Chapter 1

Purpose, Members and Itinerary of the Reconnaissance

The purpose of the reconnaissance was to investigate damage to civil engineering structures caused by the earthquake shaking as well as by tsunami, for the progress of disaster mitigation and earthquake as well as tsunami resistant design and construction.

The reconnaissance team consists of eleven members from distinguished universities, research institutes and construction companies. The experts' background cover a broad areas of science and engineering such as geology, geotechnics, earthquake resistant design, tsunami, infrastructures, risk management.

The members of the reconnaissance team composed as listed below:

Leader: Yozo GOTO (National Research Institute for Earth Science and Disaster Prevention)
Co-leader: Masanori HAMADA (Waseda University)
Members: Ömer AYDAN (Tokai University)
Shigeki UNJOH (Public Works Research Institute)
Takahiro SUGANO (Port and Airport Research Institute)
Hidetoshi NAKAJIMA (Geographical Survey Institute)
Takashi TOMITA (Port and Airport Research Institute)
Mikio TAKEUCHI (Nihon Suido Consultants Co., Ltd.)
Naoki FURUKAWA (Kajima Corporation)
S.F. Wong (Penta-Ocean Construction Co., Ltd.)
Hiroyuki YANAGAWA (JSCE International Affair Division)

The reconnaissance team visited the Aceh province of Indonesia from March 1 till March 5 to investigate and to assess the damage inflicted by the earthquake and by the induced tsunami. The team arrived at Banda Aceh together with the Sumatra Island Reconnaissance Team of the "Urgent Survey Research on the Northern Sumatra Offshore Earthquake/Indian Ocean Tsunami Disaster", which is a national technical investigation team dispatched by the Japan Science and Technology Agency (Prof. H. IEMURA, Kyoto University, and other 14 members) and conducted the investigation in cooperation with them.

It should also be noted that four researchers from Syiah Kuala University located in Banda Aceh and three researchers recommended by the Ministry of Research and Technology, Indonesia joined with us in the reconnaissance.

The topics of investigation of the reconnaissance team were specifically designated as follows:

- Transportation systems (bridges, road embankments, the new alignment between Ache and Meulaboh
- Port and Harbor Facilities (quaywalls, breakwaters)
- Lifeline systems (water, sewage and electricity)
- Geotechnical Damage (river banks, liquefaction and slope sliding)
- Buildings (RC structures, wooden houses, masonry houses)
- Education for Disaster Mitigation

Most of investigations were carried out by sub-groups through the following means:

- Land surveys through chartered vehicles
- Aerial survey through helicopters between Banda Aceh and Meulaboh
- Off-shore surveys through a chartered boat
- Documents (maps, reports etc.)

The UN helicopter flight was organized on the request of the vice-governor of Aceh province of Indonesia for the reconnaissance team of the JSCE to investigate new road alignment during the stay of the team in Banda Aceh. This flight was realized on March 4 with the collaboration of the chief and staff of UN-OCHA for the region.

At the same time, the Japan Self Defense Forces took care of us to be on board their helicopter to observe the situation of the western coast which was very difficult to access by road.

(Author of this chapter: Y. Goto)

Chapter 2

Geographical Characteristics and History

2.1 Geography

Indonesia is a huge archipelagic country extending 5,120 kilometers from east to west and 1,760 kilometers from north to south (Figure 2.1). It encompasses 13,667 islands (some sources say as many as 18,000), only 6,000 of which are inhabited. There are five main islands (Sumatra, Java, Kalimantan, Sulawesi, and Irian Jaya), two major archipelagos (Nusa Tenggara and the Maluku Islands), and sixty smaller archipelagos. Two of the islands are shared with other nations; Kalimantan (known in the colonial period as Borneo, the world's third largest island) is shared with Malaysia and Brunei, and Irian Jaya shares the island of New Guinea with Papua New Guinea. Indonesia's total land area is 1,919,317 square kilometers. Included in Indonesia's total territory is another 93,000 square kilometers of inlands seas (straits, bays, and other bodies of water). The additional surrounding sea areas bring Indonesia's generally recognized territory (land and sea) to about 5 million square kilometers.

Figure 2.1 Indonesia and Indonesian archipelago (Modified from NEIC-USGS)

The Province of Aceh (officially Nanggroe Aceh Darussalam) covers an area of 57,365 sq km. It is the western most province of the Indonesia with the Indian Ocean to the west, the strait of Malacca to the east. Bukit Barisan mountain ranges with Tangse, Gayo and Alas upland is located in the central part of this province. The highest peaks are Leuser (3,466 m), Ucop Molu (3.187 m), Abong - abong (3.015 m), Peut Sago (2.786 m), and Geureudong

Figure 2.2 Physical geography of Aceh Province (Modified from Indo Prima Sarana)

(2.295 m) and Burni Telong (2.566 m). Aceh Raya Mountain range with its peak Seulawah Agam (1.762 m) and Seulawah Inong (865 m). This area also has several lakes such as Laut Tawar in Central Aceh, Aneuk Laot in Pulau Weh and Laut Bangko in South Aceh. The rivers running in to the straits of Malacca are Krueng Aceh in the Greater Aceh regency, Kr-Peusangan, Krueng Peureulak, Krueng Tamiang. The rivers running to the Indian Ocean are Krueng Teunom, Kr.Meureubo, Kr. Simpang Kanan and Simpang Kiri.

2.2 Population

Although Indonesia seems to be extremely diverse ethnically (more than 300 distinct ethnic groups), most Indonesians are linguistically and culturally part of a larger Indo-Malaysian world encompassing present-day Malaysia, Brunei, the Philippines, and other parts of insular and mainland Asia. Most important, the vast majority of the population can speak Bahasa Indonesia, the official national language. Used in government, schools, print and electronic media, and in multiethnic cities, this Malay-derived language is both an important unifying symbol and a vehicle of national integration.

The more than 3.4 million Acehnese are most famous throughout the archipelago for their devotion to Islam and their militant resistance to colonial and republican rule. Renowned throughout the nineteenth century for their pepper plantations, most Acehnese were rice growers in the coastal regions in the early 1990s. Acehnese do not have large descent groups; the nuclear family consisting of mother, father, and children is the central social unit. Unlike the Javanese or Balinese family, the Acehnese family system shows marked separation of men and women's spheres of activity. Traditionally, males are directed outwardly towards the world of trade.

2.3 Climate

The main variables of Indonesia's climate are rainfall rather than temperature or air pressure. The archipelago is almost entirely tropical in climate, with the coastal plains averaging 28^{o}C, the inland and mountain areas averaging 26^{o}C, and the higher mountain regions, 23^{o}C. The area's relative humidity ranges between 70 and 90 percent. Winds are moderate and generally predictable, with monsoons usually blowing in from the south and east in June through September and from the northwest in December through March. Typhoons and large-scale storms pose little hazard to mariners in Indonesia waters; the major danger comes from swift currents in channels, such as the Lombok and Sape straits.

The extreme variations in rainfall are linked with the monsoons. Generally speaking, there is a dry season (June to September), and a rainy season (December to March).

2.4 History

Early inhabitants had an agricultural economy based on cereals, and introduced pottery and stone tools during the period 2500 to 500 B.C. During the period between 500 B.C. and A.D. 500, as the peoples of the archipelago increasingly interacted with South and East Asia, metals and probably domesticated farm animals were introduced.

Aceh has a fascinating history, which over the centuries has shaped and transformed the region into what it is today. The first Islamic kingdom of Perlak was established in the year 804 about 100 years after Islam is first believed to have reached the archipelago. In 1511, the Portuguese seized the important strategic port of Malacca. Aceh's dominance in trade and politics in northern parts of Sumatra in the entire region had begun and lasted until it reached its zenith between 1610 and 1640.

Aceh decline began with death of Sultan Iskandar Than in 1614, and as a result the British and Dutch both began vying for domination of the area. Eventually the signing of the London Treaty in 1824 saw the Dutch gain control of all British possessions in Sumatra in return for their surrender of enterprises in India and withdrawal of all claims on Singapore.

Dutch colonists attempted to subdue the rebellious and courageous Acehnese for a long period of time and they never succeeded. The Aceh War, which lasted intermittently from 1873 to 1942, was the longest ever fought by the Dutch costing them over 10,000 lives. The people of Aceh region were one of the foundation stones in Modern Indonesia gaining its independence from Dutch colonists.

Nowadays, 70% of the Province of Aceh is forest and precipitous mountains lie especially on the western coast. 16% is farms and rice fields, and rice is harvested three times a year. The population is 4.3 million and the 83% of the people live on the coastal plain isolated by the mountains. There are several races in the Aceh inhabitants. Oil and natural gas production is more than 50% of the gross production of the province, but one-third of the inhabitants is said to be in poverty. 97.7% are Islam and all the women are hiding their hair. An armed group called GAM is insisting on the independence of the Province of Aceh and it repeats conflicts with the Indonesian National Army from time to time.

Banda Aceh is the largest city in the Province of Aceh. The population of the city is 260,000. According to the count by the Indonesian government as of April 7, the number of missing and dead in the city is said to come up to 70,000 (missings 20,000 and deads 50,000).

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(Author of this chapter: Ö. Aydan)

Chapter 3

Geology & Tectonics

3.1 Geology

The general geological features of Indonesia are shown in Figure 3.1. The basement formation is metamorphic and it is intruded with plutonic formations. They are overlain with Mesozoic, Cenozoic, recent volcanic formations and quaternary deposits.

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

The next series of rocks consist of slates below and limestone above. It lies unconformably upon the older rocks; and the limestone contains Fusulina, Phihipsia and Productus, indicating that it belongs to the Upper Carboniferous. These beds are found only

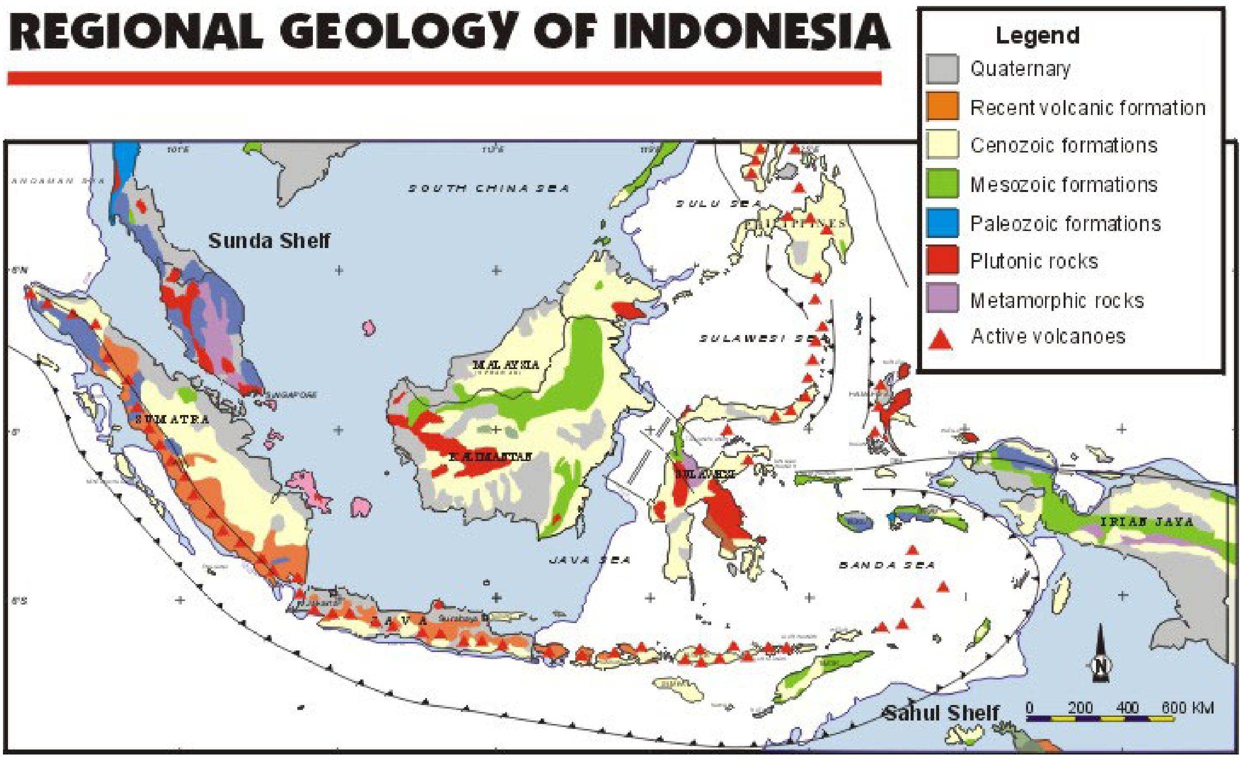

Figure 3.1 Regional geology of Indonesia (Indonesian Government)

in northern Sumatra. They are accompanied by intrusions of diabase and gabbro, and they are sometimes folded, but they are little disturbed. No Permian beds are known, and Mesozoic deposits such as Triassic clays and sandstones with Daonella have been found in the upper part of the basin of the Kwalu (East Sumatra). They rest unconformably upon the Carboniferous beds, and have been steeply tilted. Cretaceous beds also have been buckled. Tertiary deposits are very widely spread over the plains and low-lying regions. They consist of breccias, conglomerates, sandstones, marls, and limestones, with seams of coal and lignite.

The most valuable coal occurs in the Eocene beds. At the close of the Eocene period great eruptions of augite-andesite took place from two fissures which ran along the west coast. The Miocene consists chiefly of marns, with occasional beds of lignite and limestone. On the east coast it sometimes yields petroleum. The Pliocene formations occur mainly in the low-lying land and they are generally covered by alluvium. Sometimes they contain thick seams of lignite or brown coal.

Oil and gas deposits are found in Sumatra island and its continental shelf and they are located in the eastern side of the island in Aceh province. The Arun gas field was discovered in 1971 in the Province of Aceh. The field straddles the coastal plain between the Barisan Mts. and the Strait of Malacca. Condensate-rich gas is found in reef and associated carbonate facies of Lower and Middle Miocene Age that in places exceed 300m in thickness. These carbonates occur near the base of a Tertiary Age sedimentary section having a thickness of more than 3,000m. The carbonate rocks are underlain by a clastic sequence of variable thickness that rests on economic basement of pre-Tertiary Age. The reef carbonates occur on a large paleo-topographic high trending in a general north-south direction. The gas accumulation is mainly stratigraphic, having been trapped in a porous reefoid facies that is overlapped by Lower Baong (Middle and Upper Miocene) shale. Geochemical studies indicate that the Arun gas is derived directly from the Baong shale.

3.2 Volcanoes

The Indonesian region is one of the most seismically active zones of the earth; at the same time it has many active and potentially active volcanoes. It is a typical island-arc structure with its characteristic physiographic features, such as a deep oceanic trench, a geo-anticline belt, a volcanic inner arc and a marginal basin. Indonesia has some 400 volcanoes, of which approximately 100 are active.

The present volcanoes of Sumatra island lie along a line (with offshoots) which runs parallel to the west coast, but some distance to the east of the fissures, from which the early Tertiary lavas were erupted. Lava streams are seldom emitted from these volcanoes, the material erupted consisting ash and scoriae, which are spread over a very wide extent of the island. Augite-andesite predominates, but basaltic and rhyolitic volcanics are also observed. Peuet-Sague and Bur Ni-Telong active volcanoes are located in the province of Aceh.

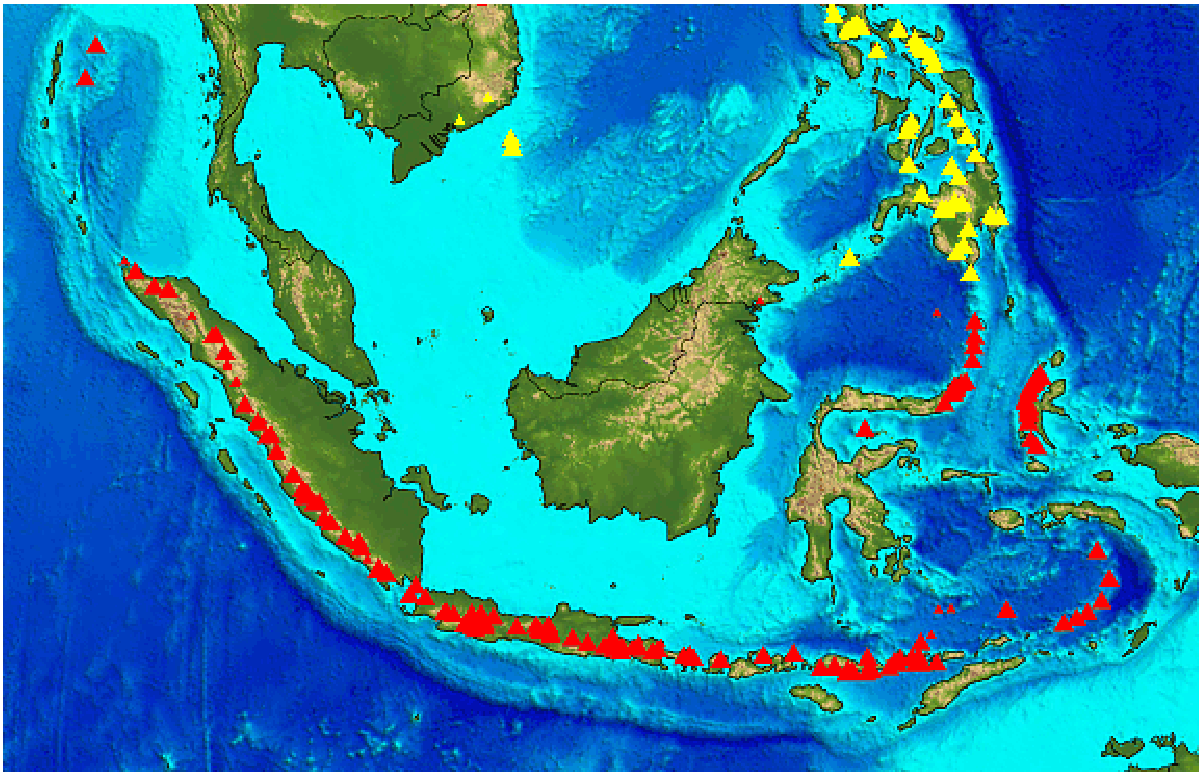

Figure 3.2 Volcanoes of Indonesia (Smithsonian Natural History of Museum)

3.3 Tectonics

Indonesia forms the southeastern extremity of the Euro-Asian lithospheric plate. It is bounded by the northward-moving Indo-Australian and the westward-moving Pacific (Philippine) plates and it is certainly one of the most complex active tectonic zone on earth. 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. Most of Indonesia's volcanoes are part of the Sunda arc, a 3,000-km-long line of volcanoes extending from northern Sumatra to the Banda Sea. These volcanoes are generally the result of subduction of the Australia Plate beneath the Eurasia Plate. Volcanoes in the Banda Sea result from subduction of the Pacific Plate under the Eurasia Plate.

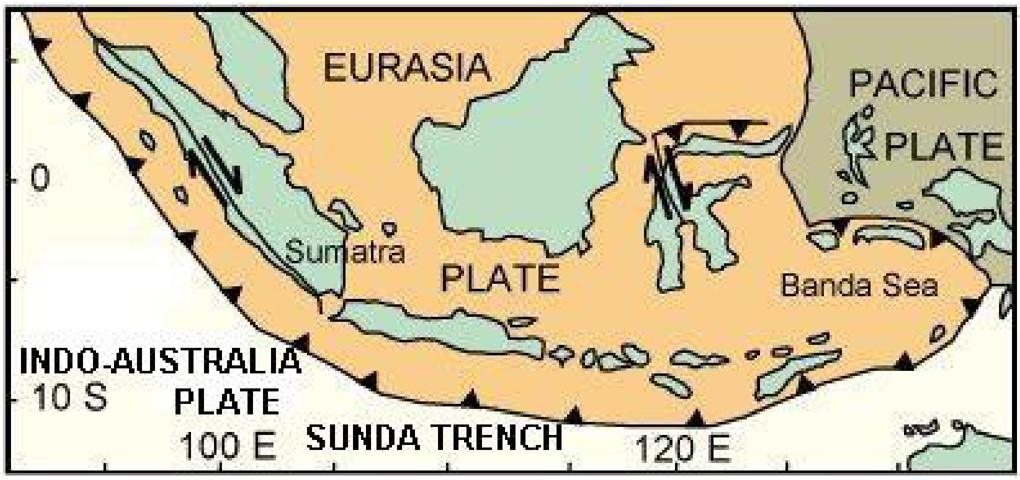

Figure 3.3 Plate tectonic model of Indonesia (Tectonics of Indonesia)

In the region of the earthquake, the Indo-Australia plate moves toward the northeast at a rate of about 6 cm/year relative to the Euro-Asian plate (Figure 3.4). This results in oblique convergence at the Sunda trench. The oblique motion is partitioned into thrust-faulting, which occurs on the plate-interface and which involves slip directed perpendicular to the trench, and strike-slip faulting, which occurs several hundred kilometers to the east of the trench and involves slip directed parallel to the trench.

This fault is named Sumatran fault, which passes through the entire island. The fault is divided into three segments, namely, southern, central and northern segments. The fault is thrust type with a dextral sense. Sumatran 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.

Figure 3.5 shows a view of Sumatran Fault in the western side of Banda Aceh city. The hills are made of heavily folded limestone and shale. The strike of folds has the trend of NW-SE. Figure 3.6 shows a view of bedding plane in limestone nearby Lhonga port, on which striations for two different episodes of relative motion are identified. The earlier event has a sense of dextral slip with a thrust component while the most recent one has a sense of dextral slip with a normal component, implying the trans-tensional deformation of Banda Aceh basin.

