STUDY ON TSUNAMI NUMERICAL MODELING FOR MAKING TSUNAMI HAZARD MAPS IN INDONESIA

Athanasius Cipta* **Supervisor: Fumihiko IMAMURA****
MEE07172

ABSTRACT

Five source models along west coast of Sumatra and one for the south coast of Java were conducted for tsunami simulations. Based on those results, waveform characteristics were analyzed. We chose the west coast of Sumatra for waveform analysis because the coast has variation in water depth, morphology and shoreline shape.

For making tsunami hazard map, we chose source parameters from the 2006 south Java tsunami event. The target area is Pangandaran Peninsula, one of the most damaged areas attacked by the 2006 event. We will compare the simulation results with the field survey results by Kongko et al. (2006). We want to know how appropriate the simulation results are for the tsunami earthquake event.

To simulate near field tsunami propagation, numerical modeling was used. We considered nested areas, in limited area around Padang (Sumatra cases) and Pangandaran (Java case). From simulations, we got results such as tsunami waveforms, run-ups, tsunami heights and inundations. Based on these results, field surveys, and some pictures taken from AMS (American Marine Survey) and Google Earth, we made tsunami hazard maps.

Keywords: Tsunami, Simulation, Inundation, Hazard Map.

INTRODUCTION

The northern Sumatra and the south coast of Java Island were hit by tsunamis which led to wave run-ups and landward inundations. The devastation at any particular location is caused by a function of the velocity, acceleration, and elevation of the water as it interacts with natural and man-made coastal objects. Clear understanding of tsunami wave behavior is indispensable to tsunami hazard assessment. Decisions affecting human safety require systematic methods for evaluating the tsunami events.

DATA AND METHOD OF COMPUTATION

Bathymetry and Topography Data

Bathymetric and topographic spatial data are the basic data for tsunami simulation, as we know tsunami wave propagates over the sea bathymetry and when tsunami wave inundates inland, floods over land topography.

For Sumatra cases, we used GEBCO (GEneral Bathymetric Chart of the Ocean) 1 arc min bathymetry for region1, nautical chart 20 arc seconds for region 2 and nautical chart 5 arc seconds for region 3. SRTM (Shuttle Radar Topographic Mission) is also used for topographic data in region 3.

For Java case, GEBCO is used for both of the bathymetric and topographic data. We used 1 arc min grid size of bathymetry and topography for region 1 and grid size of 15 arc seconds for region 2.

---

[*]Volcanological Survey of Indonesia
[**] Professor, Disaster Control Research Center, Tohoku University, Japan.

Tsunami Simulation

Tsunami simulation is recognized to be an essential tool to explain the observations and records of a tsunami (tsunami heights, travel times etc.), and to assess tsunami hazard, vulnerability and risk. Tsunami simulation can be used to provide tsunami assessment and prediction of arrival times, expected wave amplitude and coastal effects.

For these purposes we use tsunami simulation program named TUNAMI code, developed by Tohoku University (Imamura et al., 2006; Koshimura, 2008) and the Boussinesq approximation model. Cartesian coordinate system will be used in numerical simulation and the shallow water theory with bottom friction in the near-shore region in which water depth is shallower than 50 m (Nagano et al. 1991).

The most popular stability criterion is Courant-Friedrich-Levy number (C.F.L. condition) which states that the time step must be smaller than the time it takes for a wave to propagate from one grid point to the next. Spatial and temporal grid sizes are set to satisfy this stability condition in the numerical computation to avoid instability results.

The fault size parameter such as length, width, and slip amount (dislocation) can be determined by using scaling law theory for dip-slip fault in subduction region (Papazachos et al., 2004). Scaling law is useful for calculating fault parameters which is controlled by magnitude (Mw).

