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Survey Report:

Damage and Height Distribution of Sumatra Earthquake-Tsunami of December 26, 2004, in Banda Aceh City and its Environs

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A huge earthquake of magnitude M 9.0 occurred at 00:58 (UT), December 26, 2004, in the sea off the west coast of northern Sumatra, Indonesia, followed by a huge tsunami that hit almost all coasts facing the Indian Ocean. We conducted a field survey in the residential area of Banda Aceh, the town of the severest damage by the tsunami, on the west coast of the northernmost point Sumatra, Sigli City, about 80 kilometers east of Banda Aceh three-four weeks after the event. In Banda Aceh, almost all houses in the residential area about 2 km from the coast were swept away, while houses more than 3 km rarely were. Inundation continued about 5 to 6 km from the shoreline. In Lhoknga and several villages on the west coast of Sumatra Island near Banda Aceh, where tsunamis 15 to 30 meters high hit coastal villages, nobody survived. Along the valley about 1 km north of the cement plant, seawater rose to a height of 34.8 m above MSL, which is the highest recorded inundation measured in our survey.

Keywords: the 2004 Sumatra Earthquake-Tsunami, tsunami run-up height, field survey of tsunami suffering coast, tsunami damage of a city, Banda Aceh

1. Introduction

A huge earthquake of magnitude M 9.0 occurred at 00:58 (UT), December 26, 2004, in the sea off the west coast of northern Sumatra, Indonesia, followed by a huge tsunami that hit almost all coasts facing the Indian Ocean. The severest tsunami damage occurred at Banda Aceh, a city located at the northernmost point of Sumatra Island, and having a population of some 250,000. The number of casualties due to the tsunami was estimated at 70,000 and the total number of victims worldwide 250,000 – meaning that one third of the victims were from Banda Aceh. Organizing a 17-member international survey team – seven Japanese, six Indonesians, two Americans, and two French – we entered Banda Aceh in the morning of January 20, 2005, about three weeks after the event, and conducted a field survey in the residential area of Banda Aceh, on the west coast of the northernmost point Sumatra, Sigli City, about 80 kilometers east of Banda Aceh. We finished the survey at Banda Aceh on January 29.

Indonesia has suffered several large tsunamis, e.g., in 1992 at Flores Island, in 1994 in East Java, in 1995 at Biak, Irian Jaya. We sent survey teams to Flores Island in 1992, to East Java in 1994, and to Biak in 1995, but nothing prepared us for what we found in Banda Aceh.

Banda Aceh is the capital of Nangro Aceh Dalussarum Province, an area already made dangerous by battles between Indonesian army forces and Independence movement (GAM) guerrillas, so our survey was strictly regulated by Banda Aceh City police officers. We were permitted to survey only in the city of Banda Aceh and in Sigli city, about 80 kilometers east of Banda Aceh. We could not enter the mountainous region close to residential Banda Aceh because our rental car drivers feared guerrilla activity.

Another difficulty was that the tsunami had washed away about 60% of residential Banda Aceh, meaning no hotels were available and no banks open but one. We were obliged to rent three rooms in a farmhouse near the air-port. In the damaged areas, streets were malodorous from the accumulated wreckage brought in by the tsunami waves, and the bodies of victims still lay beside the roads

Fig. 1. Residential area near harbor. Almost all houses in the residential area about 2 km from the coast were swept away.

and in the fields – a daily sight.

We divided ourselves into five subteams, and hired five cars – one for each team. Subteam 1, under Yoshinobu Tsuji, mainly surveyed residential areas in Banda Aceh City and Lhoknga Village on the west coast. This subteam tried to make detailed surveys of tsunami-eroded slopes on the west coast, where we had been told serious erosion occurred. Subteam 2 under Yuichi Nishimura measured seawater inundation heights on the west coast mainly using a combined laser range and level finder, going south to Daerah Saruh Village (**Fig. 7**), about 20 km south of Banda Aceh. They made a detailed survey about 15 km long between Lhoknga and Daerah Saruh Villages (hereafter simply "west coast"). They also made surveys at Calang, about 95 km south of Banda Aceh with the aid of a helicopter provided by a US rescue team. They also made geological surveys of sand layer formation accumulated by the tsunami. Subteam 3 under Hideo Matsutomi surveyed Banda Aceh City and the west coast and Sigli City, on the north coast about 80 kilometers east of Banda Aceh and three points on We Island. Subteam 3 focused on tsunami flow speed and estimated it by measuring the difference in water marks up- and down-stream of the same buildings or hills – results were published in Matsutomi et al. (2005) [4]. Subteam 4 under Yuichiro Tanioka surveyed mainly the west coast and Sigli City, studying crustal deformation accompanying the earthquake and checking coconuts trees close to the shoreline on the west coast and estimating the amount of crustal subsidence. French scientists conducted a field research independently of us by using the last car.

Sanitation and safety in the study were very bad, although we kept in touch through portable satellite phones at least once a day during the lunch break and kept contact with Y. Namegaya at our institute, the Earthquake Research Institute (ERI), three times a day. In the evening contact, we briefly reported on safety and the day's results, which were forwarded to the Ministry of Education, Culture, Sports, Science, and Technology, Japan. Our daily report was also forwarded to the internet board of the International Tsunami Information Center (ITIC).

2. Earthquake Damage in Banda Aceh City Streets

Little earthquake damage to residential housing was observed, and damaged brick walls in general housing were rare. A few concrete buildings such as department stores were quake-damaged. Tiles from the Great Mosque were partly broken, but the building itself sustained no damage due to shaking. This suggested a long-period component was superior in seismic motion, because damage to massive buildings was worse than to general housing. We looked for traces of liquefaction, but saw none in Banda Aceh City or on the west coast.

We gathered eyewitness accounts by asking about landslides in mountainous regions around Banda Aceh, but obtained no such information during our stay in Banda Aceh.

Fig. 2. Baiturrahim Mosque at Ulee Lheue Port.

Generally speaking, damage caused by shaking was very slight in Banda Aceh, and seismic intensity on the MMI scale was estimated at about 6. No earthquake damage was seen also at Sigli, Krueng Raya, or Sabang on We island.

3. Crustal Motion

We gathered eyewitness accounts of vertical crustal motion, i.e., the sea level changed before and after the earthquake at Krueung Raya and at the port of Banda Aceh. A police officer at the port of Krueng Raya said that sea levels had not changed insofar as was evidence by concrete blocks of the wharf at the ferry port. We asked several citizens at the port bridge of Ulee Lheue in Banda Aceh, and some said no change had occurred, while others said that the sea had risen 30-50 cm. Matsutomi et al. (2005) also reported crust subsidence there of 20-60 cm. On the west coast, we found that coconuts trees stood in front of the shoreline, showing ground subsidence. Dr. Tanioka, after checking these trees precisely, pointed out that the crust had subsided about one to two meters.