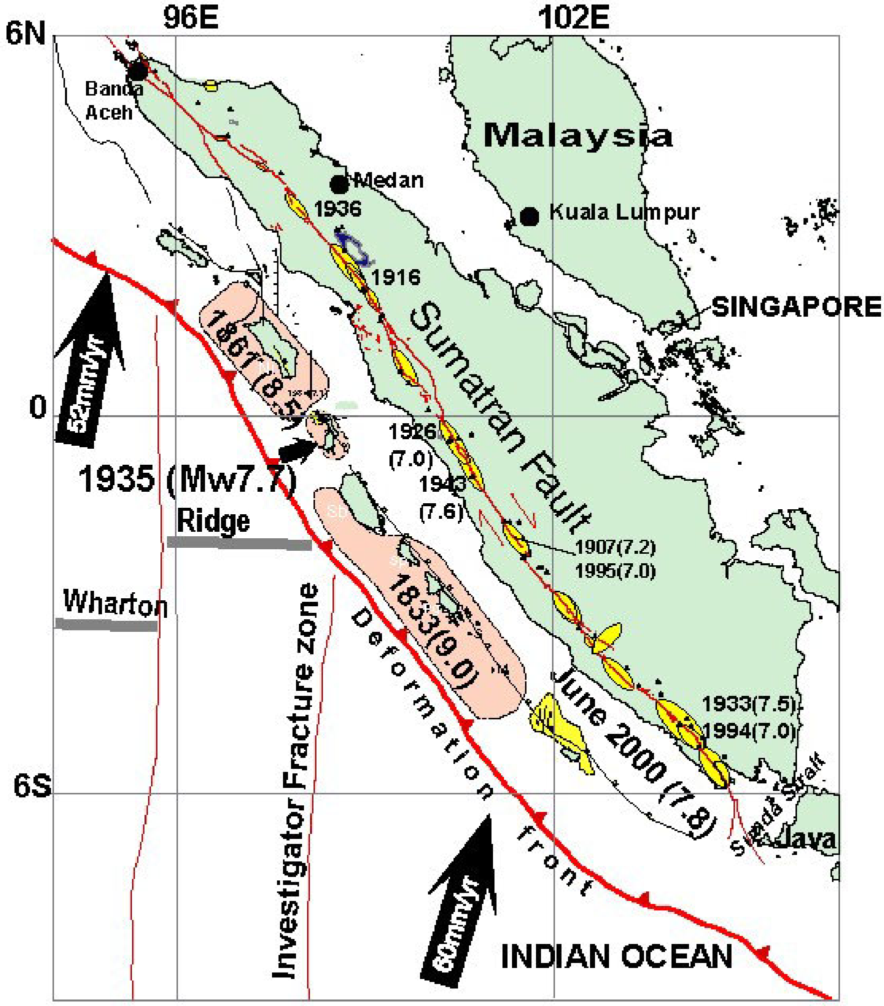

Figure 3.4 Seismo-tectonics of Sumatra Island (Natawidjaja(2005))

Figure 3.5 A view of Sumatran fault nearby Banda Aceh city(from NW to SE)

Figure 3.6 Striations on bedding plane in Lhonga
(Old and new striations associated with the motion of Sumatra fault)

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(Author of this chapter: Ö. Aydan)

Chapter 4

Seismicity and Faulting Characteristics

4.1 Seismicity

Indonesia is one of the most seismically active zones of the earth. Sumatra Island as a part of Indonesia experienced very large earthquakes in the past and this high seismic activity has been still continuing. Seismic events with a magnitude greater than 8 took place in the Sumatran section of the Sunda subduction zone before the 26, December 2004 earthquake (Figure 3.4). For example, the seismic events with a magnitude of 8.5 and 9.0 in 1861 and 1833, respectively, resulted in the uplifts of corals ranging between 70cm to 230cm. However, the tsunamis caused by these earthquakes were limited to the south of the location of the 26 December 2004 event. Figure 4.1 shows the plots of the seismic event having a magnitude greater than 6.5 since 1900. Furthermore inland earthquakes also took place along the Sumatran fault system as shown in Figure 3.4.

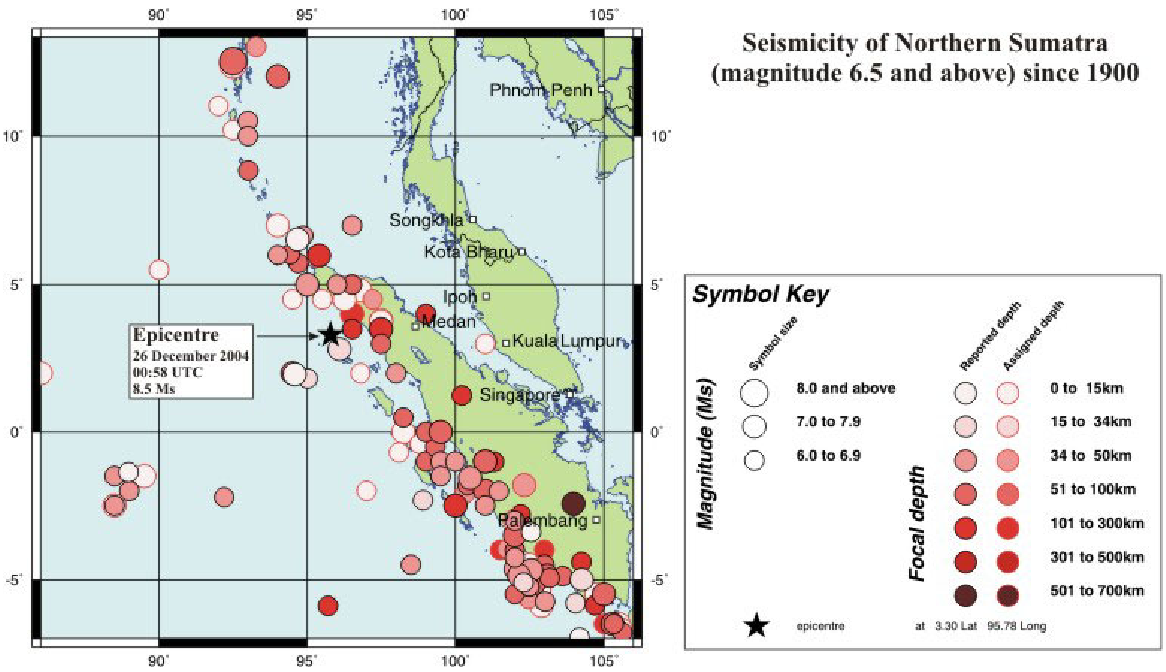

Figure 4.1 Historical seismicity of the area since 1900 (British Geological Survey)

Most of earthquakes occur along the subduction zone and they extend as far as Malacca strait. The pre-post seismicity of a region bounded between Latitudes 2°N to 6°N and Longitudes 95°E and 98°E is shown in Figure 4.2(a). The earthquake catalog of NEIC is used for this purpose and the magnitude of the earthquakes is set to be greater than 3. Figure 4.2(b) shows the seismicity projected onto a cross-section along the direction A-A shown in Figure 4.2(a), which is perpendicular to the strike of the subduction zone in the region of the earthquake. The pre-shocks occurred over a wide area. However, the distributions clearly indicate the existence of a subducting plate. Aftershocks are shallow and distributed along a gently inclined plane.

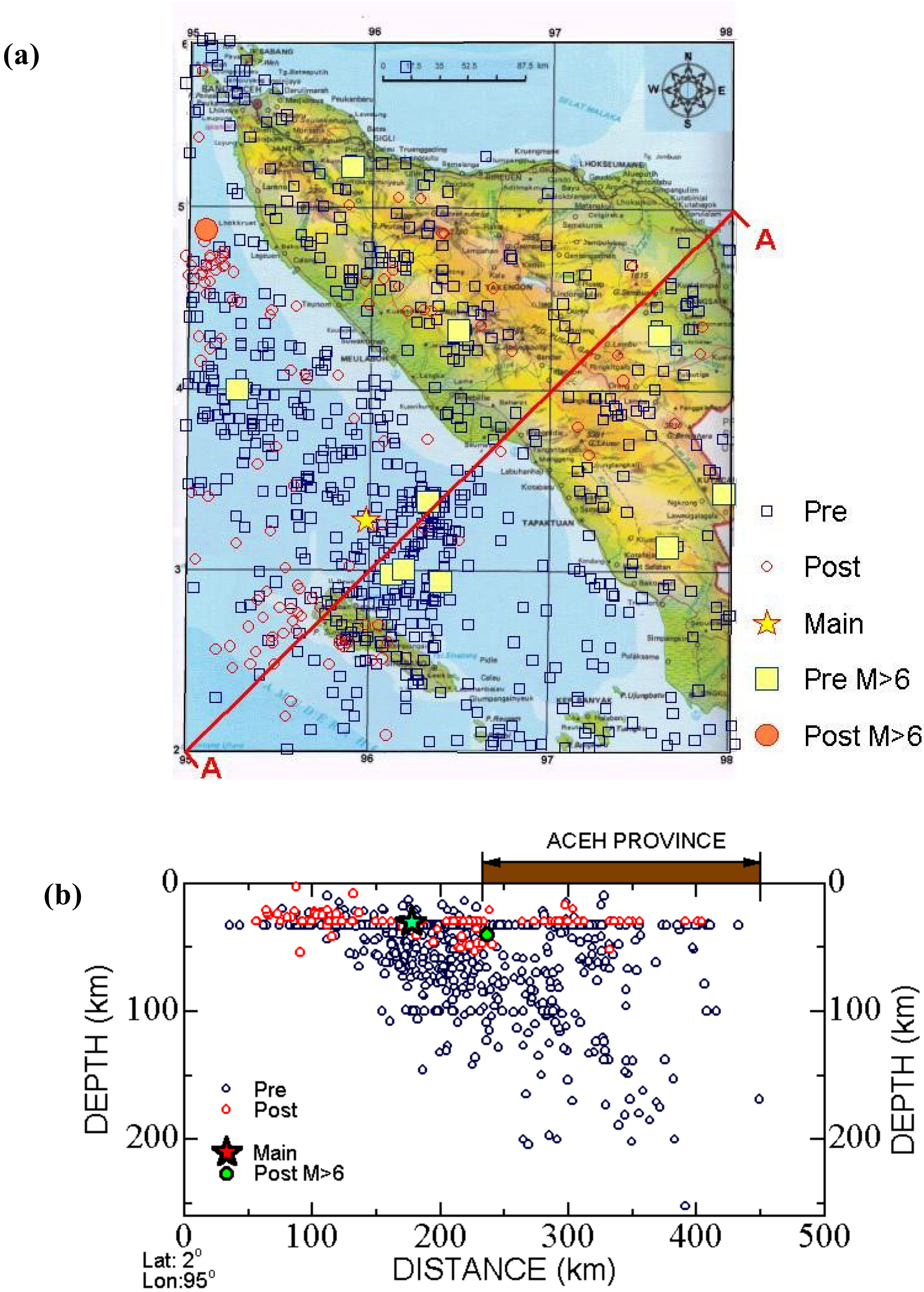

Figure 4.2 Pre-post seismicity of the region of the 26, December 2004 earthquake

(Prepared by Aydan using NEIC data and base map of Indo Prima Saran)

Figure 4.3 shows the seismic activity since 1973. The cumulative magnitude of the earthquakes since 1973 is computed and plotted in the figure. The cumulative magnitude variation seems to fit the following relation:

$$\sum M = 1.81(t - 1965)^2$$

This variation indicates an accelerating seismic activity in the region of the earthquake before the main event.

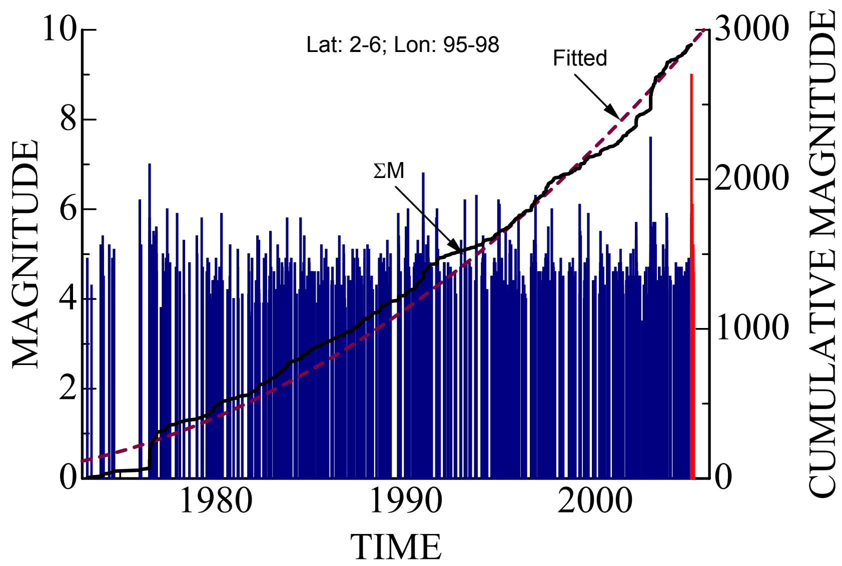

Figure 4.3 Variation of magnitude and cumulative magnitude with time
(Prepared by Aydan using NEIC data)

4.2 Faulting Characteristics

Following the earthquake, several institutes analyzed the data measured at various seismograph stations all over the world. These analyses yielded some important characteristics of this mega-size earthquake.

4.2.1 Fault Plane Solutions for Pre-shocks

The fault plane solutions (HARVARD) of the events before the main shock are shown in Figure 4.4. 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 area of the earthquake. Nevertheless, between the northern tip of Sumatra Island and Nicobar Island, dominant strike-slip faulting is also observed. The fault plate solutions indicate dextral strike-slip sense of deformation for faults trending NW-SE. The fault plane solutions for folding and striations observed at Lhonga are shown in Figure 4.5. It is of great interest that the geological traces observed on rock formations also yield some information on the likely faulting mechanisms of the earthquakes in the region.

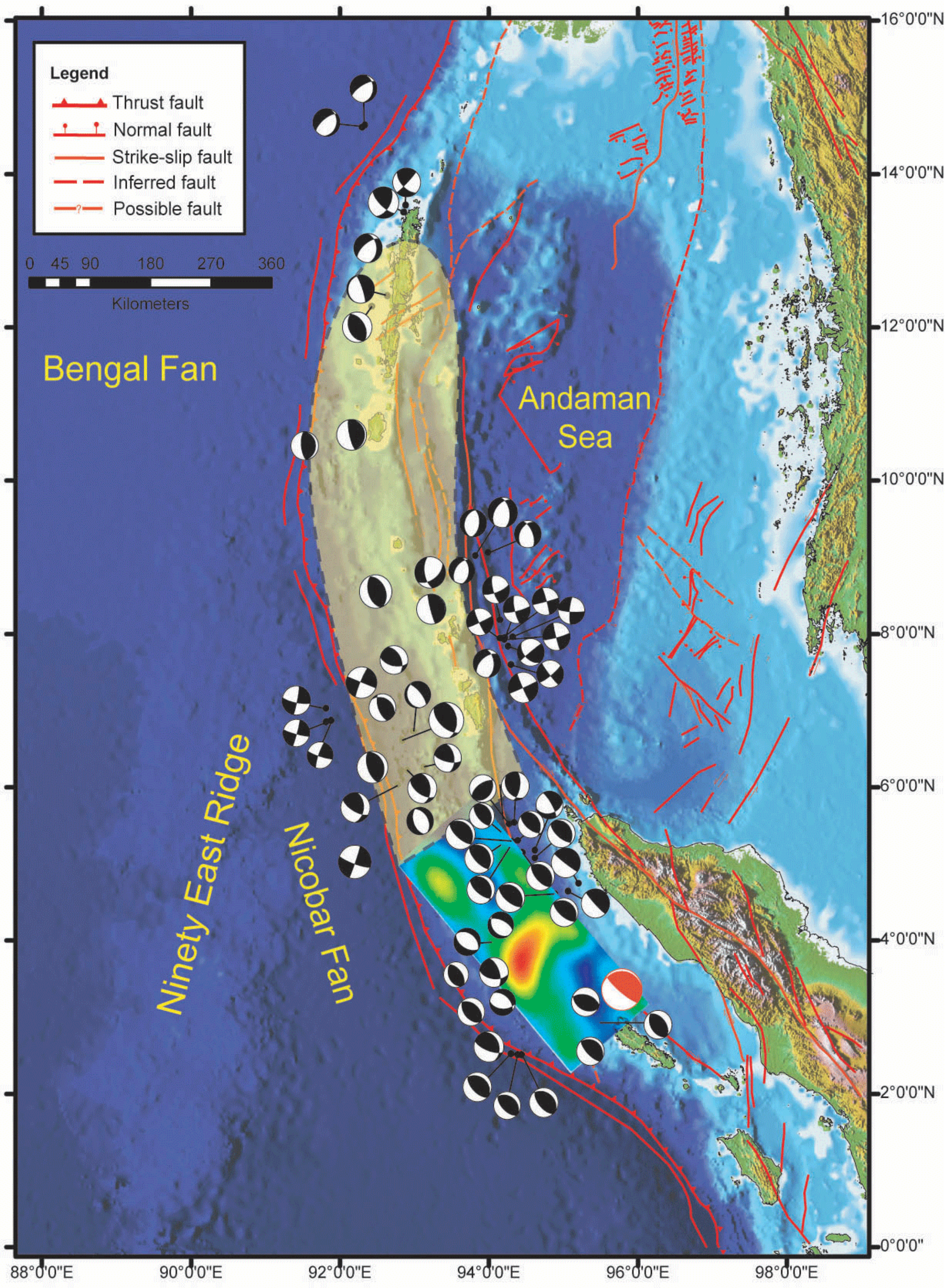

Figure 4.4 Fault plane solutions for the events before the main shock
(http://www.coas.oregonstate.edu/)

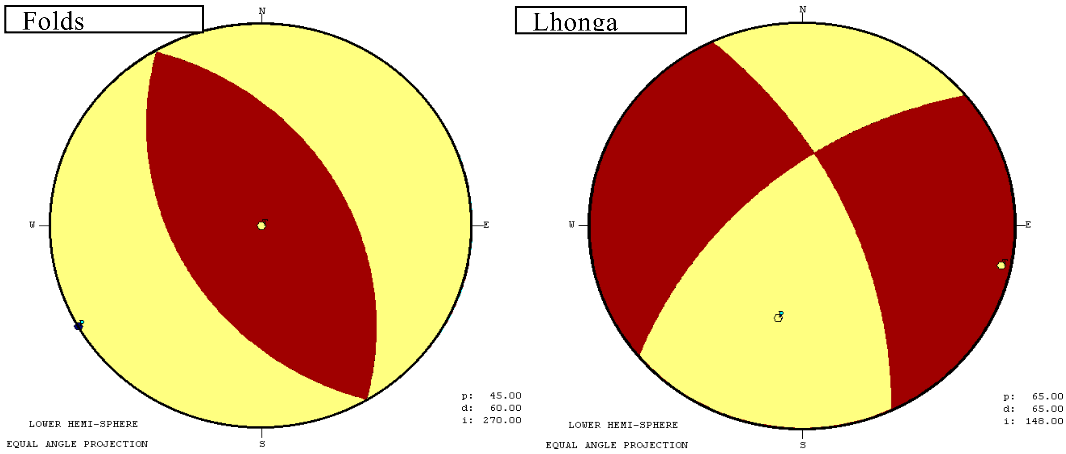

Figure 4.5 Inferred focal plane solutions for folds and striations on bedding planes
(Drawn on the measured data in Lhonga using Aydan's method (Aydan et al. 2002, JSCE))

4.2.2 Parameters and Mechanism of Faulting of Main Event

The magnitude, location and fault plane parameters of the earthquake are listed in Table 4.1. Fault plane solutions computed by various institutes listed in Table 4.1 are illustrated in Figure 4.6. The earthquake magnitude was estimated to be ranging between 8.7 and 9, and the fundamental faulting mode was thrust-type with a dextral sense. However, the solution obtained by the USGS indicated that strike-slip component of the faulting was sinistral, which is contrary to those of the solutions reported by other institutes. The inclination of the causative fault was gently inclined. Furthermore, the depth of the earthquake was shallow and it seems that it took place along the upper surface of the Indo-Australian plate in contact with Euro-Asian plate. The faulting mechanism of this earthquake has the characteristics of a subducting plate-boundary earthquake as illustrated in Figure 4.7.

Table 4.1 Main characteristics of the earthquake inferred by various Institutes

Institute	M	Mw	LAT (N)	LON (E)	DEP (km)	NP1 strike/dip/rake	NP2 strike/dip/rake
USGS	9.0	8.2	3.32	95.85	30	274/13/55	130/79/98
HARVARD		9.0	3.09	94.26	29	329/8/110	129/83/87
ERI(Japan)	9.0	9.0	3.25	95.80	10	340/8/112	
BRI(Japan)		8.7	-	-		329/10/110	
ITU(Turkey)		9.0	-	-	25	320/15/95	135/75/89
CPPT		8.9	3.00	96.00	27	350/5/112	138/86/87

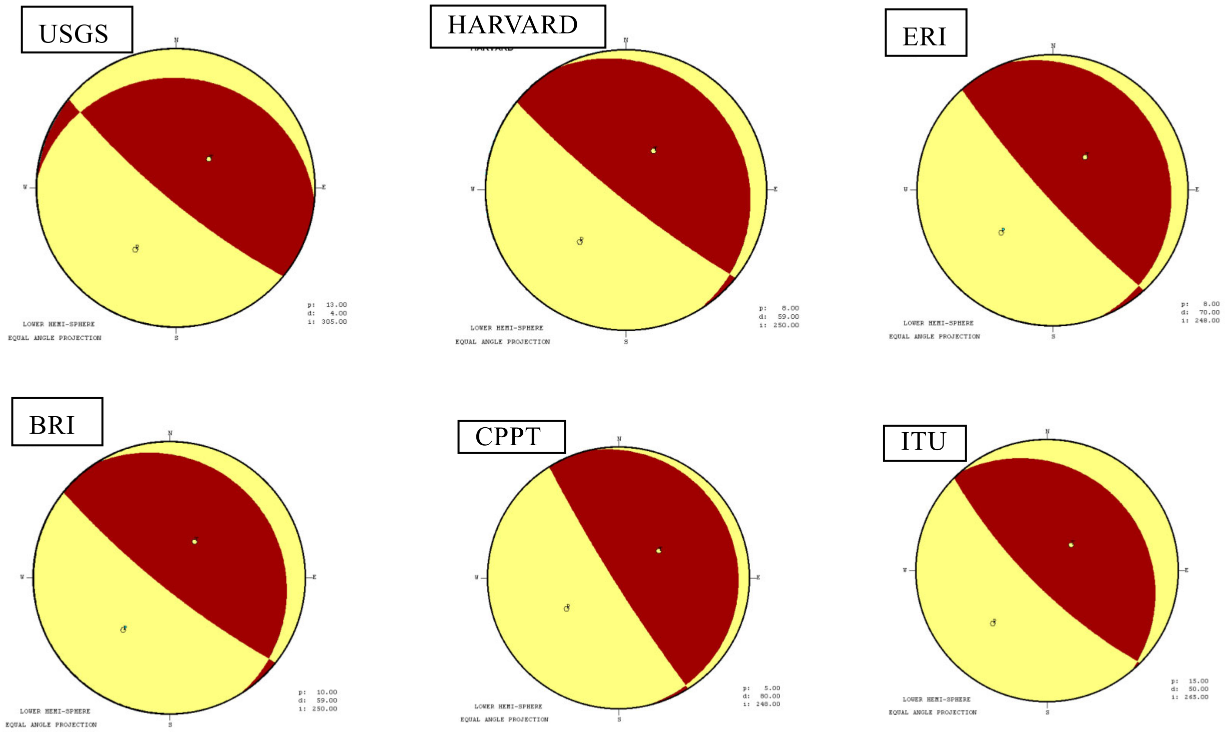

Figure 4.6 Fault plane solutions by various institutes for the main shock

(Re-dawn using the computed data by various institutes on an equal angle stereo projection net.)

