

PRESENT UNDERSTANDING OF ACEH TSUNAMI (Applications of Data from Field to Satellite Observations)

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Abstract

Application of data from field to satellite observation and simulation has been made as present understanding of Aceh tsunami. Tsunami has attracted attention after struck Aceh in December 26th 2004, generated by a strong earthquake with magnitude $M_w=9.0$. The earthquake triggered giant tsunami waves that propagated throughout the Indian Ocean, causing extreme inundation and destruction along the northern and western coast of Sumatra. Within hours, the tsunami devastated the distant shores of Thailand to east as well as Sri Lanka, India and Maldives to the west. The tsunami also caused deaths and destruction in Somalia and other nations of East Africa. The tsunami was recorded on tidal stations throughout the Indian Oceans in worldwide. Unlike the Pacific, the Indian Ocean does not yet have a network of deep-ocean pressure sensors, and so coastal tide gauges provide the only direct measurement of Indian Ocean tsunami amplitudes. We had many lessons and basic knowledge which had already been learned from this tragic event in the Indian Ocean. Many more lessons should be learned in the near future as this tragedy unfolds and reveals many failures to value and protect human life in this neglected region of the world.

Key word: Tsunami, Earthquake, Indian Ocean, Aceh

I. Introduction

About two-thirds of earth is covered by the waters of the four oceans. The Pacific Ocean is the largest in the world, covering more than one third of total surface area of our planet. The Pacific Ocean surrounded by a series of mountain chains, deep ocean trenches and island arcs, that is some times called a 'ring of fire'. The great size of the Pacific Ocean and the large earthquake associated with the 'ring of fire' combine to produce deadly tsunamis (Anonym, 2006).

Tsunamis shall also produce seismic sea waves, or incorrectly tidal waves, generally caused by earthquakes, less commonly by submarine landslides, infrequently by submarine volcanic eruptions and very rarely by a large meteorite impact in the ocean. The

submarine volcanic eruptions have the potential capability to produce awesome tsunami waves. The great Krakatau volcanic eruptions in 1883 had generated giant waves reaching heights of 125 feet above sea level, and killed thousands of people and wiping out numerous coastal villages.

Not all earthquakes intend to generate a tsunami. In order to generate the tsunami, the earthquake must occur underneath or near the ocean, and be large and create movements in the sea floor. The tsunami can occur in all oceanic regions of the world, but in the Pacific Ocean, there are frequent occurrences of large and destructive tsunamis because of many large earthquakes along the edge of the Pacific Ocean.

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In the open ocean, a tsunami uses to be less than few feet high level at the surface, but the wave height is increasing rapidly in the shallow water of the coastal area. The tsunami energy extends from the surface to the bottom of the deepest water.

In the deep ocean, a destructive tsunami can be small -often for only few feet or less in height- and cannot be seen, nor can be felt by ships. Some times the coastal water is withdrawn into the deep ocean just before the tsunami strikes. When these occur, more shorelines may be exposed than that of even at the lowest tide. This major withdrawal of the sea should be taken as a warning of the tsunami waves that will follow soon.

Where the ocean is over 20,000 feet deep, an unnoticed tsunami can travel at the speed of a commercial jet plane, nearly 600 miles per hour. It can move from one side of the Pacific Ocean to another side in less than a day. This great speed makes it important to be aware of the tsunami as soon as it has generated. Scientists can predict when the tsunami will arrive. The tsunami travel much slower in shallow coastal water which is their wave heights begin to increase dramatically.

The offshore and coastal features can determine the size and the impact of the tsunami waves. The reefs, bays, entrance to rivers, undersea features and the slop of the beach combine to modify the tsunami as its attack. When the tsunami hit the coast and moves inland, the water level can rise many feet. In extreme cases, the water level has risen to more than 50 feet for the tsunamis of distant origin and over 100 feet for the tsunamis waves generated near the epicenter of earthquake. The first wave may not be the largest wave in the series of the tsunami waves. The flooding of the tsunami can extend inland by 1,000 feet or more, covering large expanses of land with water and debris.

II. Fundamental Study of Tsunami

Fundamental knowledge of the tsunami:

1. It is primitively created by the deformation of the sea bottom configuration due to the great earthquake.
2. If the magnitude (M) of the earthquake is less than 6.9, the tsunami never occurs.
3. In general, the magnitude of the tsunami is corresponding to the magnitude of the sea bottom earthquake, but not always.
4. The tsunami will not occur only by the earthquake, but also by the explosion of volcano, the landslide at the sea bottom and the nuclear explosion.
5. The most frequent Tsunami has occurred at the coast of the Pacific rim countries, and in no more other place or called "The Circum-Pacific Earthquake Belt".

The history of tsunami in the world reveals that the most frequent tsunami has occurred at the coast of the Pacific rim countries, and in no more other place as the Circum-Pacific Earthquake Belt. Repeating tsunamis attack countries like Japan, Alaska, Taiwan, Philippine, Indonesia, Peru, Chile, Colombia and slightly attack Greek, Black Sea rim countries, Portugal, Spain.