4. Tsunami Damage

4.1. Central Banda Aceh City

Residential Banda Aceh is about 8 km $\times$ 8 km north-south and east-west, with the Great Mosque at the center. Seawater inundated the mosque's neighborhood up to one meter above ground. Eyewitness accounts mentioned that seawater rose about 20 centimeters above the floor in mosque buildings.

About 4 km north-west of the Great Mosque is a harbor called Ulee Lheue and a good residential street called Jl. Iskandar Muda between the two.

Almost all houses in the residential area about 2 km from the coast (**Fig. 1**) were swept away, while houses more than 3 km rarely were. Inundation continued about 5 to 6 km from the shoreline. Even houses flooded but not swept away had such thick malodorous mud accumulated on floors as to make them uninhabitable.

The port area had been full of trees, but the tsunami destroyed all one banyan (**Fig. 7**), where we measured inundation at 12.2 m above mean sea level (MSL).

At Ulee Lheue Port (**Fig. 2**), only the Baiturrahim Mosque still had its roof, and most other buildings had been entirely destroyed. Seawater rising to the front of the Mosque (in the direction of Mecca), broke through the front walls and rose to the upper door sill on the second floor. We found that seawater had risen to 11.95 meters above MSL. The second wave rose to the handrail on the second floor – a height of 8.35 m.

Banda Aceh Junior High School No.5 (**Fig. 3**) located about 1 km from the shore was houses in a steel-reinforced concrete building not easily washed away. The left side of the second floor, however, had been carried away by the tsunami current. The seawater had risen to 50 cm above the ceiling boards of the second floor, which was measured at 9.0 meters above MSL.

Fig. 4. Lhoknga Village on the west coast about 7 km southwest of central Banda Aceh. Only one house remained, that of Mr. Julpikar, near the right here.

Fig. 3. Damage to Banda Aceh Junior High School No.5 building.

4.2. Lhoknga Village

Driving from central Banda Aceh south-west, we reached a village called Lhoknga on the west coast of Sumatra Island, where tsunamis 15 to 30 meters high hit coastal villages. In many villages nobody survived.

Figure 4 shows Lhoknga, where comparatively rich people had lived in concrete or brick houses, all of which were entirely destroyed except for one behind the ridge of a coastal dune. It was not hit by a direct wave and so was not swept away. We measured the water mark inside of this house near the floor of the second storey: seawater had risen 12.42 meters above MSL.

A comparison of satellite images of the west coast before and after the tsunami shows that green forest covered the land clear down to the shoreline before. After the tsunami, land erosion from it left only a yellow zone bordering the forests. All vegetation and trees had disappeared from this zone, leaving a clear boundary between the green surviving forest and the yellow eroded zone (**Fig. 5**). Along the valley shown in **Fig. 5**, seawater rose to a height of 34.85 m above MSL – the highest recorded inundation measured in our survey. Near this valley, an oil tanker vessel transported by the tsunami lay stranded on sand dunes.

About 1 km south of this valley there was a cement plant, many of whose workers lived on the coastal plain. Not a single person survived in this valley. Except for scatter house wreckage no evidence remained of the residential area.

The boundary between eroded and non-eroded areas is clear in this photo. We climbed along the axis of the valley to the inundation limit, confirming that the erosion boundary was not the same as the seawater inundation limit: seawater had risen 4 to 5 m higher than the apparent erosion limit. **Fig. 6** shows the inundation limit of seawater in the

Fig. 5. Tsunami eroded valley on the west coast.

Fig. 6. Inundation limit.

valley in **Fig. 5**. Note the stranded oil tanker and the traces of residences once occupied by cement plant workers on the plain. Garbage carried by the tsunami is caught in the trees near the camera, which stands on a slope that is more than 33 m above MSL.

5. Measurement of Tsunami Inundation Height

5.1. Reference of Heights and Setting of Seven Bench Marks

The reference of height is MSL at Ulee Lheue Port, the directly measured sea surface level compensating for the astronomical tide component at the time measured. We used a program for calculating the astronomical tide by Tsuji et al. (2005) [2]. We tried to obtain MSL several times in another three days. In Banda Aceh City we found water marks at many places showing the limit of seawater inundation, on walls and columns of houses. We made a survey leveling of water marks and clarified their heights above MSL. We first set seven benchmarks along

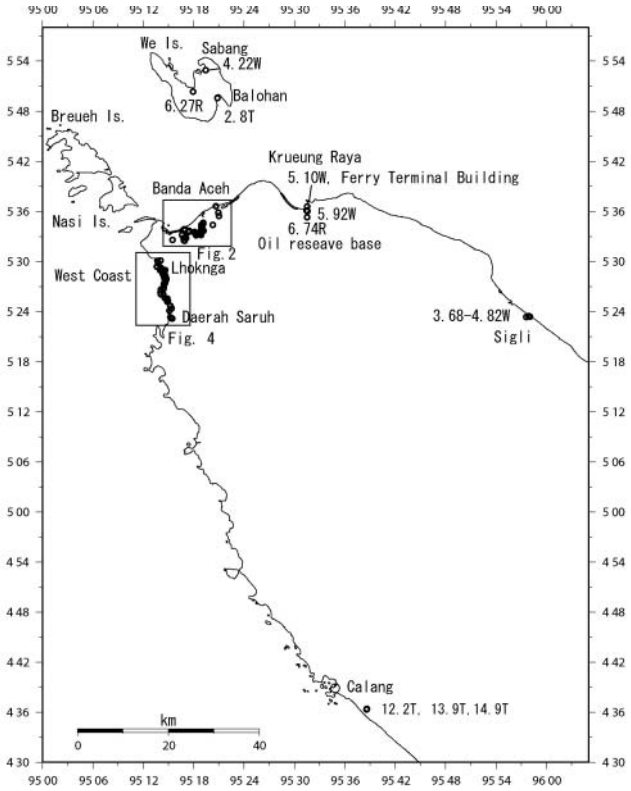

Fig. 7. Tsunami height distribution for places far from Banda Aceh. Numbers denote tsunami inundation heights in meters. W denotes water marks on walls, R run-up traces on slopes, and T traces on trees.

Table 1. Benchmarks along Jl Iskandar Muda Street (**Fig. 7**).

Banch Mark	Long. Deg.	min.	Lat. Deg.	min.	Height(m)
A	95	18.905	5	33.218	3.88
B	95	18.570	5	33.306	2.75
C	95	18.311	5	33.381	3.94
D	95	18.114	5	33.439	2.64
E	95	17.916	5	33.505	–
F	95	17.696	5	33.552	–
G	95	17.344	5	33.566	1.18

Jl. Iskandar Muda Street, and fixed points A to G from inland to the seaside at the intervals of about 400 meters (stars in **Fig. 8**). We repeatedly surveyed the height, and the location of these benchmarks from the sea level. We had prepared a table of astronomical tides, compensated for the tidal component, and finally obtained reliable data on benchmark locations and heights (**Table 1**).

