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FIELD INVESTIGATION ON THE DAMAGE OF ROAD AND INFRASTRUCTURE CAUSED BY THE TSUNAMI IN MEULABOH, ACEH, INDONESIA

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The large tsunamis from the 9.0 magnitude earthquake that struck off the west coast of northern Sumatra early on Dec. 26, 2004 caused 300,000 casualties. We carried out damage investigation in the west coast region of Aceh from January 18-22, 2005. In this report we classified damaged and non-damaged areas. There was a significant amount of damaged structures in these areas. The damage to the beach areas from tsunamis erosion and the back arc basin caused by the tectonic movement is described. Ideas for future countermeasures are also discussed.

***Key words**: tsunami, Sumatra, Meulaboh, Aceh, back arc basin, tectonic movement, experiment*

1. INTRODUCTION

An earthquake with a magnitude of 9.0 occurred at 6:47 AM (local time) on December 26, 2004. The large tsunamis from this earthquake that struck of the west coast of northern Sumatra early on Sunday caused 300,000 casualties. We carried out damage investigation in the west coast region of Aceh State, which is near the hypocenter, on Sumatra Island. We conducted our investigation from January 18-22, 2005 while travelling with a local NGO that was aiding damaged areas with support goods. Meuloboh, Aceh, which is located 200 km southeast of Banda, Aceh, is the nearest city to the epicenter. It is said that this region has the highest percentage of collapsed houses due to the tsunamis. The road to Meulaboh had been located along the gulf coast near Suak Timash Village. After the earthquake, the land changed and vanished. Therefore, the plantation roads are used to reach Mealaboh. The original road to Calang from the village is now impassable. The clean-up program for the removal of wreckage is of great importance and urgently needed for the rehabilitation and reconstruction of infrastructure.

2. TSUNAMIS DAMAGED AREA

We crossed Sumatra Island from Medan to Tapak Tuan and then on to Meulaboh, Aceh (**Figure 1**). Before this survey was conducted, the tsunamis were thought to have damaged the whole west coast area of Sumatra. However, the damaged area was limited to the area north of Kuala Tuha. One of the underlying reasons for this is that Simeulue Island seemed to aid in the prevention of tsunamis. The tsunamis hit this island.There are 70,000 people living there but there were only 7 casualties. The people of this island called the big wave that hit it during the 1907 disaster "Semong". The story of "Semong" has been passed down from generation to generation and helped to save thousands of lives there this time.

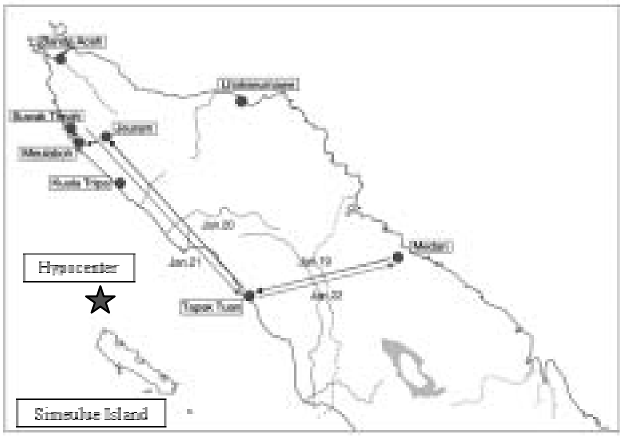

Figure 1 Survey route

3. TSUNAMI DAMAGED AREA AT MEULABOH

The damage from the tsunami was recognized along the coastline from Kuala Tuha to Meulaboh. Except for some coconut trees, all vegetation was swaped away by the tsunamis on the coastline. Ideas for future countermeasures are also discussed in chapter 7.

(1) Roads

As the roads were damaged by the tsunamis, removal of driftwood from a road poses a big problem. The main roads, rubble and driftwood were removed by the army (**Figure 2, 3**).

The tsunami runup caused road greatly erosion to the asphalt also exfoliated and the road surface was damaged in the many areas (**Figure 4**).