The generation and the traveling of the tsunami at the sea surface are exactly corresponding to the deformation of the sea bottom configuration. The velocity of tsunami can be counted by this follow equation:

$$V = \sqrt{gH} = 3.13 * H$$

where:

g : acceleration of gravity force 9.8 m .sec⁻¹

H : depth of sea (m)

If the point of ocean earthquake is far from the coast, 10 to 20 tsunamis will arrive to the coast and after that, the biggest tsunami will attack the coast. The wave height equated by the "Rule of Green" which tsunami height is amplified to be inverse proportional to root quaternary of depth of ocean: $4\sqrt{H}$. Moreover, the tsunami which enters into the bay will be superposed with the wave of peculiar oscillation of the bay, and produce much higher Tsunami.

It is very important never to be in carelessness that the highest Tsunami will attack coast after 10 to 20 waves. When we have got earthquake, we can never come close to beach in anytime. Aceh Tsunami also shows this danger. Result shows us that The tsunami from 0 m to 5 m gives damage for house, but not much people. However, the tsunami which is more than 5-10 m has killed many people and given a bigger damage for many houses washing away. Other damage is damage for bridge, harbor ship, road, train line, farming field.

III. Observation System for the Tsunami and Prediction

- a) Field Observation (in-situ observation)
 - 1) Tidal Observation (Tidal Station)
 - 2) Supersonic Tsunami Sensor
 - 3) Large Scale Tsunami Sensor
 - 4) GPS (Global Positioning System) Tsunami Sensor
- b) Real time monitoring, small spatial coverage
- c) Remote Sensing (estimation of disaster)

- 1) Air-borne: Radar, Aerial Photograph
- 2) Satellite : Optical Sensor, Active Microwave Radar
- d) Wide spatial coverage, Lack of immediacy.

The tidal observation (tidal station) measures sea surface level including with disturbance; consist of aqueduct, tidal well, static surface level, and recorder, as shown in figure 1. The supersonic tsunami sensor as shown in Figure 2 settled just above the ocean surface from the land platform and measures the tsunami height by the time lapping of supersonic wave from sensor to the sea surface and corrected by the normal tidal level.

The alert system by the large scale tsunami sensor detects the tsunami as hydraulic pressure on the land area and the alert for the large scale tsunami intrudes into inland area and is automatically received by the master data control center using the remote data link in Disaster Prevention Center and is followed by an immediate warning to the people by using the alarm or warning and also trough the telephone list.

GPS tsunami sensor uses GPS antenna on buoy to determinate the occurrence of tsunami precisely by the satellite in cm order. The tsunami is recorded as the time series of antenna location. The decision of method used in this system determines the accuracy of tsunami observation where a single method gives the accuracy approximately 30 m. the differential method increases accuracy to 3 m. The real time kinematics gives good accuracy to 3 cm and finally the static method gives sharp accuracy up to 1 cm.