Benchmark A is near the Great Mosque, and behind its site is a large river called Krueng Aceh. We connected the survey line to the river surface and confirmed that the level at the point nearest the Great Mosque was 1.0 m above MSL. Based on this result, we surveyed the residential area on both sides downstream of the river. We estimated the height of the river surface in proportion to the distance to the river mouth, obtaining the inundation height distribution in **Fig. 8** and the detailed map of the city center in **Fig. 9**.

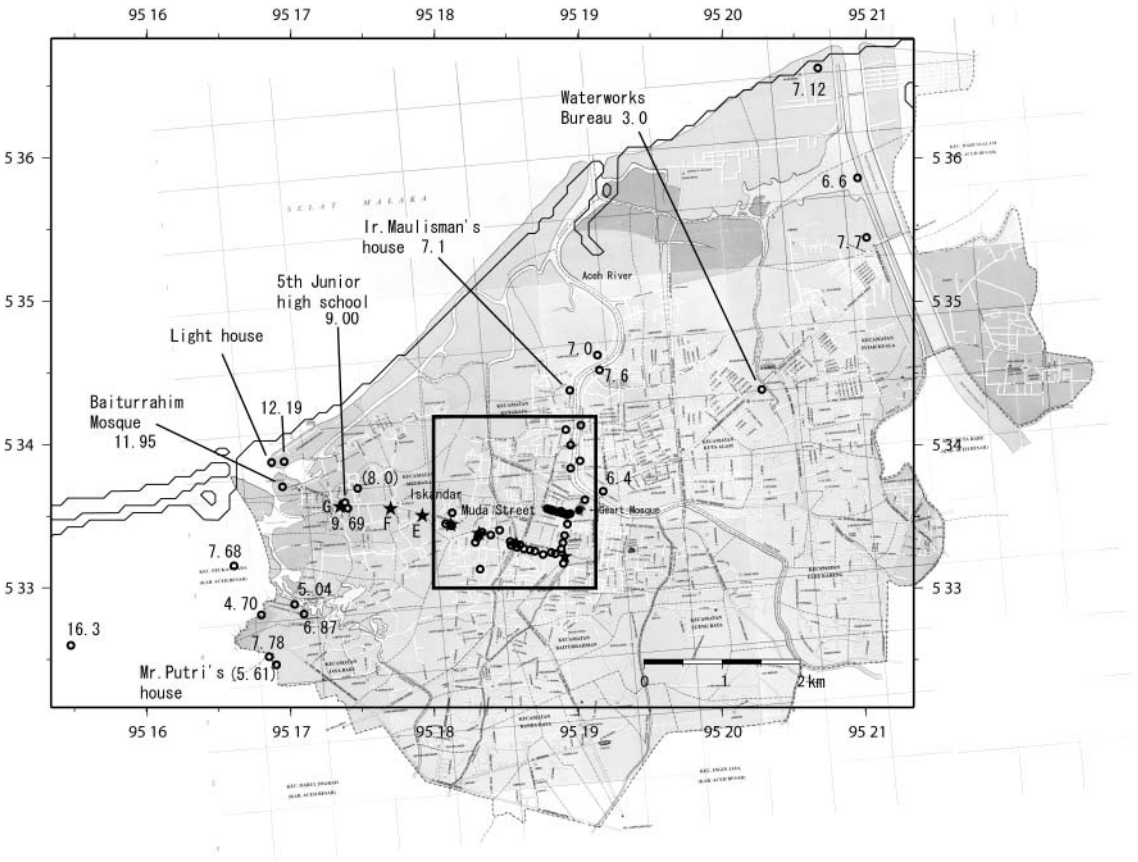

Fig. 8. Distribution of tsunami inundation heights in Banda Aceh. Terms are the same as for **Fig. 7**. The central area covered by the square is given in **Fig. 9**. Stars show benchmarks we set along Jl. Iskandar Muda Street. The dotted line shows the limit of the areas where most houses were swept away, and the solid line shows the inundation limit (after Kompas Press). All data in this figure were obtained by measuring by water marks on walls.

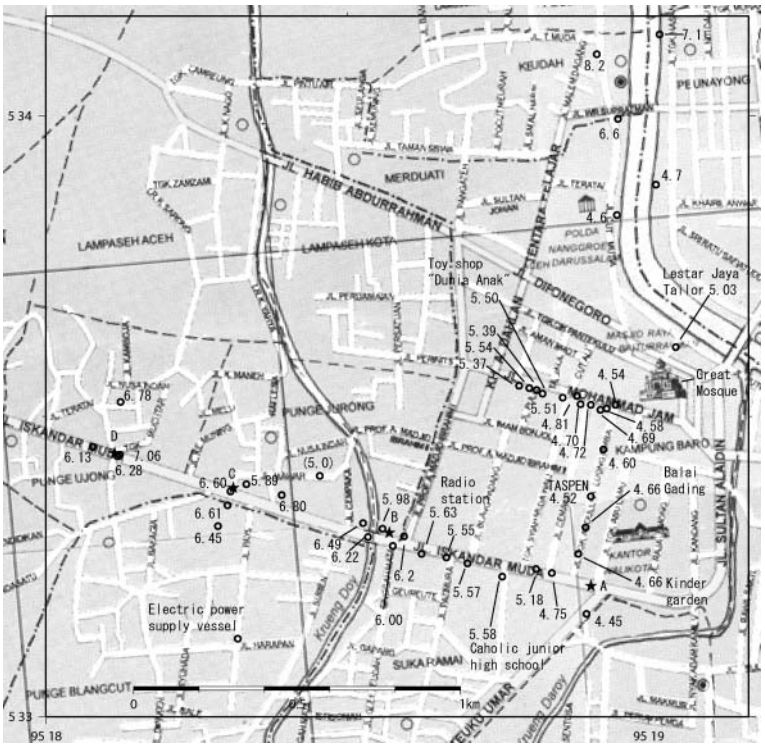

Fig. 9. Detailed map showing the distribution of tsunami inundation heights in central Banda Aceh. All data in this figure were obtained by the measuring of water marks on walls. Terms are the same as for **Fig. 8**.