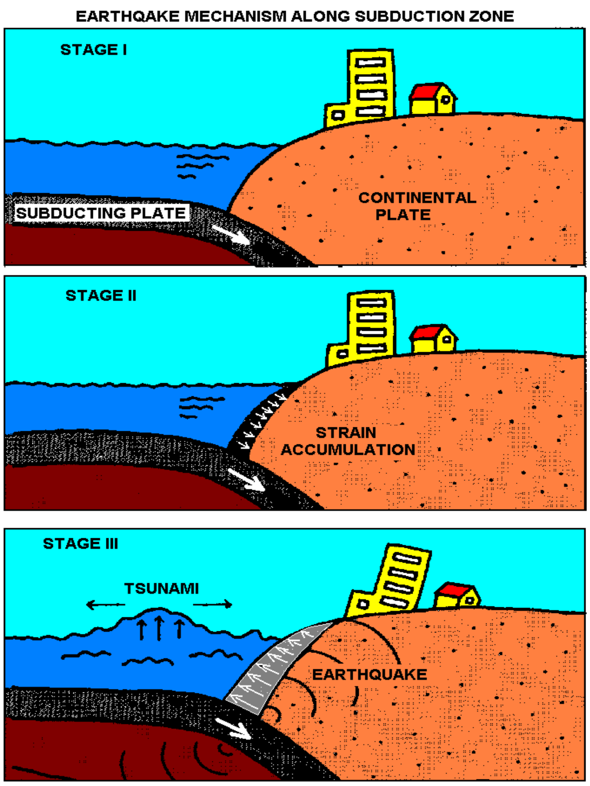

Figure 4.7 An illustration of the subducting plate-boundary earthquake

(Re-arrangement of a figure from a Japanese newspaper source)

4.2.3 Rupture propagation and slip characteristics

The rupture and slip characteristics estimated by several researchers are given in Table 4.2. Assuming that the inclination of the fault plane is about 10^o, the vertical component of the relative displacement should range between 1.5 and 3.5m. The measurements of the coastal line in Simeulue Island nearby the earthquake epicenter by Sieh confirmed these estimations.

Table 4.2 Rupture and slip characteristics of the earthquake fault

Reference	Magnitude	Length	Slip(m)	Area(km^2)
Yamanaka(ERI)	9.0	850(3segments)	8.9	850x200
Yagi (BRI)	8.7	700	18.6	700x140
Ji(Caltech)	9.0	400(1st)	20.0	400x50
Borges et al.	9.0	1000	9.0	1000x150
Taymaz(ITU)	9.0	450	9.5	450x200
Dasgupta(India)	9.0	1000	15.0	1000x100
Aydan	8.6(Ms)	975	9.75	975x45

Several researchers estimated the rupture propagation of the causative fault, and their results are shown in Figure 4.8 to 4.11. It seems that the causative fault was segmented. Depending upon the solutions, the segment number ranges from 2 to 5. The solutions released by ERI, BRI and ITU are all based on Kikuchi's method. The longest segment was very close the Banda Aceh and the distance between highest energy release point and Banda Aceh is about 80-100km. Since there could not be any direct observations on the causative fault plane, the computed results and observed aftershock activity could only give a rough idea about the faulting process and its dimensions. It should also be noted that the slip distributions inferred from those solutions should rather correspond to high-energy release locations rather than the actual relative slip, which may involve both elastic and inelastic components.

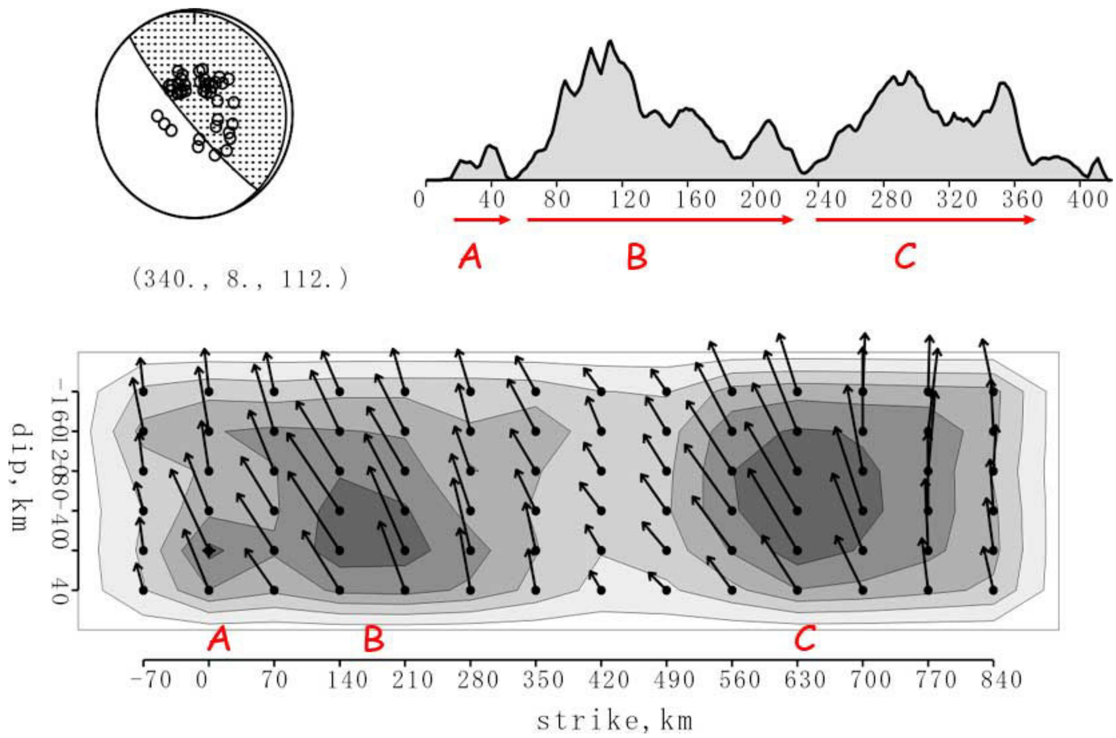

Figure 4.8 Inferred fault mechanism and slip distributions by Yamanaka (ERI)

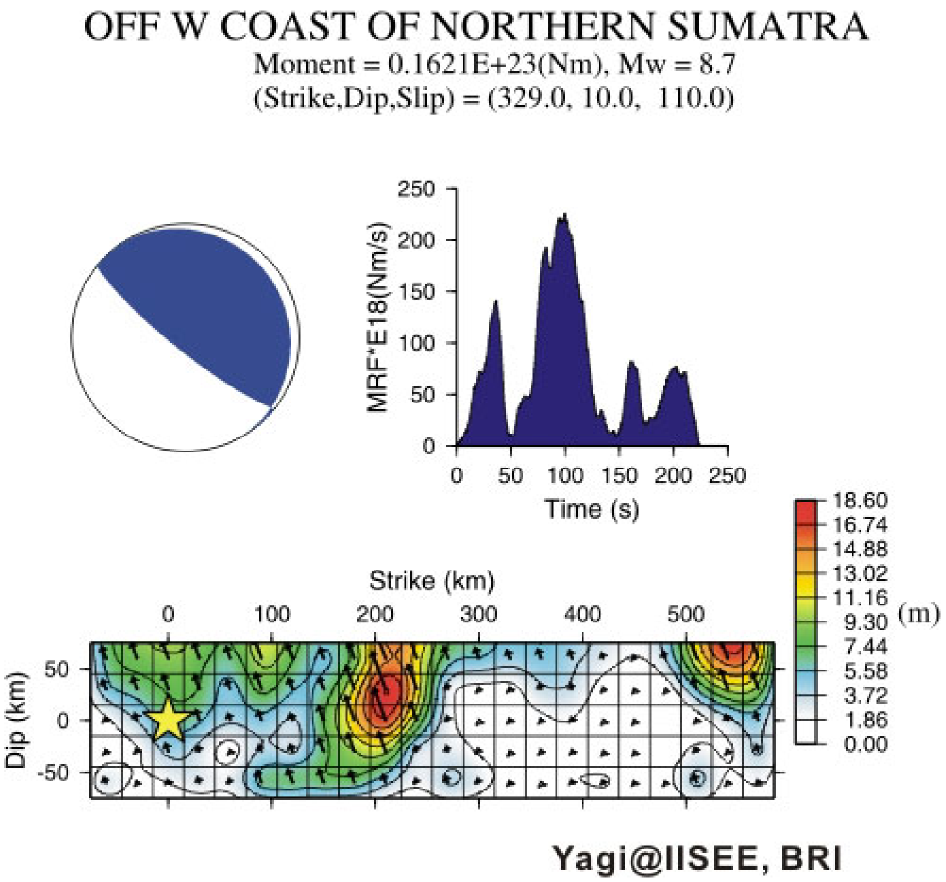

Figure 4.9 Inferred fault mechanism and slip distributions for first event by Yagi (BRI)

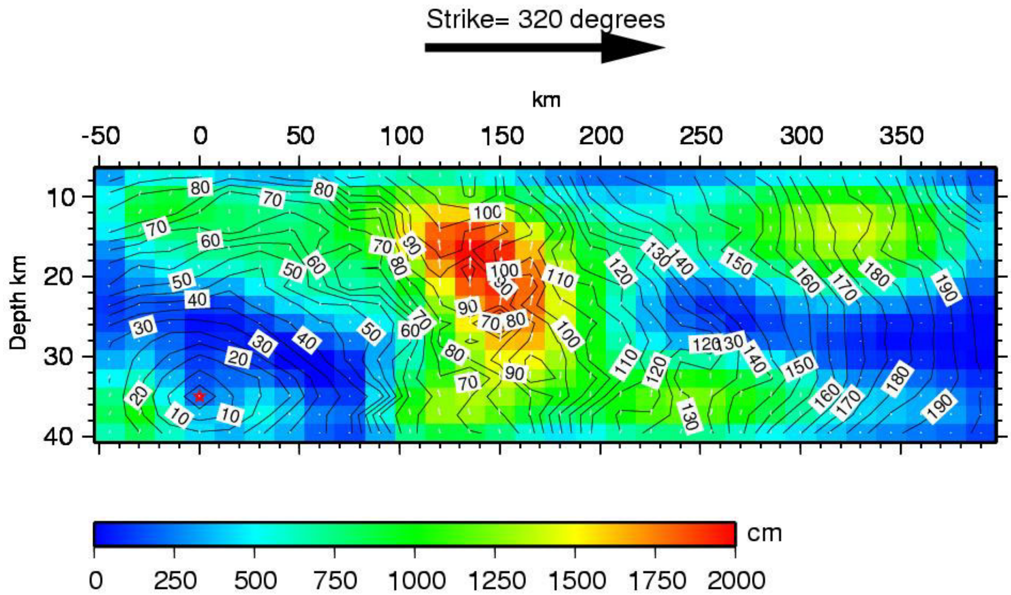

Figure 4.10 Inferred slip distributions for first event by C. Ji (Caltech)

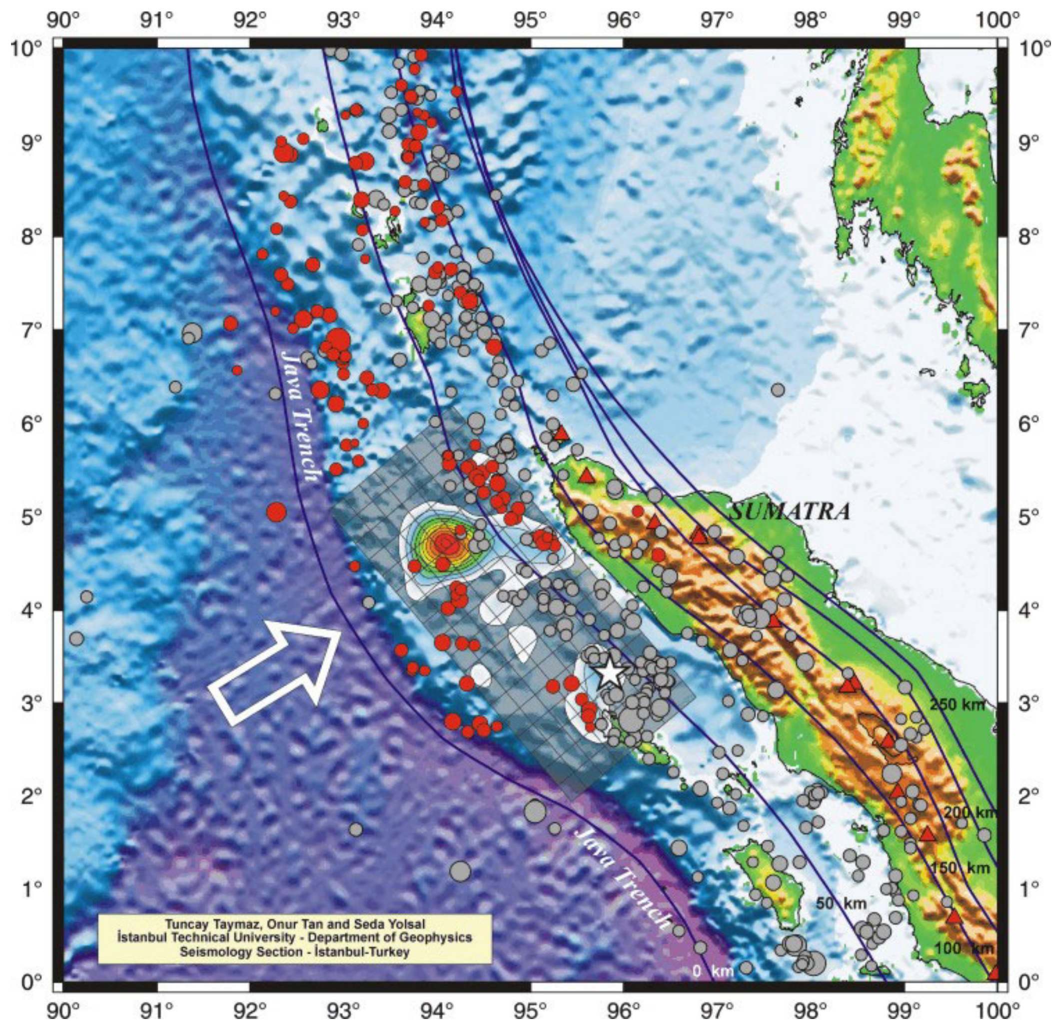

Figure 4.11 Inferred slip distributions by Taymaz et al. (ITU)

4.2.4 Fault Plane Solutions of Aftershocks

The aftershock activity was distributed over 1300km long and 200km wide area as seen in Figure 4.12. The fault plane solutions indicated that the aftershocks had basically the similar characteristics to those of the main event. Nevertheless, some strike-slip events also took place. In addition, some normal faulting events took place on the eastern side of the Sunda trench in Andaman Sea. The largest aftershock event had a magnitude of 7.3 and occurred near Nicobar Island of India on the same day.

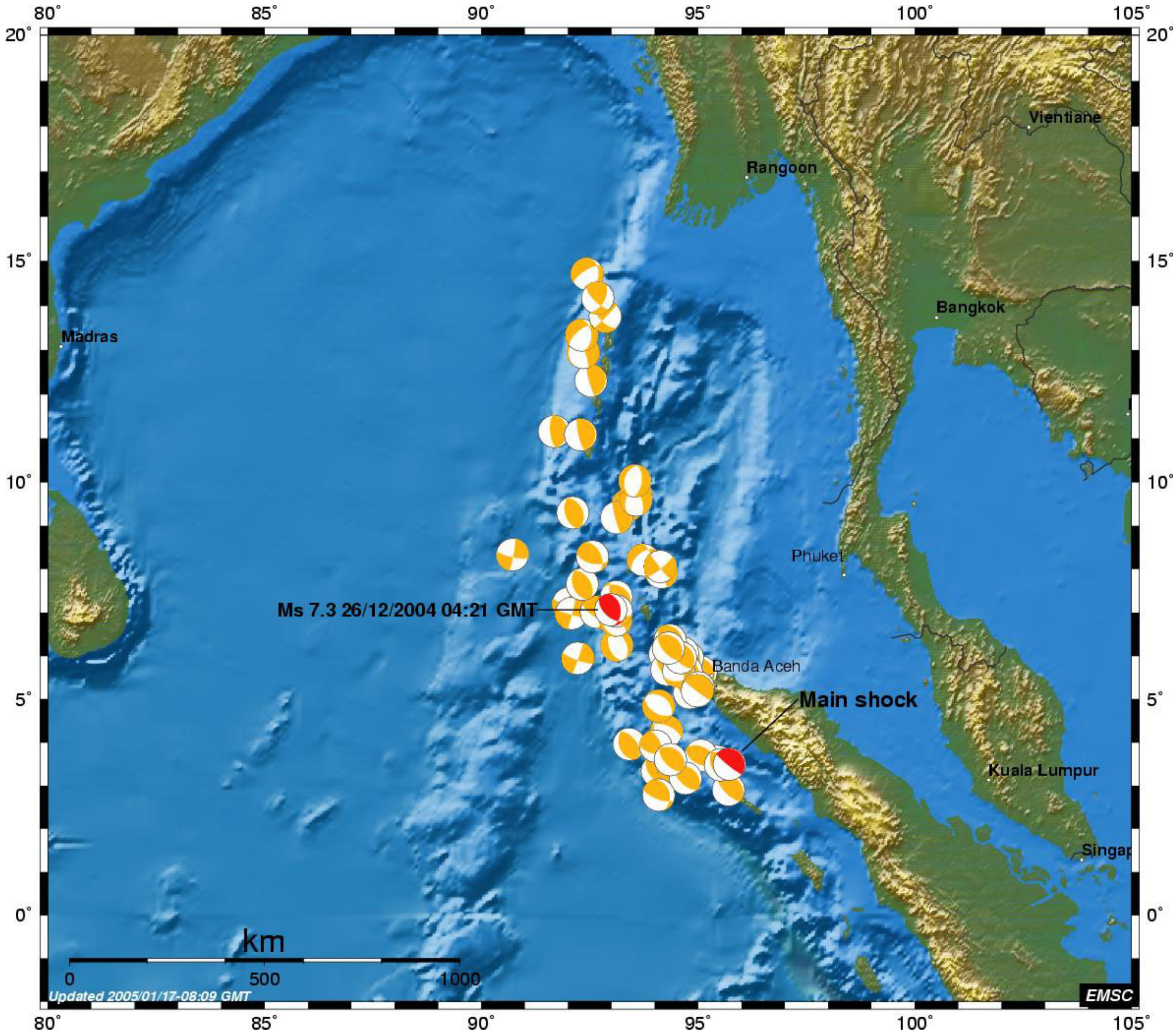

Figure 4.12 Fault plane solutions of the main event and aftershocks (EMSC)

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(Author of this chapter: Ö. Aydan)

Chapter 5

Tsunami and Its Effects

5.1 Human Loss

The tsunami caused by this earthquake probably the most disastrous so far and killed more than 200,000 people in a region from Sumatra as far as to South Africa. Approximately 170,000 people of Aceh province were killed by this tsunami. According to UN estimates, 655,000 people are homeless and sheltering in scattered refugee camps across the province. Although the tsunami caused the great damage and the great loss of lives in countries neighboring Indian Ocean, the most severely hit region was the west and north coast of Aceh province. Out of 10,000 original population of Leupung town, the estimated number of survivors was only several hundreds. According to official estimates, 8,000 of the 18,000 population of town Teunom were dead. 40,000 people of Meulaboh city with a population of 120,000 were killed by the tsunami.

5.2 Tsunamigenic Earthquakes Off the West Coast of Sumatra Island

The 26 December 2004 earthquake was not the first tsunamigenic earthquake, which occurred off the west coast of Sumatra Island. Some earthquakes generated tsunamis in past are shown in Figure 5.1. Only 7 people out of 70,000 people of Simeulue Island nearby the epicenter of the earthquake were killed, thanks to the saying of their ancestors ”if there is an earthquake run for your life”. The experience of the 1907 tsunami disaster was put to good account.

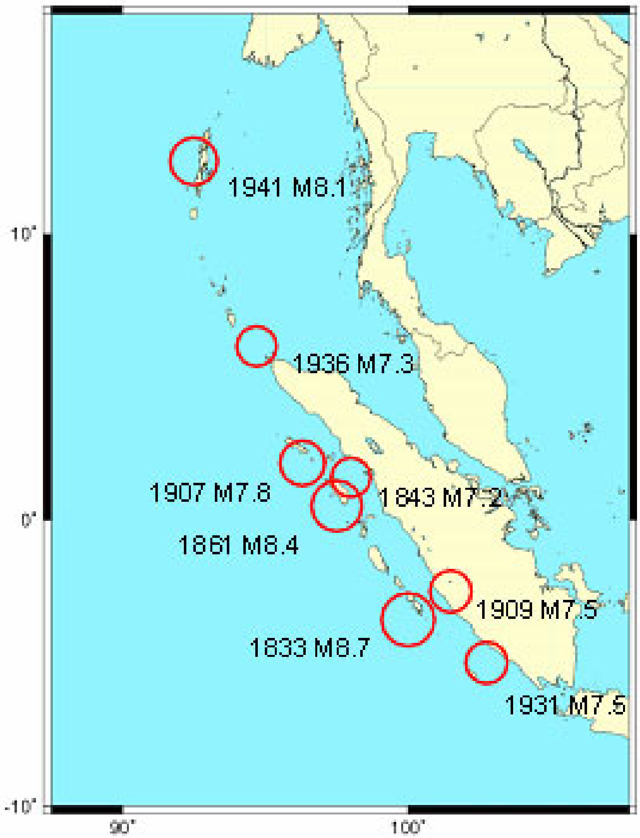

Figure 5.1 Some tsunamigenic earthquakes off the west coast of Sumatra Island (The original figure from BRI)

5.3 Tsunami Simulation

The rupture length of the causative fault was more than 1,000km and at least 2-3m vertical uplift displacement occurred on the continental side (east side). The observations of Prof. Sieh from California Institute of Technology (Caltech) on the shores of Simeulue Island indicated that the island was raised by 70-230cm and these confirmed the initial estimates on the vertical uplift displacement on the Euro-Asian side. The strike of the causative fault plane is about 80-100km from the west coast and the rupture lasted more than 400s. the tsunami waves arrived on the land within 20 minutes following the ground shaking.

The first computational estimations (Figures 5.2 and 5.3) for propagation and wave height of tsunami induced by this earthquake were done by Dr. Kenji Satake of National Institute of Advanced Industrial Sciences and Technology (AIST, Japan) by assuming that seabed was deformed as shown in Figure 5.4. Because of the fault geometry, the tsunami propagating to the East (towards Thailand) begins with a receding wave, which explains why the sea started to retreat minutes before flooding the coast. On the opposite, to the West (towards India and Sri Lanka) a large wave suddenly hit the coast without warning. 10 hours later, the tsunami reached the African coast. Following this first estimation by Dr. Satake, several researchers and institutes did similar type of simulations with better seabed topography and longer computation times. Such a computation result is useful to conduct on-site investigations effectively.