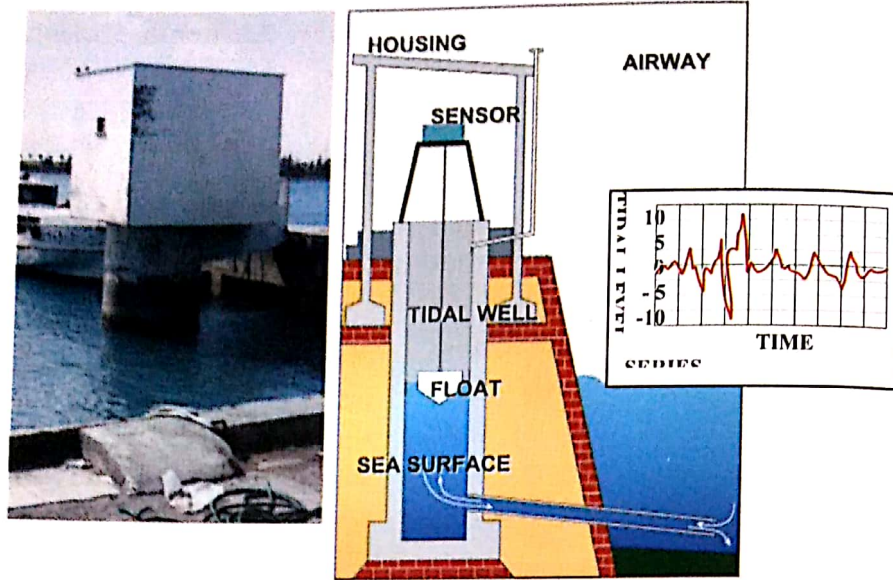


Fig. 1. Tidal Station

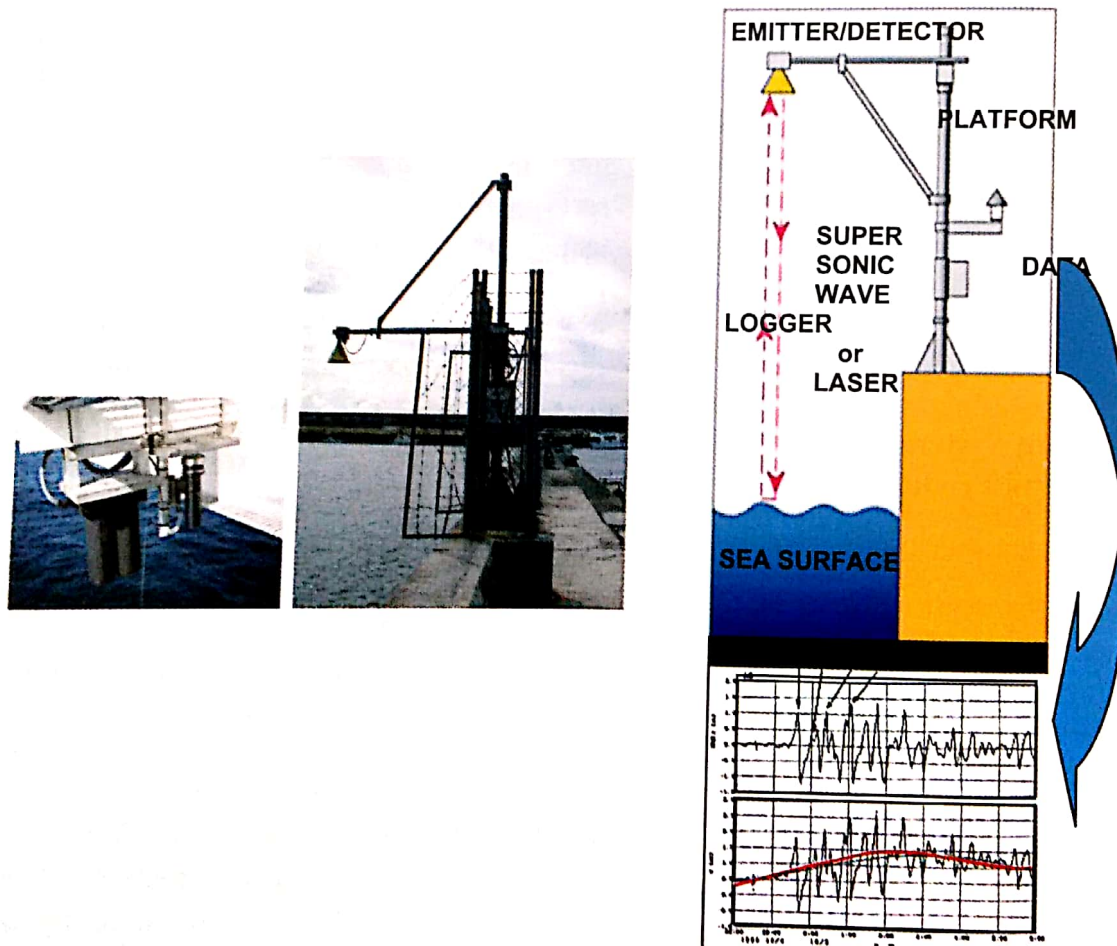


Fig. 2. Supersonic Tsunami Sensor

The simulation of tsunami using model gives understanding of tsunami initial water height as modeled by university of Tohoku, Japan. This model also reveals the maximum height and the traveling time of the tsunami. The sea surface level developed by model has relatively positive correlation with the sea surface level recorded by the satellite such as Jason-1 satellite.

IV. Overview of Aceh Tsunami

Tsunamis are not as common in the Indian Ocean such as in the Pacific Ocean. As compared to the average eight tsunamis per year in the Pacific, the Indian Ocean has one in three years or so. A catalog of tsunami shows about ninety tsunamis in the Indian Ocean out of which over 70 tsunamis are from Sunda. Some of 20 tsunamis are reported from the rest of the Indian Ocean, though source region of five of them may be in Sunda arc. Hence, eighty percent of the tsunamis of the Indian Ocean originate in Sunda arc covering Java and Sumatra, Rastogi (2006). The tsunami often occurs in Indonesia Region developed by the

movement of tectonics plate and the friction of each plate in boundary to the Northeast of plates between the Pacific and India-Australia plates. The plates move less than 1 cm/year to the Northeast.

Several big tsunamis have occurred at the trench line in the Indian Ocean by the stress of plate's motions. In 1815 tsunami killed almost 10,000, in 1883 almost 36,000 people were killed. In 1917 around 15,000 people were killed. 1992 around 1,000 people were killed. 1994 tsunami has killed 238 people. 1996 there are 9 people killed, and the biggest number of victim killed by tsunami in Indonesia happened in 2004 where around 130,000 people were killed.

Aceh (Nanggroe Aceh Darussalam) is a province located on the top of northern area of Sumatra. Banda Aceh is the capital city of Aceh (on 5°31' North and 95°25' East, with an elevation of 21 m). Relative to most of Indonesia, it is a religiously conservative area, rich with natural resources, particularly oil and gas. The population of Aceh are 4.5 million (2004) or 3% of the Indonesian population.