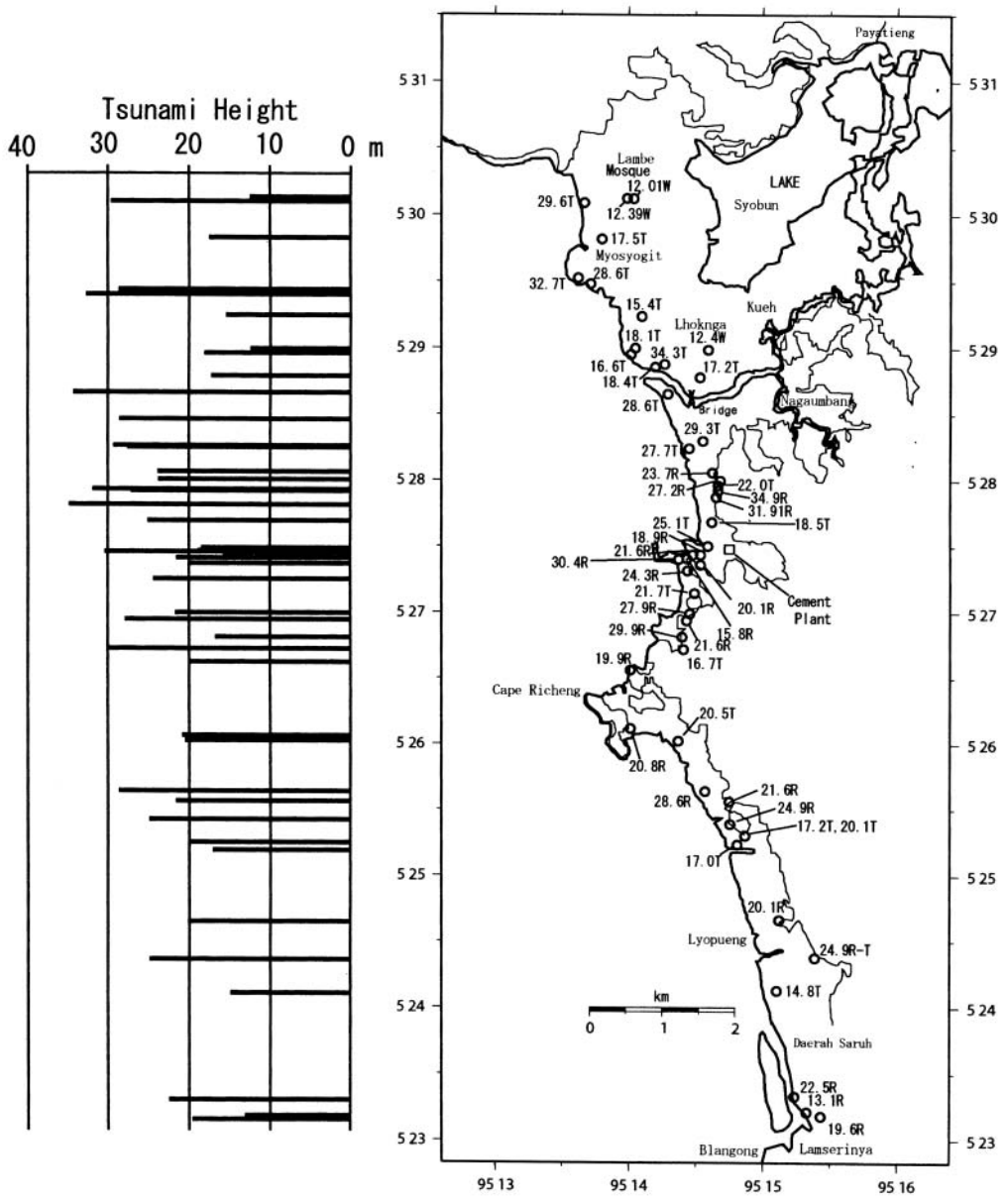

Fig. 10. Distribution of tsunami inundation heights on the west coast. Terms are the same as for **Fig. 7**. The fine line shows the boundary of the eroded (yellow) and non-eroded (green) zones judged on the satellite images.

Outside of Banda Aceh City, measurements were not always limited to water marks. We found items in the following two categories useful for surveying:

(1) broken twigs of a tree or material carried by the tsunami caught on branches of trees
(2) run-up traces on the ground of a slope, erosion traces, accumulations of floating material.

In the tsunami height distribution map, W denotes the height (in meters) obtained by watermark on walls, T traces on trees, and R traces of run-up on a slope. Generally, the accuracy and/or reliability of surveyed results is up to 1 cm for water marks, while that that obtained by traces on trees are not so good – perhaps up to 10 cm or so. The accuracy of heights obtained by run-up traces varies with the case.

To reference height measurement at points outside Banda Aceh City, we used the sea or river height at the survey time. Such values were compensated for the astronomical tide component for each point.

5.2. GPS Compensation

Each subteam used global positioning system (GPS) brought from Tokyo to Indonesia. Japan conventionally used Japan local geographic coordinates called "Tokyo Datum," but this is changing to global coordinates called "**WGS-84 Datum**." We neglected to note the differences in the two sets of geographical coordinates in using our GPS, so all records of positional data are based on "Tokyo Datum." Our results are thus not suitable for GMT mapping programs referencing WGS-84 Datum–the differ-

Fig. 11. Tsunami-eroded valley about 1 km south of the cement plant in Lhoknga Village. Seawater rose to 27.9 m above MSL. The limit of eroded limit on the slope is clear. Compare tsunami inundation height with human height (lower left).

Table 2. Adjustment between Tokyo Datum and WGS-84 Datum.

Sub-Team	Latitude	Longitude
1. Tsuji	+0.35 min	−0.1 min
2. Nishumura	+0.31 min	−0.07 min
3. Matsutomi	+0.36 min(*)	−0.09 min(*)
4. Tanioka	+0.34 min	−0.05 min

(*) The adjustment for subteam 3 should be changed by days. This values are for the first few days.

ence between the two is nearly 1 kilometers for our GPS. Using detailed city maps, satellite images, and several other data sources, we obtained calibration for working between the two. To obtain values in WGS-84 Datum, we should adjust latitude and longitude by the numbers given in **Table 2**.

5.3. Results of Tsunami Inundation Height Survey

Figure 7 shows our total survey area giving tsunami heights for places far from Banda Aceh. Numbers denote tsunami inundation heights in meters, and W, R, and T are explained in the previous section. Originally surveyed tables are given in **Tables 3-6**.

A detailed map of Banda Aceh is shown in **Fig. 8**, and central Banda Aceh is shown in **Fig. 9**. Tsunami heights on the west coast are shown in **Fig. 10**.

6. Conclusions

In the Sumatra Earthquake Tsunami occurring on December 26, 2004 tsunami inundation heights exceeded 30m art several villages on the west coast of Banda Aceh. Not one single resident of these villages survived. In the tsunami-eroded valley in **Fig. 11**, seawater rose to 27.9 m and all vegetation below 25 m was completely swept out to sea. Comparing tsunami erosion height and human height chillingly illustrates the existence of natural hazards that few if any of us will survive. In the Sanriku tsunamis of 1896 and 1933 in Japan, such wiped-out villages stand further testament to this fact.

