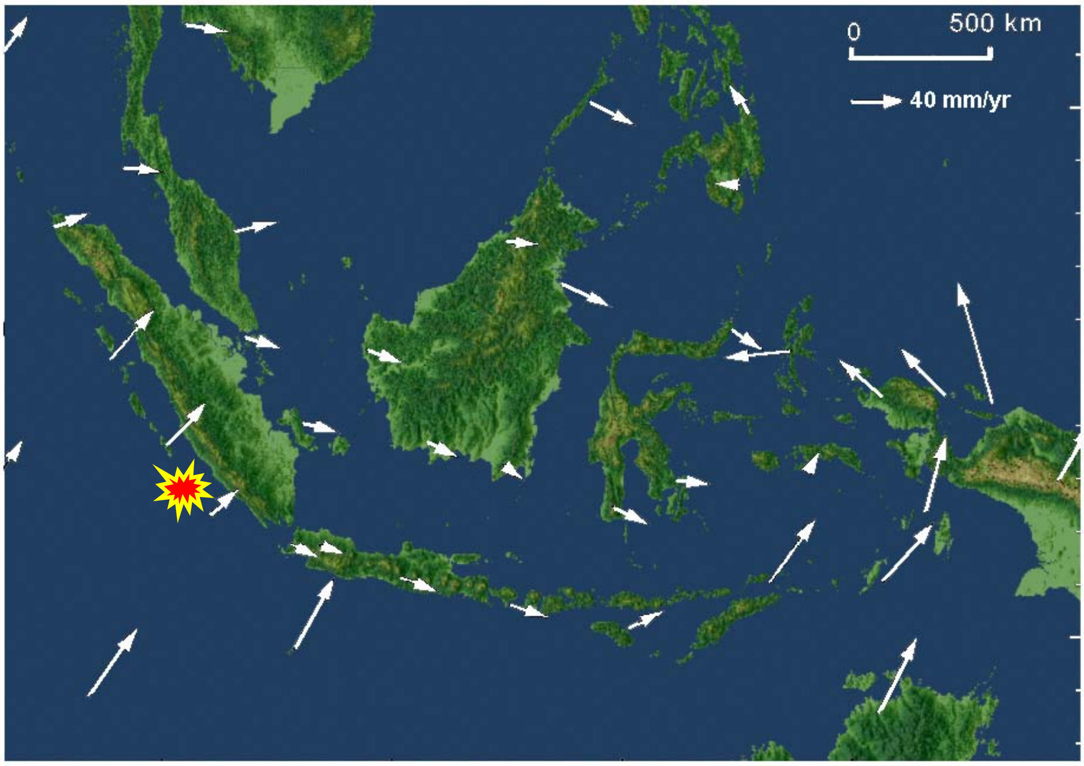
A RECONNAISSANCE REPORT
ON
THE BENGKULU EARTHQUAKE OF SEPTEMBER 12, 2007



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2007 Bengkulu Earthquake Reconnaissance Team

by

Japan Society of Civil Engineers (JSCE)

and

Japan Association for Earthquake Engineering (JAEE)

With the collaboration of

Andalas University and KOGAMI

October 2007

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i)Members of Reconnaissance Team for 2007 South Sumatra Earthquakes

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Itinerary of the joint JSCE-JAEE and Andalas University Reconnaissance Team

Date	Details	Stay
Oct. 4, 2007	Departure from Tokyo for Indonesia Dr. Ö. Aydan, Dr. F. İmamura JL725, Eta 16.50 (arrive at Jakarta) Departure for Padang with JT 356 (19.30 – 21.10)	Jakarta Padang
Oct. 5, 2007	Investigation around Padang Dr. Ö. Aydan, Dr. F. İmamura, Mr. T. Suzuki and meeting at Andalas University (Joint Team), Vice Governor & Kogami, etc	Padang
Oct. 6, 2007	The coast line between Padang & Bengkulu (see Figure i.1)	Bengkulu
Oct. 7, 2007	Investigation in Bengkulu City	Bengkulu
Oct.8, 2007	Fly to Jakarta by KI 273, 08:10 – 09.20, 11:30, Report to Japan Embassy 14:00 – 15:00, JICA 16:00, NHK & Jakarta Shinbun Departure from Jakarta for Tokyo by JL 726, 22:15	Jakarta
Oct.9, 2007	Arrival at Narita (Tokyo) 07:40 am	

Fig. i.1 Investigation locations of between Padang and Bengkulu

ii) Purpose

The reconnaissance team consisting of members from universities and institutions from private sectors has been decided to be dispatched jointly by the Japan Society of Civil Engineers (JSCE) and Japan Association for Earthquake Engineering (JAEE) to the area affected by South Sumatra Earthquake of Sep.12, 2007. This team will carry out the investigation with the strong collaboration of Engineering Faculty of Andalas University and KOGAMI. The main purpose of the team is to investigate the damage to houses, buildings, civil infra-structures such as roadways, railways, bridges, riverbanks, slopes, lifelines by the earthquake shaking and associated tsunami in the earthquake-affected area and to provide some recommendations and technical supports to our counterparts in Indonesia for the reconstruction and restoration. The team would carry out their investigation on

1) Diagnosis of causes of damage to structures by ground shaking and tsunami
2) Tsunami damage and recommendations for the mitigation for tsunami-disaster preparedness with a special emphasis on West Sumatra

The team will investigate the cities and towns in Bengkulu and West Sumatra Provinces of Indonesia, which are most severely affected by the earthquake. Specifically the towns and cities are Bengkulu, Padang, Lais, Ketaun, Mukomuko, Muara Maras, Pasar Bawa Manas and the coast-line and rivers between Manas and Padang.

Structures to be investigated by the team are as follows:

1) Residential houses, dwellings, apartment blocks
2) Public buildings (Schools, Hospitals, etc.)
3) Roadways and railways
4) Bridges
5) Embankments
6) Slopes (soil and rock)
7) Ports, waterbreaks and shorelines
8) Lifelines

Some investigations will also cover conditions and properties of ground and slopes.

The long-term activities will cover the following items:

1) Recommendation of disaster-proof reconstruction procedures for each structure type
2) Revision of structural design codes
3) Education of engineers and technician for earthquake-proof design
4) Education of children and public for public awareness and natural disaster mitigation
5) Guidelines for hardware and software mitigation measures against tsunami-disaster along Sumatra island

1 INTRODUCTION

An interplate earthquake struck South and West Sumatra Provinces of Indonesia on September 12, 2007, killing 25 people and caused heavy damage in Bengkulu and West Sumatra Provinces along the western shore of Sumatra Island. Two large events with a moment magnitude of 7.9 and 6.8 occurred after the main shock. The second earthquake with a magnitude of 7.9 in the early morning (6:49 AM on IST) was close to the shore and caused heavy structural damage mainly due to ground shaking.

Following the 2004 and 2005 great off-Sumatra earthquakes, it was pointed out the West Sumatra and Bengkulu region as well as Sumatra Fault Zone may be subjected to large earthquake in near future. Within this respect, the earthquake of March 6, 2007 occurred in Singkarak Lake along the Sumatra Fault Zone and 2007 South Sumatra Earthquake might have significant implications on the near future seismic activities along this fault zone and Sunda subduction zone. The 2007 Bengkulu earthquake took place at a region adjacent to the epicenter of 2000 June 4 earthquake and ruptured approximately 220-240km long and 60-70km wide area along the subduction zone.

The authors visited the epicentral area along Western Shore of Sumatra Island between Padang and Bengkulu during the period between 2007 October 4 and October 8. The investigation was concentrated on structural and geotechnical damage induced by ground shaking as well as associated tsunami. Although some of damage induced by the tsunami was cleaned up, the damage to the epicentral area by the tsunami can be still observed in many places in the earthquake-affected region. This earthquake induced tsunami, which hit the coastal area. The tsunami height was more than 4m in Serangai, which was also hit heavily by the strong ground shaking. Roadway running along the shore line built on volcanic deposits were damaged by the ruptures and setllement due to landslides. The damage was particularly remarkable between Serangai and Lais in Bengkulu Province. Roadway was settled by more than 1m just south of Serangai. Ground liquefaction along the shore lines was observed between Carcokok in West Sumatra Province and Lais in Bengkulu Province. In Pasir Ganting, a new arch concrete bridge was heavily damaged due to severe ground liquefaction. A 20m high coconut tree at Pasar Bantal was toppled due to ground liquefaction. The damage due to ground liquefaction were induced at several major bridges. The damage was generally due to the settlement of piers and failure of abutments as a result of ground liquefaction. Nevertheless, the bridges were all accessible in-spite of damage. Reinforced concrete structures were heavily damaged or collapsed. Although Padang City was about 400km away from the epicenter, major reinforced concrete buildings were damaged. Besides structural problems associated with collapsed reinforced buildings, the long-period ground motions and soft ground conditions might be another reasons for the damage to reinforced concrete buildings as well as bridges.

Indonesia lacks the strong motion network, which is one of the most important items in earthquake resistant design. Since 2004 Aceh earthquake too many proposals for seismic and strong motion monitoring were put forward and it has been more than 3 years and we still see no strong motion records except the one recorded at Sikuai Island installed by USGS during the 2007 South Sumatra Earthquake.

Tsunamis induced by this earthquake did not cause major damage. Nevertheless, it deserves further studies on the causes of minor damage and the response of local people to tsunamis and as well as tsunami warning by the authorities.

2 REGIONAL GEOGRAPHY AND GEOLOGY

2.1 Regional Geography

Bengkulu is a province of Indonesia. It is on the southwest coast of the island of Sumatra, and borders the provinces of West Sumatra, Jambi, South Sumatra and Lampung. The capital and largest city of the province is Bengkulu city. It was formerly the site of a British garrison, which they called Bencoolen.

The province has a population of 1,405,060 (2000 census). It occupies of 19,831 sq. km area and has about one million populations, comprising mostly Rejang, Malay, Bugis and Chinese ethnic ancestry people. Bengkulu province is divided into 8 regencies (*kabupaten*) and 1 city (*kota*).

Bukit Barisan mountain range constitutes its northeastern border, beyond which laid of South Sumatra province and Jambi province. The province also includes Enggano Island. Enggano Island is an island approximately 100 km south west of Sumatra, Indonesia. It has an area of roughly 500 km^2 and the highest point is 281 m. The three largest cities on the island are Barhau, Kabuwe and Kayaapu. The island had 1635 inhabitants in 1994.

Bengkulu lies near the Sunda Subduction Zone and Sumatra Fault and is prone to earthquakes and Tsunamis. In June of 2000 a quake caused damage and the loss of at least 100 people. Coal mining is a major economic activity in Bengkulu Province. There are several active volcanoes, which are Mt. Kaba, Mt. Daun, Mt. Sumbing and Mt. Dempo. Mt. Kaba is highly active and is located at Rejanglebong Regency. There are 8 craters show historical explosive activity. The summit area of Kaba volcano contains three high peaks - Bukit Kaba, Bukit Itam (1893 m) and Bukit Malintang (1713 m) with three craters among them called Kaba west-old crater, Kaba middle-new crater and kaba vogel sang crater, one of them is still active. Vapors are incessantly released from 12 fissures and hot water springs are found in the vicinity.

2.2 Regional Geology

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 Sumatra Fault System, show some degree of metamorphism, mainly to low-grade slates and phyllites, but younger Permo-Triassic sediments and volcanics are less metamorphosed.

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 volcaniclastic 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.

Fig.2.1 Location of the earthquakes and major city and towns (modified from Sumatra, Indonesia Regional Maps Series, Periplus Travel Maps, 2001)

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 Bengkulu soil is mostly Tertiary Pleistocene

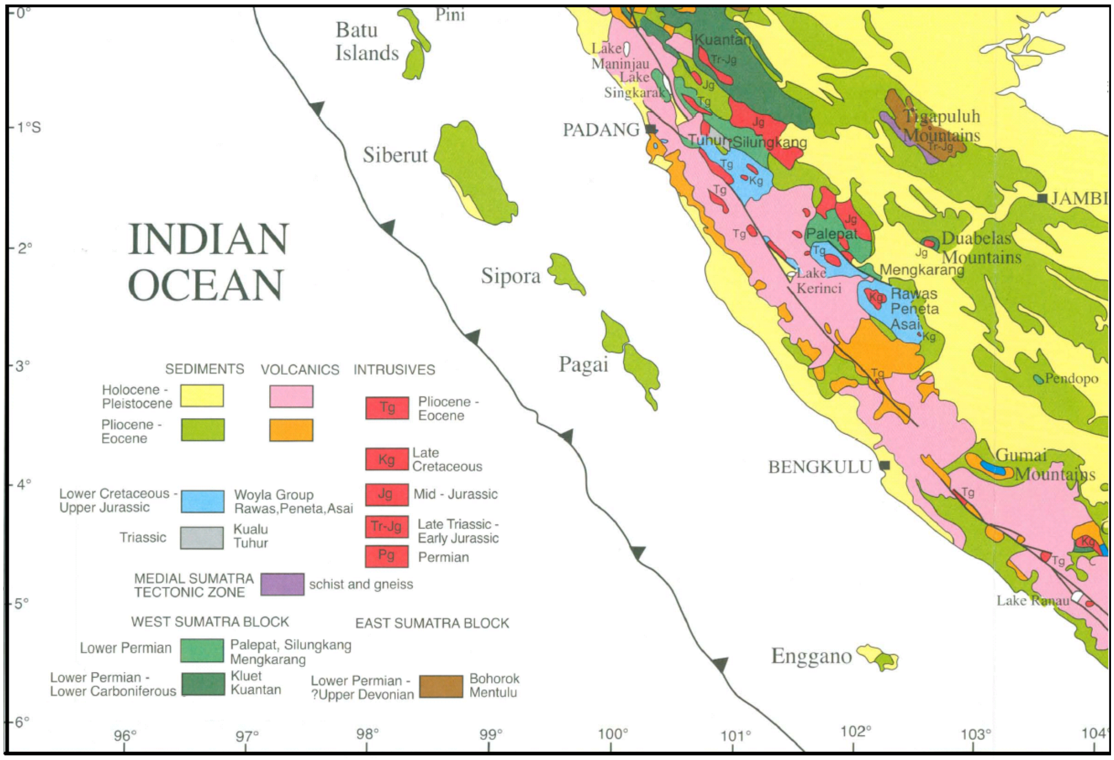


Fig.2.2 Simplified geology of the earthquake affected area

(modified from Crow and Barber, 2005)

3 TECTONICS, CRUSTAL DEFORMATION AND SEISMICITY

3.1 Tectonics, Crustal Deformation and Seismicity of Indonesia

The plates in the region bounded by latitudes S20 and N20 and longitudes E90-160 are Euro-Asian litho-spheric Plate, Pacific Plate, Philippine Sea Plate and Indo-Australian Plate. There are platelets, which are sandwiched by these major plates, are Caroline Platelet(CL), Timor Platelet(TI), Banda Sea Platelet(BS), Molucca Sea Platelet(MS), North and South Bismark Platelets (NB,SB), Brid's Head Platelet (BH), Woodlark Platelet (WL) and Maoke Platelet (Figure 3.1). The northward-moving Indo-Australian and the westward-moving Philippine Sea plates bound Sunda section of Euro-Asian Plate and it is certainly one of the most complex active tectonic zone on earth. The Sunda section or Sunda plate (SU) is said to be broken from Euro-Asian Plate in Tertiary period (Bird, 2001) The rate of subduction is some centimeters per year; for example, it is 6.0 cm per year in the West Java Trench at 0°S 97°E (azimuth 23°); 4.9 cm per year in the East Java Trench at 12°S 120°E (azimuth 19°); and 10.7 cm per year in New Guinea at 3°S 142°E (azimuth 75°).

The subduction zone around the Euro-Asian plate is called the Sunda trench. Many volcanoes are part of the Sunda arc, a 3,000-km-long line of volcanoes extending from northern Sumatra to the Banda Sea (Figure 3.2). These volcanoes are generally the result of subduction of the Indo-Australia Plate beneath the Eurasia Plate. Volcanoes in the Banda Sea result from subduction of the Philippine Sea Plate under the Eurasia Plate. In this region, there are some 400 volcanoes, of which approximately 100 are active.

Many countries in South-East Asia has established their national GPS networks for geodetic purposes while some institutes from other countries established some GPS networks for tectonics and seismological studies (i.e. Subarya, 2004; Bock et al. 1990, 2003; Kee et al. 2006; Prawirodirdjo et al. 2000). Scripps Institution of Oceanography initiated the first GPS network in 1989 and their network consisted of 150 stations (Bock et al. 2003). The Indonesian Land Agency (BPN) collected GPS data. Malaysia has established two GPS networks that partly serve the purpose of geodetic survey, namely the Malaysia Active GPS System (MASS) and the Malaysia Real-Time Kinematic Network System (MyRTKnet). Department of Survey and Mapping Malaysia (DSMM) implemented MASS and MyRTKnet on year 1999 and 2004 respectively. The Royal Thai Survey Department (RTSD) established Geodetic Network in Thailand using the Global Positioning System and the GPS observation has been performed since 1991. GEODYSSEA project that was initiated in 1994 and completed in 1997 aimed to study the plate motion and crustal deformation in the region of South and South East Asia. GPS campaigns were carried out in December 1994 and April 1996 to study such motion. Participating countries in this project were Malaysia, Japan, Philippines, Vietnam, Australia, New Zealand. The author has attempted to combine all these GPS measurements in a recent study (Aydan 2007). The evaluation of GPS measurements in a region bounded by Latitudes 15S – 15N and Longitudes 90E – 140E are evaluated. The deformation rates used in this study corresponds to those before the 2004 Sumatra earthquake and co-seismic deformations are not taken into account.

The distributions of GPS stations are not uniformly spaced in the region bounded by Latitudes 15S – 15N and Longitudes 90E – 140E. In order to obtain a uniformly spaced mesh of GPS points, some of GPS points were omitted. Aydan et al. (2000) proposed the use of maximum shear stress rate, mean stress rate and disturbing stress for identifying the potential locations of earthquakes. The maximum shear stress rate, mean stress rate and disturbing stress rate are given below:

$$\dot{\tau}_{\max} = \frac{\dot{\sigma}_1 - \dot{\sigma}_3}{2}; \quad \dot{\sigma}_m = \frac{\dot{\sigma}_1 + \dot{\sigma}_3}{2}; \quad \dot{\tau}_d = \left|\dot{\tau}_{\max}\right| + \beta\dot{\sigma}_m \qquad (1)$$

Where β is a coefficient and regarded as a friction coefficient. The concentration locations of these quantities may be interpreted as the likely locations of the earthquakes as they imply the increase in disturbing stress. If the mean stress has a tensile character and its value increases, it simply implies the reduction of resistance of the crust.

Figure 3.3(a) shows the annual crustal deformation rate, principal stress rate, contours of mean, maximum shear and disturbing stress rates. In view of Figure 3.3(a), it seems that Euro-Asian block or Sunda Plate tends to rotate clock-wise. The rotation rate in the vicinity of Banda Sea and Molucca Sea, which is north of Timor Island is very high. As noted from the figures stress rate concentrations are clearly observed in the regions of Moluccas Sea and Banda Sea area. Concentrations in the vicinity of Sunda strait and west of Sumatra Island are worth noticing. However, it should be noted that the GPS stations in the west of Sumatra Island are sparse. Therefore it is expected that the actual concentrations may be larger than those seen in Figure 3.3. Figure 3.3(f) shows the areal and cross sectional seismic activity. It is of great interest that the stress rate concentrations are closely associated with the regional seismicity.

Figure 3.4 shows the seismicity of the region bounded by latitudes 13.5N-15S and longitudes 93.3E-140E together with recent great earthquakes until September 17, 2007. One can easily distinguish several large seismic gaps from this figure. These seismic gaps are denoted as SG1 to SG8. The 2004 Aceh, 2005 Nias and 2007 Bengkulu earthquakes ruptured the subduction zone along the Sumatra fault. However, a 600km long section between Bengkulu and Nias rupture zone still remains as a non-ruptured zone. Along the entire Java Island, there are 3 large seismic gaps. Along the Lesser Sunda Island chain, to which Timor belongs, two seismic gaps may be identified from the seismicity. There are also two seismic gaps along Aru Trough and Sorong Fault zone in the north of Banda Sea.