(2) Bridges

Bridges handrails and superstructure etc. were damaged by the outflow of driftwood at handrails as well as abutment mounts due to severe tsunami erosion. At Kuala tadu river, the down stream side of the abutment was damaged when the tsunami hit. It then passed the bridge and the up-stream side was consequently damaged by the erosion (**Figure 5**).

(3) River-mouth

There was damage of the narrow part of the river-mouth where the tsunami struck. The energy of the tsunami concentrates at both sides of the river-mouth banks which causes erosion (**Figure 6**).

(4) Meulaboh airport

The 1300 m runway at the Meulaboh airport was damaged. Although 200 m of the runway were impossible to use, the runway 1100 m section was restored and made available for use (**Figure 7,8**).

(5) Ujoung Karang harbor

At Ujoung Karang harbor which suffered the damage to facilities by the tsunamis, the pier was destroyed and the caisson was also torn off (**Figure 9**). According to the inhabitants, water gushed up from the earth to approximately the height of a person. This might have been caused by liquefaction. Moreover, the coastline advanced inland after the earthquake. This phenomenon was not only caused by tsunami but also by subsidence of the ground due to the earthquake. The damage to the beach areas from tsunami erosion and the back arc basin caused by the tectonic movement is in chapter 5. The mosque, which located approximate 500 m inland, remained standing even though the first floor was completely damaged. The 3.5 m roof was partly damaged, although the glass of the skylight was not (**Figure 10,11**). Therefore, it is thought that the height of tsunami was approximately 5 m.

(6) Center of Meulaboh City

A large amount of rubble was generated from the earthquake and tsunamis. The clean up program for the removal of this wreckage is extremely important and of great urgency for the rehabilitation and reconstruction of infrastructure. Only a few masonry structures with RC columns remain standing in the tsunami-stricken areas. Moreover, The structures built continuously, it may be stop in a spread of tsunami damage (**Figure 12, 13, 14, 15**).

(7) Suwak Timah village

According to Suwak Timah Village (located 10km northwest of Meuloboh) inhabitants, only 600 of the 2500 residents survived. Casualties fled to a plantation in the north. Much of the village housing was constructed of wood with tin roofs. The earthquake occurred the coast moved inland 300-500 m. After that, the tsunami hit this area. The residents were divided into two different groups. When many of the structures were destroyed some of the residents went to rescue the injured. However, others, many of them children, went to collect fish on the beach when the sea receded and were swept away by the tsunami. The height of the tsunami, the 2nd wave, reached the top of the coconut trees (about 10m). The coastline is formed like a bay and this is thought to have amplified the force of the tsunami. Geographical features were altered and in some cases even extinguished. The road to Meuloboh from Suwak Timah village was completely destroyed. Thus, we had to use a road through a rubber plantation to get to Meulaboh. The original road now no longer connects to Calang and the only transportation there is by ship (**Figure 16, 17, 18, 19**).

(8) Kuala Tudu village

245 people of the original 700 inhabitants of Kuala Tudu Village fell victim in the earthquake. Many of the people in this fishing village lost their ships due to the tsunami. All of the survivors have moved to a village 20 km away. The main water supply for the area came from a shallow well (a depth of less than 4m) and according to the inhabitants, the water is now polluted and no longer potable. The mosqu roof was partly damaged (**Figure 20,21**). Therefore, it is thought that the height of tsunami was approximately 4 m.

(9) POSKO

We visited the local urgent correspondence place (POSKO) with KLK was working in cooperation with other local and foreign organizations to share information and give businesslike support. At the POSKO camp they had drilled a well to provide a steady, potable water supply (**Figure 22**).