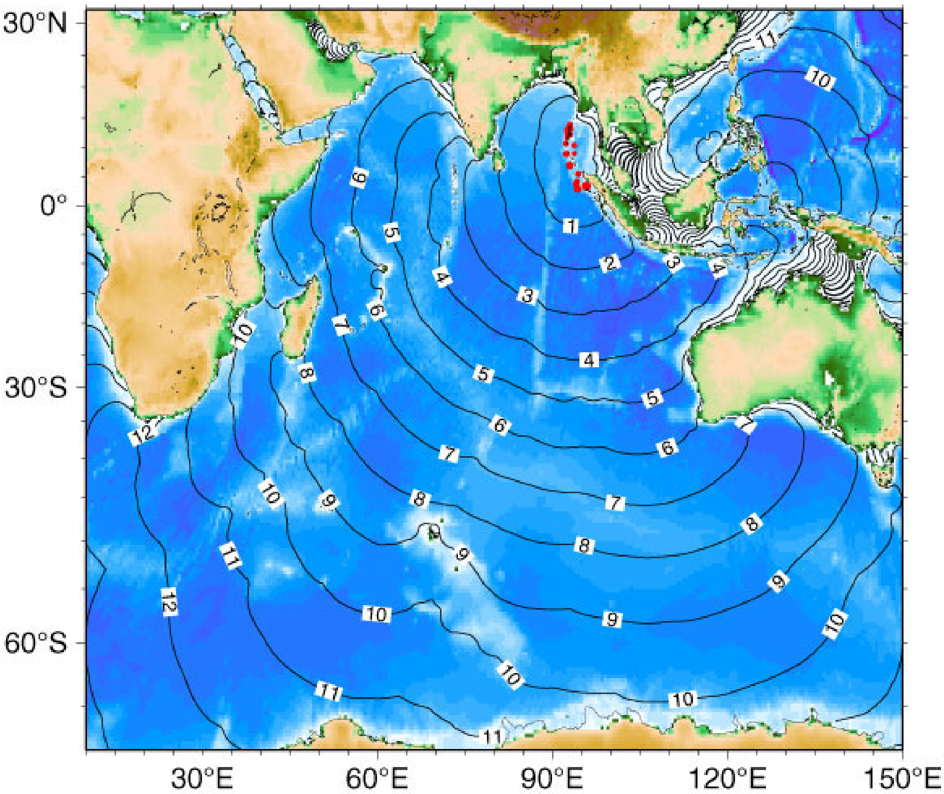

Figure 5.2 Estimated tsunami travel time by Dr. Satake

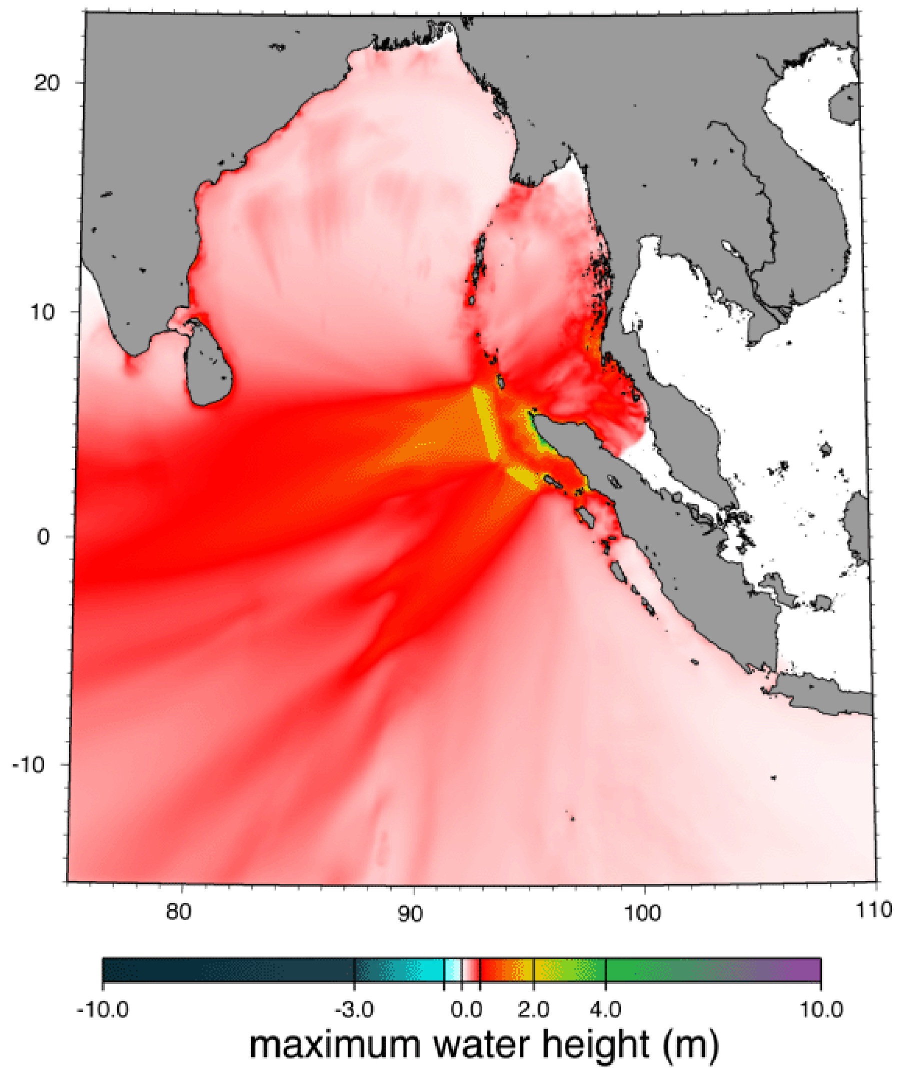

Figure 5.3 Estimated tsunami travel time by Dr. Satake

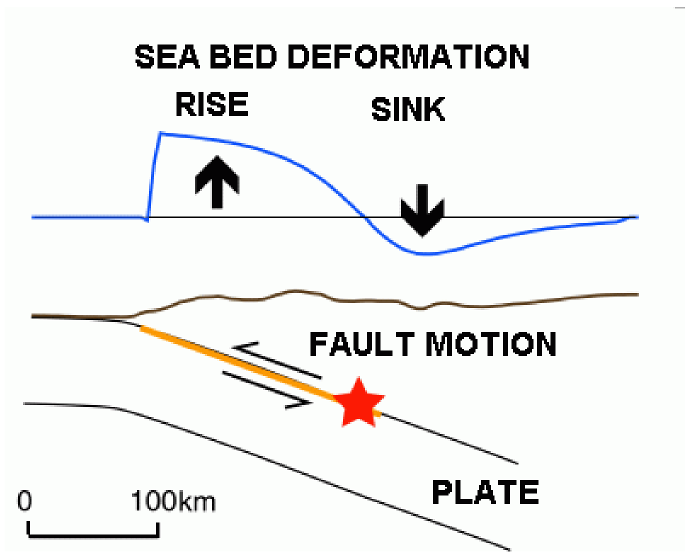

Figure 5.4 Seabed deformation model of Dr. Satake

5.4 Tsunami Trace Height

The tsunami inundated wide coastal areas especially in the west coast of Northern Sumatra and Banda Aceh (Figures 5.5, Photo 5.1 and 5.2).

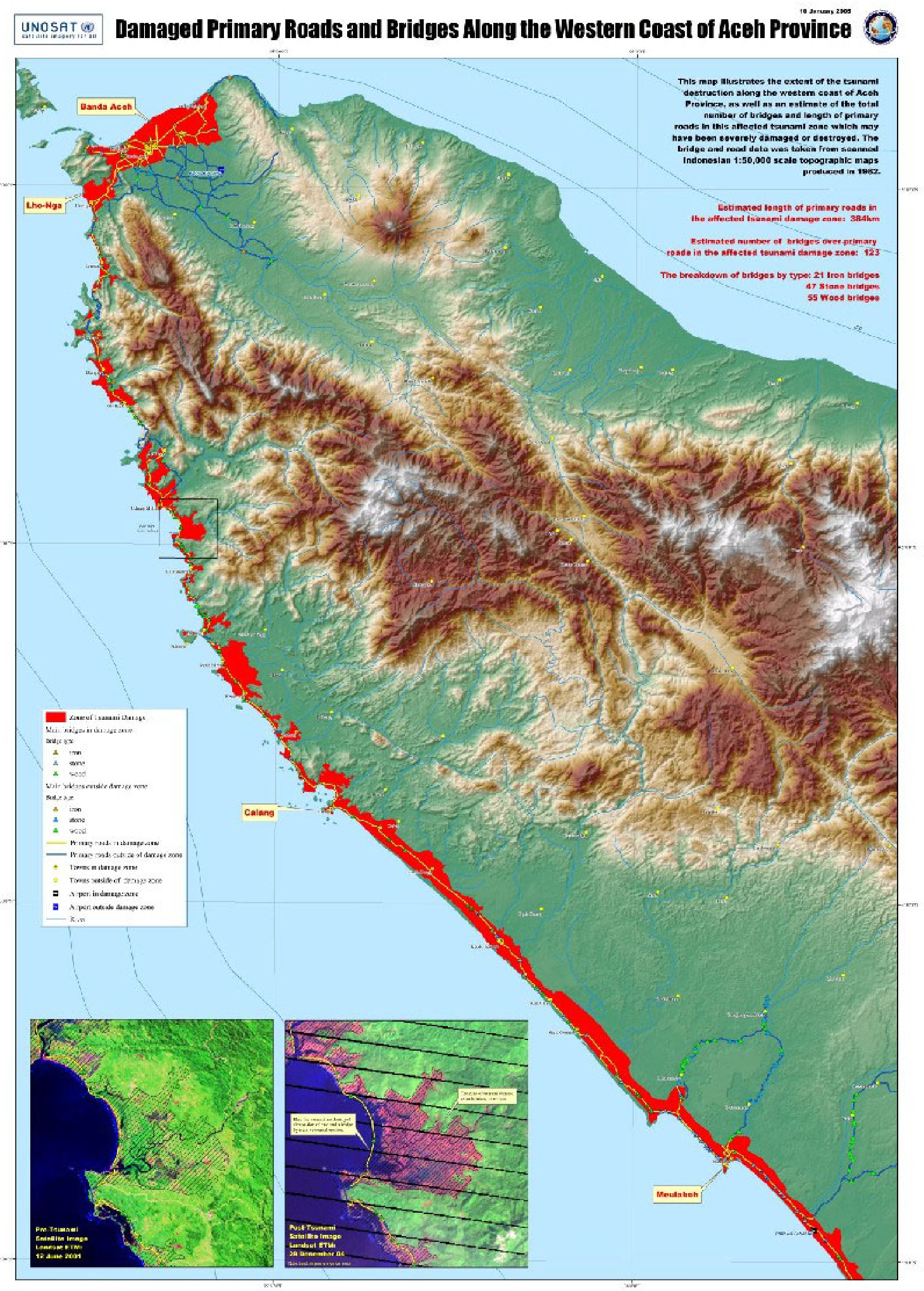

Figure 5.5 Inundated areas (red zone) in Aceh Province (UNOSAT)

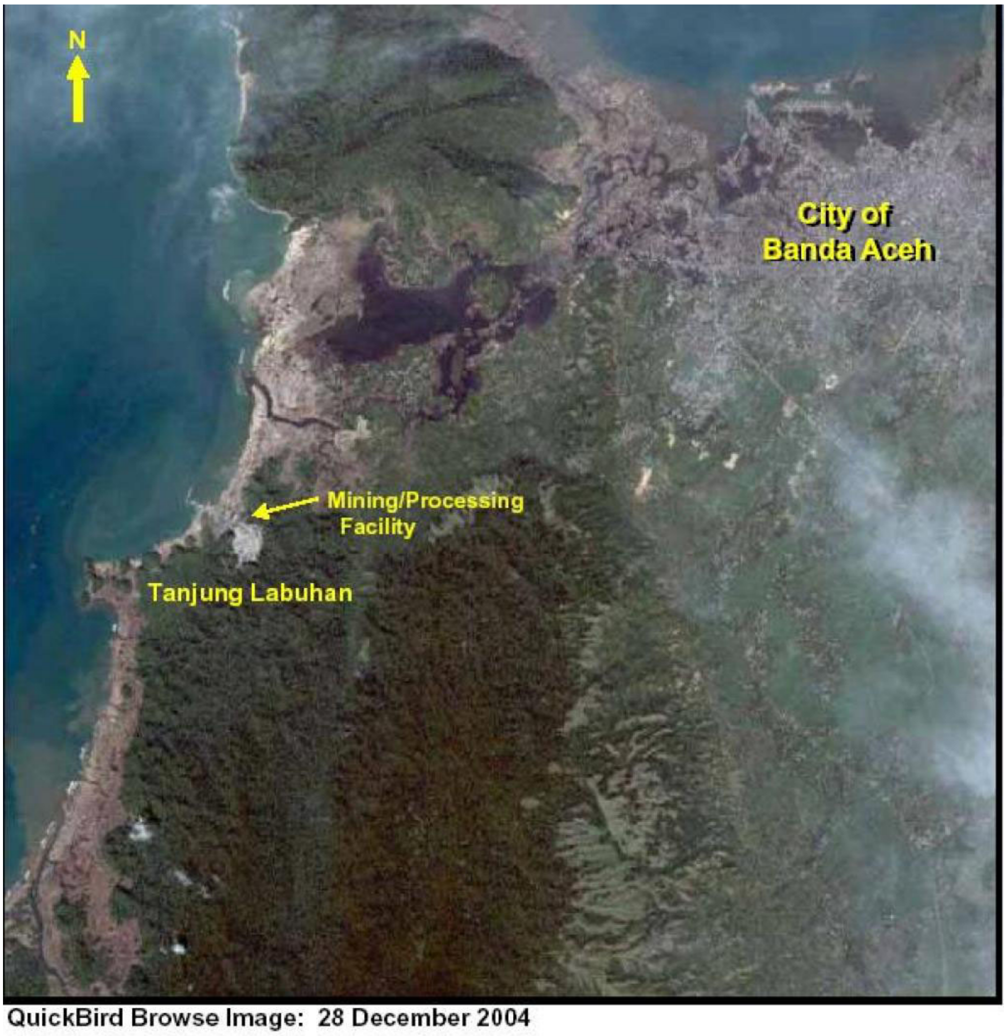

Photo 5.1 A satellite and aerial view of Banda Aceh City (US navy)

(a) Before the tsunami (on June 23, 2004)

(b) After the tsunami (on December 28, 2004)

Photo 5.2 Two satellite views of tsunami-affected areas in Aceh province (From DigitalGlobe)

The tsunami trace height and inundation distance measured by several local and international groups in the tsunami-affected regions neighboring Indian Ocean. The group led by Prof. Tsuji of ERI of University of Tokyo measured the maximum run-up height as 34.5m at Lhonga in Aceh Province (Figure 5.6), and the maximum inundation distance was about 7km according to UN reports. The run-up height was 6m in Sabang Island to the North of Banda Aceh.

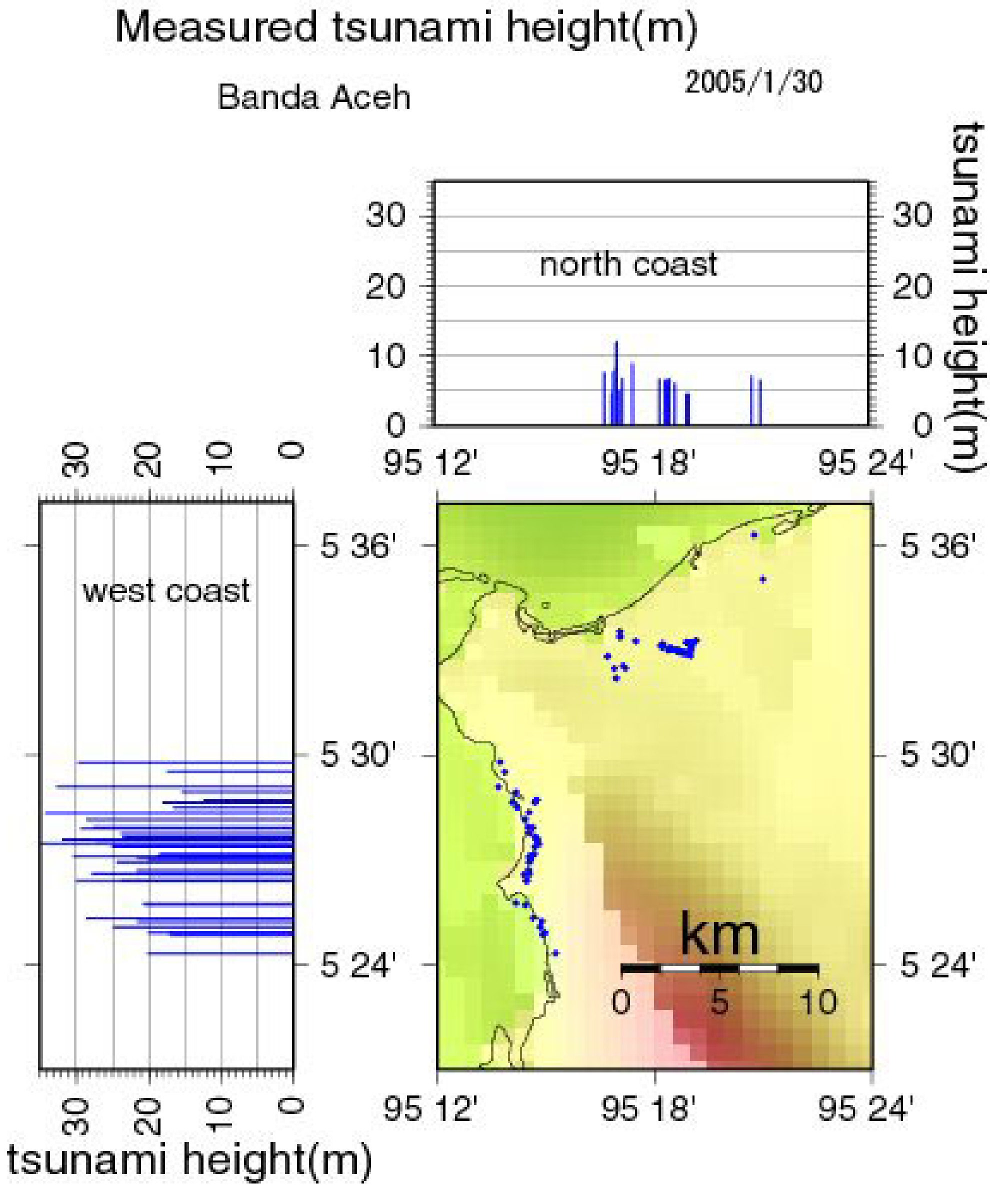

Figure 5.6 Tsunami trace heights measured by the group led by Tsuji of ERI

Figure 5.7 shows the height of tsunami traces measured in our field survey. The green numbers are the height of tsunami traces, and the yellow numbers are the elevation of the ground. The tsunami height was measured with respect to the sea surface level at the arrival time of the first tsunami. The numbers in the parentheses is the trace heights above the ground.

Figure 5.7 Measured tsunami trace and ground heights (The base satellite image from DigitalGlobe)

Photo 5.3 shows the water mark on the north side wall of the first high school as an example of the tsunami traces. The numbers with * indicate the height of the watermarks just under the ceiling of the first floor of house. It seems that the watermarks with * were left while the seawater retreated, because the hole made is likely to be by collision of a drifting body remained on the side wall of the second floor (Photo 5.4).

Photo 5.3 Watermark on the first high school in Banda Aceh

Photo 5.4 A hole by collision of an obstacle and watermark

Banda Aceh City has developed on a flat area facing the sea. In the area 2km away from the near coast, the ground elevation was about 1m above the sea level when the tsunami arrived. Such a low-lying flat area was severely inundated and the seawater reached the inland areas several kilometers away from the coast.

5.5 Tsunami Damage

The expected all forms of damage from a tsunami were observed in this event. A wide band of the coastal zone was inundated and eroded by seawater, the impact and drag force of tsunami waves destroyed buildings, towns, cities, forests, fish farms, agricultural areas, infra-structures, industrial facilities, harbors and roadways, and killed both humans and animals. Although no nuclear or thermal power plants utilize seawater as cooling agent in Sumatra Island, the nuclear power plant in the east coast of India utilizing seawater as cooling agent source had to be stopped manually due to receding seawaters due to tsunami draw-down.

In coastal areas of Banda Aceh City where the 10m tsunami attacked, and the west coast of Sumatra Island where the 20m tsunami attacked, almost buildings were destroyed. However, some rigid buildings like mosques remained. The rigid and high buildings are useful as tsunami shelters especially in wide low-lying areas like Banda Aceh City in order to save human lives.

The tsunami swept away large bodies like a power plant barge and oil tanks. The power plant which generated 7,500 KW (Photo 5.5) was moored in a new ferry port of Banda Aceh, and was washed away by the tsunami action. Finally it reached the inland town 3km away from its original site. The watermark left in the inland town was 3m above the ground. The barge can easily drift if the water depth is greater than 3m.

Photo 5.5 Power plant barge (1,700 weight ton) removed in to inland area

In the vicinity of Krueng Raya, a port of Northern Sumatra, three oil tanks, which were almost empty, were displaced by the tsunami (Photo 9.2). A big tank was moved to the neighboring town 314m away from its original site. It had the diameter of 17.5m and the height of 11.0m. From the watermarks on the tanks, which were not swept and still remained at their original position, the tsunami higher than 4m attacked the tanks.

The tsunami eroded severely the north coast of Banda Aceh (Photo 5.2). Although there were protection measures by stones in this area before the tsunami, the protection works were completely destroyed and the reclaimed areas behind the protection works were eroded more than 1.5m in height (Photo 5.6), and then the topography was changed. The topographic change is also seen in the Thailand where a sandbar was eroded by the tsunami.

Photo 5.6 Eroded sandbar in the north coast of Banda Aceh

5.6 Tsunami Warning

No tsunami warning was issued in any country neighboring Indian Ocean although the scale and possibility of the tsunami was estimated by US Pacific Tsunami Warning Center, Japan and Australia. The officials at US Pacific Tsunami Warning Center seem that they tried to get in touch with authorities in the countries to be affected by the possible tsunami. However, they could not find anybody to inform. It seems that the seismograph of National Earthquake Center of Indonesia at Padang nearby the earthquake epicenter recorded the event. However the geophysicist on duty could not get in touch with the center in Jakarta. Although there could be no or very limited time for such a warning for Aceh Province, it is unbelievable that some warnings could not have been issued to other countries in-spite of the availability of advanced communication options of this century. It is really a big SHAME for all people involved with the tsunami warning locally and internationally.

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(Author of this chapter: T. Tomita)

Chapter 6

Strong Motions

In spite of the scale of this earthquake, there is unfortunately no strong motion record nearby the causative fault. The nearest seismograph is approximately 80km from the epicenter of the earthquake. Nevertheless, the records from this seismograph are all saturated. The record of this seismograph is shown in Figure 6.1. In addition, some seismograph records taken by USGS network are shown in Figure 6.2. As noted from the figures, the fracture propagation occurred for a period longer than 400 seconds and the total length of the rupture is more than 1,000km with a width greater than 100km. Recently, some acceleration records from Singapore and Malaysia have been reported. However, the near-field effects of the fracture propagation could not be identified from these records.

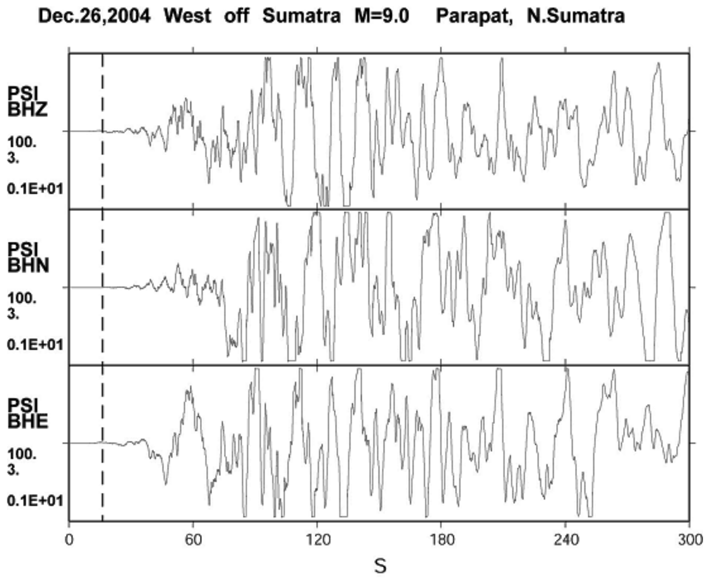

Figure 6.1 Sesimograph record at Parapat, Northern Sumatra

The seismic intensity survey was conducted by USGS in Aceh and other neighboring countries. This investigation indicated that the seismic intensity was IX on MKS scale. The investigation by Aydan of the JSCE reconnaissance team on the damage to structures in non-tsunami affected areas indicated that the seismic intensity should be about VIII on MKS scale and 5+ on JMA scale. Iemura estimated JMA scale seismic intensity by the questionnaires method originally proposed by Ohta et al., and indicated that the seismic intensity was from 5+ to 6- on JMA scale (IX on MKS scale) as shown in Figure 6.3. Figure 6.4 shows possible maximum ground acceleration as a function of MKS scale inferred from this survey results. The inferred maximum ground acceleration should be ranging between 200-400gals.