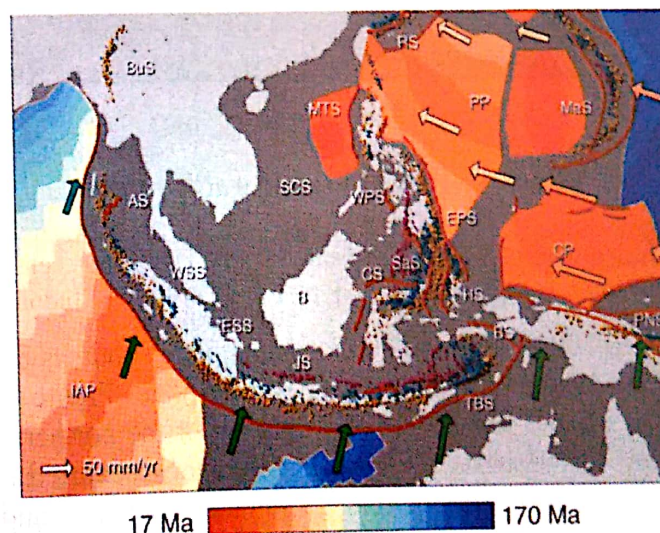


Fig. 3. Plate tectonic in Indonesia archipelago. Boundary of Plates between Pacific and India-Australia plates, Plate moves less than 1cm/year

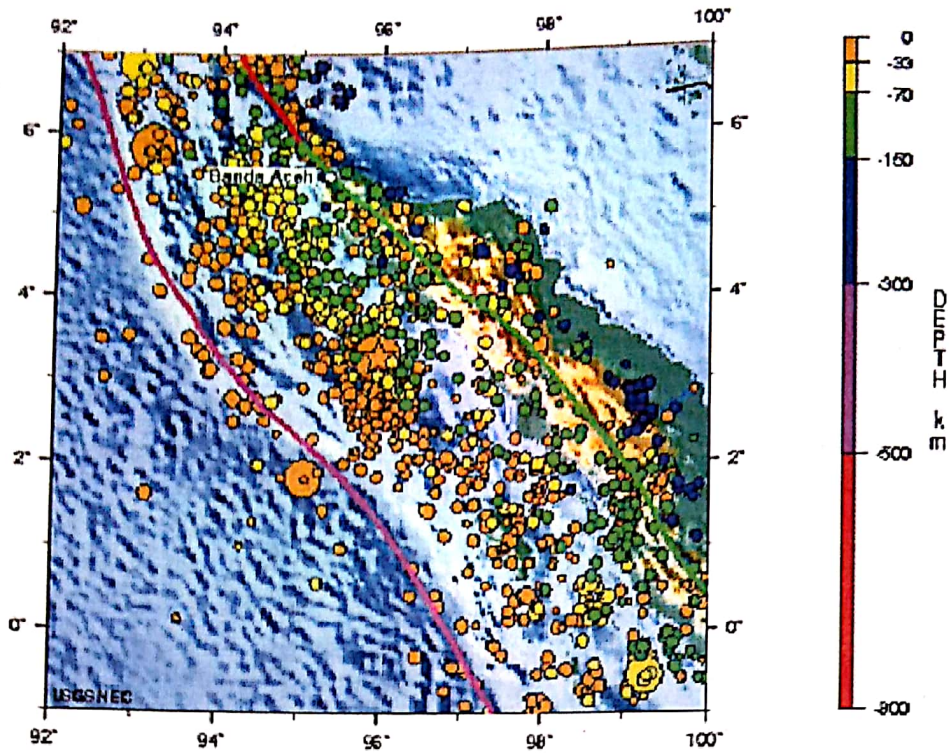


Fig. 4. Number of Earthquakes from 1990 to the present, Off the West Coast of Northern Sumatra

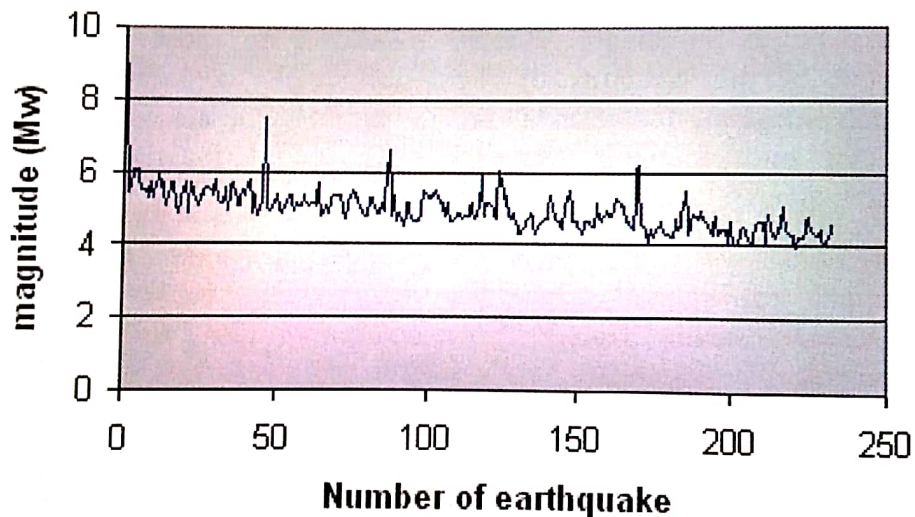


Fig. 5. Number of Earthquake from Seismic Data on December 26th 2004 (Sources: Geophysical and Meteorology agency of Indonesia)

On December 26, 2004, 00:58 (UTC), 07:58 (Local Time, Indonesia), a great earthquake occurred off the west coast of northern Sumatra, Indonesia. The magnitude of this earthquake was 9.0 and this was the fourth largest earthquake in the world since 1900. The earthquake occurred on the plate boundary where the

India plate subducts beneath the overriding Burma plate. Figure 6 shows the tectonic setting of the northern Indian Ocean. The main shock occurred off the west coast of Sumatra Island and the aftershocks extended northward along an approximately 1,000 km rupture zone.