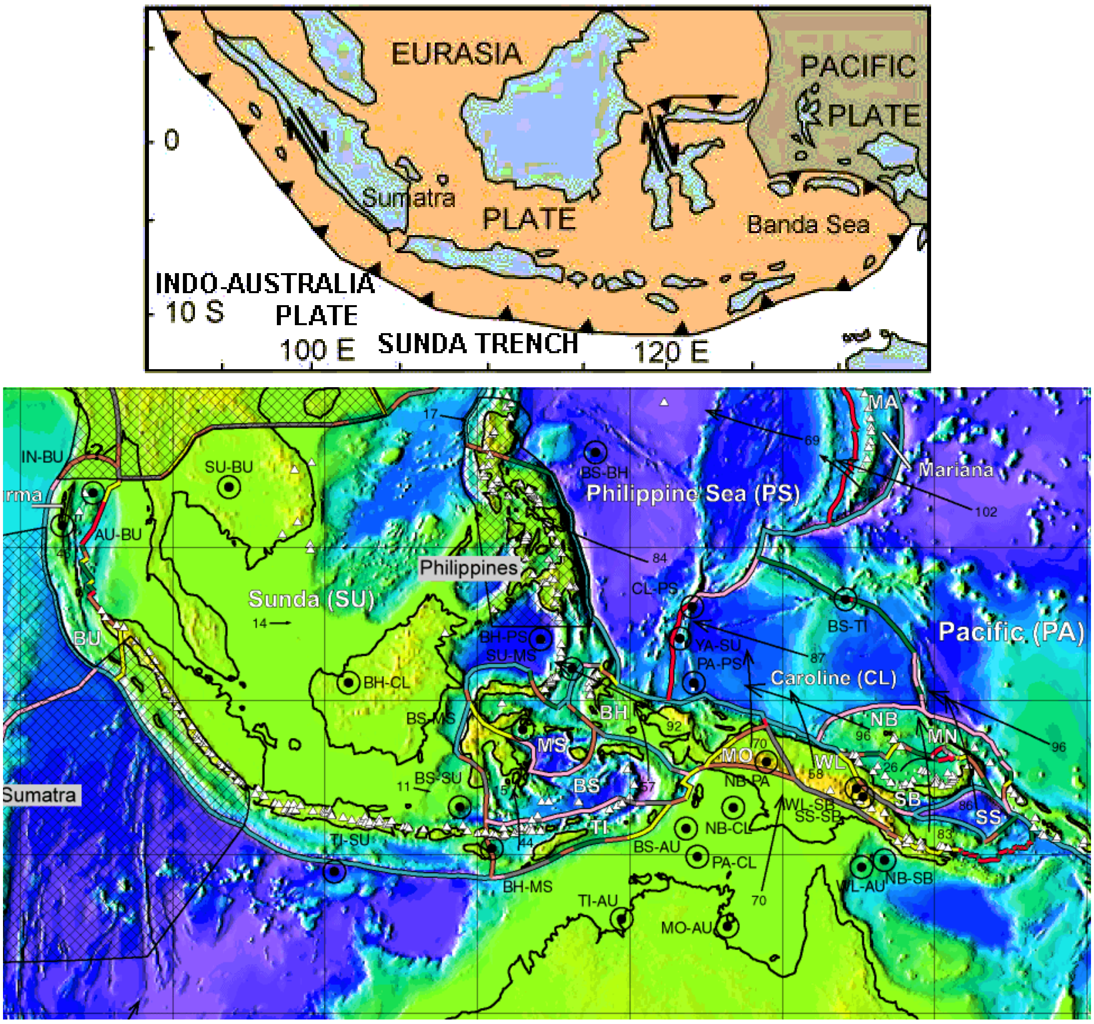


Fig.3.1 Major tectonic plates and platelets

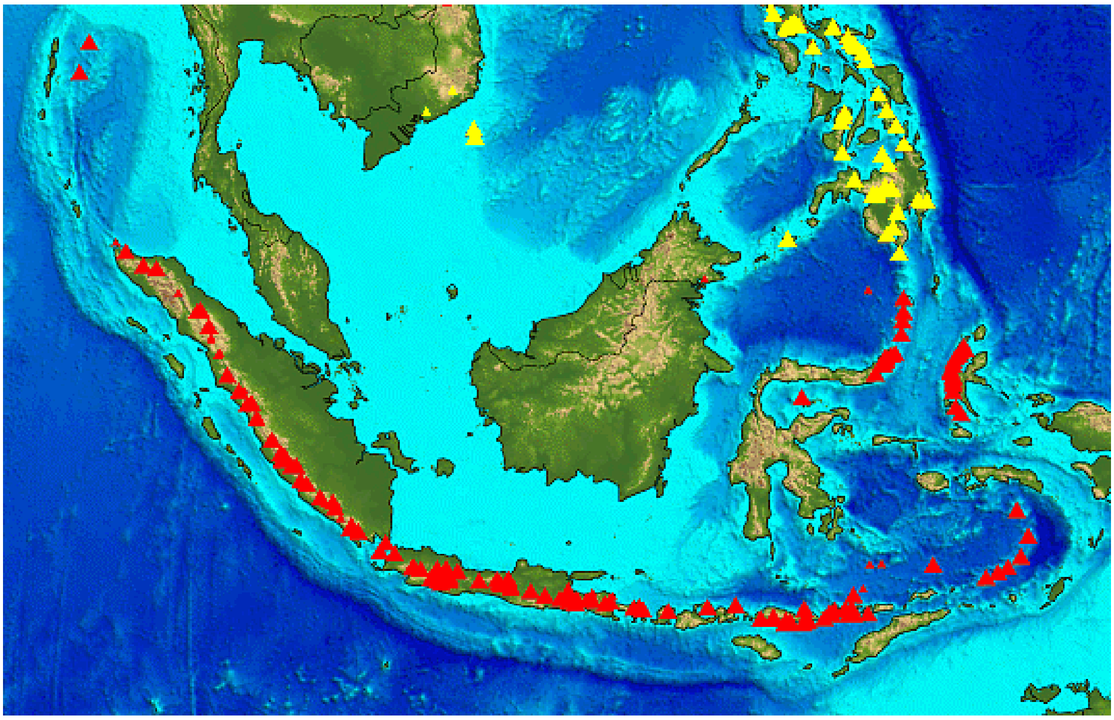
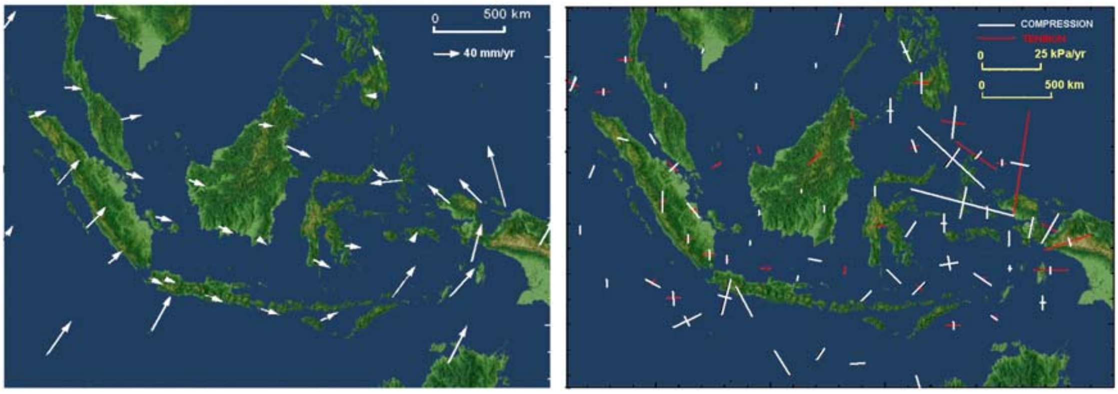
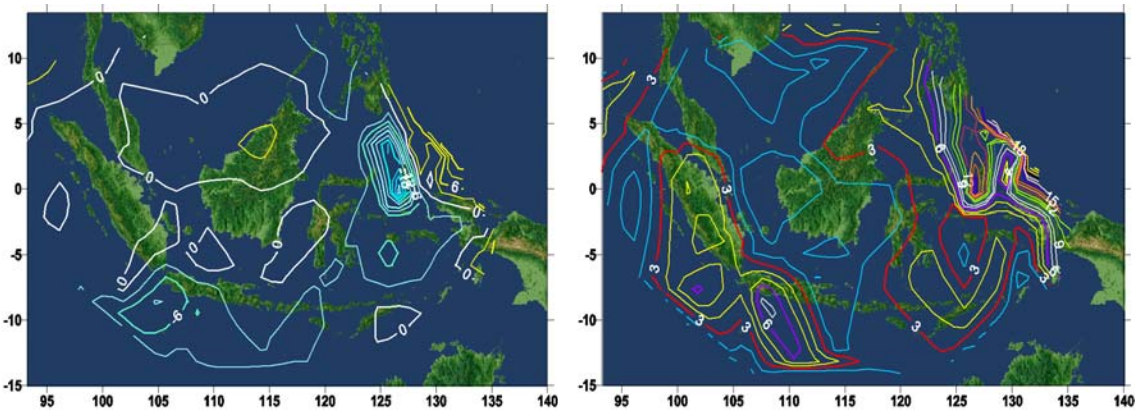


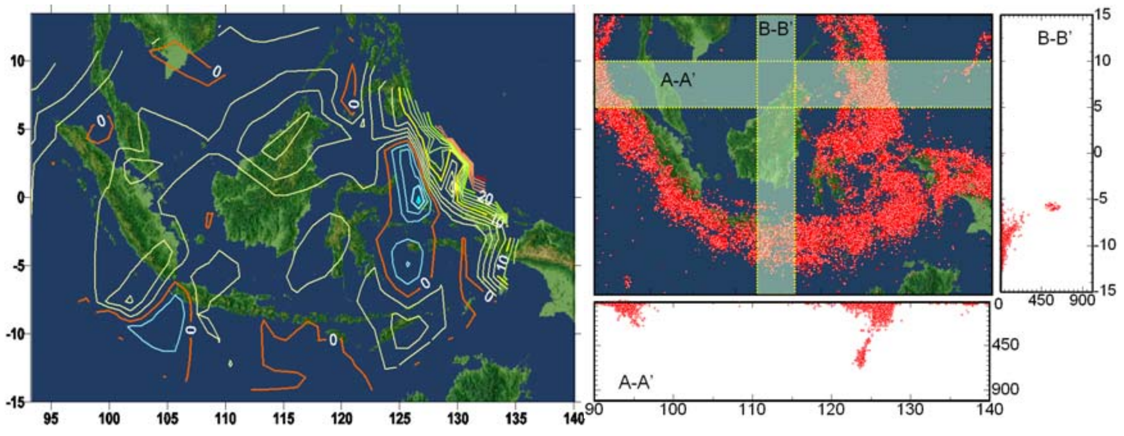
Fig.3.2 Distributions of volcanoes



(a) Annual deformation rates (b) Annual principal stress rates



(c) Annual mean stress rate contours (d) Annual maximum shear stress rate contours



(e) Annual disturbing stress rate contours (f) Comparison with regional seismicity

Fig.3.3 Measured deformation rate and computed various stress rates and comparison with regional seismicity

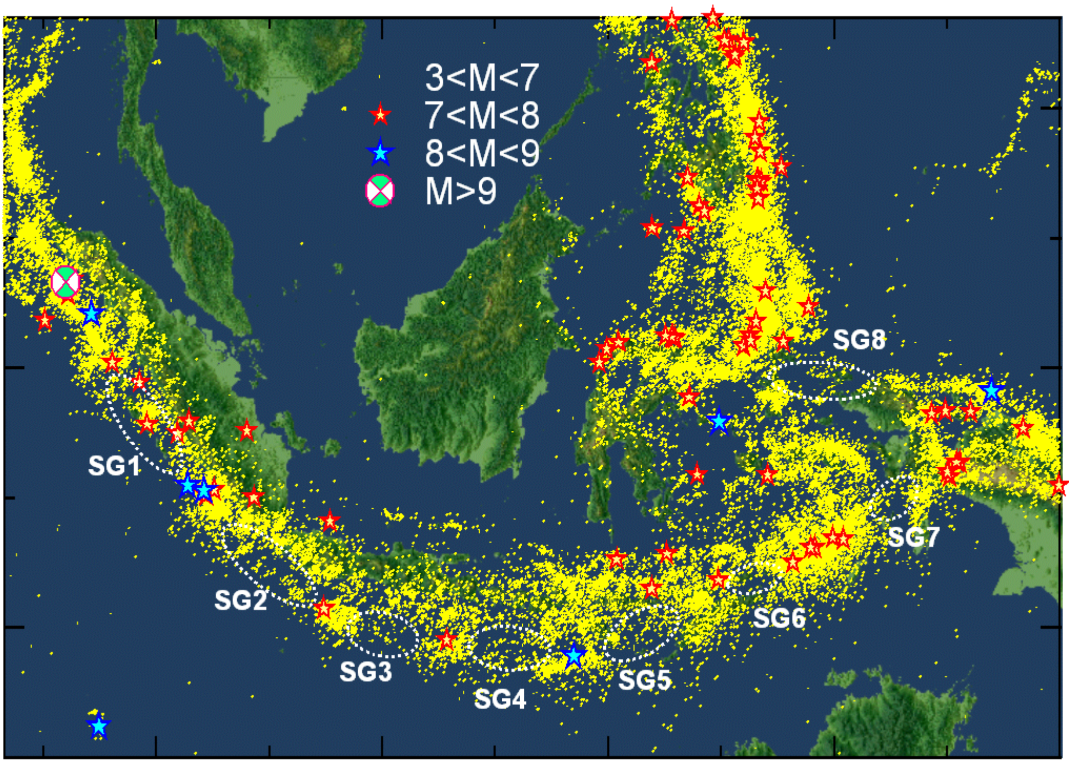


Fig.3.4 The seismicity in Indonesian Archipelago and possible seismic gaps

3.2 Tectonics, Crustal Deformation and Seismicity of Sumatra and Its Close Vicinity

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 3.5). 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.

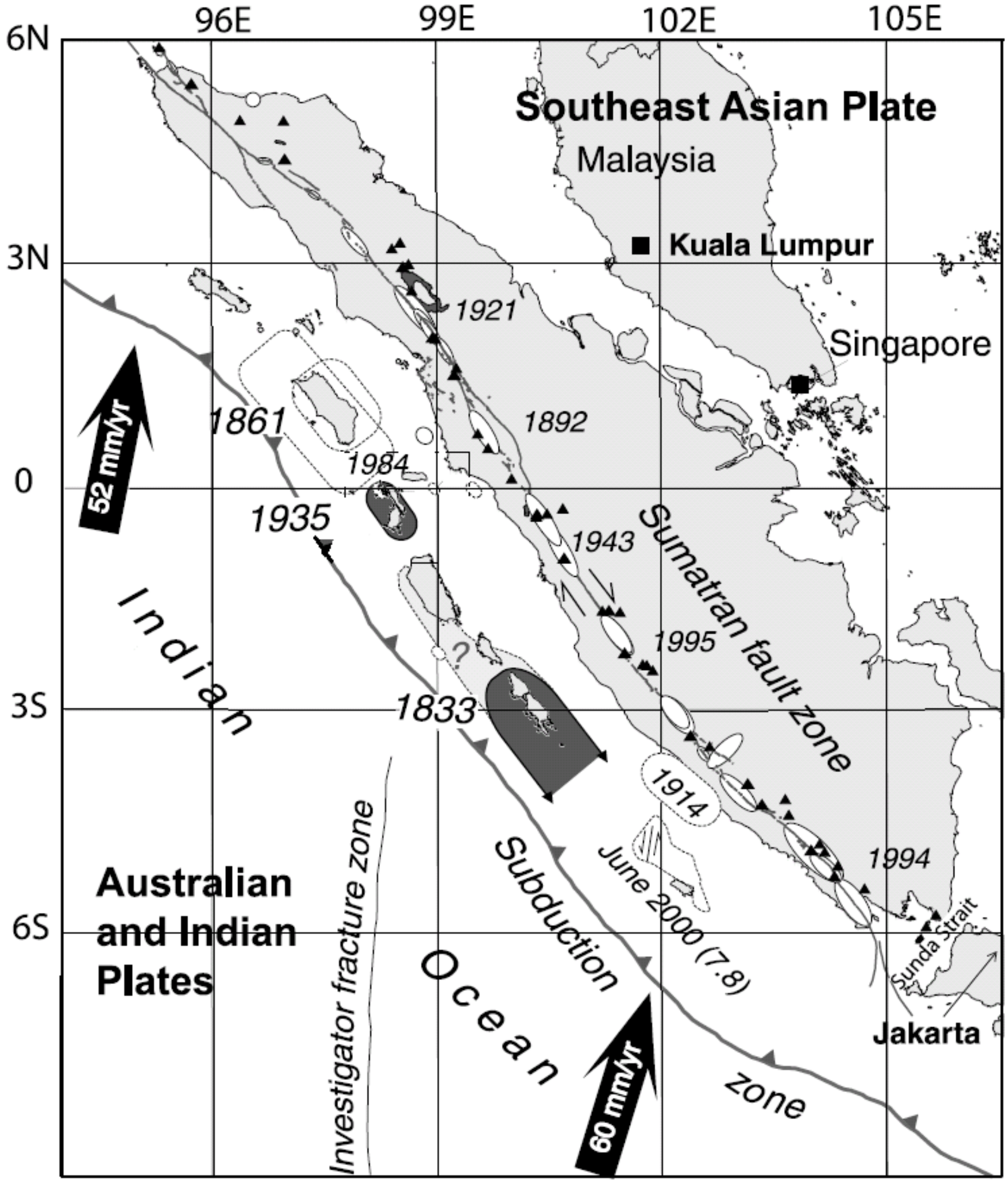
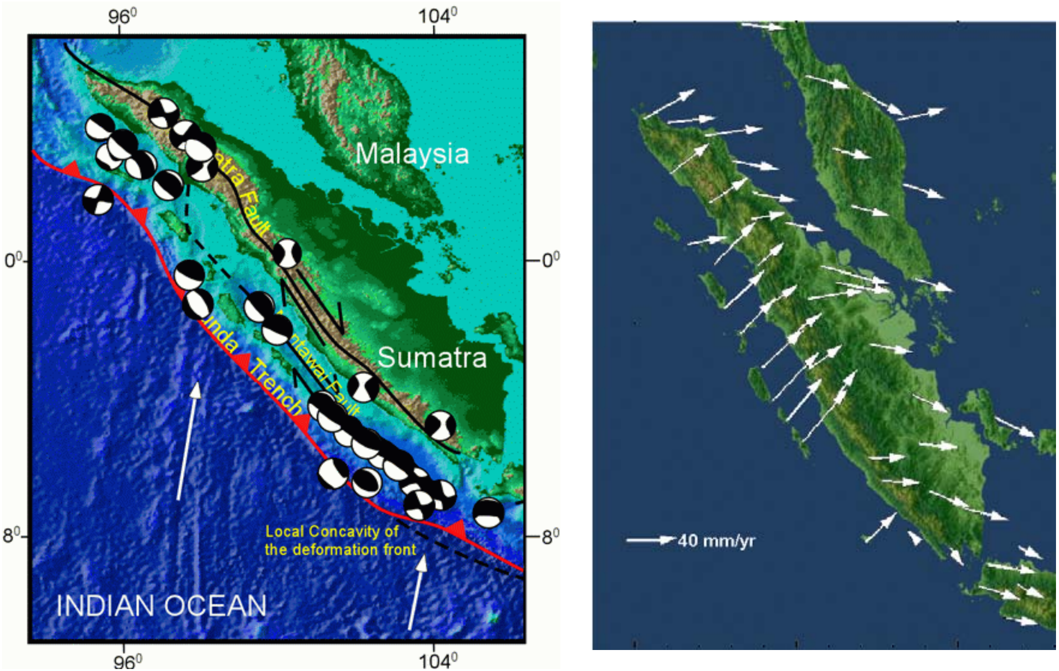


Fig.35 Seismo-tectonics of Sumatra Island (from Natawidjaja et al. 2004)

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 3.6(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 plate solutions indicate dextral strike-slip sense of deformation for faults trending NW-SE.

Figure 3.6(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 3.3, it seems that Sumatra Island tends to rotate clock wise in conjunction with Euro-Asian plate.



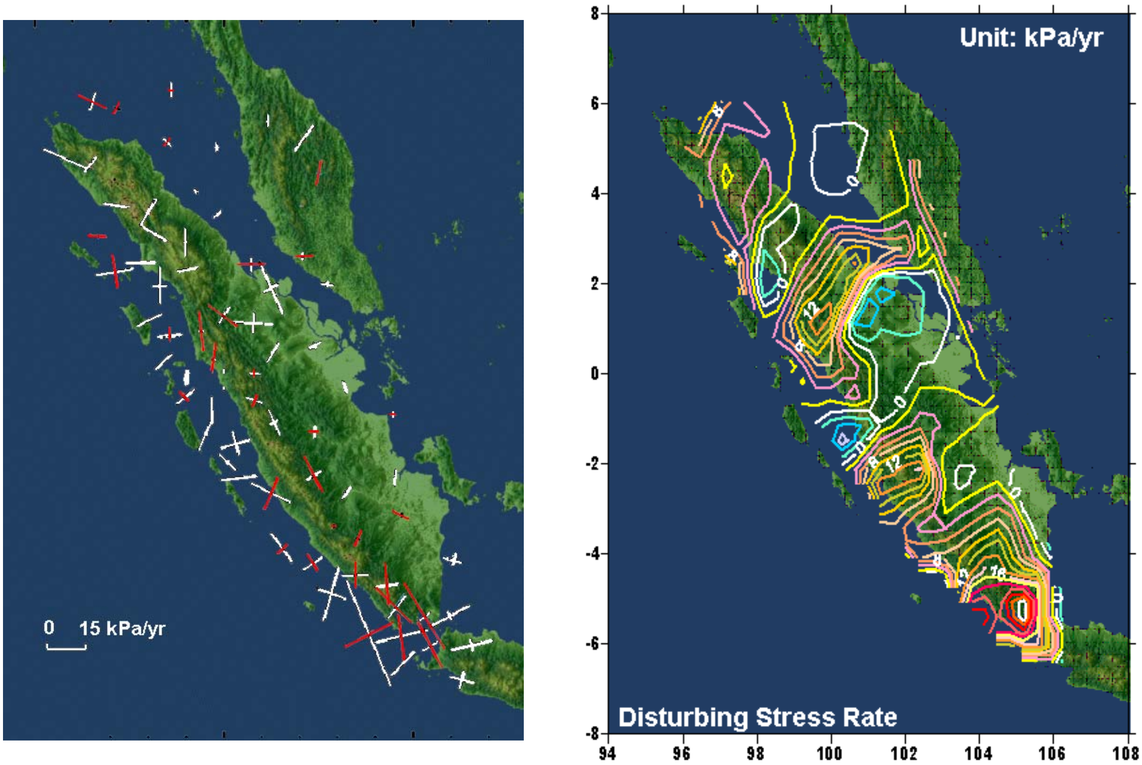
(a) Faulting mechanisms (b) Inter-seismic crustal deformation rates

Fig.3.6 Faulting mechanism and inter-seismic crustal deformation rates in Sumatra Island and its close vicinity

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 2.5, 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.