Figure 2 Road Condition from Kuala Tadu to Kuala Tripa (left)
Figure 3 Road condition near Meulaboh, road shoulder damaged by the tsunamis. (right)

Figure 4 Coastal Road from Suwak Timah village to Meulaboh. The asphalt also exfoliated and the road surface was damaged in the many areas (left)
Figure 5 Bridge at Kuala Tadu River (right)

Figure 6 River-mouse near Kuala Tuha

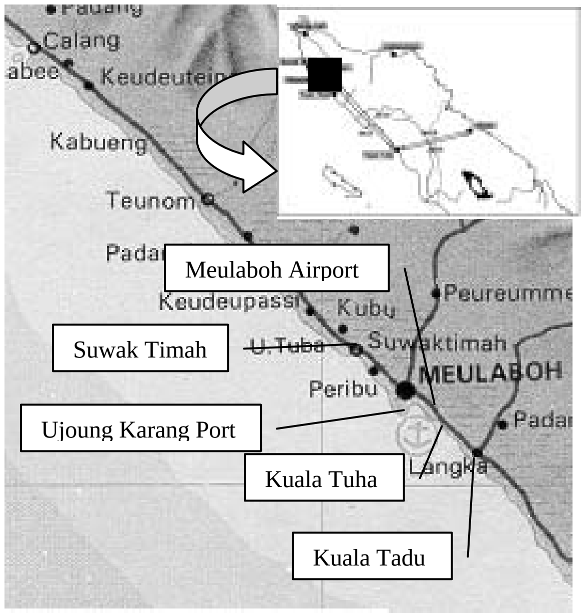


Figure 7 Meulaboh Airport (left)
Figure 8 200 m of the runway were impossible to use, the runway 1100 m section was restored. (right)

Figure 9 Ujoung Karang Port


Figure 10 Mosque near Ujoung Karang Port (left)
Figure 11 This mosque remained standing even though the first floor was completely damaged (right)


Figure 12 View of Meulaboh City, removal of wreckage (left)
Figure 13 Center of Meulaboh City, RC frame with masonry structures remained at tsunami damaged area (right)


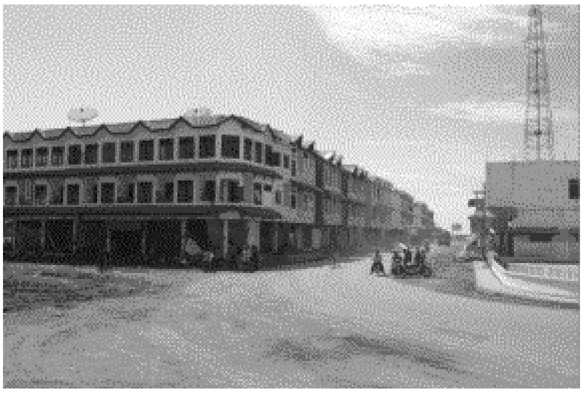

Figure 14 View of Meulaboh City. The structures built continuously, it may be stop in a spread of tsunami damage (left).
Figure 15 View of Meulaboh City. Removed the debris the road in the city. (right).


Figure 16 Suwak Timah Village, where located 10km northwest of Meuloboh (left).
Figure 17 Suwak Timah Village. Many housings of the village were wooden the structure with a tin roof (right).


Figure 18 Even if masonry structures were completely destroy at Suwak Timah Village (left).
Figure 19 At Suwak Timah Village, the height of the tsunami, the 2nd wave, reached the top of the coconut trees (about 10m). (right).


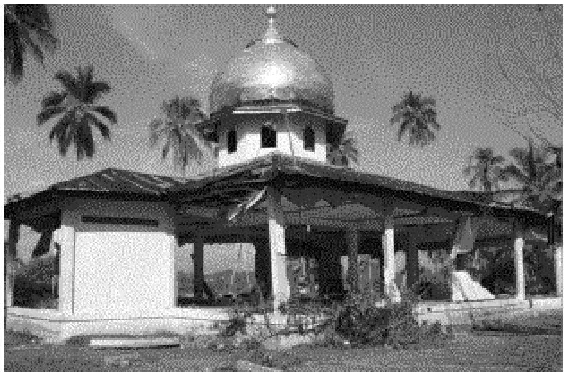

Figure 20 At Kuala Tudu village, there were 700 people resided, but after the arthquake, 245 persons fell victim (left).
Figure 21 The mosque roof was partly damaged. It is thought that the height of tsunami was approximately 5 m (right).