Acknowledgements

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References:

[1] H. Matsutomi, T. Sakakiyama, S. Nugroho, Y. Tsuji, Y. Tanioka, Y. Nishimura, T. Kamataki, Y. Murakami, M. Matsuyama, and K. Kuritsuka, "Future problems with considering the damage assessment in Banda Aceh city for the 2004 Indian Ocean Tsunami," Bull. Coastal Engineering, Soc. Civil Engineering Japan, 52, pp. 1366-1370, 2005 (in Japanese).

[2] Y. Tsuji, Y. Namegaya, and J. Itoh, "Astronomical Tide Levels along the Coasts of the Indian Ocean," 2005. http://www.eri.u-tokyo.ac.jp/tsunami/sumatera/tide/index.htm

[3] Y. Tsuji, Y. Tanioka, Y. Nishimura, H. Matsutomi, T. Kamataki, T. Sakakiyama, K. Murakami, A. Moore, and G. Gelfenbaum, "Distribution of the Tsunami Heights of the 2004 Sumatera Tsunami in Banda Aceh measured by the Tsunami Survey Team (The Head: Dr. Tsuji)," 2005. http://www.eri.u-tokyo.ac.jp/namegaya/sumatera/surveylog/eindex.htm

[4] H. Matsutomi et al., Journal of Coastal Engineering of Japan, 2005.

Appendix

Tables of tsunami height measurements.

Table 3. Survey by subteam 1 under Yoshinobu Tsuji.

Survey point	Longitude	Latitude	Ground elevation (m)	Measured time/date	Reliability	Note	Tsunami height (m)
Banda Aceh	95°16.944′	5°33.706′		12:30, 21.Jan.	A	Water mark of the 1st wave on a wall of the 2nd floor of Baiturrahim mosque (nearby the green ornament on the ceiling of the 2nd floor).	11.95
Banda Aceh	95°16.944′	5°33.706′		12:30, 21.Jan.	A	Water mark of the 2nd wave on a wall of the 2nd floor of Baiturrahim mosque.	8.35
Banda Aceh	95°17.379′	5°33.595′		16:20, 21.Jan.	A	A spider's web in the Banda Aceh 5th junior high school. The level of 2nd floor from MSL is 5.05m.	9.00
Banda Aceh	95°18.884′	5°33.271′	3.63	22.Jan.	A	Water mark on a wall of Balai Gading	4.66
Banda Aceh	95°18.896′	5°33.315′		22.Jan.	A	Water mark on a wall of kindergarten	4.66
Banda Aceh	95°18.905′	5°33.367′		22.Jan.	A	Water mark on a wall of public agency Taspen Persero	4.52
Banda Aceh	95°18.926′	5°33.445′		22.Jan.	A	Water mark on a wall of the house whose nameplate is "12".	4.60
Banda Aceh	95°18.946′	5°33.519′	2.51	22.Jan.	A	Water mark on a wall of the south gatepost of mosque.	4.54
Banda Aceh	95°18.931′	5°33.513′	2.51	22.Jan.	A	Water mark on a wall of the shop in front of the mosque.	4.58
Banda Aceh	95°18.921′	5°33.511′	2.51	22.Jan.	A	Water mark on a wall of the key shop, Toko Kunci.	4.69
Banda Aceh	95°18.898′	5°33.171′	3.81	22.Jan.	A	Water mark on a wall of a white large round building, PSSI, which stands near large tree close to the clock tower.	4.45
Banda Aceh	95°18.84′	5°33.239′		10:18, 23.Jan.	A	Water mark on a wall of the house with red roof on the street.	4.75
Banda Aceh	95°18.814′	5°33.246′		10:21, 23.Jan.	A	Water mark on a wall of the house with the brown roof on the street.	5.18
Banda Aceh	95°18.758′	5°33.233′	3.40	10:30, 23.Jan.	A	Water mark on a wall of the Catholic junior high school.	5.58
Banda Aceh	95°18.7′	5°33.255′	3.66	10:47, 23.Jan.	A	Water mark on a wall of the house with galvanized iron roof.	5.57
Banda Aceh	95°18.665′	5°33.265′		23.Jan.	A	Water mark on a wall of the house with the red galvanized iron roof.	5.55
Banda Aceh	95°18.624′	5°33.271′	3.22	11:10, 23.Jan.	A	Inundated line of 1st wave on a wall of the radio station.	5.63
Banda Aceh	95°18.624′	5°33.271′	3.22	23.Jan.	A	Water mark of 2nd wave on a wall of the radio station.	4.67
Banda Aceh	95°18.905′	5°33.519′		23.Jan.	A	Water mark on a wall of Kuta Paja Baru which stands at the west side of the kea shop "Toko Kunci".	4.72
Banda Aceh	95°18.888′	5°33.52′	2.39	23.Jan.	A	Water mark on a wall of the shop with blue door.	4.70
Banda Aceh	95°18.882′	5°33.534′	2.39	23.Jan.	A	Water mark on a wall of the southwestern gatepost in the mosque where the famous videos were taken at tsunami	4.81
Banda Aceh	95°18.858′	5°33.531′	2.94	23.Jan.	A	Water mark of the 1st wave on a wall of KANTOR.	5.51
Banda Aceh	95°18.858′	5°33.531′	2.94	23.Jan.	A	Water mark of the 2nd wave on a wall of KANTOR.	4.66
Banda Aceh	95°18.858′	5°33.531′	2.94	23.Jan.	A	Water mark of the 3rd wave on a wall of KANTOR.	3.98
Banda Aceh	95°18.825′	5°33.538′	2.39	23.Jan.	A	Water mark on a wall of the toy shop, Dunia Anak.	5.50
Banda Aceh	95°18.815′	5°33.544′	2.39	23.Jan.	A	Water mark on a wall of the shop with green garage close to a crossing.	5.39
Banda Aceh	95°18.803′	5°33.547′	2.13	23.Jan.	A	Water mark on a wall of the black colored shop.	5.54
Banda Aceh	95°18.786′	5°33.551′	2.13	14:40, 23.Jan.	A	Water mark on a wall of Budi Store.	5.37
Banda Aceh	95°18.576′	5°33.284′	2.57	23.Jan.	A	Water mark of the 1st wave on a wall with garvanaized iron roof which is close to the house with red roof near the bench mark B.	6.00
Banda Aceh	95°18.576′	5°33.284′	2.57	23.Jan.	A	Water mark of 2nd wave on a wall with garvanaized iron roof which is close to the house with red roof near the bench mark B.	4.63
Banda Aceh	95°18.559′	5°33.313′	3.41	23.Jan.	A	Water mark on a wall of the house with white wall.	5.98
Banda Aceh	95°18.527′	5°33.322′	3.93	23.Jan.	A	Water mark on a wall of the shop with black garage,	6.49
Banda Aceh	95°18.535′	5°33.299′	3.90	16:45, 23.Jan.	A	Water mark on a wall of the shop in shopping district, next door to PELANGI.	6.22
Banda Aceh	95°19.046′	5°33.615′	3.90	24.Jan.	A	Water mark on a wall of the shop, Lestar Jaya Tailor, between the Great mosque and north part of river side.	5.03
Banda Aceh	95°18.123′	5°33.436′	2.87	10:45, 24.Jan.	A	Water mark of the 1st wave on a wall of the shop, Sabena, near the Bench Mark D.(★)	7.06
Banda Aceh	95°18.123′	5°33.436′	2.87	24.Jan.	A	Water mark of the 2nd wave on a wall of the shop, Sabena, near the Bench Mark D.	4.36
Banda Aceh	95°18.123′	5°33.436′	2.87	24.Jan.	A	Water mark of the 3rd wave on a wall of the shop, Sabena, near the Bench Mark D.	3.54
Banda Aceh	95°18.119′	5°33.433′	2.89	10:55, 24.Jan.	A	Water mark on a wall of the house next door to the shop of ★.	6.28
Banda Aceh	95°18.078′	5°33.449′	2.82	24.Jan.	A	Water mark of the 1st wave on a wall of the shop with orange wall.	6.13
Banda Aceh	95°18.078′	5°33.449′	2.82	24.Jan.	A	Water mark of the 2nd wave on a wall of the shop with orange wall.	4.42