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.

In a very recent study by (Aydan 2007b) on crustal deformation and straining of Sumatra Island using the GPS deformation rates, it is found that there are three high stress rate concentration regions along the Sumatra Fault. These sections are associated with fault segments named by Sieh and Natawidjaja (2000), which are Sianok, Sumpur, Barumun, Angkola, Toru, Dikit, Ketaun Sunda, Semangko and Kumering segments (Figure 3.8). It is pointed out that tensile stress rate along the first section implies the reduction of normal stress on the Sumatra fault, which may lead the sliding of that segment in years to come. The recent 2007 Singkarak Lake (Solok) earthquake may be a part of this rupture process.



(a) Principal stress rate (b) Disturbing stress rate contours

Fig.3.7 Annual principal stress rates and disturbing stress rate contours

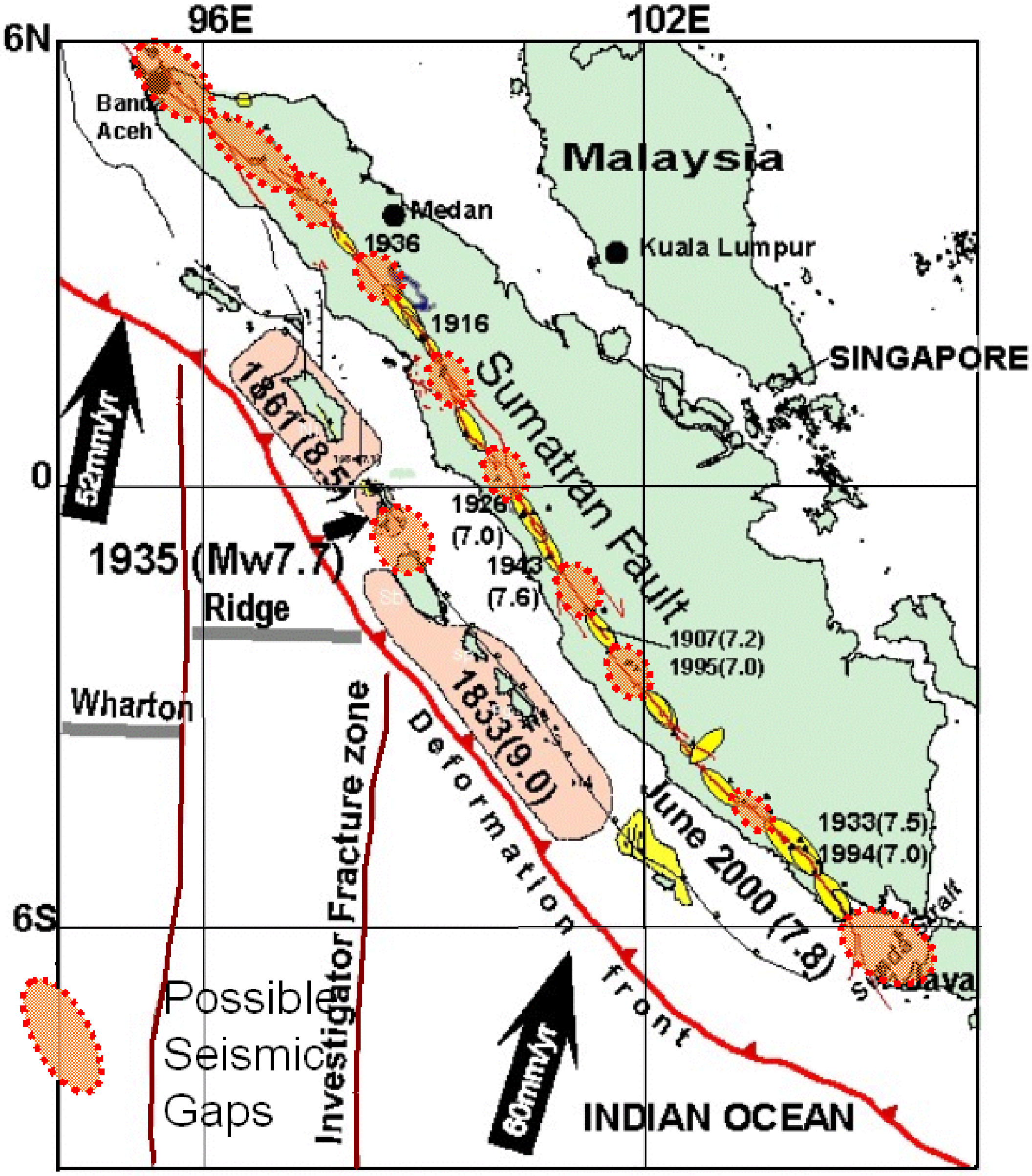


Fig.3.8 Possible seismic gaps along Sumatra Fault Zone (SFZ)

3.3 Tectonics and Seismicity of the Earthquake-affected Area

At the location of the earthquakes, the Indo-Australian plate moves northeast and subducts beneath Sunda plate at a velocity of about 60 mm/year. The direction of relative plate motion is oblique to the orientation of the plate boundary offshore of the west coast of Sumatra Island. The component of plate-motion perpendicular to the boundary is accommodated by thrust faulting on the offshore plate-boundary. Much of the component of plate motion parallel to the plate boundary is accommodated by strike-skip faulting on the Sumatra fault, (Figure 3.9).

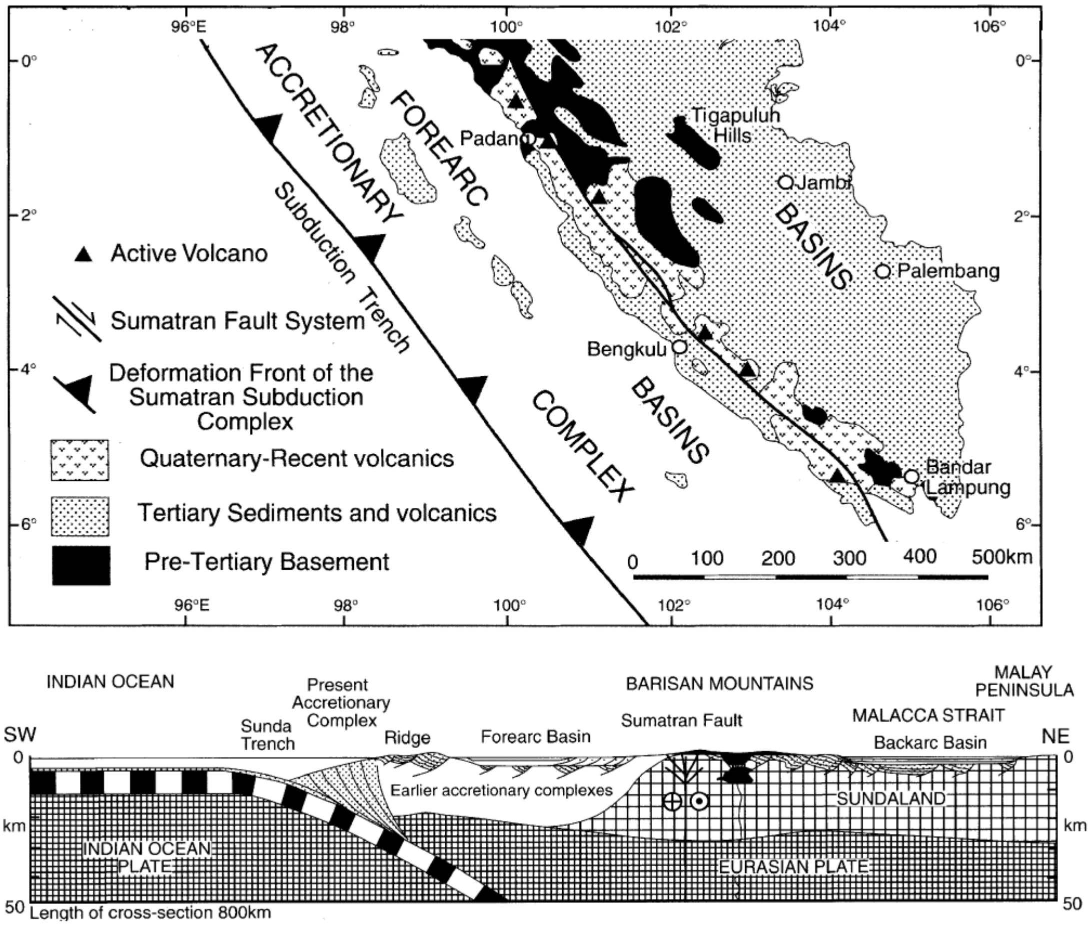


Fig.3.9 An illustration of tectonics and major geological units in the earthquake affected area (modified from Crow and Barber, 2005)

Bengkulu was hit by a 7.8-magnitude quake on June 4, 2000, which killed about 88 people and injured nearly 1,000 people seriously. The past seismic history of the epicentral area is not well known. However, it is reported that there was also an earthquake with a magnitude of 7.6 in 1914.

Figure 3.10 shows the seismicity prior the 2007 event since 1973. As noted from this figure, there are two areas of high seismicity. One of them is associated with 2000 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 3.11 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.

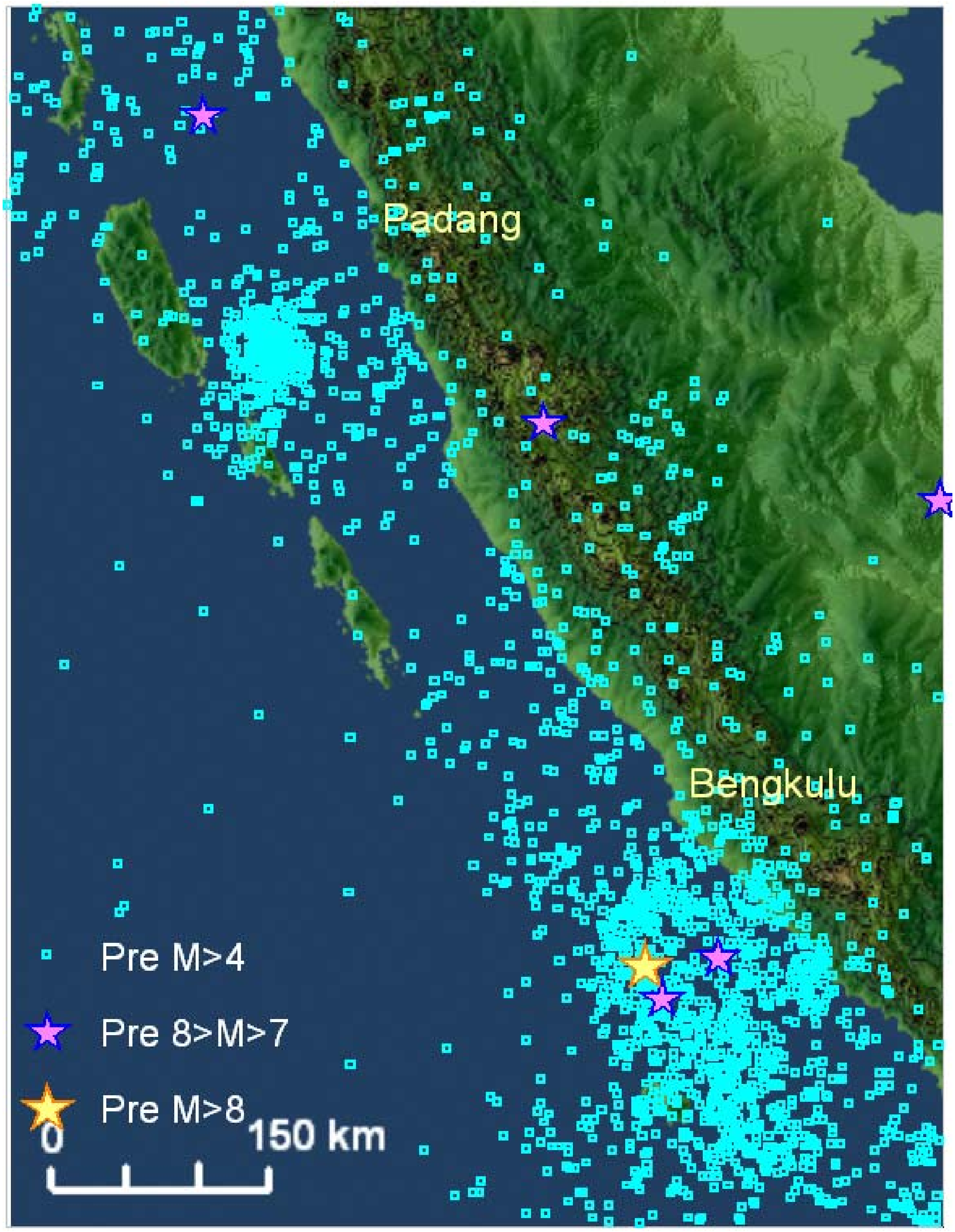


Fig.3.10 Distributions of epicenters of the earthquakes in the region bounded by Latitudes 0-6S and Longitudes 98-104E.

Figure 3.12 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.

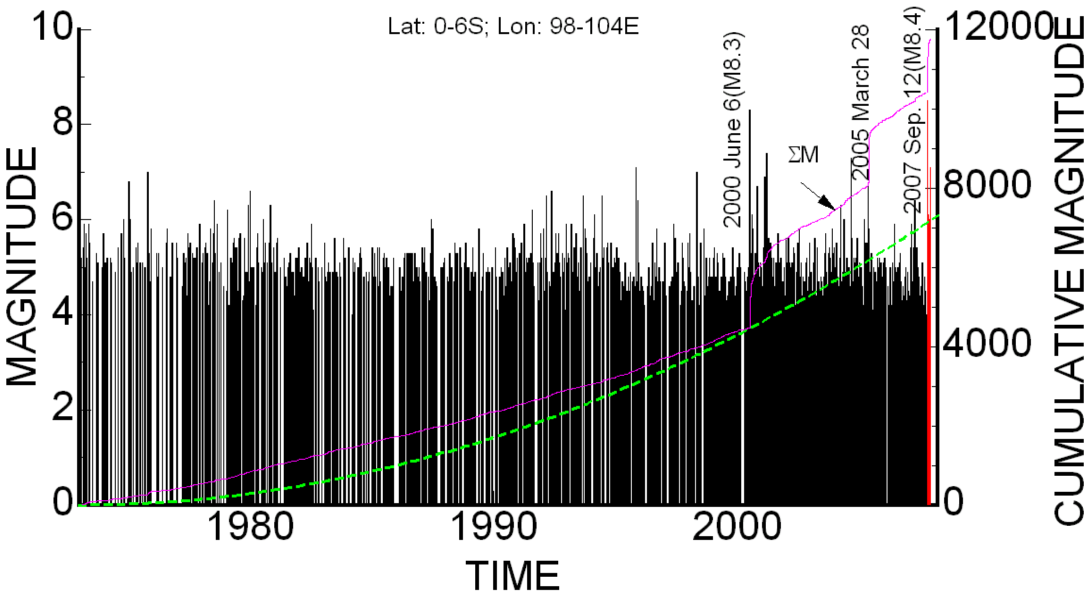


Fig.3.11 Variation of cumulative magnitude of earthquakes in the region bounded by Latitudes 0-6S and Longitudes 98-104E.

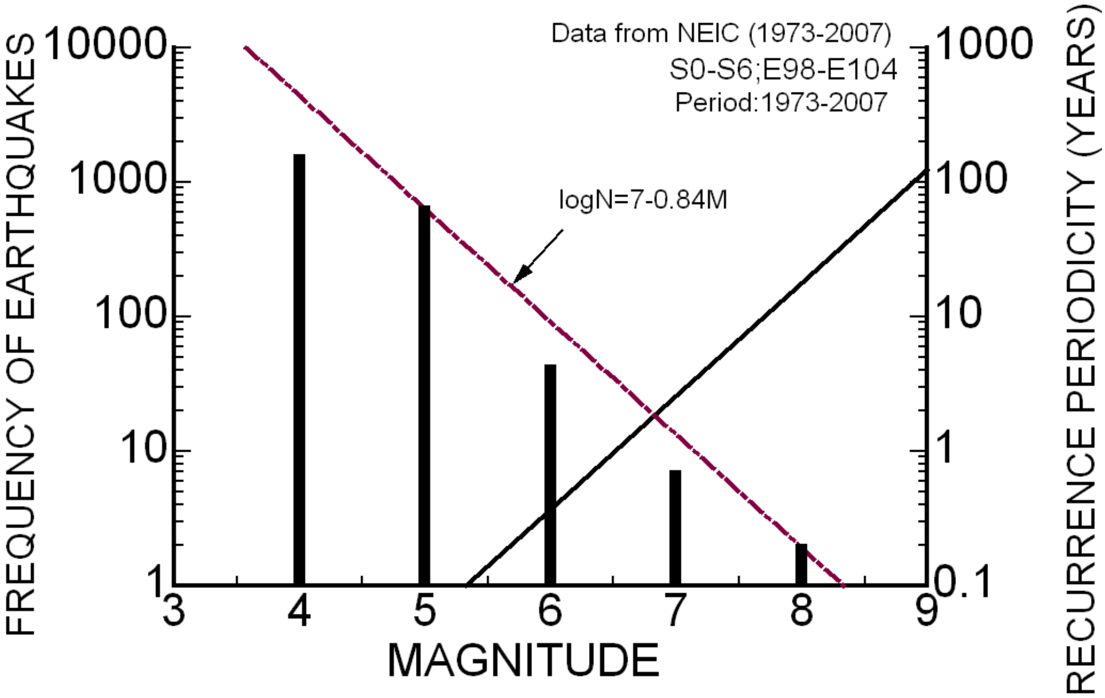


Fig.3.12 Gutenberg-Richter relation between magnitude and frequency of earthquakes in the region bounded by Latitudes 0-6S and Longitudes 98-104E.

4 CHARACTERISTICS OF THE EARTHQUAKE

The southern Sumatra earthquake of September 12, 2007 occurred as the result of thrust faulting at the boundary between the Indo-Australian plate and the Sunda plate. Some fundamental characteristics of the 2007 South Sumatra earthquakes, strong motions and causalties are described in this section.

4.1 Fundamental Characteristics

The earthquake took place as two large shocks on September 12, 2007 and September 13, 2007. The first event was at at 18:10 (11:10 UTC) with a moment magnitude of 8.4 and the second event with a moment magnitude of 7.9 was five and half hours later at 6:49 on the next day (USGS). The fundamental source parameters of the first shock and the second shock are given in Tables 4.1 and 4.2. Figure 4.1 shows the focal plane solutions by USGS-CMT and NIED for both shocks. Both institutes estimated the faulting was thrust faulting with none or 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 (Sunda) 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 although it has similar faulting mechanism. The estimated fault length for the first shock is about 280-300 km while the second shock may involve a 150km long fault. The slip analysis by Yagi (2007), Yamanaka (2007), Chen Ji (2007), indicated that the rupture of M8.4 earthquake fault started in the south and propagated in NE direction although which the computed values so different from each other. The direction and amount of slip on the land is maximum in the vicinity of Serangai and Ketaun, which may explain why damage was much heavier in this area compared to those in other areas (Figures 4.2 and 4.3).