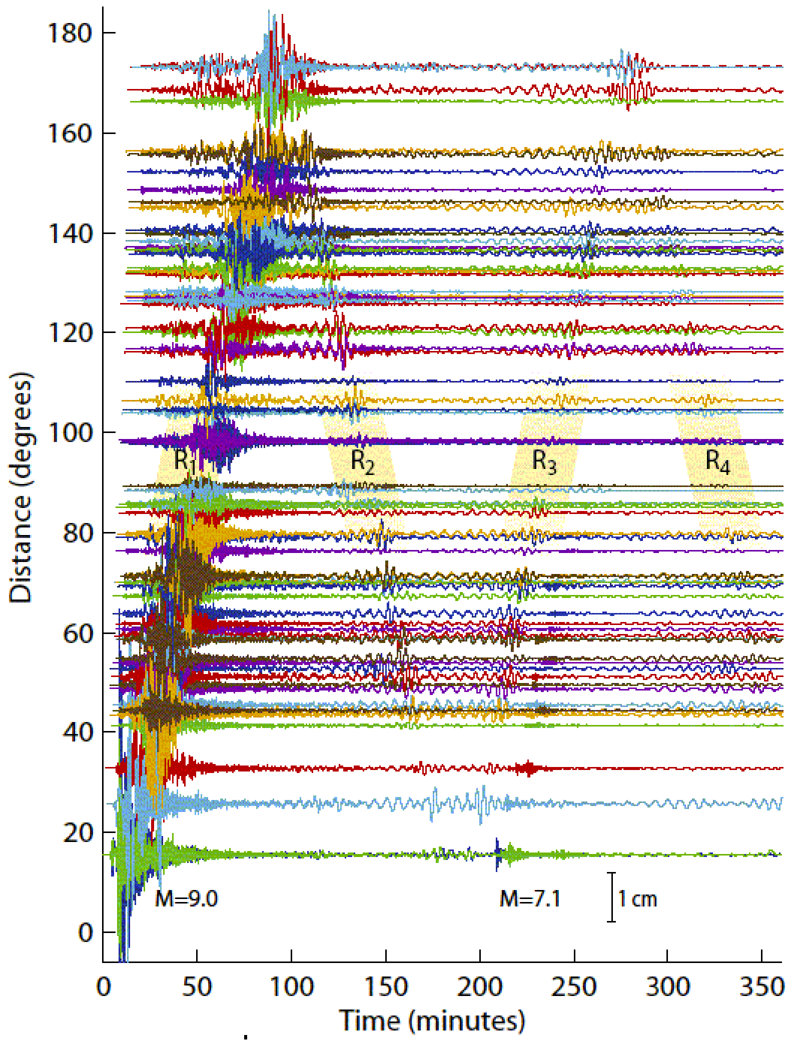

Figure 6.2 Seismograph records of USGS network (Iris-USGS Global Seismographic Network)

A: 5.56
B: 5.48
C: 5.52
D: 5.49
E: 5.51
F: 5.79
G: 5.36
H: 5.60
I: 4.92

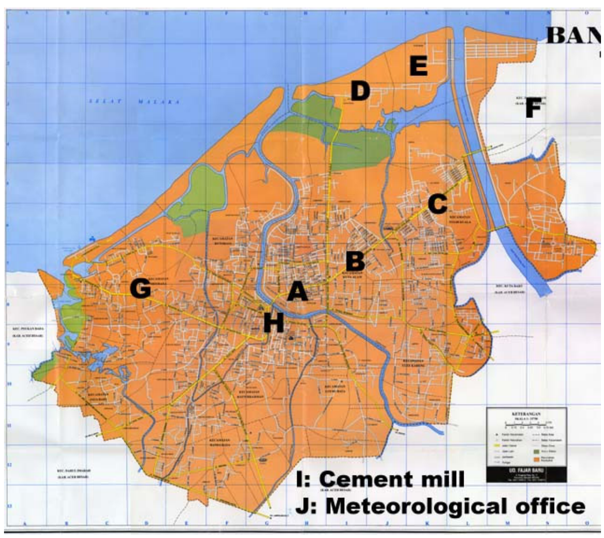

Figure 6.3 Estimated JMA Seismic Intensity by Questionnaires in Banda Aceh by Iemura et al.

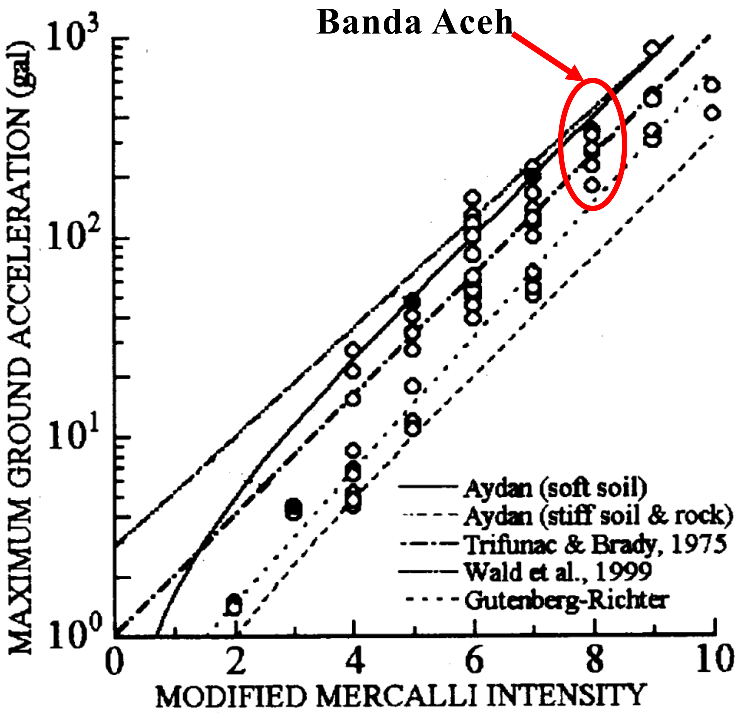

Figure 6.4 Inferred maximum ground acceleration in Banda Aceh
(Aydan (2002) together with inference for Banda Aceh)

Most of structures nearby the seashore were destroyed by the forces of the tsunami waves and the traces of collapses and failures due to ground shaking could not be distinguished from those caused by the tsunami. Some attempts were made to find collapsed, displaced or toppled simple structures in non-tsunami affected area. The simple structures were walls, poles and reinforced concrete buildings.

The some of garden walls were toppled during the ground shaking as shown in Photo 6.1. From these observations, the maximum ground acceleration should had been acted almost NS direction, perpendicular to the faulting direction. For NS direction, it should be greater than 200 gals and less than 350gal. As for EW direction, it should be greater than 110 gals and less than 170gal.

The walls shown in Photo 6.2 were toppled by the tsunami waves. Through some mechanical considerations, these walls may be useful for inferring the impact force of tsunami waves. Photo 6.3 shows pictures of collapsed RC buildings. These buildings were collapsed mainly in NS direction. Although the details of the reinforcement of these columns are not known, a rough estimation would indicate the ground acceleration should be greater than 100gal for the failure of the columns of these buildings.

Photo 6.1 Earthquake induced wall failure

Photo 6.2 Tsunami induced wall failures

Photo 6.3 Collapsed reinforced buildings in Banda Aceh

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(Author of this chapter: Ö. Aydan)

Chapter 7

Damage to Buildings

The building in the region of the earthquake can be broadly classified as follows:

- Wooden houses,
- Masonry (brick) houses,
- Reinforced Concrete buildings and
- Mosques and Minarets.

The cause of damage to buildings was ground shaking, tsunami or both. While the story number of buildings in the populated cities such as Banda Aceh and Meulaboh could be greater than 3, most of the buildings along the west coast of Sumatra were mainly single story or two story buildings.

7.1 Wooden Houses

Wooden houses are generally single story or two story buildings. These buildings were almost non-damaged in the regions, which were not affected by the tsunami. Therefore the main cause of the damage was tsunami. The tsunami may impose at least four types of loading, namely, impact force, drag force, hydrostatic water loading and buoyancy (uplift) force on wooden buildings. While impact and drag forces directly related to the velocity of tsunami, the hydrostatic and buoyancy forces depend upon the tsunami height and relative density differences between the building material and tsunami waves. Photo 7.1 shows some examples of damage to wooden houses.

Photo 7.1 Damage to wooden houses

7.2 Masonry (Brick) Houses

Masonry (brick) houses are generally single story buildings and some of them could be 2 story buildings. Solid red clay bricks or hollow concrete blocks were used for constructing the adobe houses. Although concrete column and slabs are utilized during the construction, they are merely used for achieving structural integrity. These buildings were not damaged in non-tsunami affected area. However, they were completely destroyed when the tsunami waves hit these structures. It seems that the impact force of the tsunami waves were quite high from the state of debris and the fallen tree trunks. The other force components of the tsunami waves could be drag forces and hydrostatic water loads. When the masonry (brick) houses are still standing, their walls were punched out. Photo 7.2 shows some example of damage to masonry (brick) houses.

Photo 7.2 Damage to masonry (brick) buildings

7.3 Reinforced Concrete (RC) Buildings

Most of RC buildings have 2 to 3 stories. Nevertheless, new buildings for governmental offices and shopping malls have more than 3 stories. Commonly their story number is 5. The common construction procedure for RC buildings is to construct the walls first and then cast the concrete columns and finally the slab concrete for a typical story and repeat the same procedure for the rest of stories. However, the new buildings are constructed as a frame structure by casting concrete columns and then slab concrete first and finally filling the space with solid brick in-fill walls. The floor height ranges between 3 and 4m. There was no structural damage to RC buildings having stories 3 or less than that in non-tsunami affected area. However, almost all new buildings having heavy weight on upper stories collapsed or heavily damaged in non-tsunami affected area (Photo 7.3). The collapses were mainly due to plastic hinging at column-beam connections due to the lack of required column size and stir-ups, hooking and confinement. Furthermore, the quality of concrete and workmanship were quite poor and the diameter of reinforcement bars was insufficient. The in-fill walls were too slender and they were easily separated from the concrete frame and came down by out-of plane failure mode. Besides the structural and constructional problems of RC buildings, the soft ground conditions may also play some roles on the collapses or heavy damage. The collapsed or heavily damaged RC buildings were constructed nearby rivers or swampy areas.

Photo 7.3(a) Collapsed or heavily damaged RC buildings

Photo 7.3(b) Collapsed or heavily damaged RC buildings

The RC structures in tsunami-affected areas have stories ranging between 2 and 3. Some of columns were broken and in-fill walls were punched out by the impact forces of tsunami waves and tsunami-dragged objects (Photo 7.4). Nevertheless, some of them survived against the ground shaking and also the forces resulting from tsunami waves. The columns were generally ruptured or fractured at their mid-height, which implies that there were subjected to high bending forces. Furthermore, the broken columns and punched-out walls were facing the direction of the in-coming tsunami waves.

Photo 7.4 Damage to RC buildings in tsunami-affected area

7.4 Mosques and Minarets

Mosques are generally built as single story RC structures. Due to tropical climate of the area, there are almost no in-fill walls. Most of the Mosques survived against the ground shaking and tsunami waves even in the severely hit areas (Photo 7.5). The possible reason for such a good performance against tsunami may be associated with its columnar structure without in-fill walls. One of the few mosques damaged in this earthquake is in Ulehle district. The central RC column of the wall facing the sea was fractured by bending at mid-height. Many mosques built as masjid having no minarets. The grand mosques in Banda Aceh and Meulaboh have only minarets. Their minarets were lightly damaged.

Photo 7.5 Damage to mosques and minarets

(Author of this chapter: Ö. Aydan)

Chapter 8

Geotechnical Damage

Geotechnical damage caused by the ground shaking and tsunami resulting from this earthquake may be broadly classified as

- Slope failures,
- Embankment failures,
- Liquefaction and liquefaction induced failures.

In coastal areas, it is sometimes difficult to differentiate whether the cause was ground shaking or tsunami. However, the cause of failures, where there was no trace of tsunami, can be assumed to be due to the ground shaking.

8.1 Slope Failures

Slope failures were mainly observed in the areas of stone quarries, along roadways and seashores. The seashore between Banda Aceh and Lamno is particularly mountainous and slopes are steeply inclined. Furthermore, the rock layers are folded and are inclined towards the sea. The failure of rock slopes was mainly due to sliding on bedding planes of hard sedimentary rocks and the slopes facing the causative fault plane (Photo 8.1). It is therefore thought that the ground shaking was the main cause of rock slope failures. The weathered material on the rock slopes along the seashore was stripped away for a height of 10-20m by the tsunami waves as seen in Photo 8.2. Rock falls were observed in stone quarries in Lhonga area nearby the cement factory.

Slopes involving residual soils or highly weathered volcanic rocks were failed in the form of circular sliding. Such failures are observed on slopes on headlands as seen in Photo 8. 2.

8.2 Embankment Failures

Embankment failures were observed along seashores, rivers and canals and roadways. Some of failures were in the form of typical circular sliding, erosion and liquefaction associated lateral spreading. Photo 8.3 shows some examples of embankment failures.

8.3 Liquefaction and Lateral Spreading

Ground along the western coast of Sumatra Island is mostly sandy soil. Liquefaction can be induced by ground shaking as well as by tsunami. The effects of liquefaction would be ground settlement, lateral spreading and erosion by retreating tsunami waves. The coastal area seems to be settled down and or topsoil is eroded. Photo 8.4 shows some examples of failures induced by liquefaction.

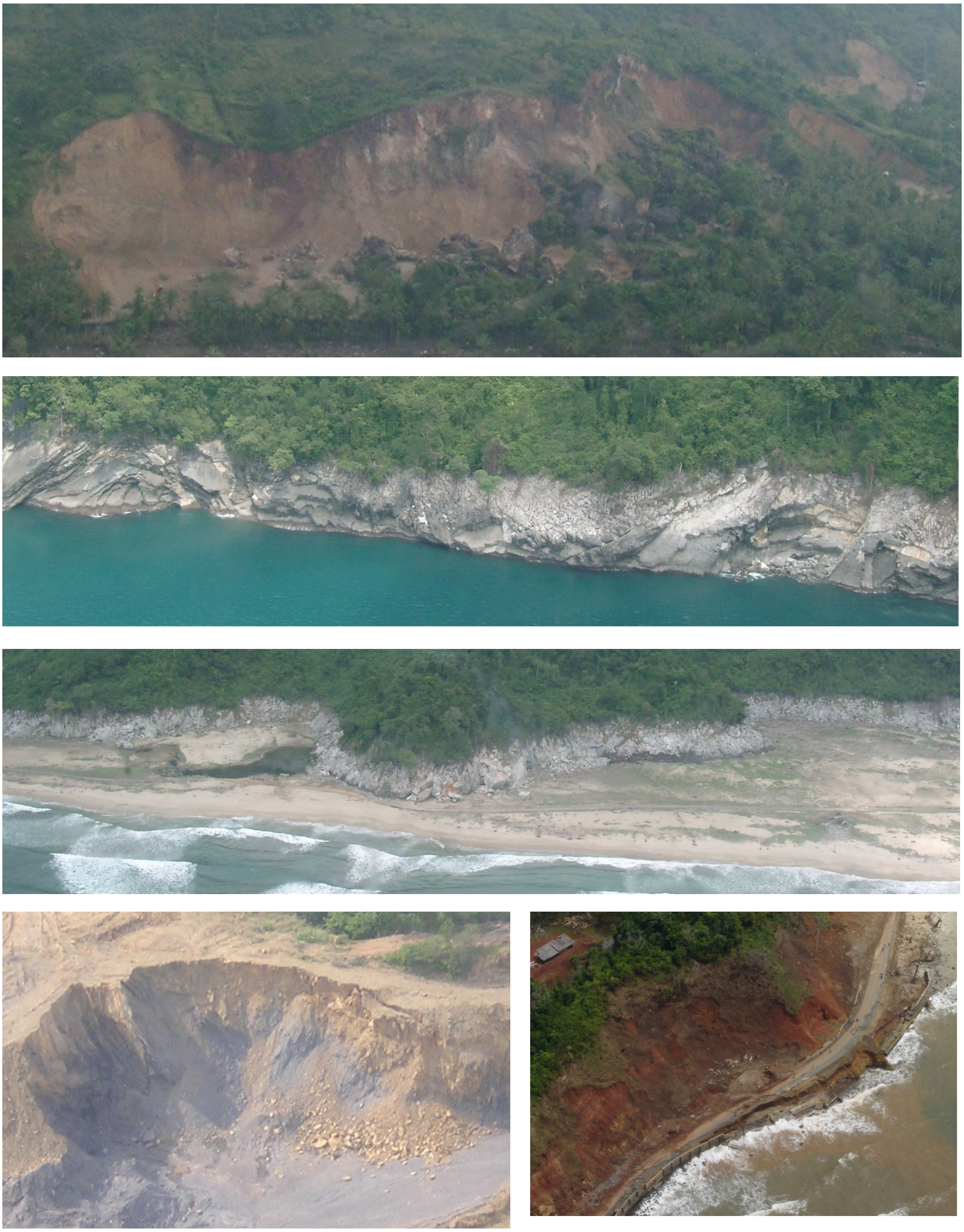

Photo 8.1 Rock slope failures and erosion by tsunami

Photo 8.2 Soil slope failures and erosion by tsunami

Photo 8.3 Embankment failures

Photo 8.4 Effects of ground liquefaction and erosion

(Author of this chapter: Ö. Aydan)

Chapter 9

Damage to Industrial Facilities

9.1 Cement Plant

Aceh Province is one of the major oil and natural gas producing region in Indonesia. These facilities are on the east coast of province. None of these facilities were damaged either by ground shaking or induced tsunami. However, the cement plant at Lhonga was heavily damaged by tsunami waves. A French company originally built the plant and the subsidiary in Indonesian now operates it. The steel structure, kiln and fuel storage tanks were heavily damaged by tsunami while RC silos remained intact (Photo 9.1). It seems that tsunami waves reached a height of 15-20m in some sections and the steel beams and columns were either bended or buckled by the impact of tsunami waves and dragged objects. There were three cylindrical fuel tanks in the plant. Two of them were completely destroyed while the other one was buckled. All of them were offset from its original location.

Photo 9.1 An aerial view of the cement plant

9.2 Oil Terminal Facility

Storage tanks from an oil tank farm in the eastern part of Banda Aceh city (Krueng Raya, about 22km east of Banda Aceh) were displaced by the tsunami waves for a considerable distance from their original position as seen in Figure 9.2. The tanks were not fixed to the ground and some damage to piping did occur. Figure 9.3 shows a buckled tank along the seashore in Meulaboh. The tank was hit by tsunami waves and that side of the tank was buckled. Furthermore, some settlement of the tank occurred probably due to the liquefaction of foundation ground.

Photo 9.2 Displaced oil tanks by the tsunami

Photo 9.3 Buckled and settled tank at Meulaboh

(Author of this chapter: N. Furukawa)

Chapter 10

Damage to Ports and Coastal Facilities

10.1 Area Investigated

Tsunami induced heavy damage to ports and coastal facilities along the west and north coast of Sumatra Island. Figure 10.1 shows the investigated facilities around Banda Aceh area. The coastal area of Banda Aceh is consists of alluvial flat area around -0.45m to +4.5m from mean sea water level. Most of area below the mean sea water level is used as aquaculture ponds.

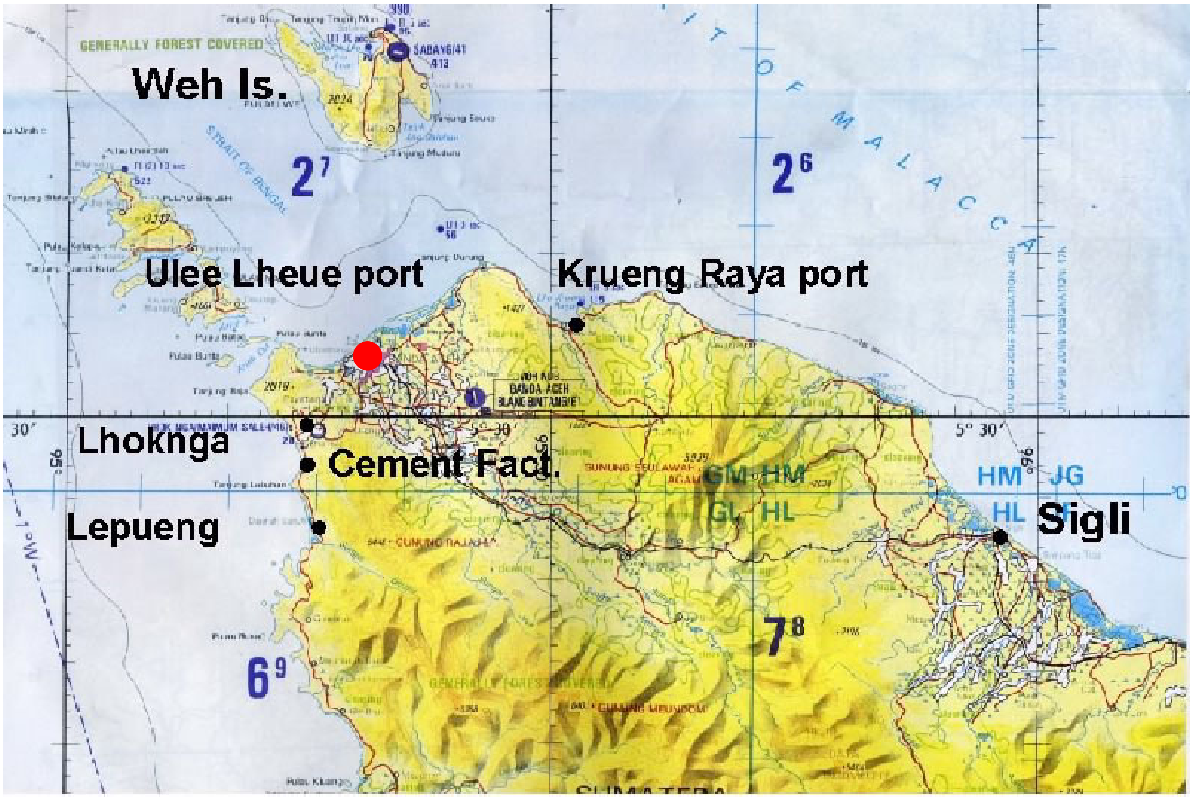

Figure 10.1 Investigated area (Northern part of Sumatra Island, Modified from TPC L-9B published by DMA-USA)

10.2 Ulee Lheue Port

Figure 10.2 show satellite views of Banda Aceh port before and after the earthquake. As noticed from the comparison of two satellite views, a huge area was damaged by the tsunami and was settled, eroded and scoured due to probably ground liquefaction induced by ground shaking as well as due to the tsunami waves. The ground consists of sandy soil in this area. It is also of great interest that some parts of the dykes of the harbor disappeared. Besides the effects of liquefaction, the flow direction of tsunami waves might have some damaging effects on the missing section of the dykes.