Banda Aceh	95°18.124′	5°33.524′	1.98	11:30, 24.Jan.	A	Water mark on a wall of the large house.	6.78
Banda Aceh	95°18.307′	5°33.375′	2.85	13:50, 24.Jan.	A	Water mark on a wall of the shop with orange wall which stands at the corner of the shopping street.	6.60
Banda Aceh	95°18.302′	5°33.352′	3.13	24.Jan.	A	Water mark on a wall of the white colored house which stands at south of Bench Mark C.	6.61
Banda Aceh	95°18.286′	5°33.317′	2.63	24.Jan.	A	Water mark on a wall of the magnificent house with the black roof.	6.45
Banda Aceh	95°18.333′	5°33.387′	2.87	24.Jan.	A	Water mark on a wall of Toko, which is next door to USAHA GEUTANYO.	5.89
Banda Aceh	95°18.392′	5°33.369′	2.31	24.Jan.	A	Water mark on a wall of the house with graffiti.	6.80
Banda Aceh	95°18.392′	5°33.369′		24.Jan.	A	Water mark on the opposite wall of the house of the previous house	6.61
Banda Aceh	95°18.455′	5°33.401′		17:05, 24.Jan.	B	A top of the garbage. A lot of garbage is on the house with red roof.	
Banda Aceh	95°17.399′	5°33.556′		18:20, 24.Jan.	C	A scratch on bark of a tree.	
Banda Aceh	95°18.948′	5°33.835′	2.16	10:33, 25.Jan.	B	Water mark on a wall of a restaurant "Asia Utama" by the river.	4.62
Banda Aceh	95°18.95′	5°33.995′	2.85	25.Jan.	B	Water mark on a wall of a shop, Fajar Studio, which is close to the bridge where a ship was stranded.	6.58
Banda Aceh	95°18.915′	5°34.103′	3.33	11:00, 25.Jan.	B	Water mark on a wall of the house with white wall at the crossing of Jl. Malem Dagang and Jl. T. Muda street.	8.22
Banda Aceh	95°18.944′	5°34.378′	2.08	11:25, 25.Jan.	B	Water mark on a wall of Ir. Maulisman's house with brown large roof.	7.07
Banda Aceh	95°19.135′	5°34.625′	1.65	11:45, 25.Jan.	B	Water mark on a wall of a yellow colored house	7.04
Banda Aceh	95°19.174′	5°33.675′	4.80	13:55, 25.Jan.	B	Water mark on a wall of the house close to the rotary south part of Jl. Panglima Polim whose nameplate is "17".	6.36
Banda Aceh	95°19.013′	5°33.886′	2.64	14:10, 25.Jan.	B	Water mark on a wall of the Office BKPMD.	4.74
Banda Aceh	95°19.019′	5°34.136′	2.10	14:25, 25.Jan.	B	Water mark on a wall of a white colored house which is partially destroyed.	7.09
Banda Aceh	95°19.149′	5°34.518′	2.87	14:45, 25.Jan.	B	Water mark on a wall of Hotel Rajawali.	7.59
Lhoknga	95°14.596′	5°28.988′	8.76	10:50, 26.Jan.	B	Water mark on a wall of Julpikar's house with brown roof.	12.42
Lhoknga	95°14.534′	5°28.78′		10:50, 26.Jan.	C	A top of garbage on a large tree. The accuracy is low. (about ±1m)	17.24
Krueng Raya	95°31.46′	5°36.118′	2.02	15:40, 26.Jan.	A	Water mark on a wall of the ferry terminal building	5.10
Banda Aceh	95°21.006′	5°35.443′	3.89	17:00, 26.Jan.	B	Water mark on a wall of the house close to a large river.	7.68
Banda Aceh	95°20.279′	5°34.383′	1.25	17:30, 26.Jan.	B	Water mark on a wall of the Waterworks Bureau.	2.99
West coast	95°14.106′	5°26.617′		10:40, 27.Jan.	A	Wreckage on the slope of a hill, about 1km south of Cement Plant	19.96
West coast	95°14.435′	5°26.94′		11:25, 27.Jan.	A	Wreckage on the slope in the valley of Fig. 11.	27.86
West coast	95°14.705′	5°27.807′		14:40, 27.Jan.	A	Wreckage in the valley of Fig. 5.	34.85
Banda Aceh	95°17.029′	5°32.885′		10:20, 28.Jan.	A	The top of handrail beside the west road. The tsunami wave run over the handrail. The concrete surface of the top of the handrail is 4.04m higher than the sea level at measured.	5.04
Banda Aceh, west	95°17.093′	5°32.816′		10:30, 28.Jan.	A	Evidence a tree by the west road.	6.87
Banda Aceh, west	95°16.797′	5°32.811′		12:00, 28.Jan.	A	A top of the parapet of a bridge	4.70
Banda Aceh, west	95°16.606′	5°33.154′	1.38	11:25, 28.Jan.	A	A bent reinforcing bar on the 2nd floor of a concrete building on the coast.	7.68
Banda Aceh, west	95°16.852′	5°32.519′	3.93	16:50, 28.Jan.	A	Water mark on a wall of a grand house.	7.78
Banda Aceh, west	95°16.869′	5°33.876′		21.Jan.		The position of reinforcing bars on the 1st and 2nd stair of the lighthouse (or monument?) which were destroyed.	
Lhoknga	95°14.518′	5°28.602′		17:30, 23.Jan.		The position of the swept away highway bridge on west coast	
Banda Aceh	95°18.319′	5°33.13′		15:45, 25.Jan.		The position of the electric power supply vessel which was stayed in the residential area.	
3km south of Lhoknga	95°14.535′	5°27.438′		27.Jan.		The position of the cement plant on west coast.	