Table 4-1 Main characteristics of the earthquake on Sept. 12, 2007(M8.4)

Institute	Mw	LAT (S)	LON (E)	DEP (km)	NP1 strike/dip/rake	NP2 strike/dip/rake	T_d sec
USGS-HARVARD	8.4	4.514	101.382	34.0	327/12/114	123/79/85	78
NIED	8.4	3.900	101.100	20.0	300/15/90	120/75/90	140

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)			
Yagi	8.2	25.0	327/18/112	350	225	115	2.5	2.1
Yamanaka	8.4	30.0	327/15/109	300	100	90		15
Chen Ji			323/12/	560	160			4.5

Table 4-3 Main characteristics of the earthquake on Sept. 13, 2007(M7.9)

Institute	Mw	LAT (S)	LON (E)	DEP (km)	NP1 strike/dip/rake	NP2 strike/dip/rake	T_d sec
USGS-HARVARD	7.9	2.525	100.964	10.0	319/19/105	123/71/85	42
NIED	8.0	2.700	100.500	20.0	315/15/105	119/76/86	108

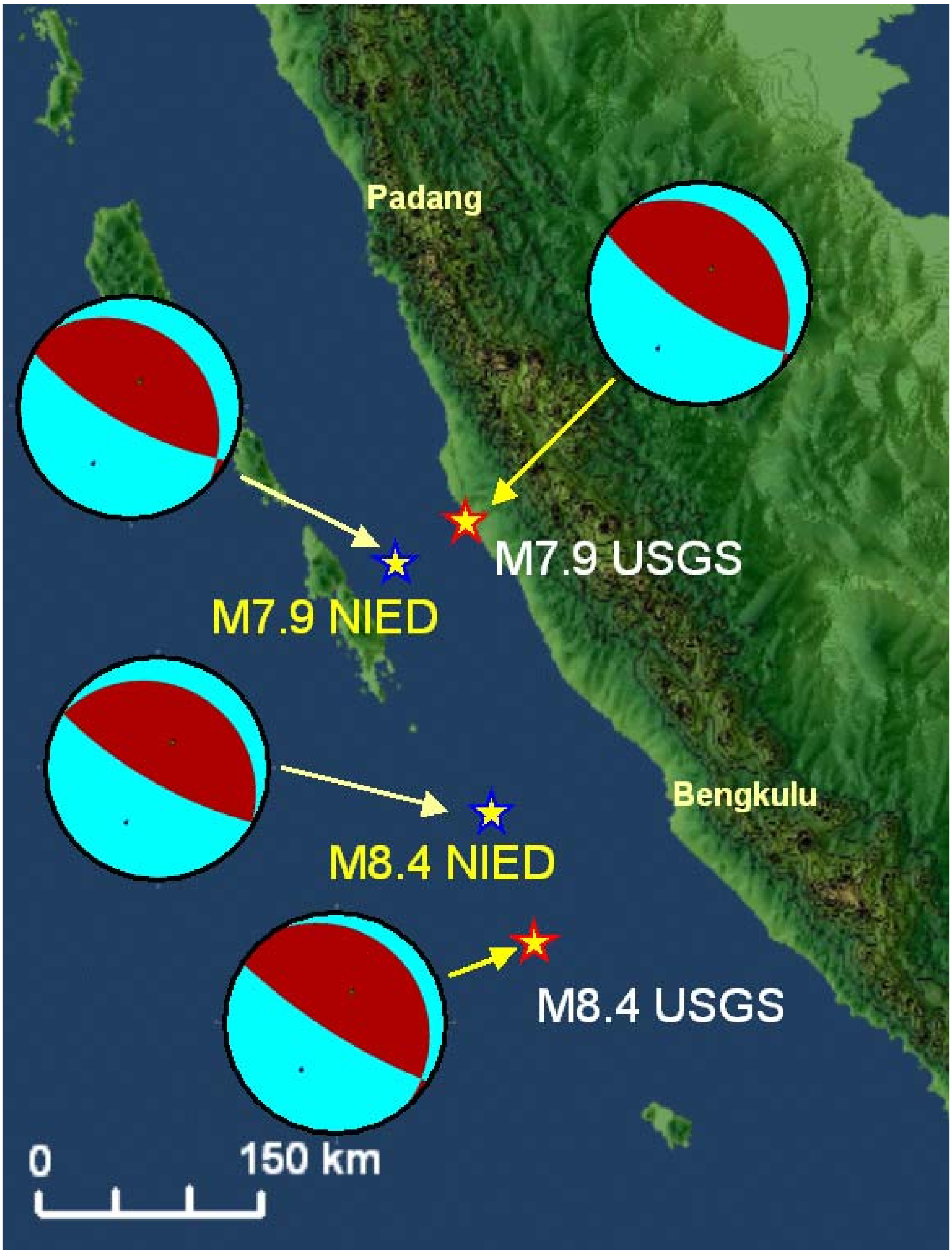


Fig.4.1 Focal plane solutions of NIED and USGS-CMT for M8.4 and M7.9 earthquakes

4.2 After-shock Activity

Except the immediate M7.9 shock on September 13, 2007, the largest aftershock in the vicinity of the fault zone had a magnitude of 7.1 at 10:35 AM (IST) on September 13, 2007 and 7.1 at 4:10 AM (IST) on October 25, 2007. The general trend of aftershocks seems to follow that of June 4, 2000 Bengkulu earthquake. The largest aftershock of the 2000 Bengkulu earthquake was 7.6.

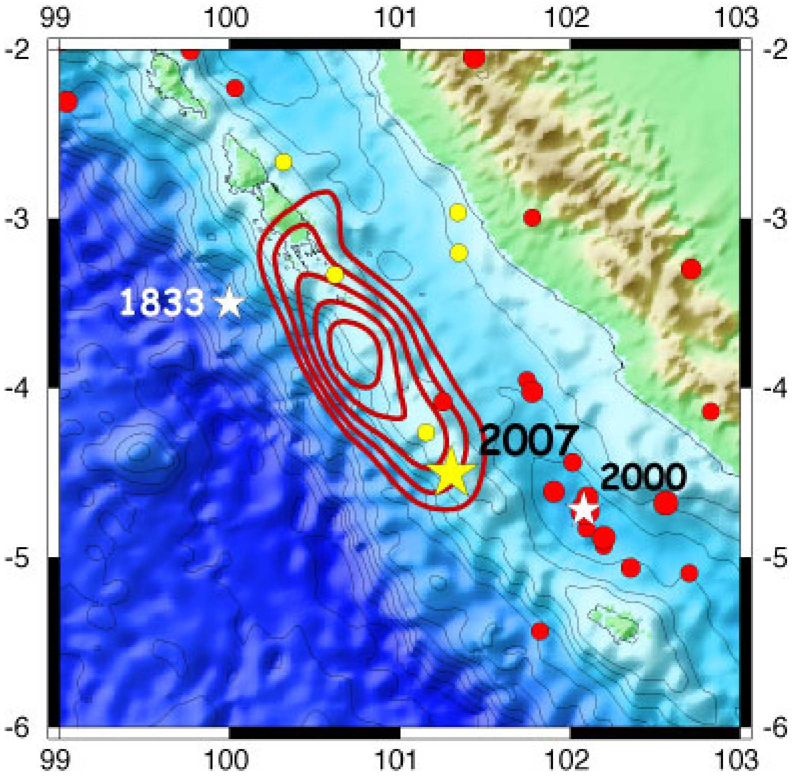


Fig.4.2 Estimated fault rupture (from yamanaka, 2007)

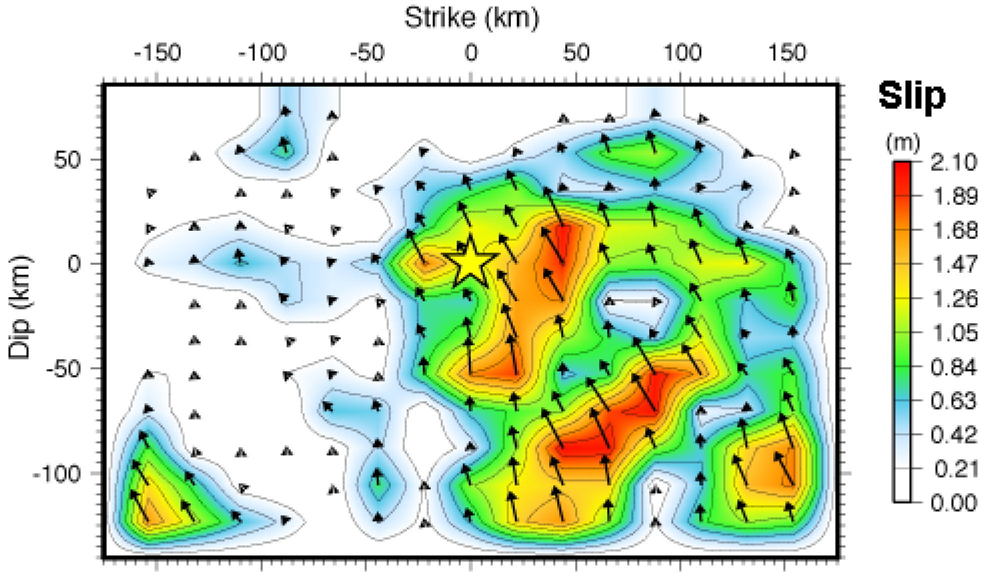
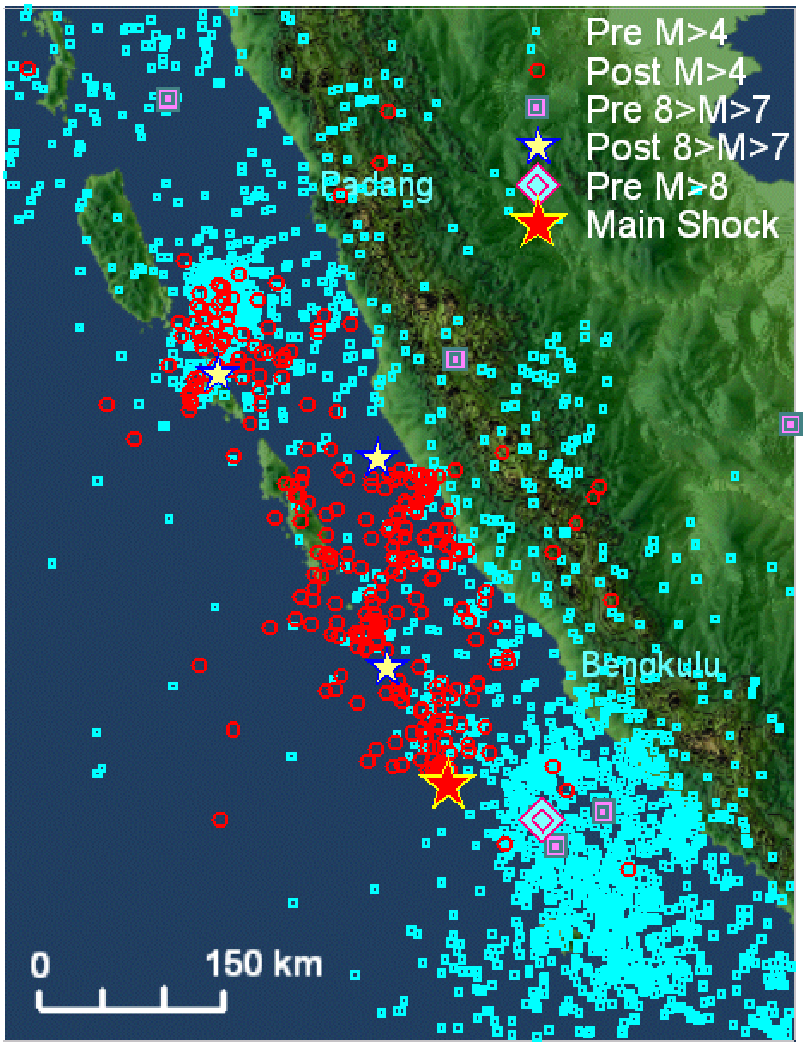
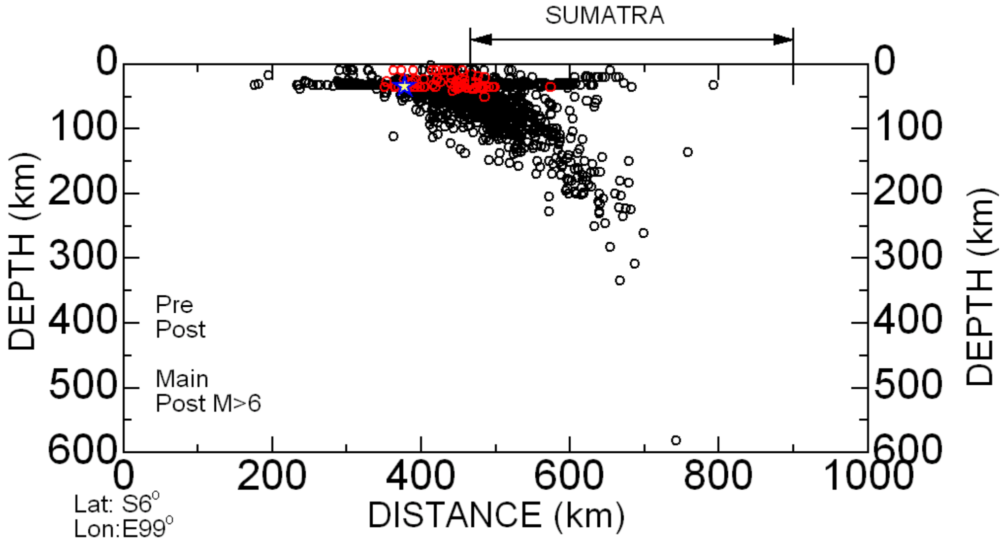


Fig.4.3 Estimated fault slip (from Yagi, 2007)

Figure 4.4 shows the distribution of epicenters of aftershock greater than magnitude 4 until October 25, 2007. The epicenters of aftershocks are distributed over the rupture surface estimated by Yamanaka (2007). Nevertheless some intensive aftershock activity is also noted in the vicinity of Sipora Island where the M7.1 aftershock took place at 10:35 AM on September 13, 2007. This area is regarded as the potential epicenter of the expected mega-thrust earthquake of the West Sumatra and its activity is of great concern.



(a) Distribution of pre-post epicenters of earthquakes



(b) A cross-section of pre-post seismicity perpendicular to the subduction zone

Fig.4.4 Pre-post seismicity of the earthquake affected area

4.3 Strong Motions

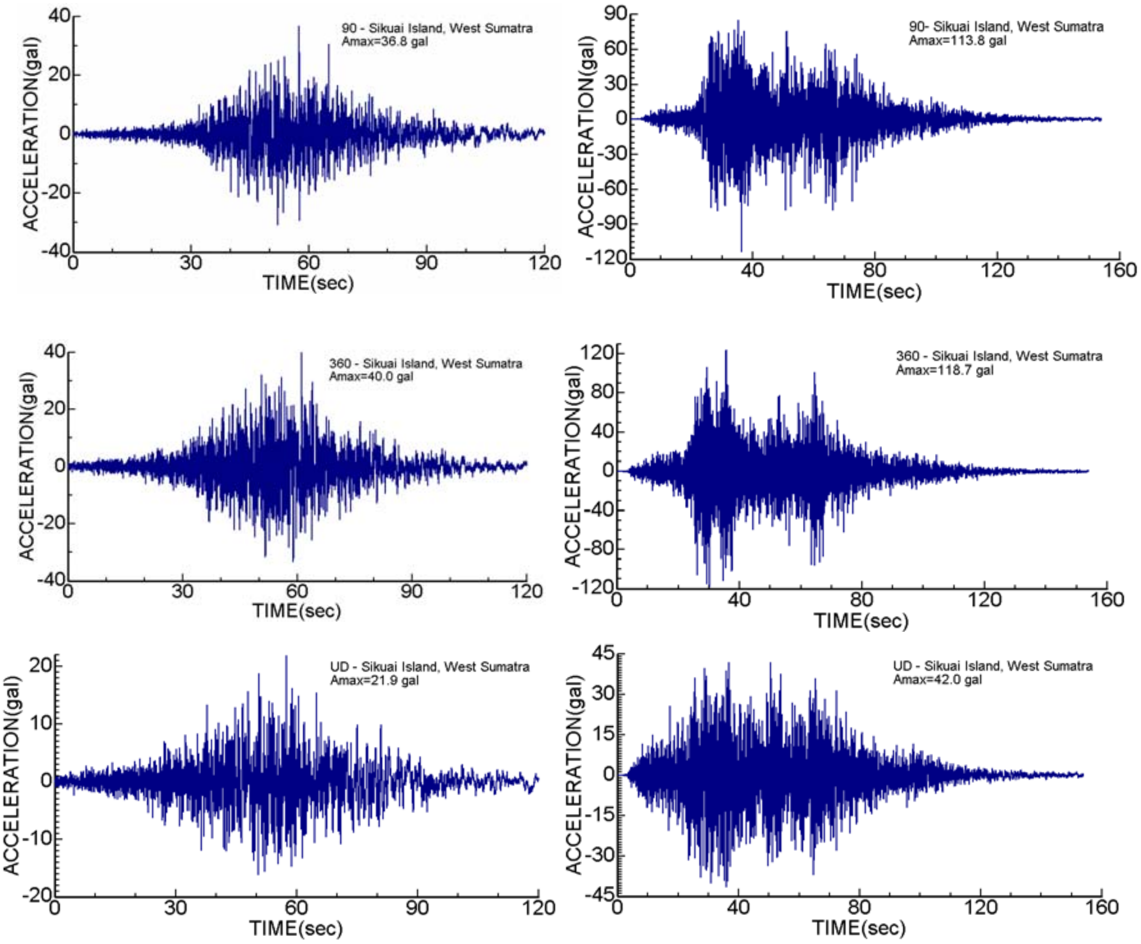
As happened in many earthquakes in Indonesia, there is almost no strong motion record for this earthquake except the one recorded at Sikuai (Sikawai ?) Island just south of Padang City (see Figure 2.1 for location) by USAID and operated by USGS. This strong motion records for this station are available for M8.4 event on September 12, 2007 , M7.9 and M7.1 events on September 13, 2007. The station is about 392 km away from the epicenter of M8.4 event and 165 km away from the epicenter of M7.9 event and the ground conditions at this station is not available yet. Nevertheless, it is expected to be fixed onto a hard ground. The records taken at this station are of great importance for the discussing the collapse of RC buildings in Padang City. The strong motion records for these two events are shown in Figure 4.5. The response spectra of records are also plotted and compared in Figure 4.6 and 4.7. While dominant periods ranges between 0.2 to 0.3, some long period components are observed for the earthquake with a magnitude of 7.1 as seen in Figure 4.7. Nevertheless, the responses may be said to be flat for a natural period ranging between 0.1 to 0.4 seconds.

Since the strong motion data is only limited to those of Sikuai station, the authors tried to infer the strong ground motions from toppled or displaced simple structures between Padang City and Bengkulu City. In this earthquake, one can find such simple structures in the epicentral area. Estimations based on simple structures according to the hypocentral distance (based on USGS estimation) are given in Table 4.4. The maximum ground accelerations and velocities are obtained at Serangai and Basar Bantal. There was severe liquefaction at Basar Bantal, which will be later discussed in Section 5.2, briefly.

Table 4-4 Estimated maximum ground acceleration and velocity at several locations

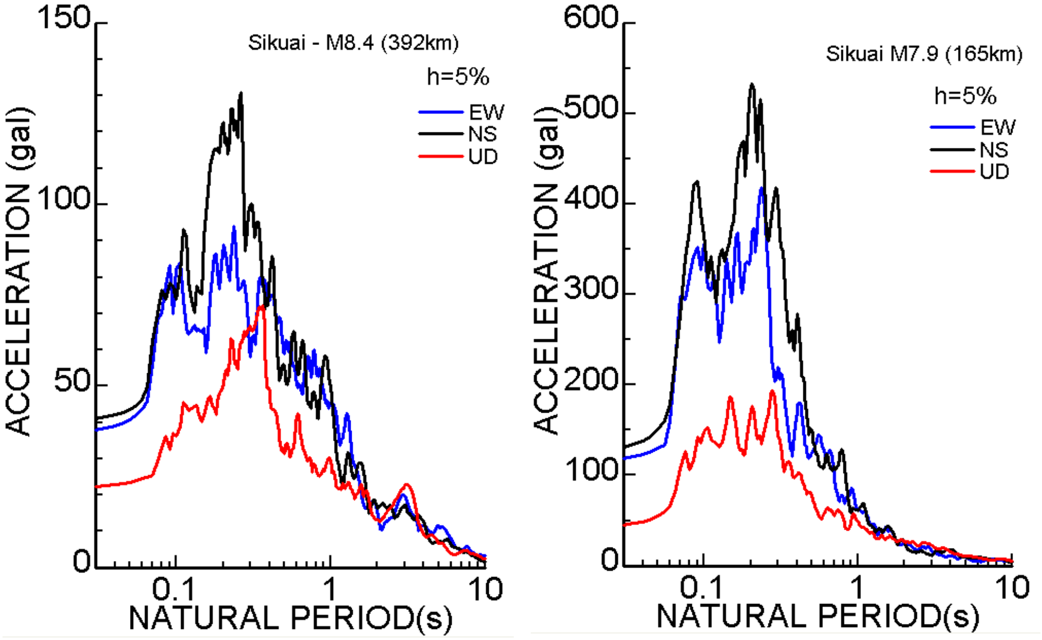
Location	Structure	R (km)		Amax (gal)	Vmax (kine)	I_{JMA}	I_{MM}
		M8.4	M7.9				
Padang	Wall	414.5	189	118	8.7	5-	7
Bungus	Wall	404.0	179	169	12.7	5-	7
Pasar Bantal	Canal Wall(liq.)	209	103	654	33.4	5+	8
Ketaun	Pole	138	136	235	18.7	6-	9
Serangai	Pole	137	101	382	28.6	6-	9
Lais	Wall	133	164	157	10.8	5+	8

Figure 4.8 shows a comparison of the attenuation of measured and inferred strong motion data with empirical relations proposed by Aydan (2007) for very soft and hard ground. The earthquakes are assumed to be of inter-plate type. Inspite of the simplicity of the method of inference, the results are close to those obtained from empirical relations. The inferred and measured results for the M7.9 event are remarkably close to the estimations from the empirical relations. However, it should be noted that it is quite difficult to differentiate the effects of M8.4 and M7.9 events unless the local people give additional information about the failure of the structure. Furthermore, the contours of maximum ground accelerations are computed for M8.4 and M7.9 events according to the formula given by Aydan (2007) and shown in Figure 4.9 and 4.10 with the consideration of epicenter locations determined by USGS and NIED. If USGS epicenter is used for M7.9 event, estimations are quite higher than observations. However, if the epicenters determined by NIED are used, the estimations are much closer to the inferred and measured ground motions..



