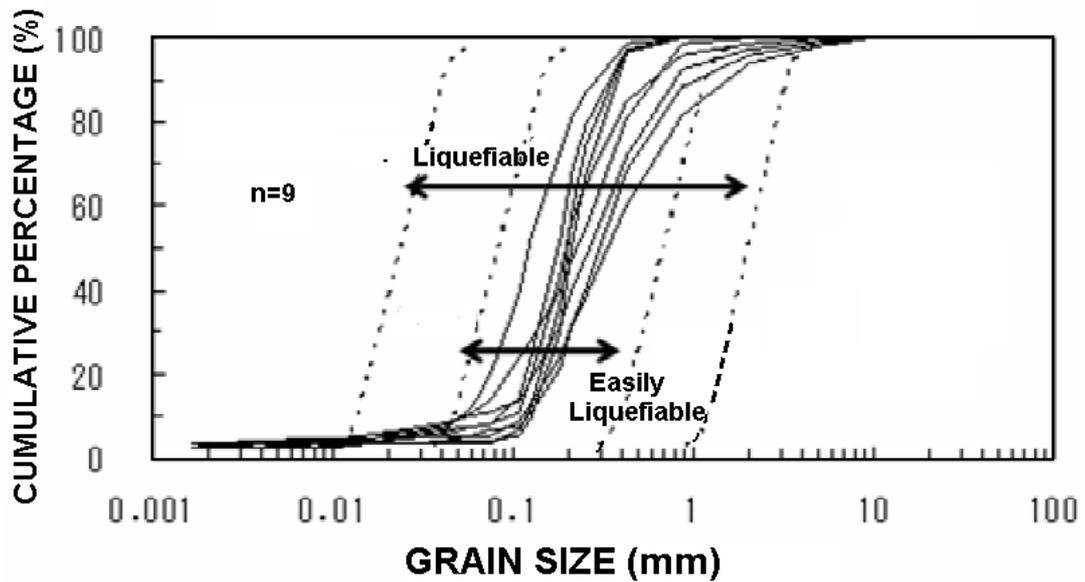


Figure 6.10: Grain size distribution of samples of sand boils.

7 CONCLUSIONS AND RECOMMENDATIONS

There is a large seismic gap between 2007 and 2005 rupture zones. The estimated magnitude would be more than 8.7. This earthquake will hit West Sumatra and the possibility of huge tsunami waves striking Padang City is quite high. **The strike of Sep. 30, 2009 earthquake is perpendicular to that of the anticipated earthquake.** M7.6 Earthquake should be interpreted as the indication higher possibility of the M8.7 Mega Earthquake might strike the West Sumatra. Therefore counter-measures against ground shaking and tsunami must be strictly and quickly implemented.

The existing buildings in Padang City and elsewhere in Sumatra Island were shown to be very vulnerable against ground shaking and they performed very poorly during this M7.6 earthquake and the 2007 Bengkulu earthquake, which was about 400km away from the epicenter of the South Sumatra Earthquake of 2007. The new buildings must be strictly built with the consideration of the anticipated mega-earthquake and appropriate retrofitting measures must be implemented. It must be noted that repairs implemented as re-plastering the cracks is not a retrofitting. **Furthermore, the buildings should be equipped with terraces and stairs for the vertical evacuation in tsunami-vulnerable areas**

Another important issue is the vulnerability of structures against ground liquefaction. The critical infrastructures such as bridges, telecommunication facilities and lifelines may be damaged by the ground failures and ground liquefaction. This earthquake was a test of bridges and the bridges performed well during this earthquake. However, **it is urgent to check the vulnerability of ground in relation to the foundations of buildings and lifelines.**

Regarding the Rehabilitation of roads in mountainous region, the construction of retaining walls (70-80 degrees) should be the cheapest solution. Other options may be Movement of people to another place or Realignment of the roads.

Loosely sedimented porous volcanic ashes with clayey layers are very prone to slide during earthquakes. The people living in those areas should be re-located. If such measure is difficult to implement, some safety zone must be introduced between the settlements and crest of the slope.

Rockfalls of large scale occurred in areas where hard rock outcrops. Some assessment and counter-measures must be implemented against **block toppling and subsequent rockfalls along Padang-Bukittinggi roadway** as well as the highway from Padang to Bungus

Padang city is located on a very flat land. It is about 3km to reach the altitude of 5m from the coast, In case of Tsunami with a height of more than 5m, it may be quite disastrous. Elder people, pregnant and handicapped people and children would be probably the most vulnerable even though a tsunami warning may be issued promptly. As proposed by Aydan (2007, 2008), the measures for the vertical evacuation are a must for the area. The vertical evacuation is only possible if the buildings can stand against ground shaking by the main shock and aftershocks. Such buildings must have terraces on top and stairs to reach the terraces. The quickest implementation of measures would be to retrofit the existing RC buildings as shown in Figure 18. If

areas do not have such buildings, some residential and/or public buildings can be built for such a purpose. Furthermore, these buildings may be used as residential flats or public offices during the ordinary times. Japan can provide the technology and expertise knowledge for constructing such buildings and implement the retrofitting in Padang City.

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