4. INTENSITY IS STRONG?

The India plate subduction caused a jump riser in the Eurasia plate (**Figure 23**) and the subsequent earthquake of *Mw*9.0[1]. This had 1400 times the energy of the Great Hanshin Earthquake. The Eurasia plate jumped and the tsunamis were generated. The sea surface on the Indonesia side rose, and the dilatational wave started off the coast. In the meantime, a compressional wave began off the coast of the Sri Lanka. There was little damage by accretion even though the hypocenter was located close to Aceh. The reason for this is that the Systemic wave contained long-period and destruction rupture from the hypocenter and seemed to propagate to the north. According to the TV news, there were two stages at Banda, Aceh. In the first stage, there was weak ground motion with slow shaking. After 50 seconds, in the second stage, strong ground motion started. This phenomenon corresponds to rupture stage (e.g., Yagi, 2005, personal communication, **Figure 24**) [1]. In the first stage, the rupture mainly propagated to the northwest of the hypocenter during the initial 50 seconds. The second rupture generated an ultra long period seismic wave. This second slow seismic wave caused the large tsunamis.

5. SUBDUCTION CASED SUBSIDENCE?

The satellite images of the Tsunami affected areas in the web page were acquired by the Centre for Remote Imaging, Sensing and Processing at the National University of Singapore[3]. They show the effects of the tsunamis on the affected areas in Indonesia by using IKONOS images. From their work, it is considered that ground sediment moved about 1 m by the earthquake at Aceh (Kimata, 2005) [4]. This margin is oblique subduction (**Figure 25**: Malod, *et al*, 1996) [5].

Next we discuss each application and how it relates to the natural examples in some active fault cases in Japan, where many active faults work in the forearc areas. **Figure 26** shows analogue modeling of the subduction-related structure (Anma, 1998) [6]. In this experiment, a tension zone occurred in the ground surface on the hanging wall side and a shear zone appeared on the foot side. A fracture might be generated that is parallel to the ground surface fault. If the subduction of the plate existed, the stress would create a shear zone near the surface. This tension stress, which causes subsidence, can explain the same mechanism of the pull-apart basins (**Figure 27** Woodcook *et al.*, 1986) [7]. In this case, the tension stress is thought to contribute to the generation of back arc basin subsidence. This phenomenon can explain themechanism of the deformation of the typical subduction (Ohsumi and Ogawa, 2004) [8].

Figure 22 Volunteers Activities. POSKO with KLK (KANTOR LATHAN KERJA)

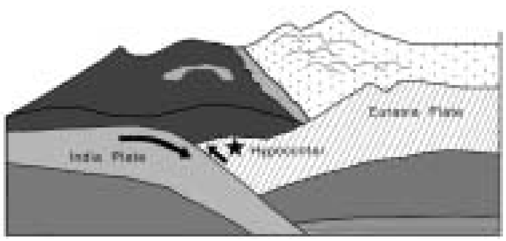

Figure 23 Hypocenter & Tectonic

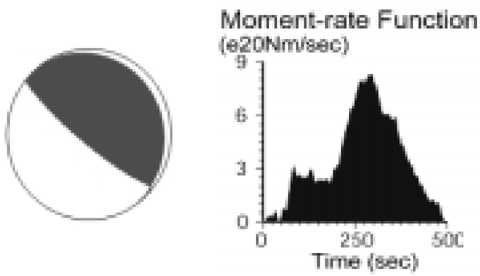

Figure 24 Focal mechanism (left) ; Total moment-rate function (right) , (Yagi, 2005)
Moment=1.736 E+23 (Nm), *M*w=9.4, D=39.3 m

And next, the digital experiment reproduced fracture patterns in the dynamic and nonlinear FEM analysis for a simple shear field. TDAP III package is used for the 2-D model of the dynamic FEM analysis for three varieties of boundary conditions. These fault models are characterized by one free side and one fixed side. This mimics the deformation of a subduction. The top being free in the open it`s surface. The shear fractures and tension fractures are shown in **Figure 28**. The tension zone occurred in the ground surface on the hanging wall side and a shear zone appeared on the foot side. A fracture might be generated that is parallel to the ground surface fault. If the subduction of the plate existed, the stress would create a shear zone near the surface. This result also explains the mechanism of the deformation of typical subduction and ground subsidence.