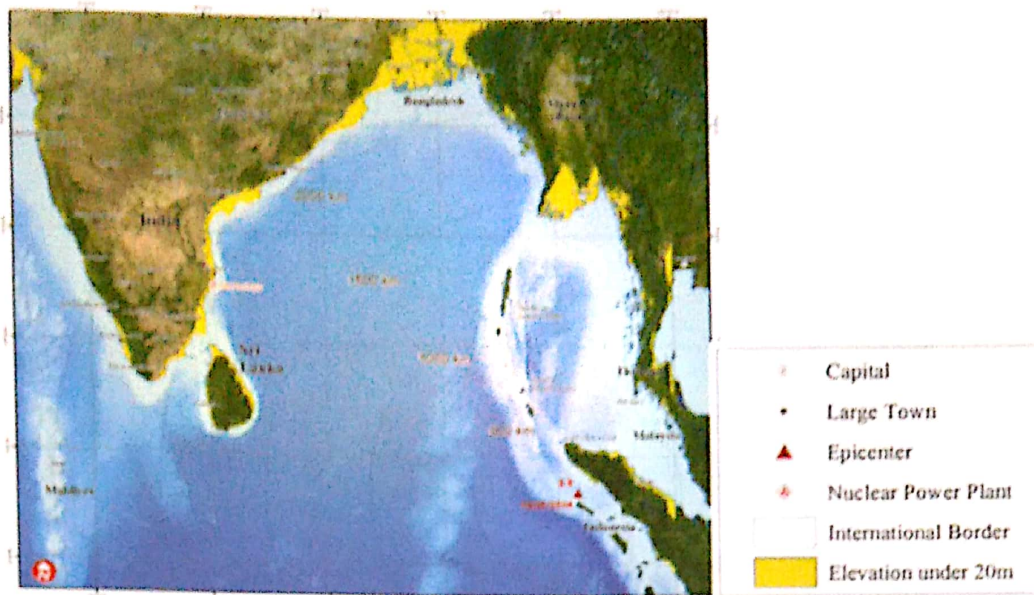


Fig. 6. Regional map of Tsunami Affected Area (UNOSAT)

The teleseismic waveform study by Ammon *et al.* (2005) shows that the rupture expanded at a speed of about 2.5 km/s in a north northwest direction, extending 1,200 to 1,300 km along the Andaman trough. They also suggested that the some slip in the northern 400 to 500 km of the aftershock zone occurred on a time scale beyond the seismic band. The Earth's free oscillation study by Park *et al.* (2005) shows that the seismic moment of the earthquake was 6.5×10^{22} Nm (Mw 9.15), with rupture duration of 600 seconds. Lay *et al.* (2005) also indicated that additional slow slip occurred in the north over a time scale of 50 minutes or longer. All of the above results suggest that the unusual slow slip nature was a part of the source process of the 2004 Sumatra-Andaman earthquake. However, the qualitative analysis of the slow slip nature using seismological data is limited, as shown by Ammon *et al.* (2005). The crustal deformation and the tsunami waveform data were essential to study the

slow source processes of the event and tsunami generation.

V. Aceh Tsunami and Environment Damage

The Sumatra Earthquake and the Indian Ocean Tsunamis of December 26th, 2004 have been described as creating one of the "worst disasters" in recent history. Twelve countries around the Indian Ocean were affected. Indonesia, Thailand, India and Sri Lanka had the largest numbers of deaths and displaced people.

The tsunami that accompanied this earthquake propagated over the entire Indian Ocean and caused extensive and significant damage. The reported number of casualties were approximately 300,000: 230,000 were killed in Indonesia (earthquake and tsunami), at least 29,000 were killed in Sri Lanka (tsunami), more than 10,000 in India (tsunami), more than 5,000 in Thailand (tsunami), and 82 were killed in the Maldives (tsunami), and more than 22,000 are still missing.