Table 4. Survey by subteam 2 under Yoichi Nishimura.

Survey point	Longitude	Latitude	Ground elevation (m)	Distance from shore.	Measured time/date	Reliability	Note	Tsunami height (m)
Lhoknga	95°14.452′	5°28.243′		72	10:40, 22.Jan.	A	Broken twig of a tree	27.61
West coast	95°14.667′	5°27.925′		331	15:08, 22.Jan.	A	Broken twig near a high hill.	21.96
West coast	95°14.602′	5°27.48′		111	15:38, 22.Jan.	A	Broken twig near the cement plant.	18.46
West coast	95°14.493′	5°28.058′		10	16:25, 22.Jan.	A	Broken twig of a tree near the stayed tanker in Fig. 6.	23.83
West coast	95°13.667′	5°30.092′		75	10:51, 23.Jan.	A	Torn bark of a tree at the west coast. This point is the most north point of our survey on west coast.	29.63
West coast	95°13.798′	5°29.818′		174	11:45, 23.Jan.	A	Broken twig of a tree	17.50
West coast	95°13.627′	5°29.392′		156	13:55, 23.Jan.	A	Broken twig at the promontory at Myosyogit Village (Fig 10). An this point, 8 trees are remained.	32.67
West coast	95°14.1′	5°29.238′		269	16:24, 23.Jan.	A	Broken twig of a tree near Lhoknga	15.40
West coast	95°14.02′	5°28.953′		60	16:37, 23.Jan.	A	Broken twig of a tree near Lhoknga	18.06
West coast	95°14.478′	5°28.657′		121	17:09, 23.Jan.	A	Wreckage on a twig of a tree. This point is at the right bank of the river south of Lhoknga	34.29
West coast	95°14.57′	5°25.642′		141	11:43, 24.Jan.	B	Eroded surface of cliff on a slope near the shore	28.61
West coast	95°14.373′	5°26.022′		121	12:31, 24.Jan.	A	Broken twig	20.45
West coast	95°14.097′	5°26.062′		160	13:04, 24.Jan.	B	Eroded surface of cliff on the south slope of the peninsula of Cape Richen (see Fig. 10) which the tsunami went over.	20.84
West coast	95°14.41′	5°26.72′		404	14:46, 24.Jan.	B	Eroded surface of cliff on the inner part of the valley where a beach hotel exists.	29.93
West coast	95°14.342′	5°26.805′		74	14:46, 24.Jan.	A	Eroded surface of cliff near the entrance of the valley where the beach hotel exists.	16.74
West coast	95°14.458′	5°26.992′		90	15:14, 24.Jan.	A	Broken twig at the south part of the port of the cement plant	21.67
West coast	95°14.472′	5°27.245′		69	15:30, 24.Jan.	B	Weed on the cliff near the port of the cement plant.	24.35
West coast	95°14.62′	5°27.685′		109	15:52, 24.Jan.	A	Broken twig in the north of the cement plant.	25.08
West coast	95°14.355′	5°28.455′		71	16:30, 24.Jan.	A	Broken twig at the left bank of the river south of Lhoknga	28.59
West coast	95°15.435′	5°23.183′		450 (from the river)	14:04, 27.Jan.	B	Eroded surface of cliff in the south part of the port near Daerah Saruh (Fig. 10)	19.56
West coast	95°15.328′	5°23.213′		50 (from the river)	14:04, 27.Jan.	B	Eroded surface of cliff on the slope along the river nearer the shore than the previous point	13.08
West coast	95°15.237′	5°23.332′		100 (from the river)	14:14, 27.Jan.	B	Eroded surface of cliff on the slope on the sea near the previous two points	22.45
West coast	95°15.108′	5°24.128′		195	15:14, 27.Jan.	A	Weed on a tree in the north part of a port in a river north of Daerah Saruh.	14.83
West coast	95°15.39′	5°24.378′		730	16:39, 27.Jan.	B	Weed on a tree on the cliff in north of the previous point	24.86
Calang	95°38.617′	4°36.39′		250 (from the river)	11:52, 28.Jan.	A	Broken twig on the top of the hill near Calang town.	12.19
Calang	95°38.598′	4°36.358′		250 (from the river)	11:52, 28.Jan.	A	Broken twig on the top of the hill near Calang town	13.94
Calang	95°38.6′	4°36.327′		250 (from the river)	11:52, 28.Jan.	A	Broken twig on the top of the hill near Calang town	14.13

Table 5. Survey by subteam 3 under Hideo Matsutomi.