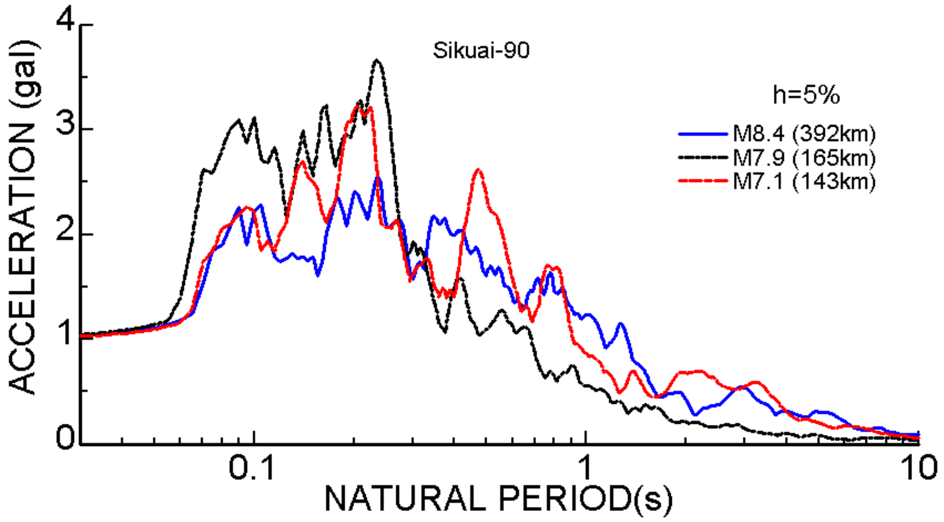
(a) M8.4 Shock (b) M7.9 Shock

Fig.4.5 Strong motion records for M8.4 and M7.9 events

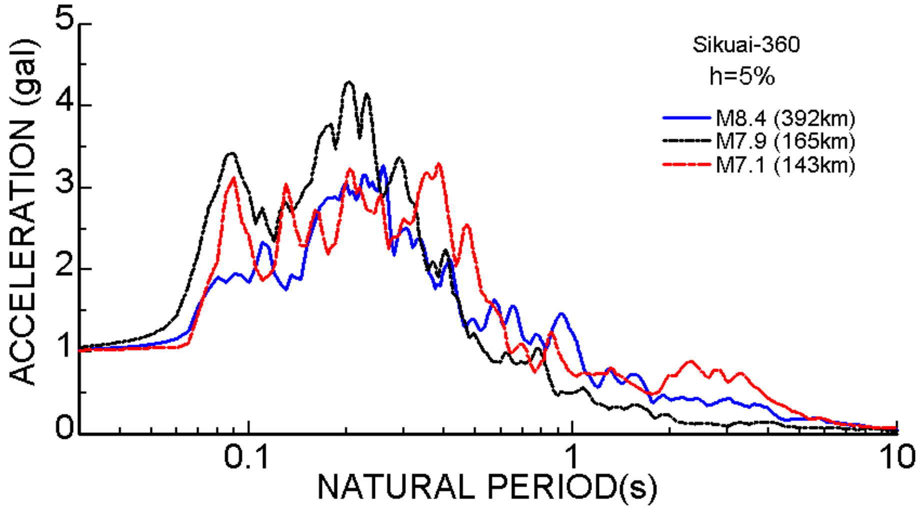


(a) M8.4 Shock (b) M7.9 Shock

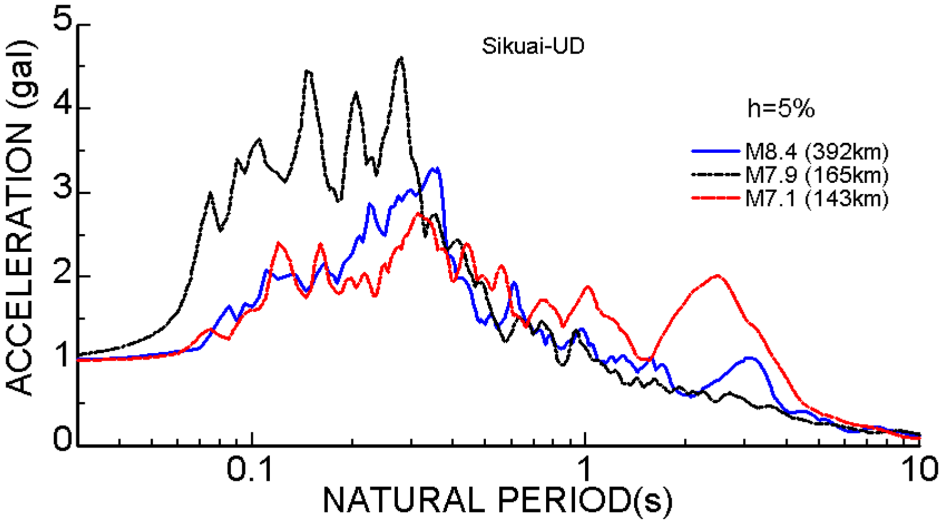
Fig.4.6 Response spectra of strong motion records for M8.4 and M7.9 events



(a) EW direction

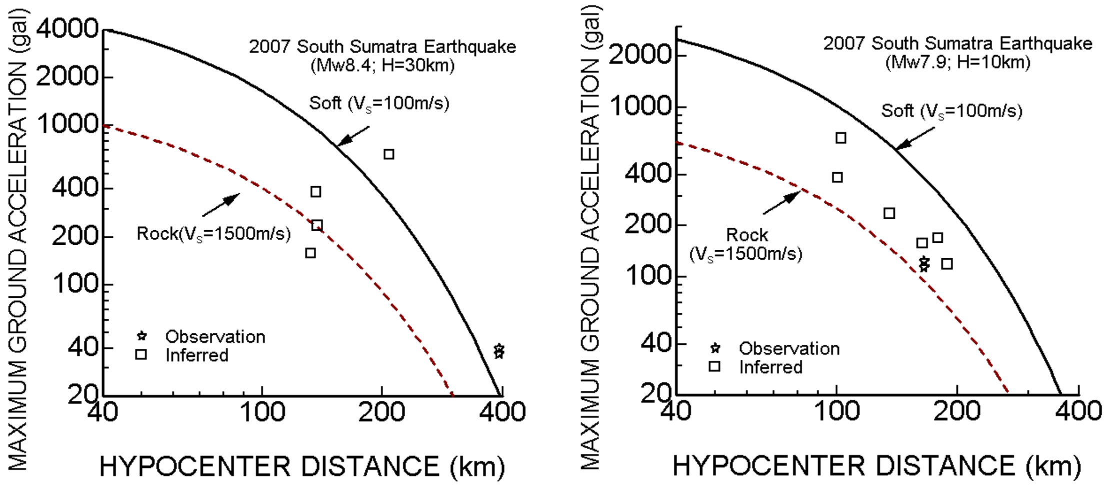


(b) NS direction

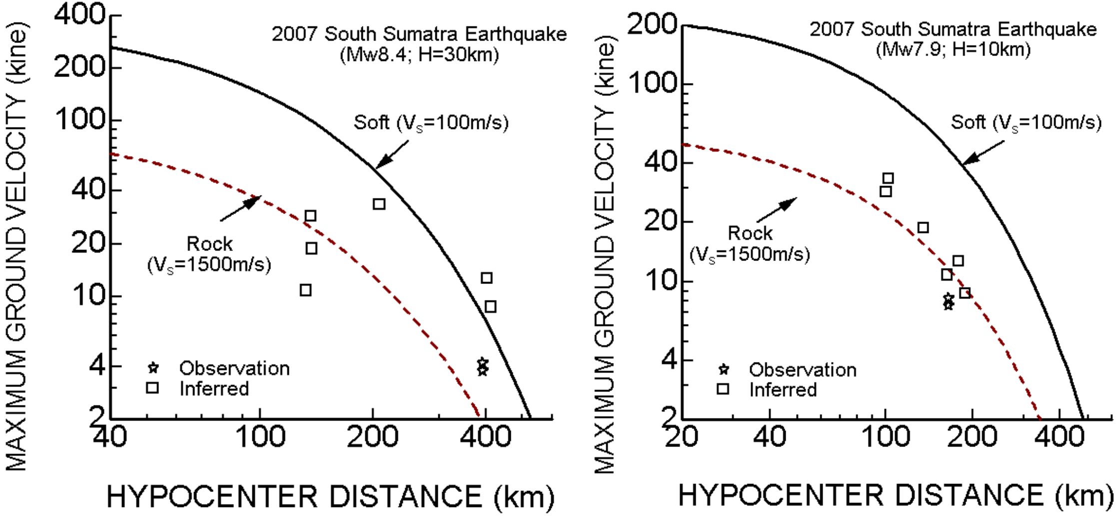


(c) UD direction

Fig.4.7 Comparison of response spectra of records at Sikuai station for each direction of M8.4, M7.9 and M7.1 events



(a) Amax (M8.4) (b) Amax (M7.9)



(c) Vmax (M8.4) (d) Vmax (M7.9)

Fig.4.8 Attenuation of maximum ground acceleration and velocity with distance

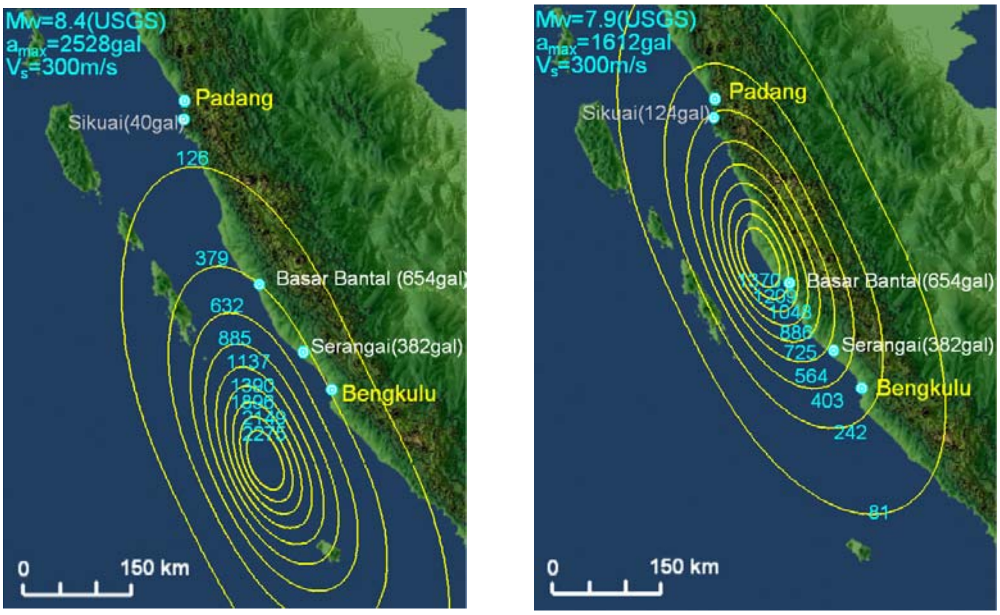


Fig.4.9 Contours of maximum ground acceleration for M8.4 & M7.9 events (epicenters determined by USGS)

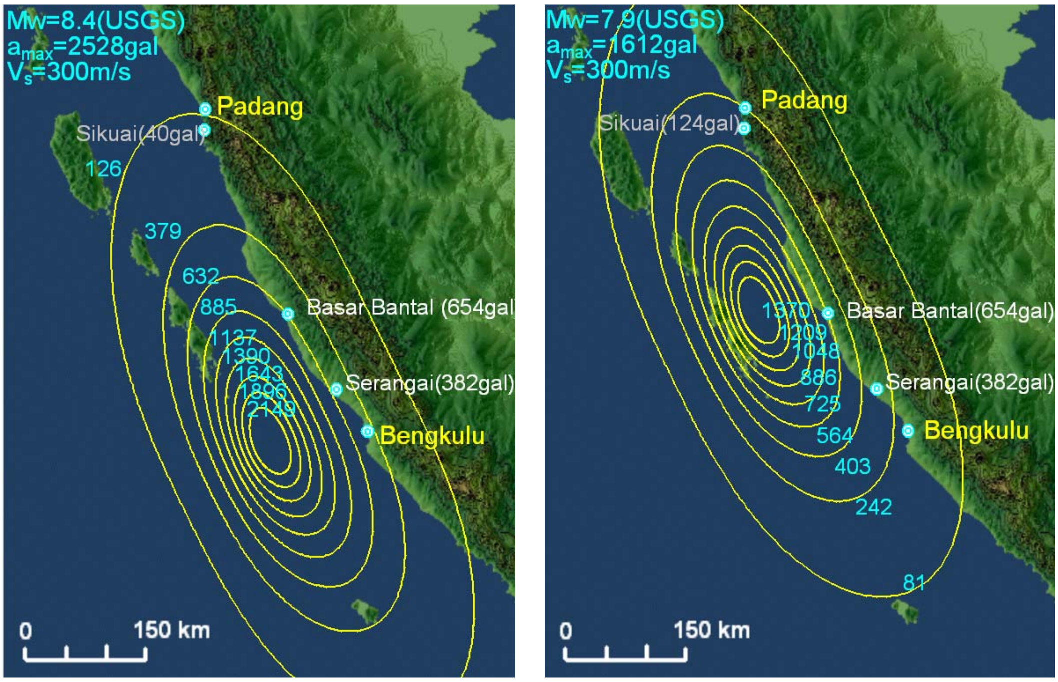


Fig.4.10 Contours of maximum ground acceleration for M8.4 & M7.9 events (epicenters determined by NIED)

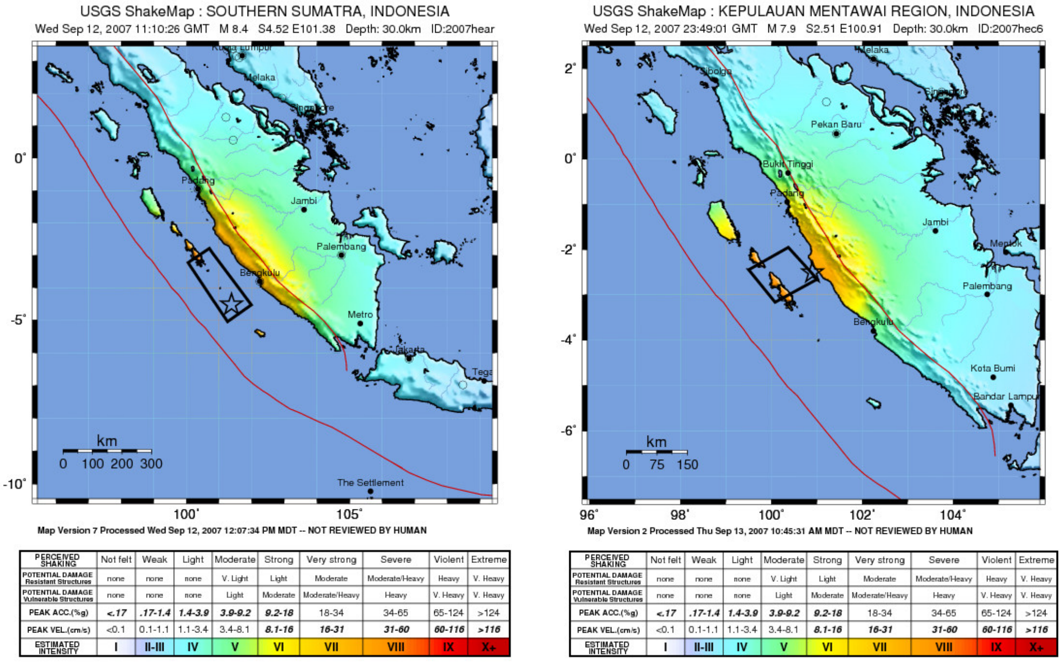
USGS also estimated the areal distribution of the maximum ground acceleration and maximum ground velocity according to some models based on the past records of the earthquakes and the results are shown in Figure 4.11 and 4.12. The USGS estimated the maximum ground acceleration and velocity to be about 340 gal and 32 kine in the vicinity of the epicenter. Although these estimations are slightly less than the ones presented herein, they are also of great help in understanding the causes of damage and structural responses during these earthquakes.

4.4 Casualties

Table 4.5 gives the number of casualties and injuries according the information released by the Natural Disaster Mitigation Coordination Agency (Bakornas). In-spite of the great magnitude of two earthquakes, the casualties and injuries are quite smaller compared to the recent 2005 Nias, Yogjakarta earthquake (2006 Central Java earthquake). One reason may be the attenuation of strong ground motions with distance and the other reason may be the low density of population. Most of houses are wooden or RC-like brick structures with a single floor. In-spite of severe damage to these structures, their failure did not result in casualties and injuries.

Table 4-5 Fatalies and injuries according to regions (data from BAKORNAS)

Area	*Fatalities*	Severe Injuries	Minor Injuries
Bengkulu	15	12	26
West Sumatra	10	29	25
Total	25	41	51



USGS ShakeMap : SOUTHERN SUMATRA, INDONESIA
Wed Sep 12, 2007 11:10:26 GMT M 8.4 S4.52 E101.38 Depth: 30.0km ID:2007hear

Map Version 7 Processed Wed Sep 12, 2007 12:07:34 PM MDT -- NOT REVIEWED BY HUMAN

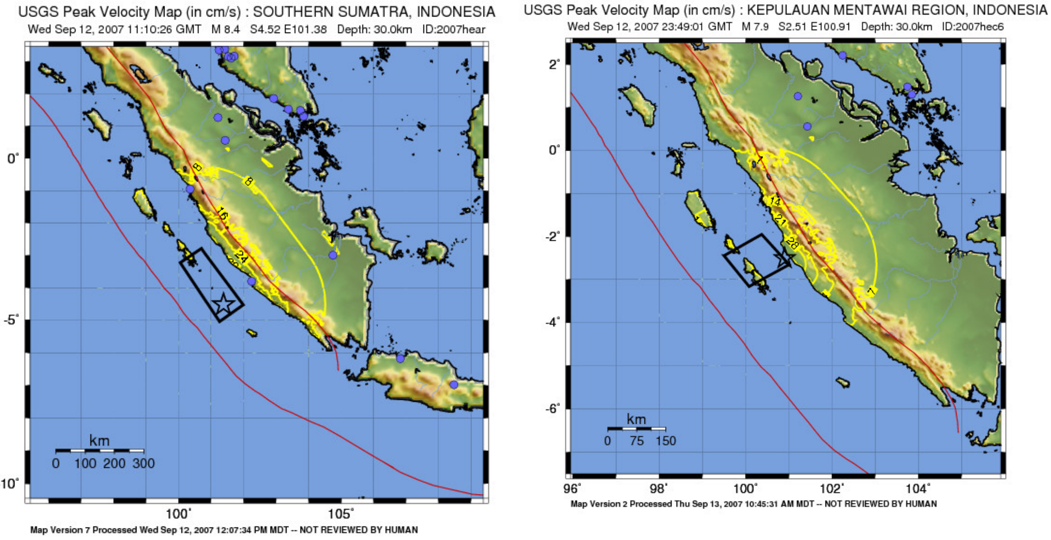
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

USGS ShakeMap : KEPULAUAN MENTAWAI REGION, INDONESIA
Wed Sep 12, 2007 23:49:01 GMT M 7.9 S2.51 E100.91 Depth: 30.0km ID:2007hec6

Map Version 2 Processed Thu Sep 13, 2007 10:45:31 AM MDT -- NOT REVIEWED BY HUMAN

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Fig.4.11 Estimated maximum ground accelerations by USGS for M8.4 and M7.9 events



USGS Peak Velocity Map (in cm/s) : SOUTHERN SUMATRA, INDONESIA
Wed Sep 12, 2007 11:10:26 GMT M 8.4 S4.52 E101.38 Depth: 30.0km ID:2007hear

Map Version 7 Processed Wed Sep 12, 2007 12:07:34 PM MDT -- NOT REVIEWED BY HUMAN

USGS Peak Velocity Map (in cm/s) : KEPULAUAN MENTAWAI REGION, INDONESIA
Wed Sep 12, 2007 23:49:01 GMT M 7.9 S2.51 E100.91 Depth: 30.0km ID:2007hec6

Map Version 2 Processed Thu Sep 13, 2007 10:45:31 AM MDT -- NOT REVIEWED BY HUMAN

Fig.4.12 Estimated maximum ground velocities by USGS for M8.4 and M7.9 events

5 GROUND SHAKING INDUCED DAMAGE

5.1 Buildings

5.1.1 Mosques

Mosques are semi-reinforced concrete structures. Although reinforced columns and beams are utilized, they are quite small in cross section (15x15 to 20x20cm) and they have 4-6 smooth steel bars with a diameter ranging between 8-12mm. The walls are either hollow cement blocks or bricks. The roof of mosques are generally light. The earthquake caused the failure of outer columns and load-bearing walls at corners and subsequent collapse of roofs (Figure 5.1).

(a) Punggasan (b) Serangai

Fig.5.1 Damage to mosques

5.1.2 Masonry Buildings

Masonry buildings are generally constructed with bricks and they are either one story or two story buildings. Old masonry buildings has no reinforced concrete lintels and/or columns. Such collapses were observed even in areas with high ground acceleration, (Figure 5.2) New constructions utilize reinforced concrete lintels and columns. There is no doubt that when such structural elements are integrated with masonry walls they perform better and they prevent the total collapse of the buildings in-spite of some structural damage.