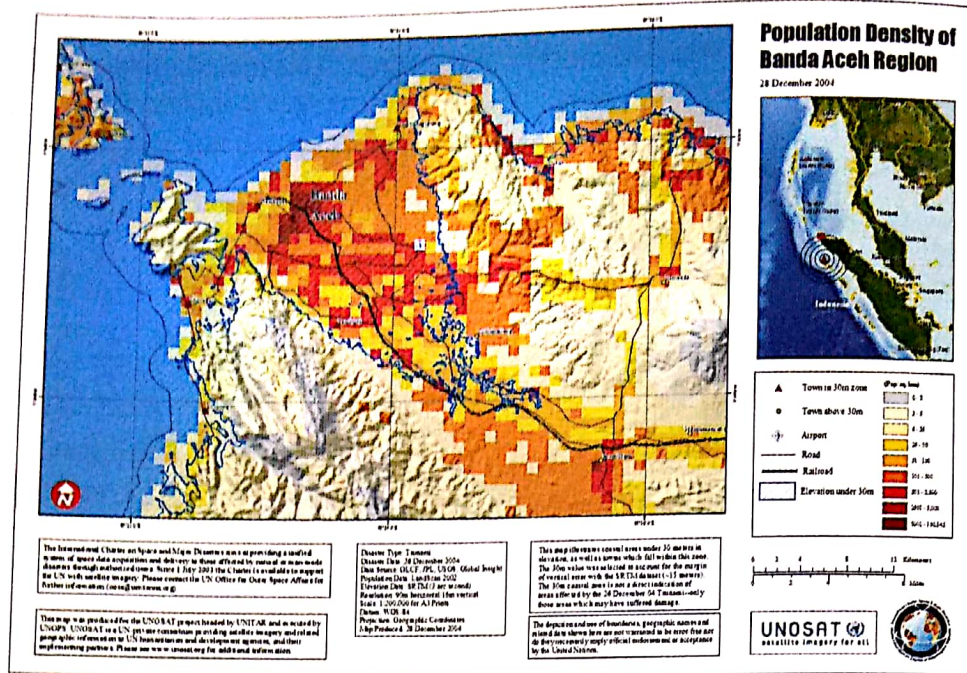


Fig. 7. Tsunami landing up Aceh City on 26, Dec., 2004: UNOSAT, using GLCF, JPL, USDS data, blue line showing arrival area of the tsunami at max. 30 m level: Inside of mosaic, color of white; 30 -50cm land level, light brown; 50cm – 1m land level, red; 5 – 25 m land level

Banda Aceh is the provincial capital and the largest city in Aceh. It is located on the northwest tip of the Sumatra Island and is surrounded by the Aceh Besar district. Banda Aceh took a direct hit from the tsunami. The residential zone, spreading between the coastline and the city centre, was completely destroyed. The commercial zone and government offices escaped total destruction but were

damaged badly by the flood. Most of the dead and missing people in Banda Aceh came from the zones mentioned above.

The province of Aceh is geographically divided into four areas: (1) Banda Aceh and its adjoining district, (2) the southwest coastal region, (3) the north coastal region and (4) the interior region. The detail numbers of victims by regions are shown in the table below.

Table 1. Number of Tsunami Victim in Aceh (Source: Disaster Countermeasures Provincial Office, 24 January 2005)

	Aceh Province	Banda Aceh & Adjoining	Southwest Coast	North Coast	Interior
Population	4,263,603	550,532	953,377	2,250,017	509,677
Dead	100,258	62,273	29,164	8,596	225
Missing	129,549	123,492	3,858	1,922	277
Displaced	417,124	150,858	120,125	140,932	5,209



Fig. 8. Post Tsunami image along West Coast of Aceh Province: 26, Dec., 2004, LANDSAT-ETM, UNOSAT (UNITAR), using data of GLCF, JPL, USGS, Value of elevation; 20 m, Tsunami landed up to more than 4km and destroyed house, road and bridge

The southwest coastal region, which consists of the districts of Aceh Jaya, Aceh Barat (West Aceh), Nagan Raya, Aceh Barat Daya and the island of Simeulue, was closest to the epicenter of the earthquake which triggered the tsunami. The only road accessible by car ran along the coastline and a number of towns and villages were located along it.

The tsunami not only destroyed towns and villages in the region but also severed the road and destroyed some bridges along it. Towns and villages were totally isolated and accessible only by boat or by helicopter. This caused a great deal of difficulty in correctly ascertaining the damage in the region. It also caused a lot of trouble for aid workers working in the region.



Fig. 9. Partially damaged family house located about 0.9 km inland in Banda Aceh. Left side is shore and right side inland. Numerals indicate inundation depths

Except for several fishing villages in this region, the tsunami did not seem to inflict severe damage, especially in comparison to other regions in Aceh. Nevertheless, the local society was greatly affected by the tsunami because survivors from the southwest coastal flocked into the towns and villages in the north coastal region. Moreover, the perception that the region was less affected by the tsunami discouraged relief aid from reaching the region. It could cause future social uncertainties if relief aid continues to be concentrated only on other regions.

VI. Aceh Tsunami from Satellite

The satellite image of Quick Bird shows the damage caused by tsunami in Aceh 2004. The satellite image received

on 23 June 2004 displays existing land cover and terrestrial matter before ruined by tsunami in 26 December 2004. The Quick Bird satellite received post tsunami image of Aceh region and showed the huge damage caused by tsunami. Many places disappear, building and road access shattered, coast land eroded. Tsunami was landing up 4 km from coast.