Survey point	Longitude	Latitude	Ground elevation (m)	Distance from shore	Measured time/date	Reliability	Note	Tsunami height (m)
Ulee Lheue	95°16.956′	5°33.881′		71	12:15, 21.Jan.	A	A piece of twig on the banyan tree.	12.19
Near Bench Mark G	95°17.467′	5°33.693′	1.76		13:05, 21.Jan.	A	Driftwood on a red roof of the house eastern of the junior high school. (Upstream)	9.69
Near Bench Mark G	95°17.467′	5°33.693′	1.76		13:05, 21.Jan.	A	Inundation line on a wall of the previous house (Downstream)	6.68
Kecamatan Jaya Baru	95°16.902′	5°32.465′		2200	16:17, 24.Jan.	A	Driftwood on Putri's white house which was recorded on videotape in tsunami attacking.	
Kecamatan Jaya Baru	95°16.902′	5°32.465′		2200	24.Jan.	A	Inundation line on a wall of the previous house (Downstream)	
Kecamatan Jaya Baru	95°16.902′	5°32.465′		2200	24.Jan.	A	Broken roof of a house with read roof on the opposite side of the previous house	
Left bank of Banjir Kanal Krueng Aceh	95°20.668′	5°36.626′	1.49	58	10:05, 24.Jan.	A	A change of color of leaves on the mouth of the left bank of Banjir Lanal, Krueng Aceh river.	7.12
Sigli	95°57.612′	5°23.356′	1.30	83	12:55, 25.Jan.	A	Water Mark on a wall of a house (Upstream)	4.40
Sigli	95°57.612′	5°23.356′	1.30	93	12:55, 25.Jan.	A	Water mark on a wall of the previous house (Downstream)	3.68
Sigli	95°57.612′	5°23.356′	1.40	108	13:11, 25.Jan.	A	Water mark on a wall of a house (Upstream)	4.42
Sigli	95°57.612′	5°23.356′	1.40	120	13:19, 25.Jan.	A	Water mark on a wall of the previous house (Downstream)	3.89
Sigli	95°57.612′	5°23.356′	1.40	111	13:27, 25.Jan.	A	Water mark on a wall of a house (Upstream)	3.89
Sigli	95°57.612′	5°23.356′	1.40	126	13:30, 25.Jan.	A	Water mark on a wall of the previous house (Downstream)	3.18
Near the oil tank in port Krueng Raya	95°31.500′	5°35.300′		764	11:36, 26.Jan.	A	Runup on a slope near the port Krueng Raya.	6.74
We Island	95°20.837′	5°49.574′		290	16:33, 26.Jan.	A	Garbage on a tree at the south port of Sabang, We Island.	2.81
We Island	95°19.447′	5°52.896′	2.78	67	17:14, 26.Jan.	A	A trace on a schoolhouse on Sabang bay which is in the north part of We Island.	4.22
We Island	95°17.937′	5°50.322′		219	18:21, 26.Jan.	A	Runup on the slope in the west coast of north part of We Island.	6.27
west coast	95°14.038′	5°30.124′		1222	13:35, 27.Jan.	A	Inundation line on a west wall of the mosque of Lambe village (Fig. 10, Upstream)	12.39
west coast	95°14.038′	5°30.124′		1250	13:28, 27.Jan.	A	Inundation line on an east wall of the same mosque (Downstream)	12.01
west coast	95°13.35′	5°30.42′		54	16:12, 27.Jan.	A	Scratch of bark of a tree	16.63
west coast	95°13.57′	5°30.3′		145	16:55, 27.Jan.	A	Scratch of bark of a tree	18.38
west coast	95°14.641′	5°28.253′	3.61	236	11:11, 28.Jan.	A	Scratch of bark of a tree	29.34
west coast	95°14.717′	5°27.998′		181	14:10, 28.Jan.	A	Runup on a hill.	23.74
west coast	95°14.757′	5°27.909′		309	14:32, 28.Jan.	A	Runup on a hill.	27.20
near the cement plant	95°14.545′	5°27.451′		50	15:37, 28.Jan.	A	Runup on the front slope of a small hill whose minor axis is 116m near the cement plant.	30.40
near the cement plant	95°14.606′	5°27.444′		250	15:37, 28.Jan.	A	Runup on the back slope of the small hill mentioned above.	15.77

Table 6. Survey by subteam 4 under Yuichiro Tanioka.

Survey point	Longitude	Latitude	Ground elevation (m)	Distance from shore	Measured time/date	Reliability	Note	Tsunami height (m)
Banda Aceh	95°18.595′	5°33.3′	3.40		22.Jan.	B	Water mark on a wall of a house beside the Bench Mark G.	6.23
west coast	95°14.567′	5°27.458′			10:57, 24.Jan.	B	Back side of the peninsula where a ship was overthrown.	18.87
west coast	95°14.507′	5°27.405′			11:16, 24.Jan.	B	Front side of the port of the cement plant.	21.56
west coast	95°14.535′	5°27.362′			11:45, 24.Jan.	B	Hill in the south east of a peninsula.	20.07
west coast	95°14.697′	5°27.925′			14:25, 24.Jan.	B	Runup on a slope	31.91
west coast	95°13.637′	5°29.432′			16:57, 24.Jan.	B	Twig of a remained tree	28.64
Sigli	95°58.032′	5°23.392′	1.12		11:35, 25.Jan.	A	Water mark on a wall of the left bank of river of Lhoknga (about 500m from sea).	4.07
Sigli	95°58.032′	5°23.392′	1.46		11:45, 25.Jan.	A	Water mark on a wall of the house beside the previous point	4.82
Sigli	95°57.907′	5°23.452′	1.55		13:07, 25.Jan.	A	water mark on a wall near the river of Lhoknga (the right bank)	4.24
Port Krueng Raya	95°31.552′	5°36.027′	2.31	244	17:50, 25.Jan.	A	Water mark on a wall of a house 244m away from port	5.92
west coast	95°15.215′	5°24.663′		486	13:10, 27.Jan.	B	The southward of the west coast of Banda Aceh (Point A)	20.13
west coast	95°14.87′	5°25.198′		65	14:01, 27.Jan.	B	A root on a roof 500m north from the point A	17.04
west coast	95°14.92′	5°25.258′		226	14:40, 27.Jan.	B	A bouy on a tree back side (land side) of the point A	17.25
west coast	95°14.92′	5°25.258′		226	14:40, 27.Jan.	B	Back side (land side) of the previous point	20.08
west coast	95°14.803′	5°25.428′		143	15:16, 27.Jan.	B	200m north from the previous point	24.86
west coast	95°14.853′	5°25.568′		463	15:16, 27.Jan.	B	About 20m north from the previous point	21.57
west coast	95°15.473′	5°32.6′		848	12:51, 28.Jan.	B	Runup height on the hill northwestern part of Banda Aceh city	16.31
Banda Aceh, east	95°20.945′	5°35.86′	2.41		16:30, 28.Jan.	C	A broken twig on the mouth of Krueng Chet river	6.58

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Selected Publications:

Y. Tsuji and Y. Nagata, “Stokes expansion of internal deep water waves to the fifth order,” J. Oceanogr. Soc. Japan, Vol.29, pp. 61-69, 1973.

Y. Tsuji, T. Yanuma, I. Murata, and C. Fujiwara, “Tsunami Ascending Rivers as an Undular Bore,” Natural Hazards, Vol.4, pp. 257-266, 1991.

Y. Tsuji, H. Matsutomi, F. Imamura, M. Takeo, Y. Kawata, M. Matsuyama, T. Takahashi, Sunarjo, and P. Harjadi, “Damage to coastal Village due to the 1992 Flores Island Earthquake Tsunami,” PAGEOPH, Vol.144, 3/4, pp. 481-524, 1995.

Y. Tsuji, F. Imamura, H. Matsutomi, C. E. Synolakis, P. Nanang, Jumadi, S. Harada, S. S. Han, K. Arai, and B. Cook, “Field Survey of the East Java Earthquake Tsunami of June 3, 1994,” PAGEOPH, Vol.144, 3/4, pp. 839-854, 1995.

Y. Tsuji, Y. Namegaya, H. Matsumoto, S. I. Iwasaki, W. Kambua, M. Sriwichai, and V. Meesuk, “The 2004 Indian Tsunami in Thailand: Surveyed runup heights and tide gauge records,” Earth Planets Space, Vol.58, pp. 223-232, 2006.

Academic Societies & Scientific Organizations:

The Oceanographic Society of Japan
The Seismological Society of Japan
The Japanese Society of Study on Historical Earthquakes (President)
The Volcanological Society of Japan