6. CONCLUSIONS

1) The total amount of damage Indonesia caused by the tsunami and earthquake is estimated to be 4.45 billion US$ (see **Table 1**). This relates to the traffic (road, harbor, airport etc.), water supply sewage, agriculture, irrigation and reconstruction plan.

2) The cost area between Kuala Tadu-Meulaboh and the Bakongan-Blangpide was cased extensive damage from the tsunami. 2/3 of the city of Meulaboh was destroyed completely, as well as villages located along the coast. The damaged area of the tsunami reached about 3 km inland. However, destruction of structures due to seismic damage. could hardly be observed in the damaged areas outside the tsunami-stricken area.

3) The coast road leading to the north from Meulaboh, Aceh sustained extensive damaged and has hindered reconstruction in the region. Not only tsunami erosion caused many bridged along the cast road of Banda, Ache destroyed, but also these area caused subduction occurred due to tectonic movement.

4) The analogue experiment can explain how a fracture parallel to the ground surface fault might be generated. If the seduction of the plate existed, the stress would create a shear zone near the surface. This tension stress, which causes subsidence, can explain the same mechanism of pull-apart basins.

5) The digital experiment can explain the tension zone which occurs in the ground surface on the hanging wall side and the shear zone which appears on the foot side. A fracture might be generated that is parallel to the ground surface fault.

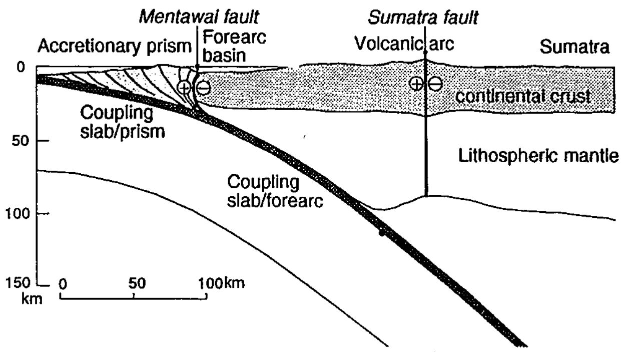

Figure 25 Schematic cross-section of the Sumatra subduction system (Malod, , *et al*, 1996) [5]

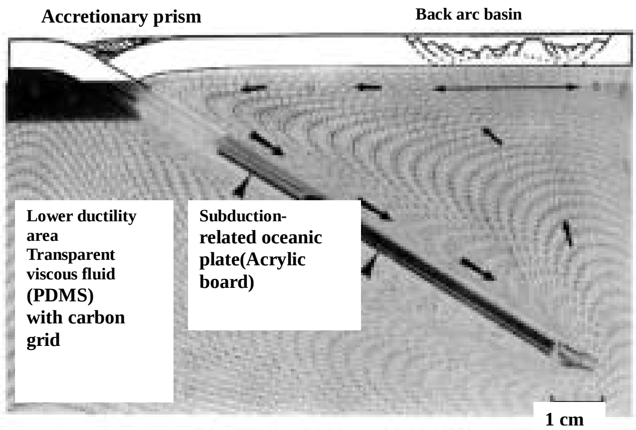

Figure 26 Analogue modeling of the subduction-related structure (Anma, 1998) [6].