Map of Banda Aceh Region 28 December 2004 shows almost whole of Banda Aceh destroyed by tsunami. It is in accordance with the location of Banda Aceh that laid under 30 m elevation as well as towns which fall within this zone. Only few part of Banda Aceh and vicinity located above 30 m, so the damage caused by tsunami spread widely.



Before Tsunami 2004/6/23



After Tsunami 2004/12/28

Fig. 10. Quick Bird Data by Digital Globe

The situation in Banda Aceh post tsunami also referred by other UNOSAT map. The space map was made on basis of satellite image SPOT 5 (2.5 m pansharpned) from 30 December 2004. This map shows the damage of urban area, forested and sparsely inhabited area, cultivated area, rice paddies, and also changes of coast line, river, channels and inland water, stream. Other damages caused by tsunami also occurred by communication network such as railway, bridges, and access road. This map also

reveals the damage of important building, hospital, mosque, and water infrastructure.

Banda Aceh after 2 years Tsunami attacked can show by Alos data image using AVNIR2 sensor. AVNIR2 sensor has spatial resolution 10 m. This image shows clearly that the urban area was almost recovered; it is indicated by the white circles that some of houses were constructed. Figure 13 shown that old coastline has been changed by Tsunami attack. Using PRISM sensor which is has higher spatial resolution 2.5 m, also can shows clearly reconstructed house.

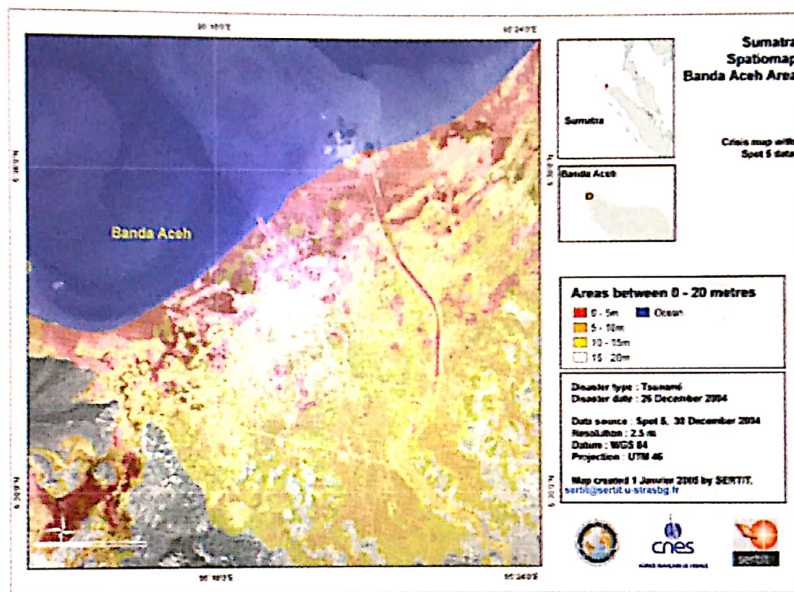


Fig. 11. Spot-5 Satellite Data after Tsunami



Fig. 12. Banda Aceh after 2 years Tsunami by AVNIR2 sensor of ALOS Data (pseudo color)

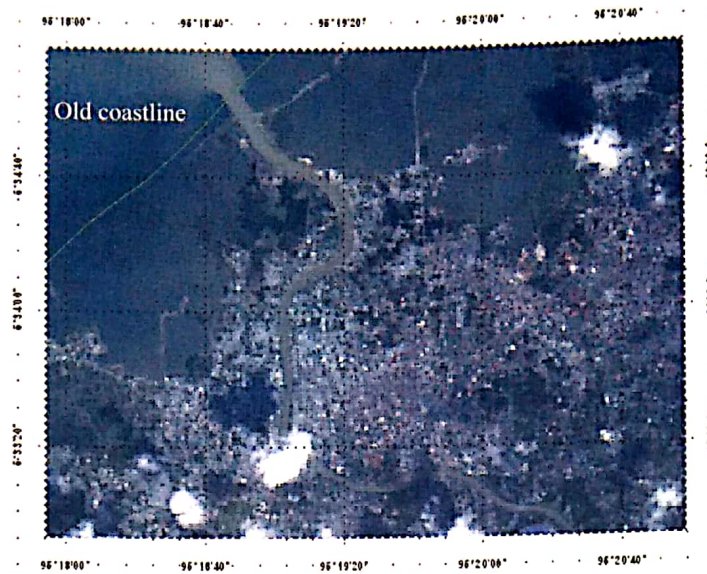


Fig. 13. Coastline change in Banda Aceh can be shown by AVNIR2 sensor of ALOS Data (RGB-true color)



Fig. 14. Banda Aceh after 2 years Tsunami by PRISM sensor of ALOS Data. Reconstructed house along coastal area

VII. Prevention of Tsunami

There were many tsunamis warning center in the world. In the Pacific ocean there are 5 tsunami warning areas split to area A, B, C, D, E of which World Tsunami Warning Center is located at

Hawaii, the center of the Pacific ocean, but in the F area including Indonesia (including Aceh) it is planned to establish the center. This is one of the reasons that Aceh had a big tsunami without any warning and killed numbers of people.