Before the earthquake

After the earthquake

Figure 10.2 Satellite views of Ulee Lheue port before and after the earthquake

The plan view of Ulee Lheue port is shown in Figure 10.3 and 10.4. The residential area is protected by rubble stone (2000kg-3500kg) revetment with gentle slope as shown in Figure 10.5. The severely damaged missing area between residential area and the ferry terminal is used as small boat/fishery boat access port with submerged breakwater as shown in Figures 10.4 and 10.5.

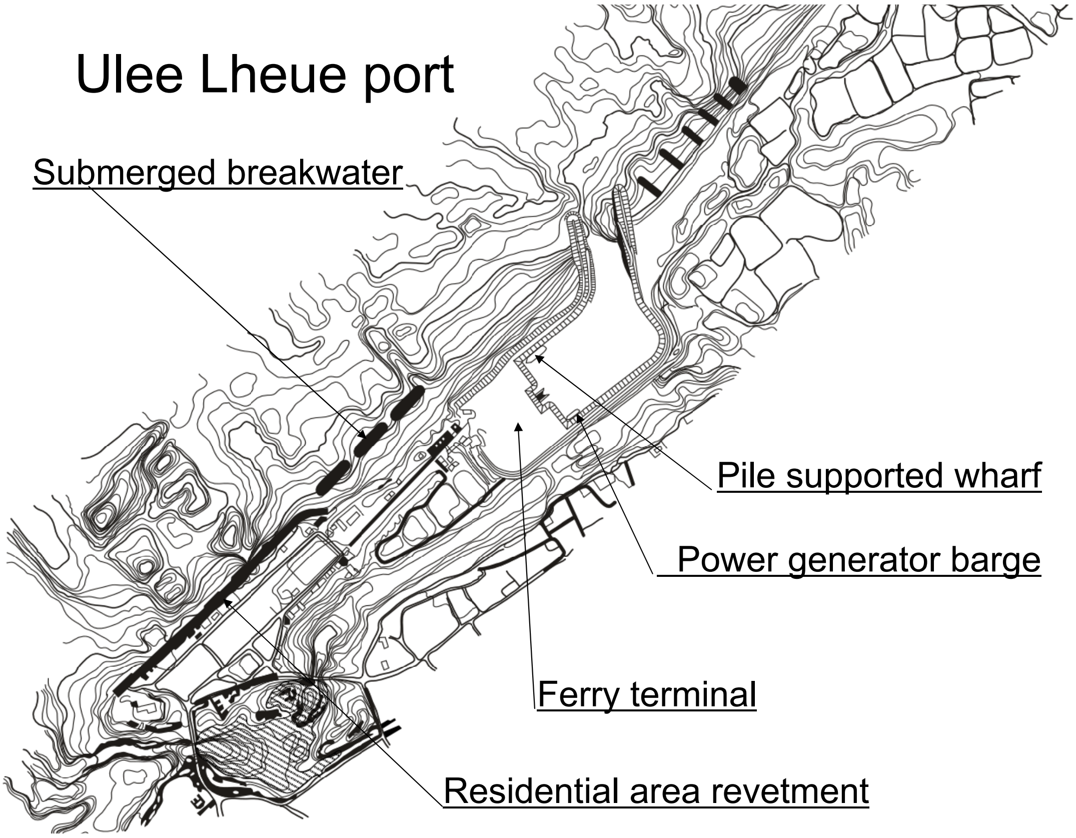

Figure 10.3 Plan View of Ulee Lheue Port
(Traced drawing of the picture provided by Departemen Permukiman dan Prasarana Wilayaha, Direktorat Jenderal Sumber Daya Air, Detail Design Panttai Syiah Kuala Kota Banda Ache, 2003)

Large stone blocks were thrown by the tsunami waves over the wharf of the port as seen in Figure 10.3 However, as shown in Figure 10.2, just behind the stone rubble revetment a residential area was disappeared. During construction of the revetment, naturally deposited sandy dyke was excavated and stone rubbles were placed and then remolded as shown in Figure 10.5 top. The remolded water pluvial sand layer should had been liquefied during the earthquake motion.

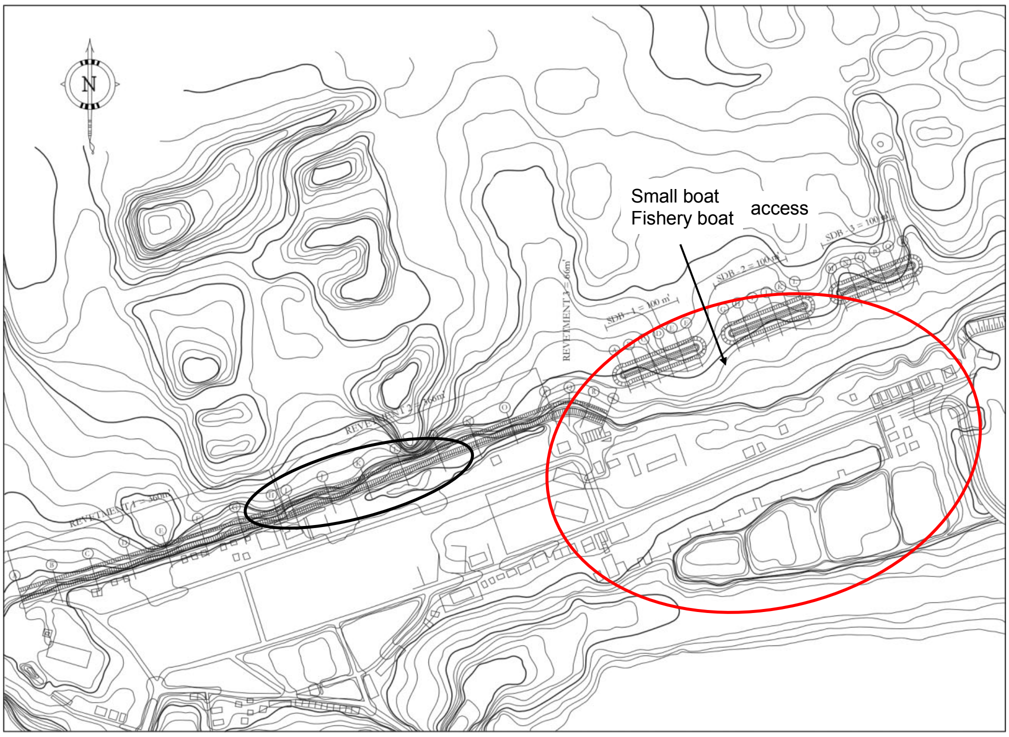

Figure 10.4 Plan view of the revetment and the submerged breakwater

(Traced drawing of the picture provided by Departemen Permukiman dan Prasarana Wilayaha, Direktorat Jenderal Sumber Daya Air, Detail Design Panttai Syiah Kuala Kota Banda Ache, 2003)

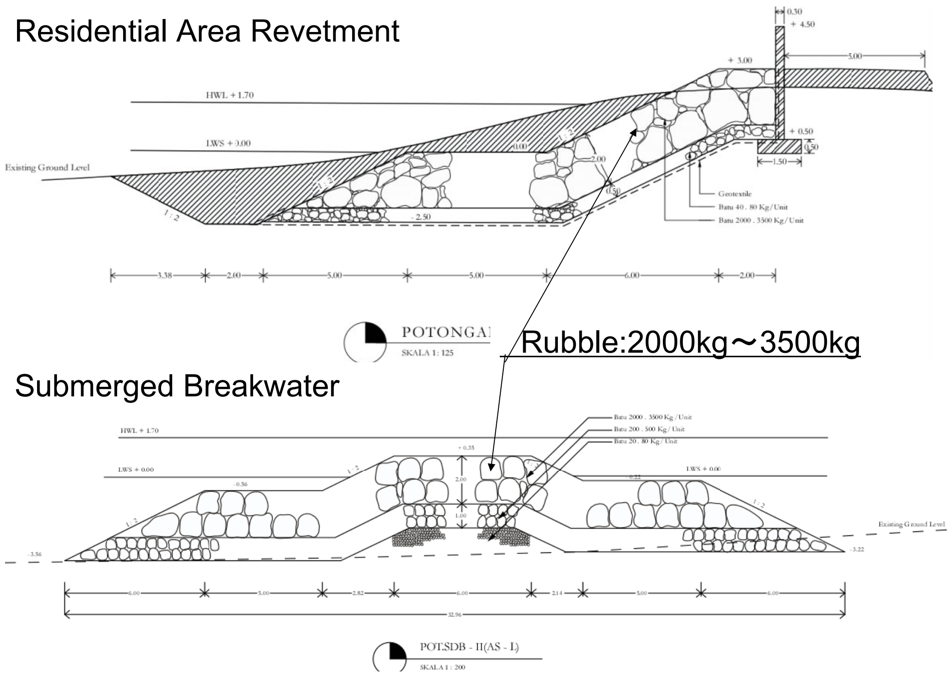

Figure 10.5 Cross section of revetment and submerged breakwater

(Traced drawing of the picture provided by Departemen Permukiman dan Prasarana Wilayaha, Direktorat Jenderal Sumber Daya Air, Detail Design Panttai Syiah Kuala Kota Banda Ache, 2003)

The pile supported wharf for ferry boat (Figure 10.6) has no damage during the earthquake motion and the tsunami. However, two pieces of rubble stones (2,000kgf-3,500kgf) observed on the deck as shown in Photo 10.1 due to the tsunami wave.

Photo 10.1 Pile supported wharf for ferry boat

Although the dolphin for a barge with a power generator was not damaged by the tsunami as seen in Photo 10.2, the barge (Photo 10.3) was displaced from the dolphin to a distance of 3km inland.

Photo 10.2 Dolphin for a power generator barge

Photo.10.3 Power generator barge

The RC building of the port facility collapsed at the ground floor as seen in Photo 10.4. However, the main cause of collapse was ground shaking rather than the tsunami waves because of the second floor with slightly damaged columns was survived during the tsunami waves (Photo 10.5). The ferry terminal building, which is a RC pile-deck structure without shear walls, collapsed at ground floor and the ground floor columns acted as a base isolation system. The second and top floors survived the earthquake and the tsunami.

Photo 10.4 Ferry terminal (collapsed ground floor)

Photo 10.5 Ferry terminal (2nd Floor)

The port facility for the cement factory was also damaged by the tsunami. The 5m high gravity type parapet with a trapezoidal cross section was overturned as shown in Photo 10.6. Totally, three blocks were overturned, two blocks of the parapet were overturned outside direction of the port and other one was overturned opposite direction. To investigate the overturned scenario, detail consideration of the layout of the parapet and tsunami wave action should be needed.

Photo 10.6 Damaged seawall at cement factory

Photo 10.7 shows the damage of pile-supported wharf due to the capsized ship impact force during the tsunami. A pile supported wharf showed good performance during tsunami waves as mentioned in section 10.2, however, it must be considered drifting object's impact force against the structures.

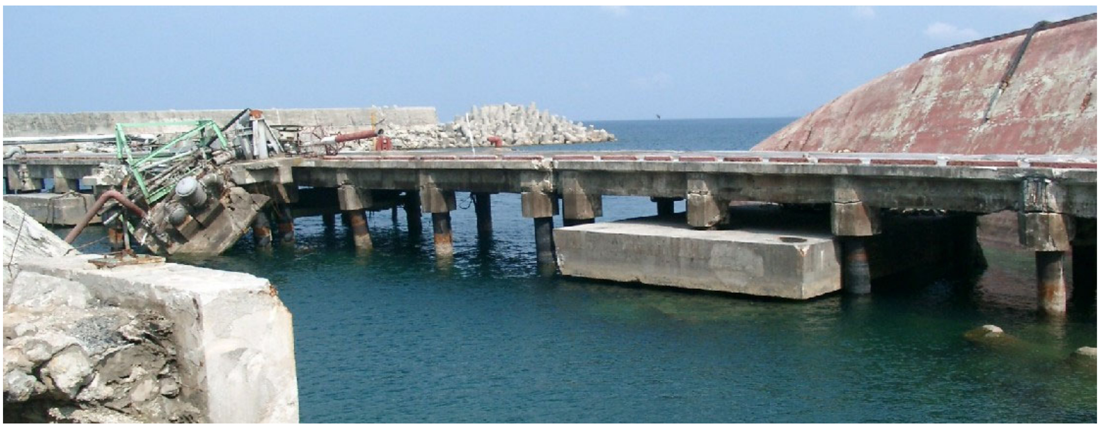

Photo.10.7 Damaged pile-supported wharf at cement factory

10.4 Remarks

From the site observation/investigation of Banda Aceh coastal area facilities, following findings are summarized.

(1) It was quite difficult to distinguish between damages of port/coastal area facilities caused by the earthquake motion and by the tsunami wave action. Significant damages were caused by scouring phenomenon and impact force of drifting objects during the tsunami. However, the possibility of double action effect by the earthquake motion and tsunami wave should be considered.

(2) The pile-deck structures such as pile-supported wharf, pile-supported dolphin and the ferry terminal pile-deck structures (pilotis style) showed good performance during tsunami wave. A pile-deck structure with a high seismic performance should be effective as a tsunami refuge structure as shown in Photo 10.8 (an actual tsunami refuge terrace in Japan). It must be noted that the impact action of drifting objects should be considered in the design of structures against tsunami.

Photo 10.8 Tsunami Refuge Terrace at Aonae fishery port, Hokkaido, JAPAN
(Refugees run up the terrace and then evacuate to mountain area through the overpass deck when tsunami warning alert is announced.)

(Author of this chapter: T. Sugano)

Chapter 11

Damage to Transportation Facilities

The damage of transportation facilities were mainly associated with roadways and bridges along the west coast between Banda Aceh and Meulaboh cities in Aceh province. The significant damage including washout of bridge superstructures and soil structures were caused by the tsunami waves. Some damage to bridge bearings caused by earthquake ground motion was also observed. In the following, the damages to the transportation facilities in cities of Banda Aceh and Lho'nga, and along the route between cities of Banda Ache and Meulaboh are briefly summarized.

11.1 Damage to Bridges and Roadways

11.1.1 City of Banda Aceh

The city of Banda Ache is located at the north of the Sumatra Island. There are about 20 bridges in the affected area by the tsunami at Banda Aceh. The height of the tsunami in the seaside area was estimated to be about 5-10m. Out of 20 bridges in the affected area, the superstructures of 3 bridges were completely washed out and fallen down, and 7 bridges were remarkably affected by the effect of the tsunami.

Photos 11.1 and 11.2 show one of the significantly damaged bridges. The simply-supported pre-stressed concrete girder bridge with a span of about 20m was washed out by the tsunami. The girder was just set on the top of abutments and there seemed to be no shear connection at the bearing supports. The tsunami height was just as the same height as the ceiling level of the 1st story of the houses. A temporary bridge was built soon after the earthquake to assure the traffic. At the time of investigation (about two month after the

Photo 11.1 Repair of Washed-out Girder Bridge

Photo 11.2 Collapse of Water Pipes

the earthquake), the washed-out girder was reused and already placed on its original location as the permanent repair.

Photos 11.3 and 11.4 show another bridge where the superstructures were completely washed out. It was reported that the bridge had a relatively shallow superstructure made of wooden materials. Substructures were made of masonry materials connected with concrete.

Photo 11.3 Complete Washout of Bridge (being reported as wooden bridge)

Photo 11.4 Masonry Substructure and Washout Effect of Surrounding Soils

The complete washout of superstructures was observed at one more bridge although its picture is not shown in this report. It was made of a pre-stressed concrete girder and had a shallow deck with 1 lane. The substructures to support girder laterally was failed by the lateral force effect of the tsunami and the girders were washed out as a result.

Photos 11.5 to 11.8 show the typical damage to a bridge in which the significant lateral displacement was developed by the effect of Tsunami. The superstructure of the bridge was 3 span simply-supported reinforced concrete girder bridge and was supported by the wall type reinforced concrete piers. The rubber sheet type bearings were used and there was no shear key to connect between girder and substructures. The decks were moved about 50cm laterally and the rotation occurred at the decks since the decks were wedged geometrically between the both abutments. The handrails were partly but heavily damaged and it was estimated that the handrails were broken by the effect of the impact of boats or driftage. The washout effect at the backfill soils of abutments was also found.

Photos 11.9 and 11.10 show another bridge where the significant displacement was observed. The bridge is a simply-supported reinforced concrete girder with a span of about 20m. The deck was moved in the transverse direction about 1m due to the tsunami effect. The girder was supported by the rubber sheet type bearing and there was no shear connection between girder and substructures.

Photo 11.5 Damaged Bridge

Photo 11.6 Washout Effect of Backfill Soils

Photo 11.7 Lateral Displacement of Deck

Photo 11.8 Rubber Sheet Type Bearing and Lateral Displacement at Bearing

Photo 11.9 Lateral Displacement of Deck

Photo 11.10 Displacement at Bearing

Although several bridges were significantly damaged caused by the tsunami effect, there are several bridges without any significant damage even though they seemed to be strongly affected by the tsunami. Photos 11.11 and 11.12 show a bridge without any significant damage by the tsunami. The height of the tsunami was estimated to be about several meters over the bridge deck level. Heavy damages to houses were found around the bridge. The bridge was a long bridge with a 10 span simply-supported concrete girder bridge which was supported by circular reinforced concrete columns. The rubber bearings were used and the concrete block shear keys were provided. Although the attached facilities beside the girders were heavily failed, the main body of the bridge was not damaged. Slight damage to the shear keys such as cracking was observed. Although the detailed investigations such as the tsunami height are necessary, it was estimated from the bridge behavior that the shear keys seemed to work well to resist against the lateral force imposed by the tsunami.

Photo 11.11 Undamaged Bridge by Tsunami

Photo 11.12 Concrete Block Shear Keys

Photos 11.13 and 11.14 show another bridge to show the slight damage to shear keys. The bridge was a 3 span simply-supported concrete girder bridge and supported by the rubber bearing and concrete block shear keys. The bridge was not affected by the tsunami. The shear keys were slightly damaged including the concrete cracking. The damage was considered to be caused by the strong ground motions.

Photo 11.13 Bridge affected by Shaking

Photo 11.14 Slight Damage to Shear Keys

As will be discussed later, many truss bridges with relatively longer spans were washed out along the west coast route from Banda Aceh to Meulaboh. Although The detailed investigation could not be made for all of the collapsed bridges, some collapsed bridges did not have the connection and shear keys between decks and substructures. Photo 11.15 and 11.16 show the behavior of the truss bridge with stiff connections between deck and substructures. Since the bridge is located at the east of Banda Aceh, the Tsunami height might not be so significant. But the Tsunami height was clearly exceeded over the upper member level of the truss. There was no damage at the bridge. It seems that the stiff connections between deck and substructures can be one reason for "no damage".

Photo 11.15 Steel Truss Bridge without Damage

Photo 11.16 Steel Bearing Supports

Photo 11.17 and 11.18 show the damage to soil embankment structures. Complete washout of river dikes and damage to pavement on the river dikes was found. Since the height of the tsunami was estimated to be widely over the height of the river dikes, the washout effect of soils were observed at several sections.

Photo 11.17 Washout of River Dike

Photo 11.18 Washout of Pavement and Soils

11.1.2 City of Lho’nga

The city of Lho’nga is located at the west of Banda Aceh along the west coast. The area was significantly affected by the Tsunami and the Tsunami run-up height is estimated to be over 30m at maximum. Photos 11.19 to 11.21 show the complete washout of a 2-span steel truss bridge, which was supported by the wall type reinforced concrete columns. The decks were supported by the bearings and bolts were used to connect deck and substructures. There was no shear connection between deck and substructures except the bolts. Since the truss girders were washed out to the upstream side and the bolts connecting deck and substructure were bended toward the upstream side, it is estimated that the decks were washed out by the tsunami waves in the direction of upstream side. This route is an important route to connect Banda Aceh with the Meulaboh in south, the temporary bridges were built for emergency measures. It should be noted here that it is estimated the truss type bridge is employed for a relatively longer span bridge in the area.

Photo 11.19 Washing out of Steel Truss

Photo 11.20 Temporary Bridge

Photo 11.21 Bearing Support and Bolt to connecting Deck and Substructures

Photo 11.22 and 11.23 show the behavior of the reinforced concrete box culvert bridge. The bridge is located in the cement factory, which was significantly damaged by the tsunami. Some damage was found at the sidewall but there was almost no damage on the main body of the bridge.

Photo 11.22 Concrete Box Culvert Bridge

Photo 11.23 Concrete Box Culvert Bridge

11.1.3 Route from Banda Aceh to Meulaboh

The city of Meulaboh is located at about 250km south from the city of Banda Aceh. There is a seaside route which is only roadway to access many towns and villages along the seaside between two cities. The tsunami was significantly affected the route. According to the data investigated by the Katahira & Engineers International, total section of 56.6km of roads was impassable and 126.7km was seriously damaged. Also, there are 186 bridges along the roads and 81 bridges were washed out or heavily damaged. Although the JSCE team could not investigate all bridges through the land survey, the investigation from the helicopter was made.

Photos 11.24 to 11.28 show the washout of the bridges in the route. All photos shown here were taken by UN on the behalf of Aceh Provincial Government. There are several steel truss bridges and the deck was completely washed out toward the upstream side. Since the most piers and abutments remained at the original location, it is estimated that the superstructures were washed out by the tsunami. Although detailed investigations are needed, it is estimated that the stiff connection or shear key enough to withstand the washout force was not provided at the bearings in view of the bridge designs in Banda Aceh.

Photo 11.24 Washout of Truss Bridge (1)
(courtesy of Aceh Provincial Government)

Photo 11.25 Washout of Truss Bridge (2)
(courtesy of Aceh Provincial Government)

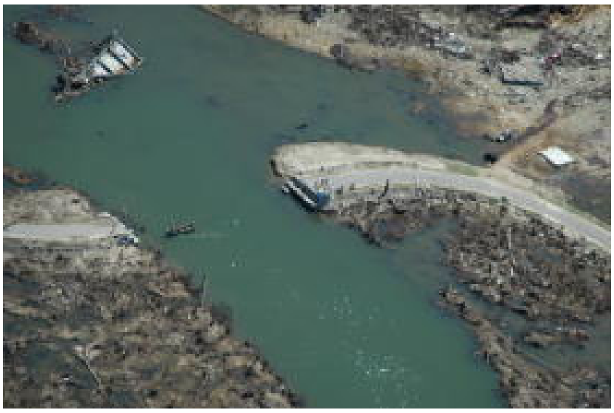

Photo 11.26 Washout of Truss Bridge (3)
(courtesy of Aceh Provincial Government)

Photo 11.27 Washout of Truss Bridge (4)
(courtesy of Aceh Provincial Government)

Figure 11.28 Washout of Truss Bridge (5) (courtesy of Aceh Provincial Government)

Photos 11.29 to 11.33 show the washout of the roadways, which were completely eroded by the tsunami effect. The land itself was also estimated to have sunk one half to one meter in elevation along the coast but the erosion of the coastline was much more significant.