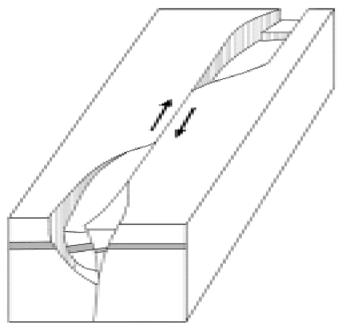

Figure 27
Those both ends part caused pull-apart basin by tension zoon (Woodcook *et al.*, 1986) [7].

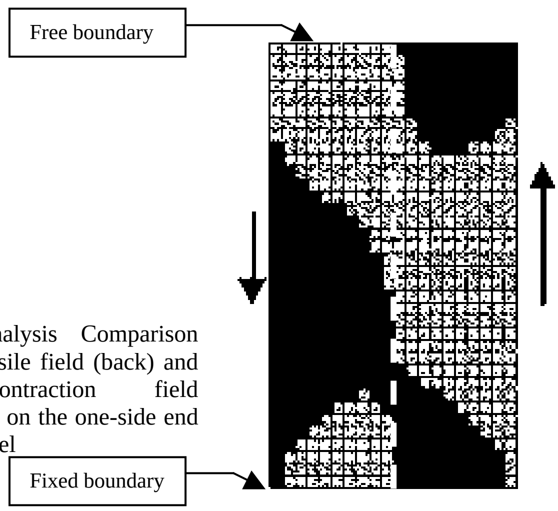

Figure 28
FEM Analysis Comparison of the tensile field (back) and the contraction field (hatching) on the one-side end fixed model

7. KEY ISSUES

1) Though the villages and cities of Meulaboh to Banda, Aceh area sustained a large amount of damage due to the tsunami, it is difficult for aid support to reach these areas due to the damaged logistics system. It is expected that the road reconstruction will be technically difficult due to the high construction costs. Thus, it is anticipated that this large amount of money required will pose problems for the future reconstruction plan.

2) The clean up program for the removal of wreckage is the most important basis and is urgently needed for rehabilitation and reconstruction of infrastructures. The above program should be considered not only for the urban areas but also farm fields, since the tsunami brought much wreckage and waste into the farm fields. Refugees would like to re-build their houses as a first priority. To realize their views, the share of responsibility and duty between refugees and governments should be clarified as soon as possible. In addition, government should confirm land registration and re-survey, if necessary.

3) Although the display by the satellite photograph of the tsunami damaged area was effective, the region which greatly differed from the damage area also existed, we discovered that some regions significantly different from those photographs. We took many photographs and obtained route maps with a lot of GPS data. However, as we only had limited time to survey, we would like to further research and classify the damaged and undamaged areas in the future.

4) At Simeulue Island, causality of the tsunamis reduce because of the story has been passed down from generation to generation. The other hand, at Suwak Timah village, their children went to collect fish on the beach when the sea receded and were swept away by the tsunami. So the awareness is important for the tsunami disaster mitigation.

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Table 1 The total amount of damage Indonesia caused by the tsunami and earthquake. (unit：US$million)

	Facilities Damage Cost	Loss Amount	Total
Social Sector	1674.9	65.8	1740.7
-Housing	1398.3	38.8	1437.1
-Education	110.8	17.6	128.4
-Health	82.5	9.4	91.9
-Culture and religion	83.4	-	83.4
Infrastructure	636.0	240.8	876.8
-Transport	390.5	145.4	535.9
-Communication	18.9	2.9	21.8
-Energy	67.8	0.1	67.9
-Water and Sanitation	26.6	3.2	29.8
-Flood control and Irrigation	132.1	89.1	221.2
Productivity Sector	351.9	830.2	1182.1
-Agriculture and Livestock	83.9	140.9	224.8
-Fisheries	101.5	409.4	510.9
-Enterprises	166.6	280.0	446.6
Cross Sector	257.6	394.4	652.0
-Environment	154.5	-	154.5
-Governance and Adm.	89.1	-	89.1
-Bank and Finance	14.0	-	14.0
Total	**2,920.4**	**1531.2**	**4451.6**

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