For Sumatra cases, we assumed four sources at 102.1°E and 6.39°S (fault 0), 100.25°E and 4.25°S (fault 1), 98.48°E and 2.14°S (fault 2), 96.71°E and 0.03°S (fault 3). All the cases have parameters: Mw 9.0, fault length 575.44 km, fault width 144.54 km, slip 2.5 m, top depth of fault 10 km, strike 320°, dip 10° and rake 12°. Fault 4 is assumed at 100.0°E and 1.0°S with the fault parameters: Mw 8.5, fault length 300 km, fault width 79 km, slip 6.0 m, top depth of fault 10 km, strike 320°, dip 10° and rake 12°, although the fault 4 is not a realistic case and only for simulation. Tsunami propagation was calculated for 24 assumed tide gauge (TG) stations as outpoints along the west coast of Sumatra. Tsunami sources from fault 2 and fault 3 are used because of the biggest effects to Padang City (target area) and Mentawai Islands, off Padang shoreline.

For Java case, we assumed an earthquake source at 107.82°E and 10.285°S, Mw 7.7, fault length 80.9 km, fault width 40 km, slip 2.5 m, depth of fault 20 km, strike 289°, dip 10° and rake 95° (Yukselme, 2006). Tsunami propagation was calculated for 13 assumed TG stations, along the affected area by the 2006 South Java tsunami.

RESULT AND DISCUSSION

Sumatra Cases

Tsunami Wave and Water Depth

Figure 1 shows the location of TGs and assumed faults. Each TG is located at the different depth that will affect to calculated tsunami waveform.

In the shallow sea, amplitude of tsunami wave is getting higher, wavelength and celerity are decreasing. Figure 2 right (shallow water) shows that amplitude is higher than in Figure 2 left (deep sea). These oscillations are the result of reflection. Padang TG is located inside the channel, between mainland and islands arc west of Sumatra, tsunami wave that goes inside the channel approaches mainland and is trapped inside the channel. Direct wave resonances with reflected wave, second reflected and so on. In this case shoreline acts as wave reflector.

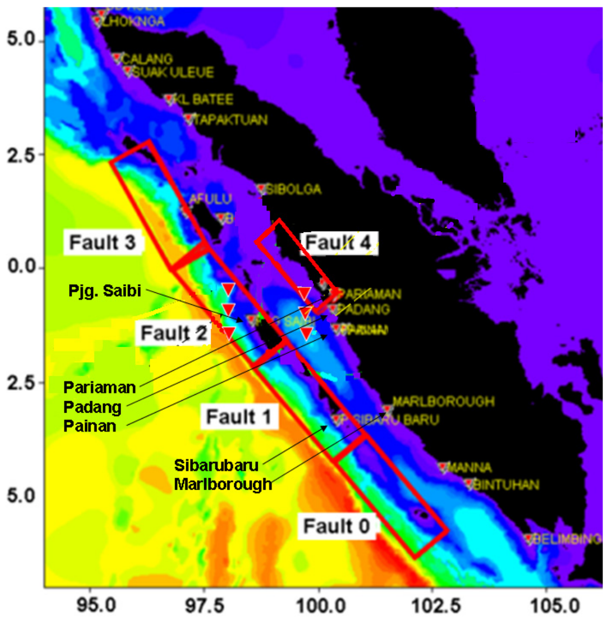

Figure 1. Location of the assumed faults.

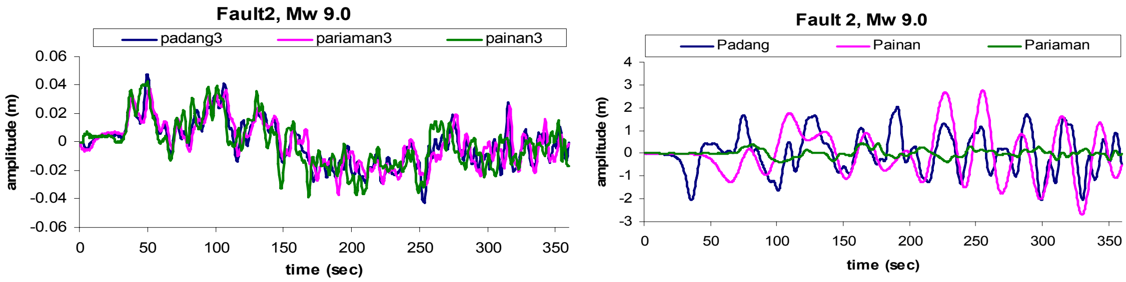

Figure 2. Tsunami waveforms affected by water depths, calculated at Padang, Painan and Pariaman TGs.