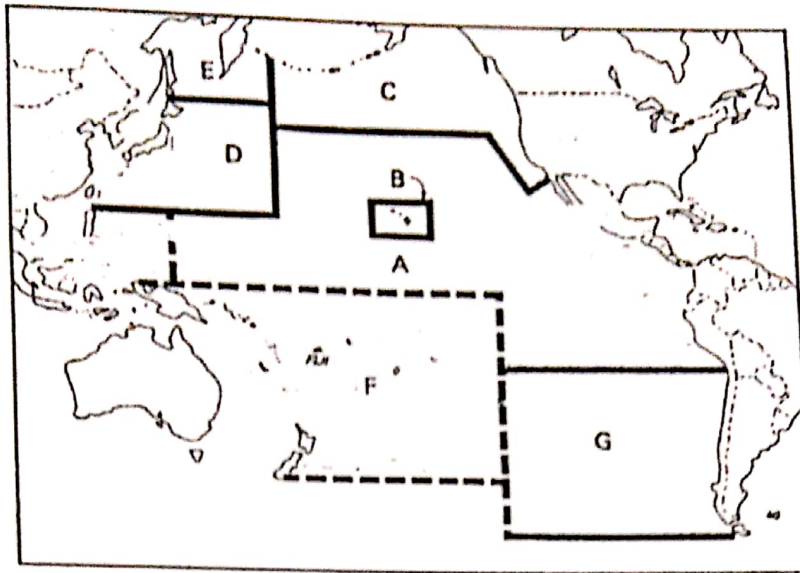


Fig. 15. Network of Tsunami Warning System

The network of Tsunami Warning Center has a system of Tsunami observation; using the in-situ buoy system and tide gauge at the coast in the Pacific Tsunami warning area and send the real time data to WPTC through the satellite. On the other hand, the real time Tsunami data are informed to each country in WTC area through the satellite.

The other important thing is to establish a local organization network in each country with the aims to pronounce the occurrence of tsunami, to inform the coming of tsunami to the local citizen in coastal zone and to take shelter from tsunami.

Thanawood (2006) explain the prevention and mitigation of tsunami as follow:

1. Mitigation measures

1.1 The establishment of land use plan for coastal areas based on vulnerability assessments and risk analysis. Critical facilities such as schools, hospital, hotels or high occupancy buildings

should not be built in the vulnerable areas. The existing tourism facilities, shrimp farms and aquaculture infrastructure located in areas at risk should be relocated.

- 1.2 The provision of appropriate incentive packages and the attractive livelihood opportunities to encourage coastal communities to abandon settling in vulnerable locations and/or living in poor-designed houses, particularly along low-lying areas of the coast.
- 1.3 The maintenance of environmental and ecological stability of the coastal areas through the enrichment of mangrove and beach forests to act as the first line of defense from the tsunami waves, and rehabilitation of lost and degraded coral reefs and sea grass beds to help stabilize the coastline and prevent beach erosion.

- 1.4 Reconstructing the removed coastal sand dunes and protecting the remaining sand dunes to act as a barrier against the giant waves. The creating of the buffer zones along the coastlines to protect coastal communities from tsunami waves is established. The buffer zones or green belts can be created through the establishment of the buffer strips of between 300-400 metres, planted with mixed vegetation.
2. **Preparedness measures**
 - 2.1 The installation of a local tsunami warning system, which includes siren towers at popular and crowded beaches, and a tsunami warning sensor floating offshore in the most vulnerable provinces.
 - 2.2 The development of education programmed through schools and universities to educate vulnerable coastal communities about the nature and processes of the tsunami hazard and how to protect themselves at the time of the impact as well as the importance of mangrove forests, beach forests and coastal sand dunes in mitigating the effects of tsunami.
 - 2.3 The formulation of a detailed plan for emergency evacuation of vulnerable coastal communities as well as organizing the evacuation drills in order to make the appropriate response more of an instinctive reaction, requiring less thinking during an actual emergency situation.
 - 2.4 Raising the awareness of the coastal communities about the dangers posed by a deadly tsunami. Brochures, posters, calendars, and announcements on the radio and the television can be used to stimulate public awareness.
 - 2.5 Construction of a tsunami memorial to commemorate areas devastated by the 2004 tsunami. The memorial would become a major attraction for both locals and visitors, helping them to understand the coastal geomorphology and ecosystems, and to remind them of the disastrous consequences of the December 2004 tsunami events.

VIII. Conclusion

Tsunami has a great deal to be concerned by the development of fundamental studies of seismology and tsunami, the establishment of the World Tsunami Warning, the establishment of system in Indian Ocean and Local Network, the development of satellite observation system in real time and finally establishment of Tsunami defense provision.

The biggest Aceh tsunami on December 2004 is not normal one concerned with the biggest magnitude of earthquake. There were in offshore of western part of Sumatra Island, long distance bottom crust was broken 600 km for only one hour. This long distance motion for long time caused non-linear mechanism for biggest tsunami. It is the most important study at moment to make clear of dynamical processes of non-linear tsunami.

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