Photo 11.29 Washout of Bridge and Soil
(courtesy of Aceh Provincial Government)

Photo 11.30 Erosion of Road and Coastline
(courtesy of Aceh Provincial Government)

Photo 11.29 Erosion of Road and Coastline
(courtesy of Aceh Provincial Government)

Photo 11.30 Erosion of Road and Coastline
(courtesy of Aceh Provincial Government)

Photo 11.31 Erosion of Road and Coastline (courtesy of Aceh Provincial Government)

11.1.4 Summary of Damage to Bridges and Roads

Detailed investigations and careful reviews of the damage are still needed. Nevertheless, the following findings were so far obtained on the bases of the above investigations.

1) Tsunami Effect: Since Tsunami is basically fast, strong and thick water flow with driftage, lateral water pressure, floating effect and washout effect are the primary mechanical effects.
2) Concrete Bridges: If a bridge had a concrete deck with appropriate shear keys at bearing supports, the bridge did not have a significant displacement or was not washed out during Tsunami effect. If there was no shear key, there were some bridges in which the deck was completely washed out or significantly displaced in the transverse direction.
3) Steel Bridges: The detailed investigation for all of the collapsed steel truss bridges could not be made. The washed-out truss bridge located in Lho'nga did not have any shear keys. On the other hand, one truss bridge with stiff bearings at the east of Banda Aceh did not suffer any damage. Therefore, it is estimated that the shear keys work well against the lateral tsunami force. For a steel bridge, which is relatively lighter, the effects of weight and thrust of driftage should be considered for the design of truss bridges. The floating effect can be also controlled by the uplift stopper which connects between superstructures and substructures at bearings.
4) Foundations: It was found that some of the substructures as well as superstructures were completely either washed out or missing. It is also important to protect the substructures against the washout. Wall-type piers, which are usually used in this area, seemed to be survived well, and the foot protection work at foundation section is effective if the surrounding material is prone to wash out.
5) Abutment Backfill Soils: Several damaged abutments with the backfill soils washed out were observed. To fill the soils as a temporary measure to assure the traffic is relatively easy. But if such damage should be prevented for higher abutments in long term, more substantial repair works are necessary after the earthquake and the bank protection measures for abutments are effective.
6) Soil Structures: If the roads are constructed on the stiff ground (possibly, cutting ground, stiff clay layer/rock and so on), the roads seemed to be survived. On the other hand, the roads are on the soft or sandy soils (possibly, soil embankment with soft materials which is easy to be washed away), the roads seemed to be completely washed out. Such sandy soils sections are generally located closed to the seaside, or the current or past river areas. Also, the erosion effect is so significant.
7) Ship Effect: As observed during the investigation, the driftage of large ships seemed to influence the damage significantly. But to directly consider the effect of the impact of ships on structural design is not generally reasonable. Ship control measures during tsunami should be devised.

11.2 Damage to Airports

The only airport in the affected region by the earthquake is the Iskandar Muda Airport to which commercial flights are in operation. This airport was not damaged either by ground shaking or by tsunami waves as shown in Photo 11.32. At the Meulaboh Airport, the dislodgement at the airstrip was developed as shown in Photo 11.33 and the section of 1,100m within 1,300m was used for the flight.

Photo 11.32 No Damage to Iskandar Muda Airport

Photo 11.33 Damage of Airstrip at Meulaboh Airport

Photo 11.34 Damage of Airstrip (courtesy of Dr. Osumi)

Acknowledgements

Regarding to the information on the bridge and road damage, the authors would like to express sincere appreciation to; Mr. Kazuo Yumita and Mr. Takashi Okumura of Katahira & Engineers International for their detailed information on the bridge damage from Banda Ache to Meulaboh, Dr. Tsuneo Osumi of Nihon Koei for his information on the damage at Meulaboh, and the Vice Governor of Ache Province for the information and the air photos of bridge damage from Banda Ache to Meulaboh.

(Author of this chapter: S. Unjoh)

Chapter 12

Damage to Lifeline Facilities

12.1 Water Supply System

The general plan of water distribution facilities for Banda Aceh city is shown in Figure 12.1. Major break places of the distribution network by the tsunami disaster are shown in the figure. Also in the figure, the tsunami-affected area and its run-up area are distinguished by different colors.

Topographically the city is mostly low-lying area. Since well water is occasionally saline in the area, treatment facilities for surface water to ensure the domestic water were built before the disaster. The water supply pervasion rate, which is defined as the percentage of the population served by public water supply to total population in the area, was 75% before the disaster. However, it went down to 25% by the damage caused by the earthquake and the tsunami.

As for the water supply system, raw water is taken at the intake seen in Photo 12.1 and the water is transmitted to the treatment plant shown in Photo 12.2 and then the treated water is transmitted to the elevated Tank 1 by the dual steel pipes with diameters of 500 mm and 600 mm.

The elevated tank 1(2,000m^3) of Photo 12.3 had not been functioning before the earthquake. However, the foundation of the tank was seriously damaged by the bending stresses caused by the earthquake. The tank should be demolished as soon as possible for safety reasons. The pipe next to the bridge nearby the Great Mosque crossing the Aceh River was washed away by the tsunami. As seen in the left picture of Photo 12.4, a rubber hose is temporarily installed on the river bed for water transmission to the other side of the river. The elevated Tank 2 of Photo 12.5 was also damaged with some minor cracks by bending stress in its foundation. Now the tank is used for emergency raw water supply from the nearby river. The water supply in the city is still critical now.

Distribution pipe network was broken in many places, and the public hydrants installed on the fringe area are not connected with the distribution network. Therefore, the supply of water in the most part of the city depends on the well and the deterioration of quality of well water, which is contaminated by salinity and drainage intrusion, is feared. Incidentally, three members of the JSCE reconnaissance team suffered from diarrhea immediately after the site trip.

2.2. Drainage system

Figure 12.2 shows the location of drainage pump stations and main drains in Banda Aceh City. The area, where the pump stations are located, is a low-lying urban area. The tsunami affected zone are back shaded in the same figure. All the pump stations from P2 to P9 except P1 were washed away by the tsunami and the drainage system is almost out of order. The drain ditch in the low-lying area has been clogged by debris, mad and sand carried by the tsunami, as shown in Photo 12.6. The backhoe during the cleaning work of debris is seen behind. The stocked water supply pipe has been scattered in mud at a water supply pump station as shown in Photo 12.7.

As domestic wastewater is flowing into the drainage system and water in the drains is stagnated at the moment, the hygienic environment is extremely poor. Immediate improvement is required.

Since the city suffered from floods every year even the rainfall for less than two hours and from frequent attacks of high tide, drainage system augmentation is one of the most critical issues for the area. The improvement as well as reconstruction of the drainage system is one of the most important issues for the city.

12.3 Electricity

The power generation in the earthquake affected area is attained through thermo-electric power plants located on the land and on barges at the shore. The power generation plants (38MW) built on higher ground were not affected by the ground shaking, and they are operational. However, the power generators on barges at the seashore were displaced from their mooring wharfs into the land. For example, the barge with thermo-electric power generator (7.5MW) in Ulhe Lhee district was displaced 3km inland by the tsunami (Photo 12.8). Since almost one third of the city and its population were destroyed by the tsunami, the loss of power generators on the barges does not directly affect the excess supply capacity of electricity for Banda Aceh city.

Many RC electric poles were broken in the area affected by the tsunami (Photo 12.9). However, either ground shaking or the tsunami did not damage transmission facilities from Medan (10MW).

Figure12.1

Water Supply Map and Disconnected Point of Banda Aceh City

(A local company of water works provided information, which the author drew on the city map.)

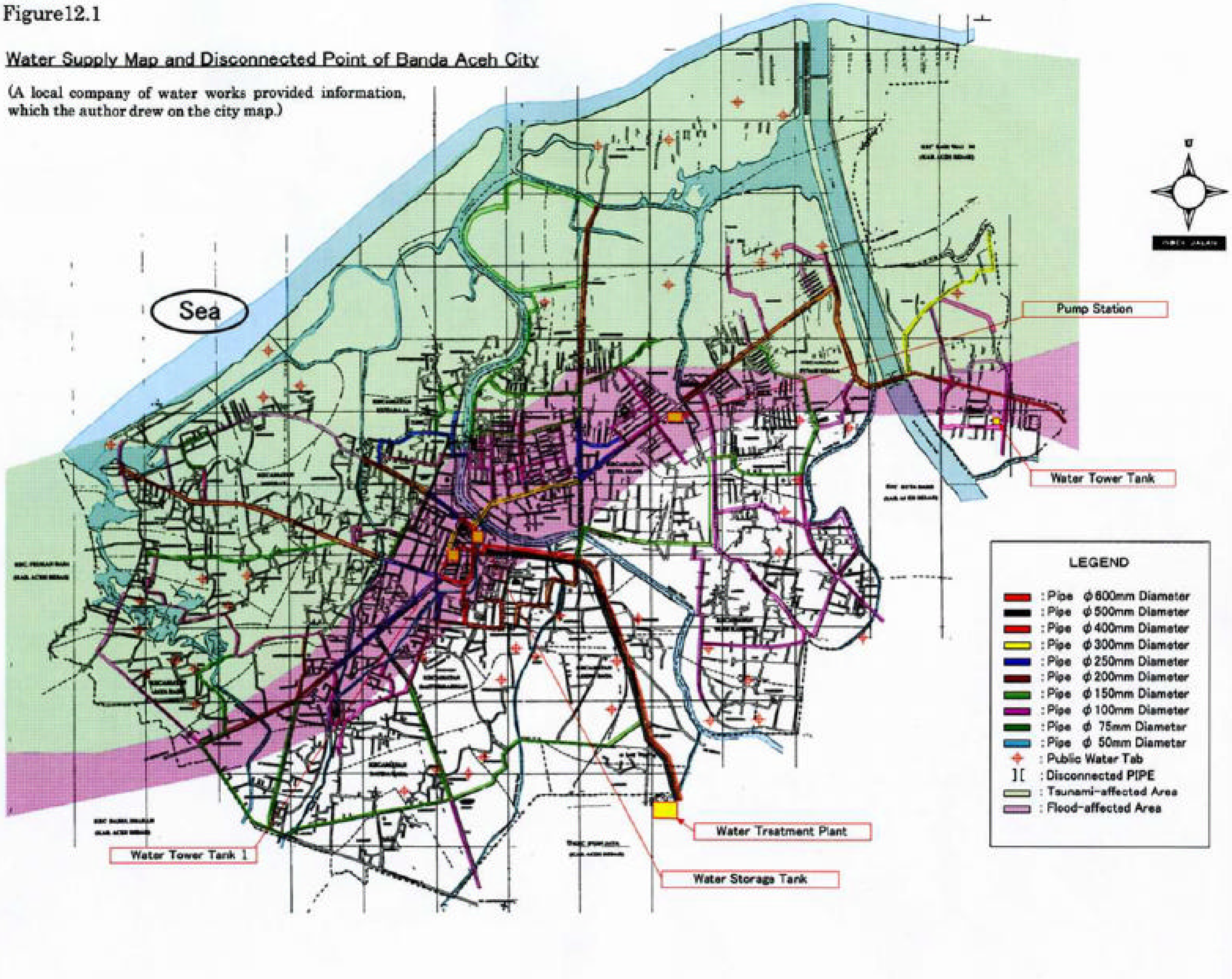

Figure12.2

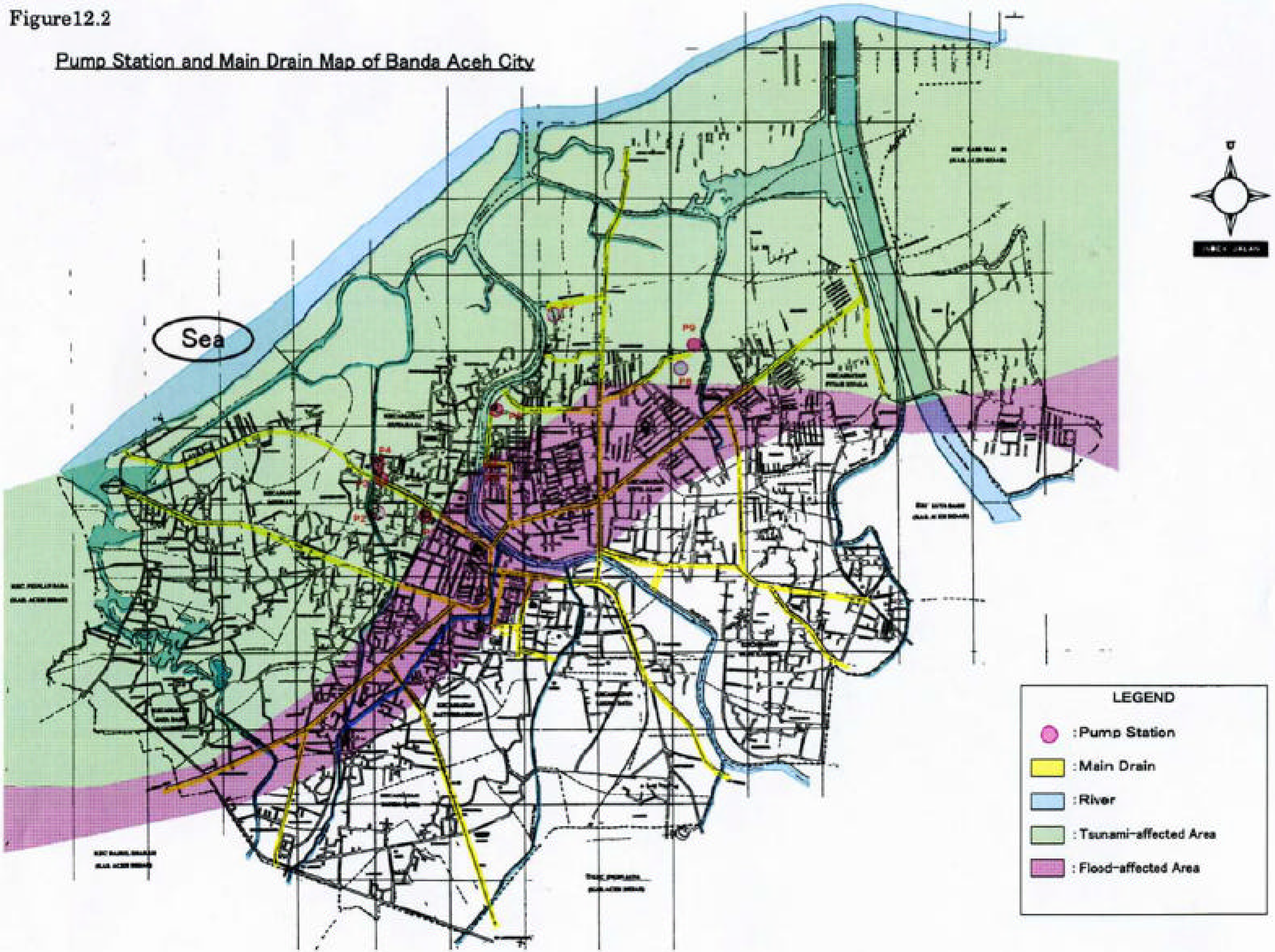
Pump Station and Main Drain Map of Banda Aceh City
Sea
LEGEND
:Pump Station
:Main Drain
:River
: Tsunami-affected Area
: Flood-affected Area

Photo 12.1 Intake site

Photo 12.2 Emergency measure at the treatment plant

Photo 12.3 Water tower tank 1

Photo 12.4 Broken water pipes nearby or attached to bridges

Photo 12.5 Slightly damaged elevated water tank 2

Photo 12.6 Drain ditches are clogged with mud and debris. Backhoe is operating for removal of deposit of the flood.

Photo 12.7 Scattered transmission pipe around pump station

Photo 12.8 Displaced barge with a thermo-electric power generator

Photo 12.9 Broken electric distribution poles

(Author of this chapter: M. Takeuchi)

Chapter 13

Casualties

The casualties induced by this earthquake are almost all related to the tsunami although the total collapse of some RC buildings did occur in Banda Aceh city. Some casualties reported from South Africa, to where the tsunami waves arrived 10 hours after the earthquake. Citizens of 54 countries were killed by tsunami resulted from the M=9.0 December 26, 2004 North Sumatra earthquake. The destructive waves affected more than 5 million people, including 1 million homeless. Although the exact number of casualties in Indonesia, Sri Lanka and India are not known, Table 13.1 gives the number of casualties, missing and displaced people on the country basis. Table 13.2 and Table 13.3 give the casualties in the districts of Aceh province. Table 13.3 was compiled by the Indonesia Branch of Tobishima Corporation in Jakarta using multiple sources and seems to be more reliable.

Figure 13.1 shows a graphical illustration of casualties in each country released by UN. Figure 13.2 shows the damage distribution and names of the districts mentioned in Table 13.2.

According to the count by the Indonesian government as of April 7, the missing was adjusted, and the number of deaths of Banda Aceh city was said to come up to 70,000 (missing: 20,000 and deaths: 50,000) and the total toll in the Aceh Province was said to come up to 170,000 (missing: 40,000 and deaths: 130,000).

Table 13.1 Casualties in each tsunami affected countries (UN)

Country	Dead	Missing	Injured	Displaced	Affected
Indonesia	101199	127774		417124	
Sri Lanka	30959	14000		396170	
India	10749	5640		112558	
Thailand	5322	3144	8457		54672
Somalia	150			5000	102000
Myanmar	90	10		3200	
Maldives	82	26		21663	
Malaysia	68	6	300	4296	
Seychelles	3			40	

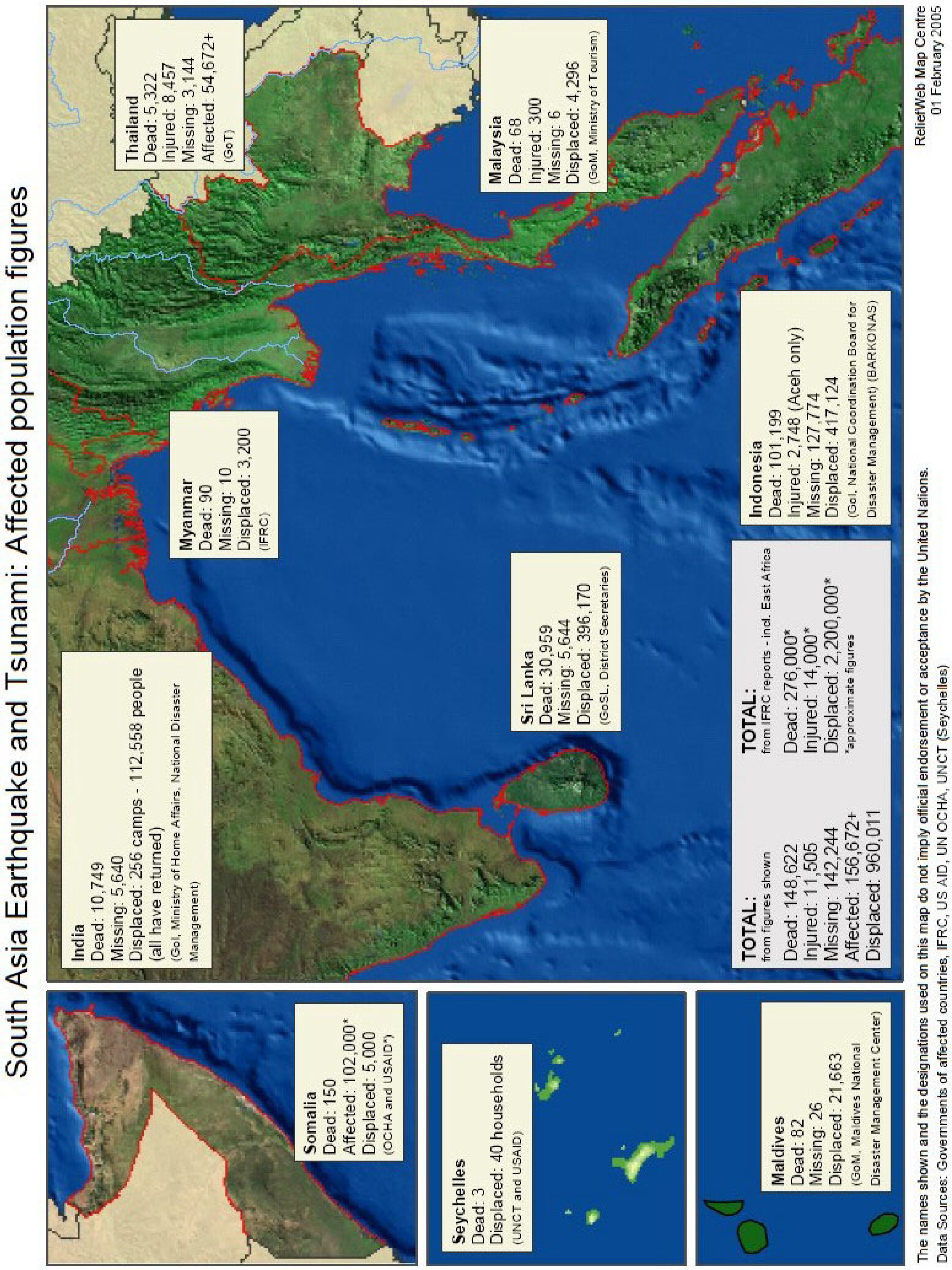

Figure 13.1 Casualties induced by the tsunami (UN)

Table 13.2 Casualties in each district of Aceh Province from UN

DISTRICT	DEAD	MISSING	IDPS	POP	% AFFECTED
KODYA BANDA ACEH	31576	8700	12000	269091	**19.4%**
ACEH SELATAN	9	79	5448	200000	**2.8%**
ACEH BESAR	47217	245459	116984	306718	**133.6%**
ACEH UTARA	2385	747	97942	395800	**25.5%**
ACEH BARAT	10200	7100	47921	227278	**28.7%**
PIDIE	4525	581	49421	517452	**10.5%**
BIREUEN	912	526	35648	350964	**10.6%**
LHOK SEUMAWE	189	50	17000	156478	**11.0%**
ACEH JAYA	19200	8700	31465	93547	**63.5%**
NAGAN RAYA	1338	100	11281	152748	**8.3%**
ACEH BARAT DAYA				153411	**0.0%**
ACEH TIMUR	224	49	22000	253151	**8.8%**
LANGSA	224			141138	**0.2%**
ACEH TENGGARA				168034	**0.0%**
ACEH TENGAH	132	277	3454	158641	**2.4%**
SIMEULU	7	1	22849	76629	**29.8%**
GAYO LUES				83695	**0.0%**
ACEH SINGKIL		4		174007	**0.0%**
ACEH TAMIANG			2800	238718	**1.2%**
KODYA SABANG	8	2	2400	27447	**8.8%**
BENER MERIAH	10	2	948	120000	**0.8%**
TOTALS	**118156**	**272377**	**479561**	**4264947**	

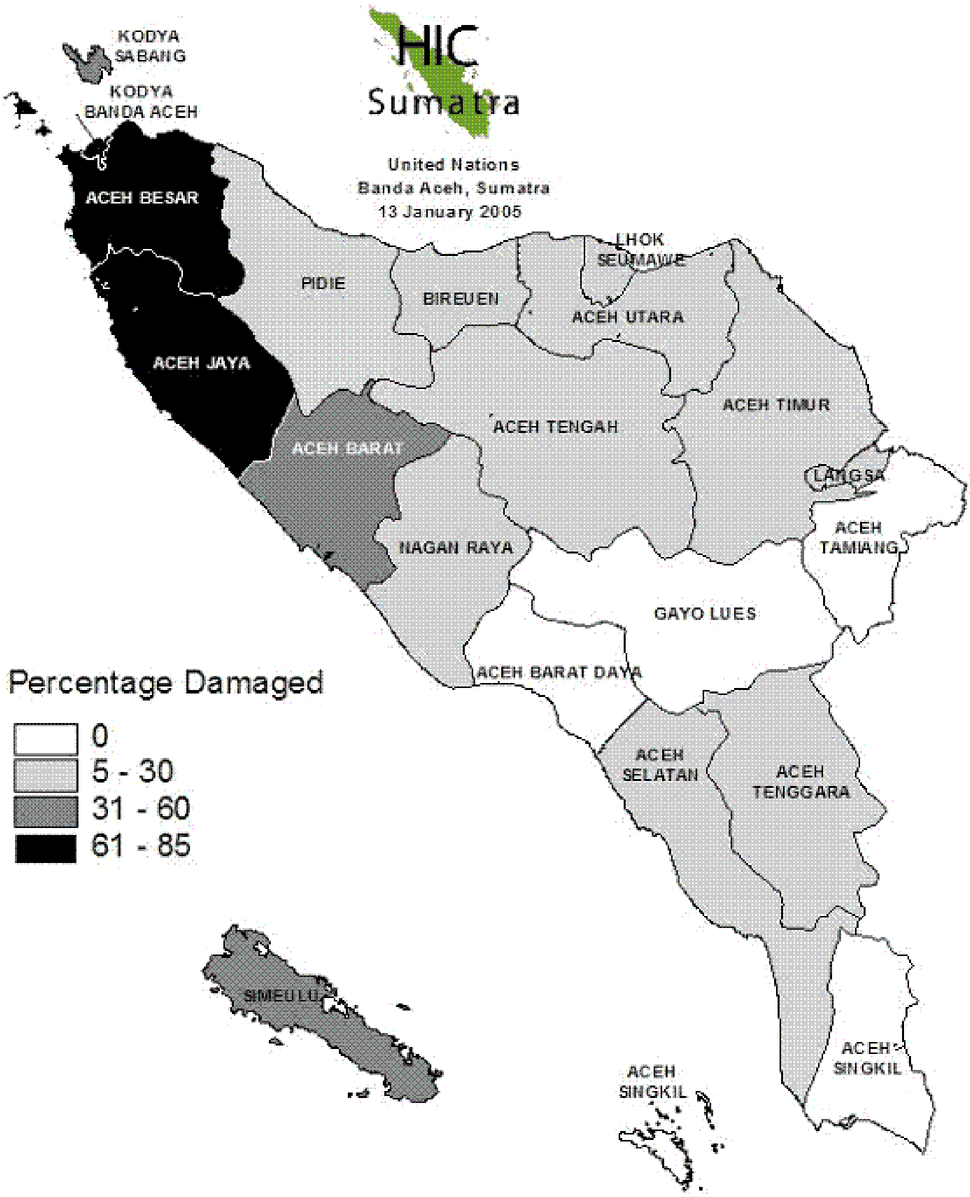

Figure 13.2 Damage distribution and districts of Aceh Province (UN)

Table 13.3 Casualties in each district of Aceh Province
from Military Area Commando and Red Cross Organization

TEMPORARY DATA OF EARTHQUAKE/TSUNAMI VICTIMS

NANGGROE ACEH DARUSSALAM PROVINCE

As of : March 21, 2005 / 08:00 a.m.