Tsunami Wave and Seafloor Morphology

Figure 3 shows different tsunami waveforms, affected by seafloor variation. Sibarubaru TG is facing to the open sea and located at shallow water. This conditions cause tsunami wave has higher amplitude and shorter period. The first incoming tsunami wave was not the maximum tsunami, the maximum one came later. The amplitude and period of tsunami wave changed after 225 min and amplitude became lower and period became shorter. After 275 min, amplitude and period increased and tsunami wave reached the maximum in height. The complexity of seafloor morphology causes oscillation wave, amplitude change and period change.

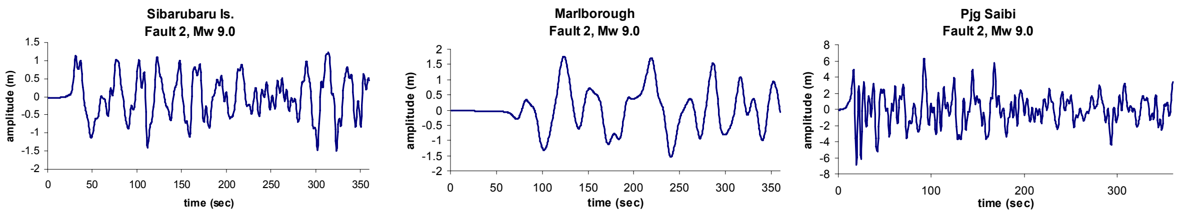

Figure 3 Tsunami waveforms calculated at Sibarubaru Island, Marlborough and Pjg. Saibi.

Sibarubaru is located at the southernmost of this passage, facing directly to the open sea and Marlborough is located at the southernmost of the passage (Figure 4). Tsunami wave hits Sibarubaru and rapidly attenuates. After 150 min, amplitude of tsunami wave becomes lower and lower. Marlborough TG shows that wave periods changes by time, from 100 to 150 min period is larger than before. After 150 min, period becomes smaller and increases again after 250 min. First tsunami wave went inside passage, hit Sumatra Island, reflected and resonance with next incoming tsunami wave. Amplitude of tsunami wave does not attenuate rapidly because tsunami wave is trapped inside the passage.

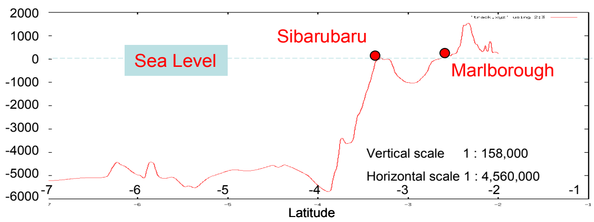

Figure 4 Cross section Sibarubaru-Marlborough, passage between Sibarubaru and Marlborough.

In front of Pjg. Saibi TG, there are 2 sea ridges, both on the right and left side, form a passage, hereupon, tsunami wave is concentrated in this passage and propagate to Pjg. Saibi. After 150 min, tsunami wave amplitude tends to decrease and becomes lower gradually.

Tsunami Wave and Shoreline Shape

Maximum tsunami height varies depending on the location of each TG. Different location gives different result as shown in Figure 5. In Padang, tsunami wave amplitude was slightly lower than in Pariaman and Painan because Padang TG is located at the straight coast line, although Pariaman is located at straight coastline but at the shallower water than Padang TG.