Fig.5.2 Collapsed or heavily damaged brick masonary houses

5.1. 3 Wooden Houses

There are many wooden houses. Compared to brick masonary houses with or without RC lintels and/or columns, they performed better and there was almost no total collapse due to ground shaking. However, they failed due to the embankment failures as seen in Figure 5.3

Fig.5.3 Total collapse of a wooden house in Pasir Banting due to embankment failure

5.1. 4 RC Buildings

RC buildings with two or three stories suffered heavily from the earthquakes. Many RC buildings either totally collapsed or heavily damaged in Padang City even though they were about 400km away from the epicenter. The reinforced concrete structures are framed structures with integrated or non-integrated in-fill walls. The reinforcing bars are generally smooth and infill walls are built with red-burned solid clay bricks using mortar. The floor height in the region ranges between 3 to 4m. The inspections of the reinforced concrete buildings indicated that they are mainly failed in the pancake mode. RC buildings are generally found in cities and large towns. The concrete buildings having 2 or more stories were either collapsed or heavily damaged. The causes of damage to RC buildings are similar to those observed in other recent earthquakes in Indonesia and elsewhere (Figures 5.4). They may be re-stated for this earthquake as follows:

a. Soil liquefaction and lack of the soil bearing capacity (particularly in Padang)
b. Large ground settlement of embankments nearby river banks
c. Fragile structural walls and lack of lateral stiffness,
d. Poor concrete quality and workmanship,
e. Plastic hinge development at the beam-column joints,
f. Lack of shear reinforcement and confinement,
g. Soft story,
h. Pounding and torsion and

Ground motion characteristics (i.e. multiple shocks etc.).

(b) School building

(a) Padang

(c) Collapsed show room in Argamakmur

(d) Mitsubishi showroom

Fig.5.4 Examples of damage to RC buildings

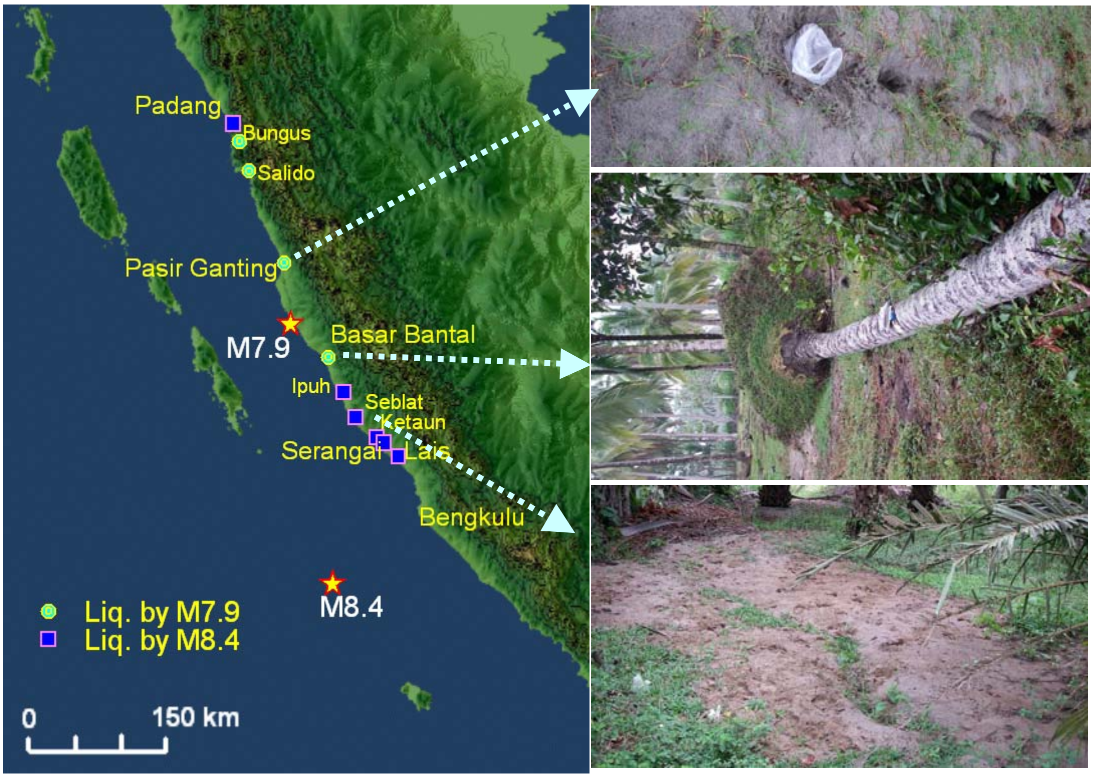
Many RC buildings suffered some damage and repairs implemented are just to re-plaster the cracks caused by the ground shaking (Figure 5.5). These buildings are probably the most vulnerable to collapse during a next strong earthquake.

Fig.5.5 Re-Plastered columns of an RC building used as an hotel in Padang

5.2 Geotechnical Damage

5.2.1 Liquefaction and Lateral Spreading

Ground liquefaction were observed in many places along the sea-coast and banks of major rivers (Figure 5.6). Except the heavy damage to a newly constructed 60m long arch bridge by ground liquefaction, the effects of liquefaction on structures such as bridges were quite small. However, the ground liquefaction did cause some damage to abutments of bridges and resulted in the non-uniform settlement of bridge foundations. Furthermore, lateral spreading was observed even in Padang City. The good engineering design bridges against ground failures and liquefaction could be a factor on the limited effects of ground liquefaction on super structure. Figure 5.7 shows the grain size distribution of soil samples from sand boils from Pasir Ganting, Basar Bantal and Seblat bridge.



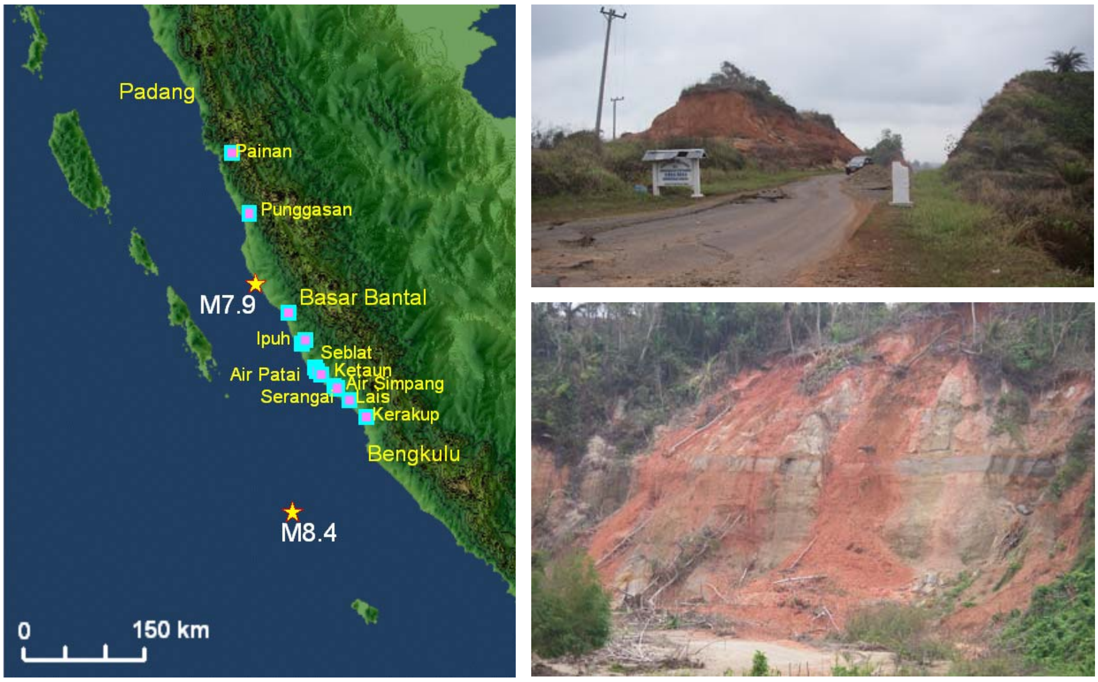
(a) Locations of observed liquefaction (b) views of some ground liquefaction

Fig.5.6 Locations and views of sites where ground liquefaction were observed

5.2.2 Slope and Embankment Failures

Extensive slope failures observed in along the coastal road between Padang and Bengkulu (Figure 5.7). The number of slope failures between Ketaun and Lais was much higher as compared with those in other areas. The slope failures took place within the volcanic sediments and volcanic sedimentary soft rocks. However, most of slope failures were shallow seated.

Embankment failures of roadways and rivers were also widespread in the area where the ground motions were high. The embakment failures at infilled sections of the roadways were quite severe and the general trend was quite similar to those observed in Noto Toll Road (Figures 5.8). Since the ground was more resistant and ground shaking was mild, the translational movements did not cause the total collapse of the embankments. Furthermore, the approach embankments of bridges were severely damaged by settlement and lateral spreading of ground at their base.



(a) Locations of observed slope failures (b) views of some slope failures

Fig.5.7 Locations and views of sites where slope failure were observed

Fig.5.8 Some examples of failures of embankments of roadways

5.3 Transportation Facilities

5.3.1 Roadways

The roads are open to traffic and accessible to affected areas. Damage to roadways was caused at several places due to surface ruptures and embankment failures along the rivers and rock cuts (Figures 5.7 and 5.8). Some of these roadways were re-asphalted while some of them were re-surfaced with soil. The roadway embankments along the shore-line between Ketaun and Lais were extensively damaged.

5.3.2 Bridges

Bridges in the epicentral area are truss, arch or simple beam bridges. The earthquake shaking did not cause any major damage to the bridges of roadways even in the nearest location to the epicenter of the earthquake (Figure 5.9) except the newly built arch bridge at Pasir Ganting. The damage to bridges were caused by the failure of approach embankments and uneven settlement of piers (Figure 5.10 and 5.11). However, almost all bridges were open to traffic with some speed limitation.

Fig.5.9 Damage to the arch bridge at Pasir Ganting due to ground liquefaction

Fig.5.10 Slight damage to Seblat River Bridge due to uneven settlements

Fig.5.11 Damage to approach embankments of bridges

5.3.3 Airports

The airports in the earthquake-affected area are Tabing air-force airport and Minangkabau civil airport in Padang City and Bengkulu airport. Minangkabau airport is newly re-built in 2001 by Shimizu Corporation and PT Adhi-Karya through a soft loan 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 damage to its runway and terminal building. Furthermore, the airport traffic was not suspended following the earthquake. Some cracks can be observed in the terminal building of Bengkulu airport.

However, there was no major structural damage to the runway and control towers of the Bengkulu airport.

5.3.4 Lifelines

Power lines and communication were cut in the affected region following the earthquake (Figure 5.12). In some areas, electricity has returned to normal soon after the earthquake. At some locations, where shaking or geotechnical damage was heavy, some power lines were damaged. The electricity was fully recovered in the next day.

Telephone lines were temporarily cut off and jammed but started functioning again in the next day of the earthquake. PT Telkom reports that there was no damage to communication networks caused by the earthquakes.

Fig.5.12 Views of some damage to utility poles and a non-damaged elevated water tank

5.4 Industrial Facilities

Most of industrial facilities are located in Bengkulu City of Bengkulu Province and in Padang City and Teluk Bayur Port of West Sumatra province. The inspection of some industrial plants between Padang and Bengkulu indicated that the earthquake did not cause any major damage to industrial facilites except some small scale damages to connections and rolers etc. (Figure 5.13 and Figure 5.14)

Fig.5.13 Tank yards in Teluk Bayur Port of Padang Ciity and Painan City

Fig.5.14 Slightly damaged Conveyor of loading facility at Teluk Bayur Port

6 TSUNAMI

6.1 Generation of the 2004 Banglahulu Tsunami (South Sumatra)

A tsunami caused by a great earthquake of M=8.2 occurred offshore Banglahulu, where a seismic gap is pointed out after the 2004 Sumatra earthquake in Indian Ocean, on 12 September and hit the coastal area in the western Sumatra, which resulted in a death toll of nearly 25 people and great damage on the area. The several aftershocks have been generated so far including the earthquake of M7.9 on 13 September, which also generated the tsunami.

The tsunami was to be a water wave train generated by impulsive disturbances of water surface due to the fault motion from the offshore of the southwestern Sumatra where the Indian-Australia plate is subducting under the Eurasia one and several earthquakes with M=8-8.5 have happened followed by tsunamis in the past.

The nature of damages by this earthquake is similar to the great earthquakes with magnitude over 8, which will occur along the Nankai Trough in Japan, but their epicenters are very close to the land. They will generate strong ground motion and great tsunami. We in Japan should remind that the similar damage due to the earthquake and tsunami should happen, so that the mechanism of them should be studied and the lessons should be shared.

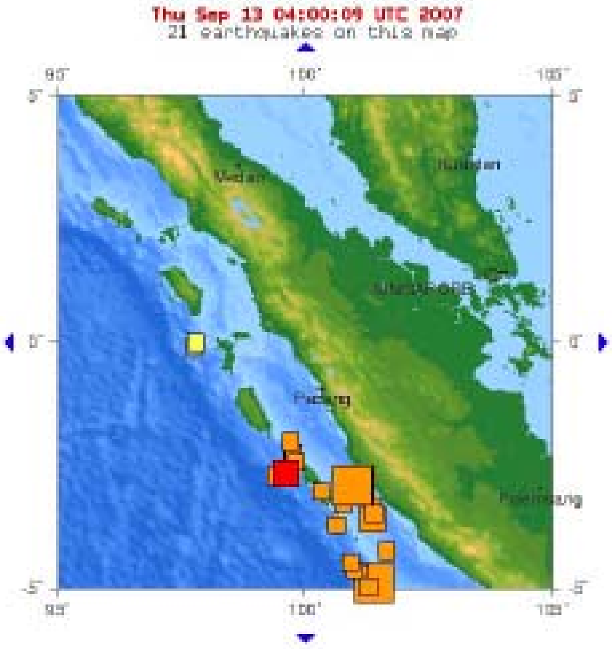


Fig.6.1 USGS earthquake information of the main shock and aftershocks in the west-southern Sumatra Is.

The earthquake induced tsunami after the 2004 Sumatra of M= 9.2 in Indian ocean was generated, followed by the trans-oceanic tsunami generated in the trench propagating mainly toward east and westward direction because of the wave directivity of energy. There is a seismic gap in the west of Sumatra between the 2005 Nias earthquake and the edge of south Sumatra, which should generated an earthquake followed by a tsunami in near future.

Figure 6.2 shows the main shock and aftershocks in September 2007, suggesting the tsunami source area offshore Banglahulu, in which there is a negative source in a shallow sea region and positive one in the deep sea. The pattern of sea bottom displacement suggest that the tsunami would recede in the first and the positive wave proceed to follow along the coast of the western Sumatra. The ranging 2-4 m runup heights in the western shore of the Sumatra could be estimated by the simulation.

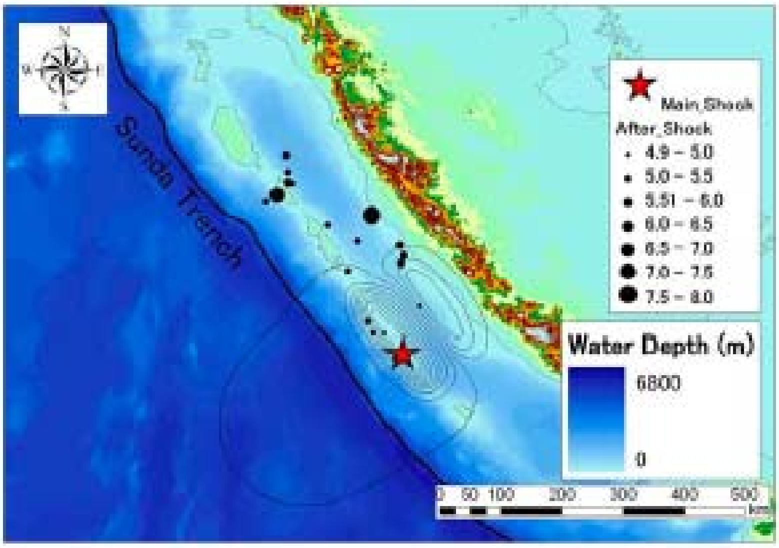


Fig.6.2 The main shock and aftershocks in September 2007, suggesting the tsunami source area

Figure 6.3 is one of example of the tidal records to measure the sea level change during the tsunamis attacks at Padang city which station renewed recently with the real time data transmission is shown in Figure 6.3. The tsunamis were generated by the not only main-shock and but also M=7.9 aftershock on 13 September. The receding wave was observed in the beginning.

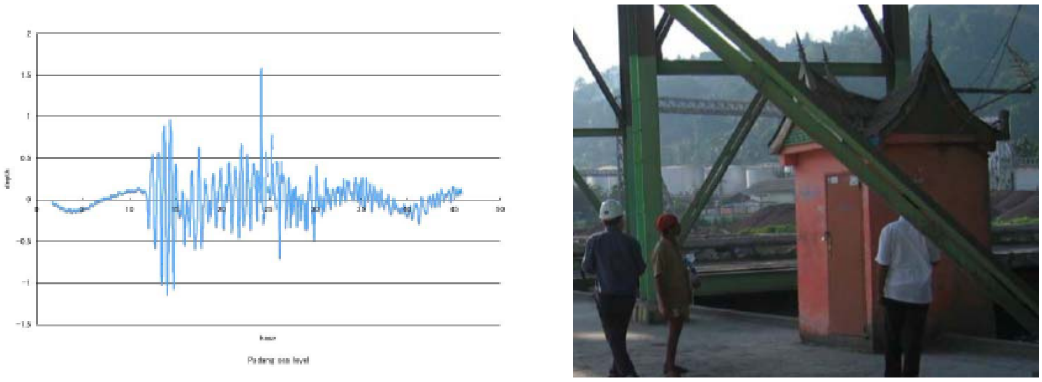


Fig.6.3 Tidal records in Padang on 12 September

6.2 Effect of the tsunami in 2004 and 2007

Due to the Indian tsunami disaster on December 26, 2004, countries around the Indian Ocean were severely damaged. Rebuilding and recovery processes have been carried out with help from both national and international agencies. Meanwhile, the efforts are still in their initial stages. Many people have yet to re-establish secure livelihoods, and continue to need relief assistance. On country levels, environmental and disaster management programs are required for protection and prevention of future disasters. Lessons of the catastrophe can be summarized into the following:

- Developing the monitoring and warning system with information technology evacuation system
- Integrated disaster mitigation program for each region to mitigate tsunamis as well as typhoons, erosion and flood.
- Data Base to compile the all available data; measured and observed, videos and photos, interview and media in newspaper
- International network for the community for research, education and Hazards map for society

Almost three years have passed since the 2004 Sumatra. The 2006 earthquakes in the middle and southwest of the Java were triggered to be happened by the 2004 earthquake. The huge damage of destroyed houses and killed people in two events were repeated to be caused, meaning that the lessons of the 2004 Sumatra have been not yet shared and the developing countermeasure in the country is still under the process. Especially the large number of casualties in the 2006 SW Java was reported to be caused by the tsunami because of the less information of the tsunami, no warning, and less evacuation under the law awareness among the people there.

In this event of the 2007 south Sumatra earthquake, much less damage by the tsunami has been reported. This is the important case to know what condition can reduce the damage and what issues are still not solved.

The numerical simulation of the tsunami in the 2007 Banglahulu, Sumatra is carried out to know the impact and hazard to the coastal area in the west.

For the tsunami simulation, the estimation of the source by using fault parameters is important, we assumed that the fault length; L=1.7E+5 in meter , width; W=8.4E+4 m, slip direction; TH=327,slip angle; DL=12.0, dislocation angle ; RD=114., focal depth=23.3E+3 m, dislocation ; D=7.52 m.

The tsunami numerical simulation with the above parameters of the fault gives us the information on the maximum water level and time histories at several points. Figure 6.4 shows the example of the results from the simulation, indicating the large tsunami energy found along the coast near Banglahulu. And figure 6.5 shows the comparison between computed and measured time history of water level at the tidal station of Padang, which shows the very good agreement.