REGENCY	POPULATION	MISSING		DECEASED		REFUGEES	
Banda Aceh City	260,478	60,725	23.31%	51,960	19.95%	49,921	19.17%
Aceh Besar Regency	302,405	26,358	8.72%	38,462	12.72%	97,485	32.24%
Sabang City	26,303	108	0.41%	25	0.10%	3,712	14.11%
Pidie Regency	517,898	877	0.17%	4,401	0.85%	85,860	16.58%
Bireun Regency	361,528	58	0.02%	461	0.13%	49,803	13.78%
North Aceh Regency	523,717	218	0.04%	1,583	0.30%	27,112	5.18%
Lhokseumawe City	167,362	11	0.01%	189	0.11%	2,494	1.49%
East Aceh Regency	331,636	0	0.00%	52	0.02%	13,709	4.13%
Langsa City	122,865	0	0.00%	0	0.00%	6,156	5.01%
Aceh Tamiang Regency	225,011	0	0.00%	0	0.00%	3,224	1.43%
Aceh Jaya Regency	98,796	77	0.08%	16,797	17.00%	40,422	40.91%
Aceh Barat Regency	195,000	2,911	1.49%	10,874	5.58%	72,689	37.28%
Nagan Raya Regency	143,985	865	0.60%	1,077	0.75%	17,040	11.83%
Aceh Barat Daya Regency	115,358	0	0.00%	3	0.00%	3,480	3.02%
Aceh Selatan Regency	192,947	1,086	0.56%	1,563	0.81%	16,148	8.37%
Simeulu Regency	77,761	1	0.00%	7	0.01%	18,009	23.16%
Aceh Singkil Regency	124,758	4	0.00%	0	0.00%	105	0.08%
Aceh Tengah Regency	160,453	277	0.17%	192	0.12%	5,288	3.30%
Bener Meriah Regency	112,000	0	0.00%	2	0.00%	648	0.58%
Aceh Tenggara Regency	150,776	0	0.00%	31	0.02%	611	0.41%
Gayo Lues Regency	86,448	0	0.00%	0	0.00%	234	0.27%
Total (temporary) :	**4,297,485**	**93,576**	**2.18%**	**127,679**	**2.97%**	**514,150**	**11.96%**

Remarks :

* Deceased persons, data source : Military Area Commando and Red Cross Organization

* 132 deceased victims, buried down in Aceh Tengah is deceased victims from neighbor areas

* Data source for refugees: Coordination Unit I, II, III

(Author of this chapter: Ö. Aydan)

Chapter 14

Disaster Management

In this chapter, the disaster management implemented by Banda Aceh City and Aceh Province is reported. The contents of the report are based on the interview with officials of Banda Aceh City and Media Center (Banda Aceh Local Headquarters). However, this report is tentative because of the very short period of the survey. Therefore the more detailed investigation shall be done in the future.

14.1 Banda Aceh City (Mar. 2, 2005)

- There had been no knowledge, no information, no education and no measures against tsunami before the tsunami disaster. So no manual and no measures against earthquakes and tsunamis had been prepared.
- As a system to alert residents, each village had such primitive alert system as a public official rang a bell.
- 3 districts of the 9 districts in Banda Aceh city were devastated due to the tsunami.
- It was very hard to arrange water and food to victims for several weeks after the earthquake.
- Since the Mayor was killed by the tsunami, the secretary acted as a commander.
- Searching for missing people and identifying them were very tough. It was being continued at the time of our investigation.
- Schools were examined whether they were able to be used as refuges or not. About a half of them lost their functions. Schools in Banda Aceh were reopened on January 26, 2005.
- The estimation of the amount of damage was conducted by the divisions of tax and infrastructure.
- Order of priority of reconstruction of damaged infrastructures was discussed by the city, the province and the national government.

14.2 Banda Aceh Local Headquarters (Media Center) (Mar. 2, 2005)

- Under the president's direction, the headquarters was established on Dec. 29, 2004.
- The headquarters was composed of staffs of the city, the province, the police and the military.
- After the earthquake, issues on emergency response and recovery were divided up and assigned to each agency by the president (Figure 14.1).
- Inquiries to the meteorological agency of the Indonesian government were made everyday because there was no experience and no information about tsunamis, while the

local governments had taken little communication with the meteorological agency before the tsunami attack.

- After the earthquake, a pamphlet about tsunamis was distributed to residents.
- Establishing the information center office at each village and summing up the damage information through the office, the headquarters has reported them to Jakarta regularly. (Figure 14.2 shows the organizational tree of governors in Indonesia.)
- Because the telecommunication system did not work, walkie-talkies had been used for contacting persons.
- Figure 14.3 shows the time-shift of issues on emergency response and recovery. Several issues are common with those raised by the 1995 Kobe earthquake except that it took much time to search and identify victims.

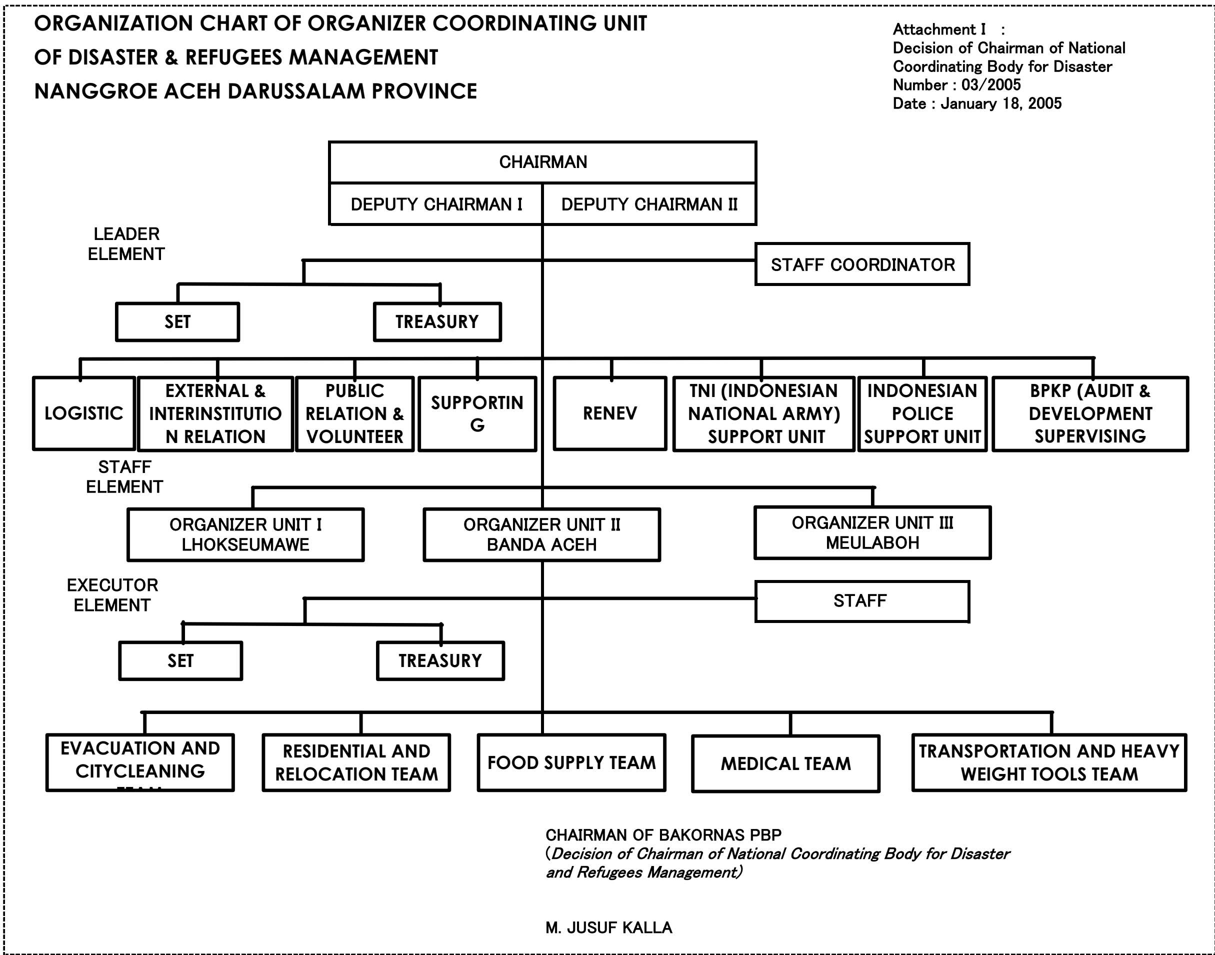

Figure 14.1 Organization Chart of Organizer Coordinating of Disaster & Refugees Management

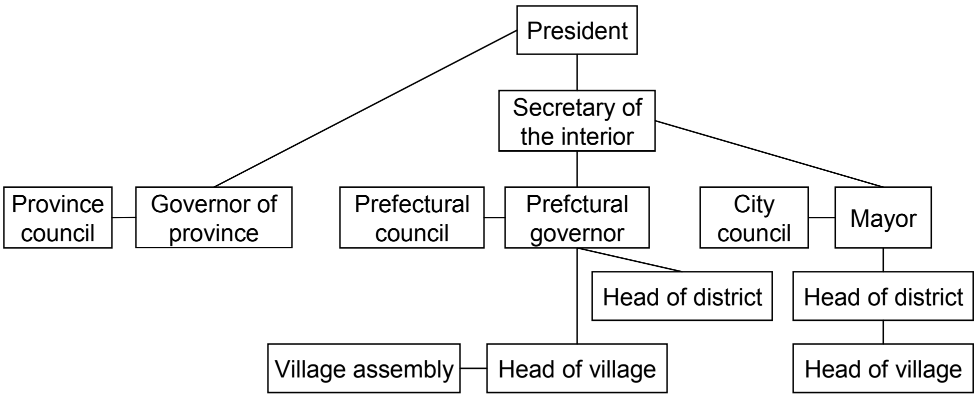

Figure 14.2 Organizational Tree of Governors in Indonesia

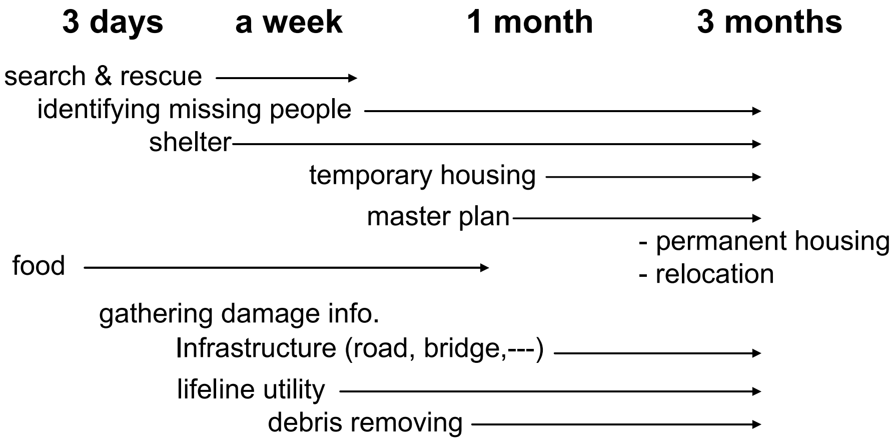

Figure 14.3 Time-shift of Issues on Response and Recovery

14.3 Alert System

The most important thing on emergency is how to notify alert to residents, end-users of the alert information. Therefore, in the occasion to set up an effective disaster alert system, it should be considered not only the information facilities among disaster-related organizations but also the notifying way to residents at the same time. On the other hand, the capacity building of residents as the receiver of alert information is also very important to raise effectiveness of the system.

Based on the observation, the authors propose a mosque-centered disaster reduction system. Because, mosques have several features as follows.

Mosques are;

-engineered structures relatively strong against earthquake and tsunami in the local communities,

-built in almost all the villages of Aceh Province,

- regionally close facilities to residents' livelihood,
- to be able to give refugees a shelter,
- and already equipped a loudspeaker facility.

Functions of the system at the period of pre-disaster are education and disaster drill, and at the period of post-disaster, are to alert residents, to give refugees a shelter and to assist activities for survivors.

Acknowledgment:
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Chapter 15

Summary of Findings and Proposals

We, the reconnaissance team of Japan Society of Civil Engineers (JSCE), investigated actual damage caused by the earthquake shaking as well as tsunami from March 1 to March 5 in Aceh Province of Indonesia. During our reconnaissance period, the damage to civil engineering structures and buildings caused by the main-shock and after shocks as well as those caused by the tsunami have been documented and geotechnical and structural response data were collected. We have tried to identify the causes of damage from the investigations and summarized our findings. The outcomes of these investigations are summarized and recommendations and proposals are presented in the followings

15.1 Observations and Main Findings

(1) Bridges and Roads

1) Several bridges were completely washed out by the Tsunami. Although the washed-out bridges did not have any shear keys, some bridges with shear keys, which were significantly affected by Tsunami, were not washed out and not displaced. Therefore, the appropriate shear keys and stoppers against at the bearings are one of the key design issues against the Tsunami effect. Backfill soils at abutments were washed out at several bridges.

2) When the roads were constructed on the stiff ground, the roads seemed to be survived well against Tsunami. On the other hand, the roads were on the soft or sandy soils, the roads seemed to be completely washed out by the effect of erosion. Such sandy soils sections are generally located closed to the coastline, or the current or past river areas.

(2) Port and Harbor Facilities against Tsunami

1) It was quite difficult to distinguish between damages of port/coastal area facilities caused by the earthquake motion and by the tsunami wave action. Significant damages were caused by scouring phenomenon and impact force of drifting objects during the tsunami. However, the possibility of double action effect by the earthquake motion and tsunami wave should be considered.

2) The pile-deck structures such as pile-supported wharf, pile-supported dolphin and the ferry terminal pile-deck structures (pilotis style) showed good performance during tsunami wave. A pile-deck structure with high seismic performance should be effective as a tsunami refuge structure. It must be noted that the drifting object's impact action should be considered during a tsunami.

(3) Lifeline facilities

1) Water network

- The most important issue is to attain good quality water sources.
- The quality of well water may be deteriorated due to the seepage of wastewater.
- Construction of the multipurpose dam (water reservoir, electricity generation, flood control, agricultural) should be considered rather than relying on Aceh River for water source. This would be also useful for industrial development.

2) Sewage

- It is urgently necessary to improve sewage systems to keep sanitary environment.
- It would be desirable to use separate drainage system for rainwater and wastewater. This work should start as soon as possible and the wastewater treatment plant is urgently needed.

3) Electricity

- The electricity is needed for industrial facilities as well as for the daily life of people.
- The electric capacity of the region should be increased through building multi-purpose dams.

(4) Geotechnical Damage

- Failures of river and canal banks were occurred. They were mainly due to soil liquefaction and erosion by tsunami. Liquefaction resulted in lateral spreading and settlement of the embankments. In cohesive soil, sliding took place.
- Slope failures were observed in mountainous section due to ground shaking. Failures were generally associated with the geological features of rock masses.
- Weathered loose materials on slopes at the seashores were washed away.
- Missing of the central part of small peninsula could be due to liquefaction or landslide in addition to tsunami.

(5) Damage on Buildings

Building stock in the area mainly consists of RC buildings, wooden houses and adobe houses.

1) RC buildings

- The story number of heavily damaged RC buildings generally is generally more than 3 and ground shaking mainly caused the damage.
- The RC buildings having story number less than 3 were in tsunami affected area were destructed by impact force of tsunami waves and objects dragged by tsunami.
- Some buildings survived well against the forces imposed by tsunami waves.
- Intensity of ground motion is was from 5+ to 6- on JMA scale (IIIV-Ⅸ on MKS scale).
- It seems that the ground motion has a directivity effect and many structures are either collapsed or heavily damaged in N-S direction.

2) Wooden houses

- Wooden houses were mainly damaged by the uplift force of seawater and impact force of tsunami waves and objects dragged by tsunami.

3) Adobe houses

- Adobe houses were mainly damaged by impact force of tsunami waves and objects dragged by tsunami.

(6) Education of Children for Earthquake and Tsunami Disasters

Presentations of “Evacuation from Tsunami Attack” were carried out for about hundreds students and children Sekolah Menengah Atas high school and junior high school by using a video of non-fictional story in Japan. There were many questions about the mechanism of the occurrence of the earthquakes and tsunamis and about the measures for disaster prevention. It is necessary to provide an exact information and knowledge on these topics that will result in the disaster prevention from a long-term point of view. The Japanese team will send materials such as video and books for disaster prevention to the schools in Aceh.

(7) Several of the time-shift of issues on emergency response and recovery are common with those raised by the 1995 Kobe earthquake except that it took much time to search and identify victims.

15.2 Recommendations and Proposals

(1) For the safety against tsunami

- How to escape from the tsunami disaster should be considered. Protection of tsunami is also important but it is very costly.
- A pile-deck structure with high seismic performance can be an effective tsunami refuge structure like the existing tsunami refuge terrace in Japan.
- Mosques can have a function for tsunami evacuation buildings.
- International collaboration and sharing protocol on tsunami warning must be established
- Tsunami Research Institute has to be established including tsunami simulations.
- International Symposium on the Earthquake & Tsunami Disaster should be held.
- Cooperative researches between Indonesia and Japan should be promoted.

(2) Not to forget the TSUNAMI

- The monumental exhibition hall or museum should be built.
- The stone monumental poles with the Tsunami height in the corners of streets should be erected. These monuments should keep the records of Tsunami height for a longer period of time.

(3) Education and Training

- Education and training for evacuation are urgently necessary.
- It was found that many people did not know even the word of Tsunami from hearing

surveying.

(4) Building earthquake-resistant structures

- Present RC structures should be retrofitted with the use of shear walls.
- RC structures should be built according seismic design codes.Residential houses should be built according earthquake resistant codes together with the use of low cost and effective methods.

(5)Accelerometers should be installed to measure and to have quantitative information on ground motions.

(6) New Road Construction and Rehabilitation between Banda Aceh and Meulaboh

1) Based on the fundamental policy for future city planning under the resident agreement in the area, it should be decided to reuse current route as much as possible, or to fully set-back the current route out of the Tsunami affected area (plus potential area).

2) If basically the current route is reused as much as possible, then fundamental policy can be;

- Consider the acceptable damage. Heavy damage, which is related to the loss of life or long-term repair works, is not acceptable. Without loss of life, acceptable damage to roads should be considered.
- Consider the return period of the occurrence of large earthquake (risk evaluation for next one)
- In this concept, the Tsunami warning measure is essential for the residents because the area is anticipated to suffer again in next event in future.

3) If the Tsunami effect is not acceptable completely, the cities and roads have to be totally realigned to the higher area with necessary height.

4) The bottleneck sections on roads are the following sections and conditions.

- Long bridges on wider rivers (Washout of bridges)
- Settlement at seaside (Complete erosion and missing of roads)
- Washout of soil section (Stable soil section was well-survived from the Tsunami. Soft-soil and sandy soil are generally weak.)

5) Basic Policy of Repair and Rehabilitation Work can be:

- If the reuse of current route is basically decided, the Tsunami warning measures are prerequisite to save resident lives.
- Concrete girder bridges with appropriate shear keys and wall-type columns including concrete culvert is much stable against Tsunami.
- When a steel bridge for longer span is needed, the lateral force effect and uplift force effect should be considered at the design of bearings.
- If the roads are on the soft ground condition and it can not be easily realigned, the soil improvement to strengthen against the washout effect is effective.
- If the roads are at too low level compared with the sea level, the roads should be realigned to the inland area with necessary height or make higher embankment with

stable material against washout effect.

- Some important section (sections in city area and sections which are hard to be repaired should have double routes (one be in inland area).
- In mountainous areas of the roadway, there may be landslides since rock mass is generally layered and the layers dips towards sea. Attentions should be given to the geological features for prevention of large-scale slope sliding.

15.3 Closing Remarks

Finally, we sincerely hope that the cooperation and collaboration on earthquake hazard mitigation will be strengthened between Indonesia and Japan, since two countries have shared similar experiences of huge disasters.