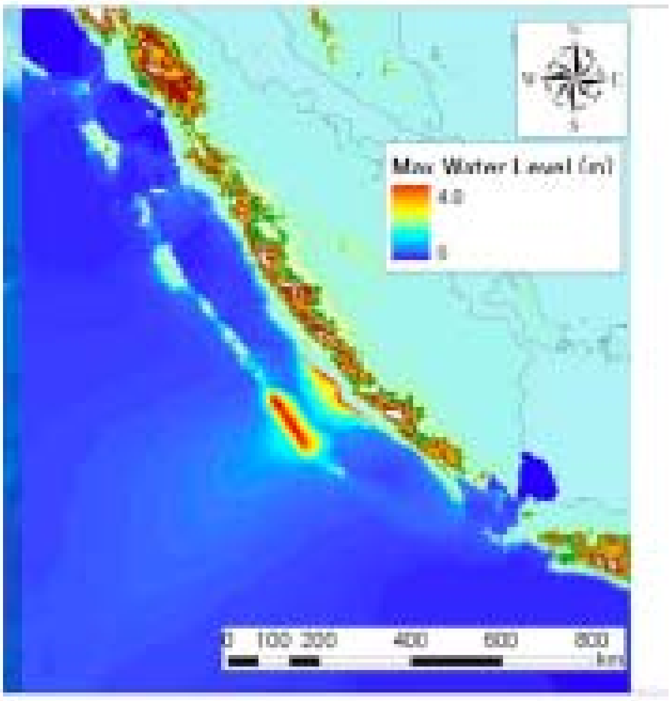


Fig.6.4 Maximum water level estimated by the tsunami simulation

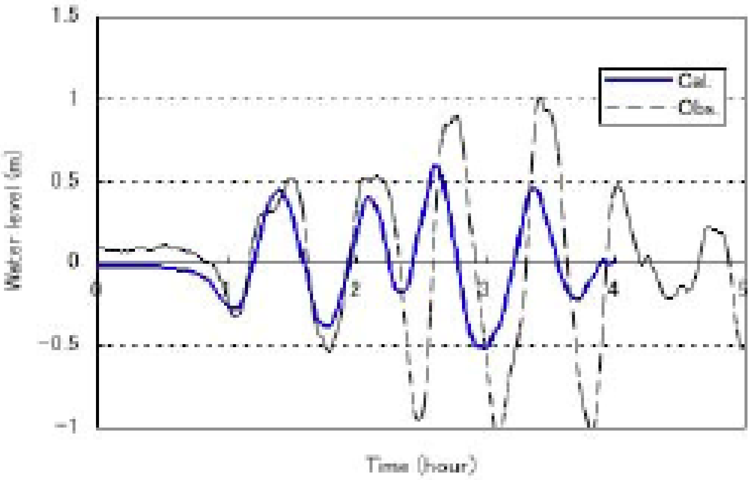


Fig.6.5 Time history at the tidal station of Padang

6.3 Field Survey in the damaged area

The international tsunami community conducts many field investigations immediately after an event: e.g. Nicaragua in 1992; Flores Island, Indonesia, in 1992; Okushiri Island, Japan, in 1993; East Java, Indonesia, in 1994; Shikotan Island, Russia, in 1994; Mindoro Island, Philippines in 1994; Irian Jaya, Indonesia, in 1996; Indian Ocean in 2004 [e.g. Yeh et al. (1993), Synolakis et al. (1995), Imamura et al. (1997)].

Members of the ITST (International tsunami Survey Team) decided that a field survey was necessary as soon as possible to try and determine the true value of the maximum run-up and to make an accurate map the run-up distribution along the coast. Subsequent investigations by international and locally-based scientists included two onshore investigations by international teams (the First and Second International Tsunami Survey Teams). The standard of the way of tsunami survey is compiled by IOC(1998). Another role of the ITST has been to advise the government and the survivors about the safety of this sector of coastline.

In the 2007 south Sumatra earthquake and tsunami, the 1st and 2nd team were conducted to visit the affected coastal area from Banglahulu to Padang. There are some gaps of non-measured points by the two teams, which are our target area to make field survey of the tsunami in order to fill in. The figure 6.6 shows the area surveyed by the 1st and 2nd teams. We try to visit the gaps of the area.

When we reach to the area for the tsunami survey, we try to find the eyewitnesses who directly watched the tsunami or its trace on the wall or the tree. The behavior of the tsunami as well as the response of the people are interviewed and compiled into the filed note. Once we confirm the traces of the tsunami, we try to measure the height of them above the ground and the sea level at the time when we measure during the survey. The heights should be corrected by the tidal level when the tsunami attacked.

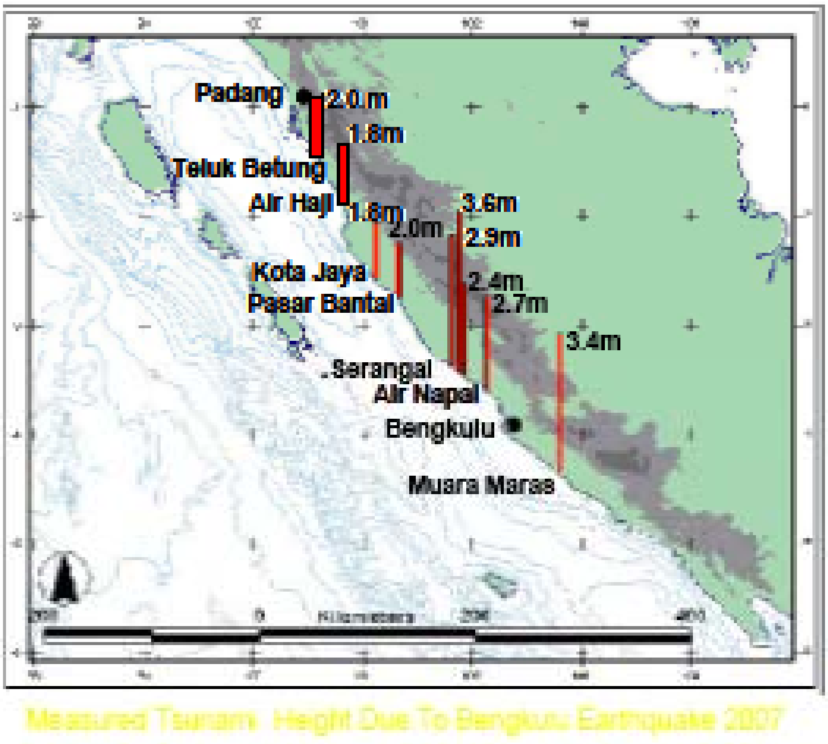


Fig.6.6 Survey results by the 2nd team (Dr.Subandono, MMAF, Indonesia)

Fig.6.7 Interviews to the residents at the damaged area

Fig.6.8 Measuring tsunami height of water marks on the wall above the ground

6.4 Type of damage due to a tsunami

There are several damage due to a tsunami, which can be divided into direct and indirect damage. The first is human loss, houses and infrastructure damage by the inundation or destructive wave force. The second is floating material, oil spread, and no use of harbor facility. The process and mechanism of each damage due to an impact of a tsunami should be investigated and studied for evaluation and mitigation in the future. The traces and evidences of tsunamis as shown in Figure.6.9 are very important item for the field investigation.

Fig.6.9 Example of the tsunami trace

In the 2004 Sumatra earthquake, the severest affected area of Indonesia is the Northern part of Sumatra, and it is reported that the coastal areas along the coast are completely destroyed by the strong shake and sudden attack of the big tsunami. The inland inundation mark was found up to 5 kilometers from the coast, and there were lot of debris such as pulled out trees, destructed house and ships carried out by the tsunami wave into the center of the city, which should increase the destructive power of the tsunami. It was observed that the tidal surge had reached over 40 meters-height on the hilly area where the tsunami run over the top of the peninsula with a saddle shaped hill. The damage in industrial area are found, which are oil tanks moved by the tsunami and erosion and destruction of harbor facilities.

In this event, the tsunami damage can be judged to be small except for the specific area such as Serangai which is located in the front of the tsunami source.

6.5 Effects of tsunami on the coastal environments

Large tsunami waves strongly affect the coastal environments, and damage severely to the agriculture and the fishery activities. For example, ponds for aquaculture are destroyed and trees are fell down by the impact of tsunami waves, and vegetations within the inundation area were blighted due to the salty seawater. Moreover, the sea bottom, coastal topography and river drastically change due to the erosion as shown in

Figure.6.10 and re-sedimentation of the sea bottom and the beach sediments. A large amount of sediments are transported landward and cover the wide area of the coastal area to form the tsunami deposits.

Fig.6.10 Example of tsunami erosion along the coast at Seblant, Koto-bani

Mangrove forests, in particular, shield coastlines by reducing wave amplitude and energy. Coastlines fringed by mangroves were strikingly less damaged than those where mangroves were absent or had been removed. Field observations in the past tsunamis indicate that mangroves also prevented people being washed into the sea, which was a major cause of death. In addition, mangroves trapped driftwood preventing property damage and injury to people Green belts of other trees, coastal dunes, and intact coral reefs performed similar functions as shown in Fig.6.11. On the other hand, coastal vegetations would be fell down and pulled up by the strong tsunami impact, and fragments of fallen trees convert to the dangerous floating materials. We try to get a criteria of fell trees/mangrove due to the moment/force of the tsunami, which is necessary to discuss an effective tsunami disaster reduction plan that uses coastal vegetations.

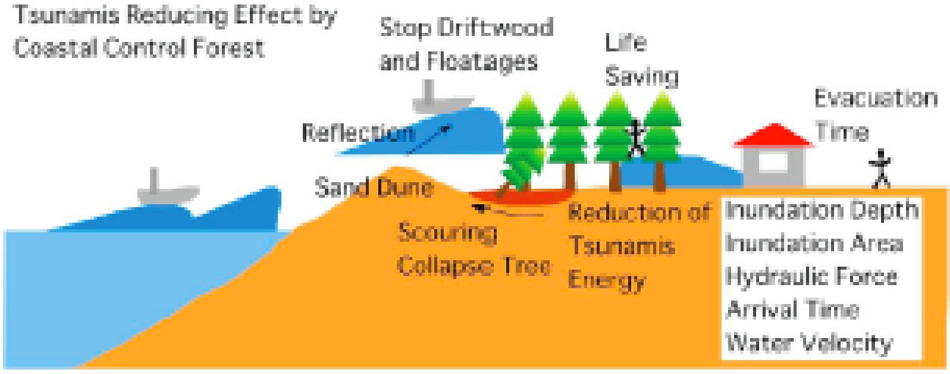


Fig.6.11 Functions and effect of coastal control forest to reduce a tsunami disaster

In this event, at Serangai there is green belt composed of the Mangrove along the coast, which could stop the floating material of timbers moved by the tsunami from coast. However, the houses behind the green could not be survived and completely destroyed. Because there are so many timbers on the sea, which can be not trapped. And wave force of the tsunami should be so strong that the green rule is not enough to reduce them. The width of the green would be small at this area. This suggests the limitation of the green belt to reduce the tsunami impact force.

Fig.6.12 Floating timbers trapped by the Mangroves on the shore

Fig.6.13 The house damaged and moved by the tsunami

6.6 Comparison between 2006 SW Java and 2007 S Sumatra

Since the 2004 Sumatra earthquake, there are a series of earthquakes followed by the tsunamis. The worst of the tsunami damage among those is the 2006 SW Java. Table 6-1 shows the comparison between 2006 SW Java (Imamura, 2007; BAKORNAS, 2006) and 2007 S Sumatra, including the earthquake intensity, tsunami runup and damage on the human and houses. Although the magnitude of the 2006 is smaller than the 2007, the tsunami and its human damage of the 2006 is mush larger than the 2007, on the other hand, the intensity of the 2007 is larger than the 2006, causing the much more houses damage. This suggest that the severe house damage due to the strong quake by the earthquake of M8.4 in 2007 is significant, however the quick response of the people after the quake and tsunami information on TV and radio based on the awareness of the tsunami after the 2004 could save their lives.

Table 6-1 Comparison between 2006 SW Java and 2007 S Sumatra

	2006 SW Java	2007 S Sumatra
Earthquake Magnitude and Max.Mercari Modified Intensity scale	M7.7 , MMI< 5	M8.4, MMI=7-8
Tsunami Runup heights	2-7m	2-4m
Dead	637 Most due to the tsunami	21 Not due to the tsunami
Missing	165	0
Heavily injured	624	18
Heavily damaged houses	1,317	>13,000

6.7 Recorded tsunami

In the following, P2P means peak to peak or wave height, Z2p means zero to peak or wave amplitude; so no confusion this time all times 9/12 GMT

Table 6-2 Tsunami observation at tidal stations

Station	Arrival Time(hh:mm)	P2P(Meters)	Z2P(Meters)	Period (mm:ss)	T(hh:mm)
Padang	11:54	2.27	1.20	38:00	14:08
Cocos Is	12:28 12:36	0.24	0.11	20:17	
Cilicap	13:13	0.52	0.23	70:30	15:16
Prigi	13:17 17:05	0.42	0.19	15:00	
Sibolga	?	0.30	0.16	30:30	16:26
Sabang	13:19 16:21	0.16	0.15	47:00	
Benoa	13:24 16:41	0.045	0.02	20:35	
Dart 23401	13:47 14:02	0.046	0.023	45:15	
Trinconmalee	14:58	0.60	0.28	35:45	15:15
Colombo	15;12 17:23	0.60	0.245	30:00	
Kotaphao Noi	15:05?	0.08	0.04	60:00?	15:27
Diego Garcia	15:20	0.09	0.07	09:00	15:29
Gan	15:18	0.13	0.07	47:00	16:16
Male	15:31 16:19	0.21	0.12	39:00	

7 EARTHQUAKE SOCIAL IMPACTS ; TSUNAMI PANIC IN PADANG

7.1 Example of information on the tsunami response in Padang

The following message is reported by Ms.Patra R.D. of KOGAMI(komunitas Siaga Tsunami) member, which indicates the detail of the information, response of the people, and damage at Padang;

On September 12 when the earthquake happened, the electricity was off suddenly. I and my colleges had been walking to Padang Command centre to check RA-NET about the location. Unfortunately, RA-NET did not work because the power was off and when we tried to use generator and turned the RA-NET on, we still had no updated data.

Then, we realized that if the electricity was off, RA-NET could not send the "delay" data. It is not like receiving SMS (Short Message of System) from our cellular phone. If we switch off the phone, we still can get message soon after we switch it on again. Five minutes after earthquake, we got sms from BMG (Meteorological and Geophysic Bearau) that the earthquake has tsunami potential. We started walking to higher ground and observed the route. Only few people went for evacuation. 10 minutes after earthquake, our mayor gave information to the people through RRI (radio station) and calm down the people. He repeat the information from BMG that the source of earthquake were from Bengkulu and there was no command for evacuation.

Few buildings cracked and the cement peeled off, there was no fatalities. On September 13, The strongest earthquake in my life happened, about 6.45 am. It was first day of Ramadhan (fasting month), so I thought everybody already woke up early in the morning and had more awareness. It was very strong, I could not stand up properly. Everybody had to squad or hold something to make the body stable. Immediately after the shaking stops everybody entered their houses (at least I saw my neighbors did) to take the prepared bags and walked to higher ground (earthquake as the early warning). Along the evacuation route, I saw families walked in group and brought radio with them. I had been driving at that time because my parents wanted me to drive. They were so afraid. Then, I realized that it is not easy for the people to make right decision when they should care about parent's feeling. Honestly, I did not choose the best route at that day because my father give me a command to choose another route. It was so difficult situation but fortunately I could reach high ground in 20 minutes after shaking stop.

10 minutes after the shaking stopped, our mayor started giving information through radio station (RRI). It was so confusing because BMG said the location was 140 km from southwest of Sungai Penuh, Jambi. That was too far from the real source Mentawai sea. What if people don want to evacuate because of misunderstanding about information?

Luckily, our people still trust information from mayor who keep asking them evacuate to high ground. All Mosques relay this information by using loud speaker. It helped. Not only mayor was in radio station, but also Community leader and scientist, so the people can ask information as much as they need. Two hours after earthquake, people went back to the house, only few people stay outside house because they are not sure about their houses condition.

I think TEWS in local (Padang) is already ok but for National level still need to redesign. We need clear information from BMG. Could you imagine that we got two tsunami warnings in 1.5 hours? I am afraid that people will not trust warning anymore because they already know that BMG will give warning if there is strong earthquake -more than 6.5 magnitude, on the sea floor, and shallow.

7.2 Tsunami Information and evacuation in the damaged area

11:10:26 UTC earthquake 4.517° S, 101.382° E
130 km (80 miles) SW of Bengkulu, Sumatra, Indonesia
11:24 4.5 SOUTH 101.3 EAST M7.9
11:53 M8.2
12:30 PADANG 0.35M
13:21 COCOS 0.4FT
14:40 DART 23401
15:05

-------- Original Message --------
Subject: Indian-Ocean-Wide Tsunami Watch Bulletin
Date: Wed, 12 Sep 2007 11:24:58 +0000 (GMT)
From: PTWC <ptwc@ptwc.noaa.gov>
Reply-To: ITIC Tsunami Bulletin Board <tsunami_bb@infolist.nws.noaa.gov>
To: ITIC Tsunami Bulletin Board <tsunami_bb@infolist.nws.noaa.gov>

ITIC Tsunami Bulletin Board
TSUNAMI BULLETIN NUMBER 001
PACIFIC TSUNAMI WARNING CENTER/NOAA/NWS
ISSUED AT 1124Z 12 SEP 2007

THIS BULLETIN IS FOR ALL AREAS OF THE INDIAN OCEAN.

... AN INDIAN-OCEAN-WIDE TSUNAMI WATCH IS IN EFFECT ...

A TSUNAMI WATCH IS IN EFFECT FOR

INDONESIA / AUSTRALIA / INDIA / SRI LANKA / THAILAND /
UNITED KINGDOM / MALDIVES / MYANMAR / MALAYSIA / BANGLADESH /
MAURITIUS / REUNION / SEYCHELLES / MADAGASCAR / SOMALIA / OMAN /
PAKISTAN / IRAN / YEMEN / COMORES / CROZET ISLANDS /
MOZAMBIQUE / KENYA / TANZANIA / KERGUELEN ISLANDS /
SOUTH AFRICA / SINGAPORE

THIS BULLETIN IS ISSUED AS ADVICE TO GOVERNMENT AGENCIES. ONLY
NATIONAL AND LOCAL GOVERNMENT AGENCIES HAVE THE AUTHORITY TO MAKE
DECISIONS REGARDING THE OFFICIAL STATE OF ALERT IN THEIR AREA AND
ANY ACTIONS TO BE TAKEN IN RESPONSE.

AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

ORIGIN TIME -	1110Z 12 SEP 2007
COORDINATES -	4.5 SOUTH 101.3 EAST
LOCATION -	SOUTHERN SUMATERA INDONESIA
MAGNITUDE -	7.9

7.3 EARTHQUAKE SOCIAL IMPACTS: TSUNAMI PANIC IN PADANG

Following the 2005 Great Nias Earthquake, Aydan (2005) pointed out the possibility of earthquake at a seismic gap in Mentawai Island. This issue was seriously taken by UN and donor countries for Aceh earthquake and some early tsunami warning systems are being installed along the west coast of Sumatra Island. So far, three early tsunami warning buoys provided by the Indian Ocean Tsunami Early Warning Center have been installed. Padang city and the local government are very much concerned and they are trying to do their best to cope with tsunami disaster mitigation and they prepared horizontal evacuation plans and they do some drills (Figure 11.1). Padang City has a very low elevation and the 5m elevation contour line is about 3km away from the shoreline. Depending upon the location of the earthquake, tsunami arrival time may ranges between 20-60 minutes. The tsunami evacuation drills clearly indicated that traffic jam and panic extremely obstruct the evacuation. The organizers of the drills recommend to people not use vehicles. The distance is extremely long for elderly people, small children and pregnant women as well as handicapped people. The best and quickest alternative is the vertical evacuation alternative. Although Japan and USA built some special terraces in such areas, the existing buildings, which are strong against shaking and having terraces on the top with unobstructed stairs, are designated as vertical Tsunami evacuation facilities in Japan. Therefore, the cities such as Padang and alike having potential tsunami risks in Indonesia must undertake actions to utilize such public and private existing or newly constructed buildings with sufficient shaking resistance and terraces for providing refuge to the people.

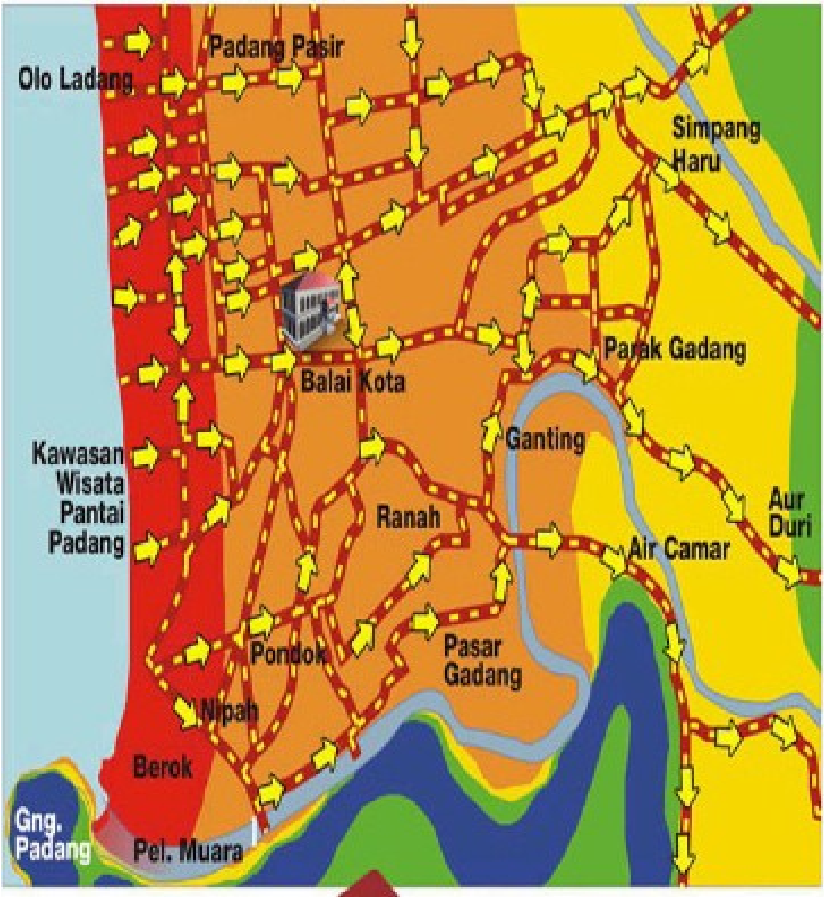


Fig.7.1 Horizontal Tsunami evacuation routes for Padang City

The second important issue is the release of the accurate information to the public as soon as earthquakes occur. Meteorology and Geophysics Agency (BMG) of Indonesia is responsible for releasing such information. However, this agency failed to release such information in most recent earthquakes of 2004 Aceh, 2005 Nias, and 2006 South Java as well as 2007 Singkarak (Solok) earthquake except the 2007 South Sumatra event. The information must be provided to public at most in 5 minutes time. The system must be capable of estimating if earthquake has the potential for causing tsunami. If so, it should provide information on expected arrival time and tsunami height. The system used in Japan is probably the most effective one so far in the world. There was a huge panic in Padang city since people did not get information about the location, magnitude and its potential for causing tsunami in due time by Meteorology and Geophysics Agency (BMG) of Indonesia. In-spite of drills, the people tended to use vehicles, motorbikes, bicycles causing traffic jams (Figure.7.2).

Fig.7.2 Panic in padang city following 2007 Singkarak Lake earthquake

In addition, some terminologies used by earthquake geologists and earth-scientists to describe the inter-seismic and co-seismic crustal deformations are misunderstood by public. For example, the settlement of some parts in Nias Island after the 2005 Great Nias earthquake was interpreted by the people of Nias Island that their island was sinking into the sea. Therefore, an ethical obligation of earth-scientists is required to describe the inter-seismic and co-seismic crustal deformations without causing any misunderstanding by public when they communicate with people directly or indirectly through mass media.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

An interplate earthquake with a magnitude of 8.4 and subsequent aftershocks struck Bengkulu and West Sumatra Province of Indonesia on September 12 and 13, 2007. This earthquake killed 25 people and caused heavy damage in the cities of Bengkulu, Padang Provincial capital cities and several cities, towns and villages along the coast between Padang and Bengkulu. Two large events with a moment magnitude of 8.4 and 7.9 occurred at an interval five and half hours. This reconnaissance report covers seismo-tectonics, earthquake engineering and tsunami aspects of this earthquake with a special emphasis on the tsunami damage and social response. Some of conclusions and recommendations drawn from this earthquake may be summarized as follows:

1) In a very recent study by (Aydan 2007b) on crustal deformation and straining of Sumatra Island using the GPS deformation rates, it is pointed out that there are three high stress rate concentration regions along the Sumatra Fault and seismic gap between the 2005 Nias and 2007 South Sumatra rupture areas along the Sunda subduction zone. The recent 2007 Singkarak Lake (Solok) earthquake and 2007 South Sumatra earthquakes may be a part of this rupture process.
2) As happened in many earthquakes in Indonesia, there is also no strong motion record for this earthquake except the one at Sikuai strong motion station, which is very close to Padang City. Indonesia lacks the strong motion network. It is strongly recommended to establish it as soon as possible. The estimations maximum ground acceleration and velocity at the epicenter for a ground with shear wave velocity of 300m/s are greater than 400 gal and 40 kine, respectively. These results are quite similar to the estimations from collapsed or displaced simple structures as well as to those estimations by the USGS.
3) When masonry buildings are constructed with bricks without reinforced concrete lintel and columns, they were fragile against ground shaking observed in this earthquake. However, constructions utilizing reinforced concrete lintels and columns with the integration of masonry walls within the load bearing system performed better and they prevented the total collapse of the buildings in-spite of some heavy structural damage.
4) The causes of damage to RC buildings are similar to those observed in other recent earthquakes in Indonesia and elsewhere. They can be re-stated for this earthquake as follows:
    - ✓ Soil liquefaction and lack of the soil bearing capacity (particularly in Padang)
    - ✓ Large ground settlement of embankments nearby river banks and sea shores
    - ✓ Fragile structural walls and lack of lateral stiffness,
    - ✓ Poor concrete quality and workmanship,
    - ✓ Plastic hinge development at the beam-column joints,
    - ✓ Lack of shear reinforcement and confinement,
    - ✓ Soft story,
    - ✓ Pounding and torsion and
    - ✓ Ground motion characteristics (i.e. multiple shocks etc.).
5) Transportation facilities performed relatively better than other structures. However,

there were some obstructions due to slope and embankment failures and settlement of bridge abutments..

6) Extensive slope failures observed along roadways between Ketaun and Lais. Extensive liquefaction observed along the sea shores and major rivers. The bridges performed well inspite of ground liquefaction in the vicinity of their foundations and abutments. There is no doubt that it will be desirable to carry out detailed geotechnical investigations for determining the properties of ground conditions and evaluate the performance of bridges and roadways.
7) Major industrial and port facilities in West Sumatra and Bengkulu provinces did not suffer any major damage by this earthquake.
8) No human loss and less damage by the tsunami in the 2007 South Sumatra
9) High awareness on the people in effected area, and quick evacuation after the quake toward elevated places or trees
10) Quick earthquake and tsunami information by TV, radio and speaker at the mosques
11) Effective statement from major or governor by radio and so on
12) The tsunami runup height ranges 2- 4 meter
13) The receding wave observed as the initial tsunami
14) Slow or gently in the tsunami motion reported except for Serangai where strong wave force and current should happen
15) Rule of the dune, band and sea wall of 1-3 meter, as shown in Photo 8.1 to reduce the tsunami observed
16) Less effect of the green belt on the coast at Serangai to mitigate the damage on the houses behind them

8.2 Recommendations for Padang against Future Mega-thrust Off-shore Earthquake

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. The unbroken part is more than 400km and it may result in mega-thrust earthquake with a magnitude greater than 8.7 (Figure 8.1). Padang city is situated on a very flat liquefiable ground. To reach the altitude of 5m from the coast, one has to walk more than 3km. In case of Tsunami with a height of more than 5m, it may be quite disastrous. Elder people, pregnant and handicapped people and children may be vulnerable even though a tsunami warning issued. This section outlines what measures can be taken for this vulnerable city.

Fig.8.1 Location of future mega-thrust earthquake off Sumatra Island

Recommendations for Measures against Ground Shaking

The existing buildings in Padang City and elsewhere in Sumatra Island and the rest of Indonesia are generally very vulnerable against ground shaking. There were even some collapses of RC buildings in Padang city, which was about 400km away from the epicenter of the South Sumatra Earthquake of 2007. Furthermore, many RC buildings suffered some damage and repairs implemented are just to re-plaster the cracks caused by the ground shaking. These buildings are probably the most vulnerable to collapse during a next strong earthquake. **The existing buildings must be retrofitted against strong ground shaking and they should be equipped with terraces and stairs for the vertical evacuation in tsunami-vulnerable areas** (Figure 8.2).

Fig.8.2. Buildings of Shoyo High School of Tokai University Education System in Miho Peninsula in the tsunami-prone area of the expected Tokai earthquake

Another important issue is the vulnerability of ground against liquefaction. The critical infrastructures such as bridges, telecommunication facilities and lifelines may be damaged by the ground failures and ground liquefaction (Figure 8.3). Therefore, **it is urgent to check the vulnerability of ground against ground liquefaction in relation to the foundations of superstructures and infrastructures.** Bridges are probably of the major concern as they facilitate the transportation and evacuation.

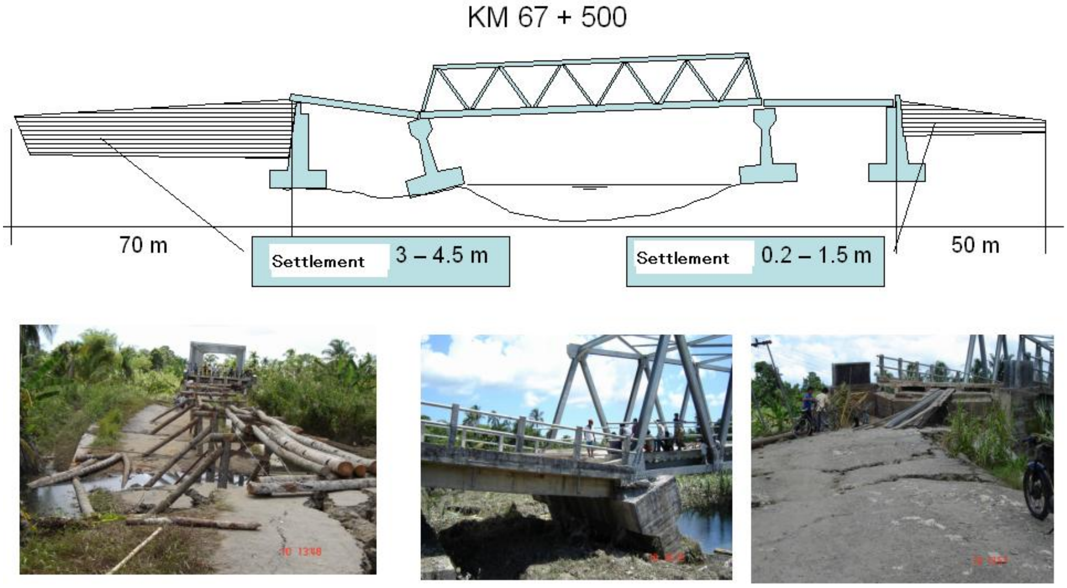


Fig.8.3 Liquefaction induced damage to Muzoi River bridge by 2005 Nias earthquake

Recommendations for measures against Tsunami

Following the tsunami disaster caused by the Aceh earthquake, some international actions taken against potential tsunami disasters in Indonesia and South-East Asia and neighboring countries along the Indian Ocean. Germany and USA have now installed some sophisticated tsunami-buoys for tsunami warning. The system itself is still under development and its reliability is questionable. They also require that many of these expensive devices must be installed along the entire subduction zones. The most important items for a tsunami warning system are to know the arrival time and expected wave height at the shoreline. Furthermore, the tsunami warning information must be conveyed to the people within few minutes (less than 5 minutes). **The system developed in Japan is probably the most efficient one in the world**. This system utilizes a database of pre-computed numerical simulations of tsunami for different earthquake scenarios and the determination of magnitude and hypocenter of the earthquake. This information is automatically conveyed to the broadcasting establishments such as TV and radio and local authorities, which may inform people through also loudspeakers. Prof. M. Hamada, who was the former president of the JSCE, proposed a tsunami warning system based on the fundamental idea of the Japanese tsunami warning system developed by JMA system together with the incorporation of mosques to relay the information to the local people (Figure 8.4). This system was actually implemented in the recent South Sumatra earthquake on September 12, 2007. There are also some Indonesian experts educated in Tohoku University, which is well known for the tsunami research for decades, and capable of creating such data-base for entire Indonesia. **These experts and the know-how from Japanese Meteorological Agency (JMA) and Tohoku University together with the collaboration of the BMG of Indonesia and broadcasting enterprises can create such a system in a short period of time, which is very important for saving lives against tsunamis.**

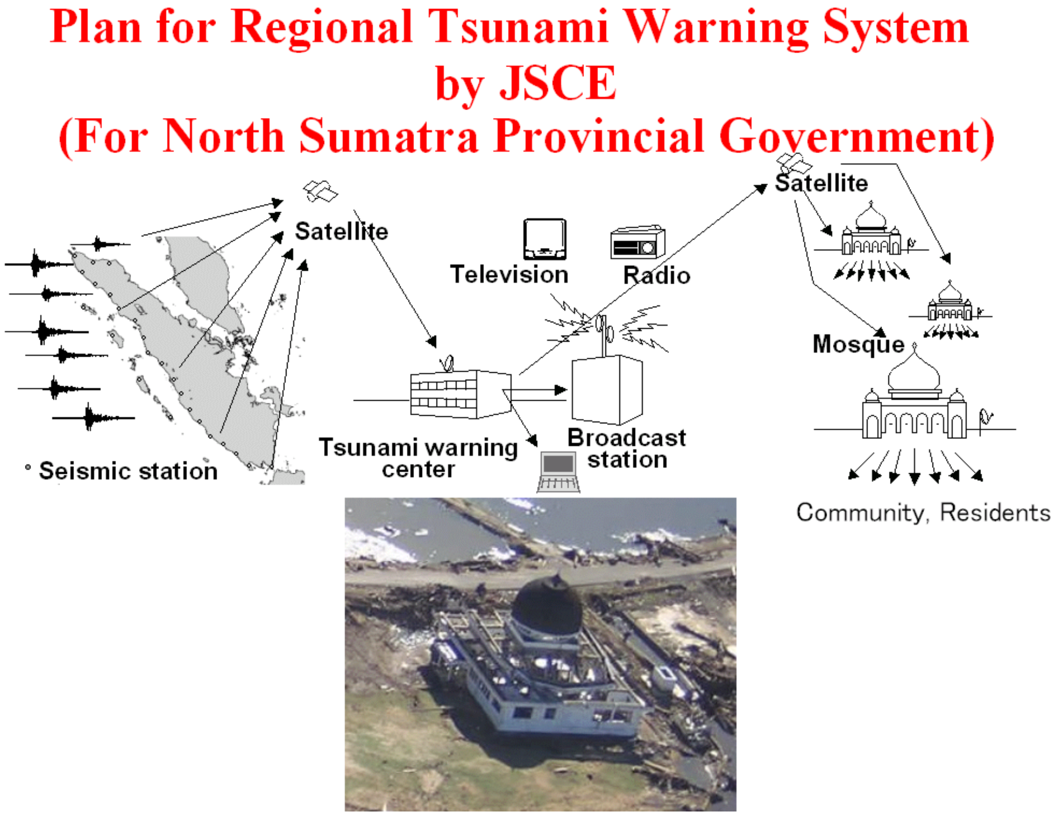


Fig.8.4. Tsunami warning system proposed by Prof. M. Hamada for Sumatra

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 a 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. Therefore, 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 8.2. 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 and schools during the ordinary times. Japan can provide the technology and expertise knowledge for constructing such buildings and to implement the retrofitting techniques to Padang City.

Building dykes, elevated tsunami shelters, gates and water breaks and planting trees along the coast line can be also implemented as hardware measures against tsunami disasters (Figure 8.5).

The education of children and people is of great important for the public awareness against the earthquake and tsunami disasters. The NGO named KOGAMI of Padang City have been doing a tremendous job for such a purpose. The activities of KOGAMI and other related establishments must be further promoted and supported through educational materials and financial support for their activities.

Fig.8.5 Sea dike with the height of 2-3 m at Padang, which prevent a small tsunami and stop the inundation.

Monitoring

Indonesia including Sumatra Island lacks a **strong motion network**. There were no strong motion records during the recent mega-thrust earthquakes. Any engineering design requires much information on the ground shaking characteristics and ground conditions. It is a must to install strong motion devices and to establish the strong-motion network for West Sumatra Province as well as for other areas of Indonesia. Of course, the maintenance and continuous operations of such a system must be strictly carried out.

Real-time GPS technology may be also useful technique to monitor the crustal deformation and straining in the vicinity of the potential earthquake source. A recent example from M6.2 Miyagi Hokubu earthquake clearly showed that time evolution of crustal straining could be a good measure for predicting the potential earthquake (Figure 8.6).

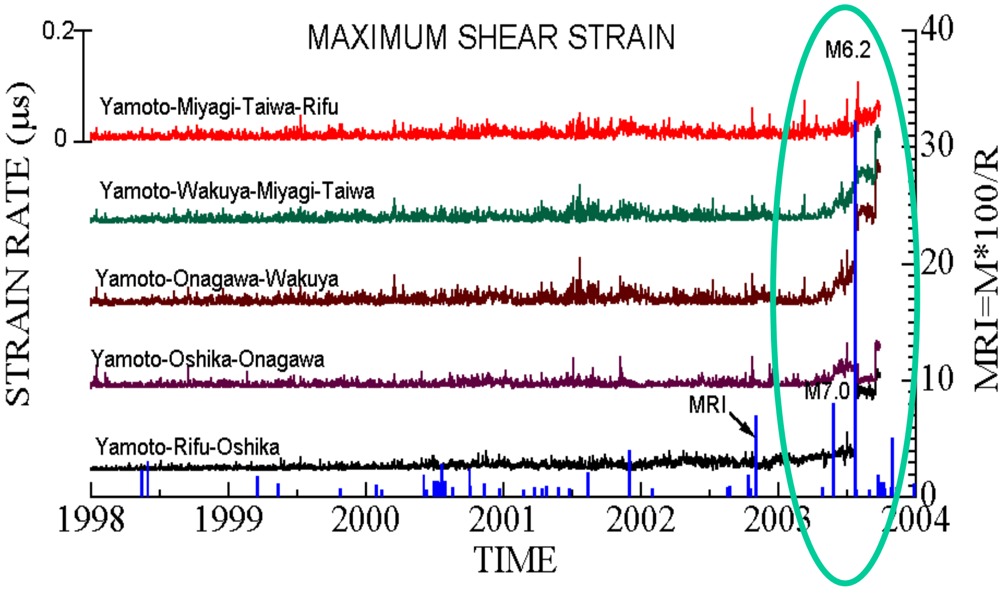


Fig.8.6 Maximum shear strain variations with time in the vicinity of the epicenter of 2003 Miyagi Hokubu earthquake (from Aydan, 2004)

The physical and chemical variations at hot springs are also another source of information for the potential earthquakes. Electric, magnetic, thermal and chemical observations may be utilized. However, such systems would require some fundamental understanding for the interpretation of measured responses.

REFERENCES

Aydan, Ö., (2000): Annual strain rate and stress rate distributions of Turkey from GPS Measurements, Yerbilimleri, *Bulletin of Earth Sciences Application and Research Centre of Hacettepe University*, *22*, 21-32.

Aydan, Ö. (2004): Implications of GPS-derived displacement, strain and stress rates on the 2003 Miyagi-Hokubu earthquakes , Yerbilimleri, No.30, 91-102.

Aydan, Ö. (2007a): Some Thoughts on Crustal Deformation, Seismicity and Tsunami in Indonesia with a special emphasis on Sumatra Island. The International Symposium on Disaster in Indonesia (ISDI): Problems & Solutions, Padang.

Aydan, Ö., (2007b). Inference of seismic characteristics of possible earthquakes and liquefaction and landslide risks from active faults. The 6th National Conference on Earthquake Engineering of Turkey, Istanbul.

Aydan, Ö., Hamada M., Suzuki, Y. (2005): Some observations and considerations on the damage induced by the tsunami of the 2004 Sumatra earthquake on structures and coast. Journal of The School of Marine Science and Technology, No.1, Vol. 3, 2005.

BAKORNAS, (2007). National Coordinating Board for the Management of Disaster

Crow, M.J. and Barber, A.J. (2005). Simplified geology of Sumatra, Lyell Collection, Geological Society of London.

HARVARD: HARVARD Centroid Moment Tensor, Department of Earth and Planetary Sciences, HARVARD, University, Cambridge, MA, USA.

Imamura, F., D. Subandono, G. Watson, A. Moore, T. Takahashi, H. Matsutomi, and R. Hidayat, 1997: Irian Jaya Earthquake and Tsunami causes serious damage, EOS Transactions, AGU, Vol.78, No.19, p. 197 and pp. 201.

Imamura, F., The 2006 SW Java tsunami and its damage, Fire and science, vol.6, no.1,No.19, pp.52-59, 2007, in Japanese

IOC, 1998: Post-Tsunami Survey Field Guide, Manual and Guides, No. 37, UNESCO

JSCE (2005): A report of the reconnaissance team of the Earthquake Engineering Committee of Japan Society of Civil Engineers on the damage induced by Sumatra Earthquake of December 26, 2004, and associated tsunami, Tokyo, Japan.

McCaffrey, R. (1988). Active tectonics of Eastern Sunda and Banda Arcs. Journal of Geophysical Research, v. 93, B12, 15163-15182.

Natawidjaja, D. H. (2003), Neotectonics of the Sumatran Fault and paleogeodesy of the Sumatran subduction zone, Ph. D. thesis, Calif. Inst. of Technol., Pasadena.

Natawidjaja, D. H., K. Sieh, S. Ward, R. L. Edwards, J. Galetzka, B. Suwargadi, 2004, Paleogeodetic records of seismic and aseismic subduction from central Sumatran microatolls, Journal of Geophysical Research, v. 109, B4, B04306

NIED(2007): http://www.hinet.bosai.go.jp/topics/

Sieh, K., and D. Natawidjaja, 2000, Neotectonics of the Sumatran fault, Indonesia: Journal of Geophysical Research 105, 28,295-28,326.

Sieh, K., S. Ward, D. Natawidjaja and B. Suwargadi, 1999, Crustal deformation at the Sumatran subduction zone revealed by coral rings. Geophysical Research Letters 26, 3141-3144.

Synolakis, C., F. Imamura, Y. Tsuji, H. Matsutomi, S. Tinti, B. Cook, Y.P. Chandra, and M. Usman, 1995: Damage, conditions of East Java Tsunami of 1994 analyzed, EOS Transactions, AGU, Vol. 76, No. 26, p. 257 and pp. 261-262.

USGS: U.S. Geological Survey, National Earthquake Information Center, Golden, CO, USA. http://earthquake.usgs.gov/

Yagi, Y. (2007): Source process of South Sumatra Earthquake (in Japanese) http://www.geo.tsukuba.ac.jp/press_HP/yagi/

Yamanaka, Y. (2007). Source process of South Sumatra Earthquake (in Japanese) http://www.seis.nagoya-u.ac.jp/sanchu/Seismo_Note/

Yeh, H., F. Imamura, C. Synolakis, Y. Tsuji, P. Liu, S. Shi, 1993: The Flores Island tsunamis, EOS Transactions, AGU, Vol. 74, No. 33, pp. 371-373..