Maximum tsunami heights in Pariaman and Painan do not show significant difference even though these cities are located in different shoreline shapes. Pariaman is located in straight shoreline and Painan is located inside the shallow circular bay. Even Painan is located inside the bay, but tsunami wave did not concentrate in this bay because this bay is too wide and beach slope is too steep.

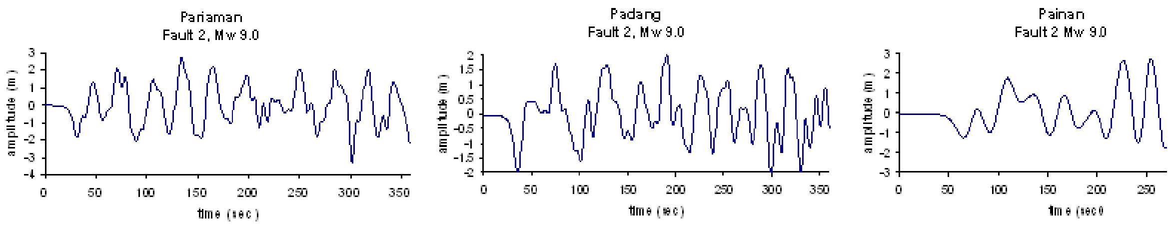

Figure 5. Tsunami waveforms calculated in Pariaman, Padang and Painan TGs.

Tsunami Wave and Location of Fault

Tsunami wave calculated in Afulu TG has very high amplitude for fault 3 case. One of the reasons is that the position of earthquake source is located parallel to Afulu, and tsunami wave propagated from south to the north, then many times tsunami waves reflected on beach of Sumatra, reflected wave resonance with later incoming wave and produced higher amplitude wave. Figure 6 shows that maximum tsunami height came later and tsunami wave did not attenuate rapidly.

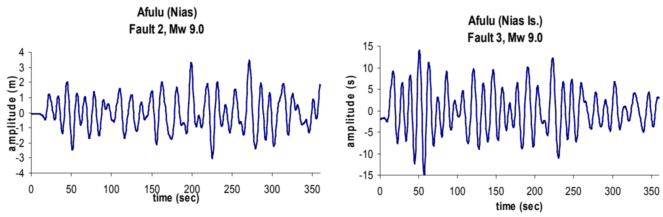

Figure 6. Tsunami waveform recorded in Afulu TG.

Tsunami wave has short period because it propagated in shallow water. Tsunami wave did not attenuate rapidly because the reflected wave came, reflected and came again and sometimes made resonance with later incoming wave

Java Case

Tsunami Travel Time

Tsunami travel time (Figure 7) is time between earthquake occurrence time and tsunami wave arrival time. The shorter the tsunami arrival time, the nearer the coastal area, many evacuation facilities should be built. Tsunami travel time is important also for people to decide to evacuate themselves as soon as possible.

Tsunami wave hit Pangandaran about 30 min after the earthquake occurred. If tsunami early warning was issued 5 min after the earthquake, it would mean that people near coastal area have only 25 min for evacuation.

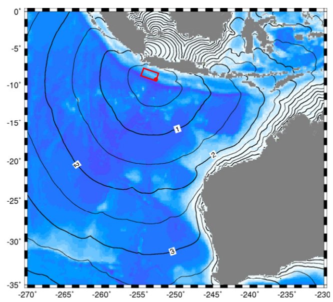

Figure 7. Tsunami travel time.

Inundation Area

Naturally, inundation area breadth is controlled by tsunami height, force of tsunami, inland morphology, and stream pattern. Variation of feature of earth surface gives various possibilities for inundation.

The coastal areas are lying below the mean waterline due to its down sloping characteristics. Furthermore, the back water system is generally running parallel to the shoreline and the coastal areas are like a narrow lane of land (barrier beach) lying between the backwater and sea. This condition caused tsunami inundated farer and wider inland because tsunami wave inundated through streamline.

Maximum Inundation Height

Maximum inundation height is controlled by shoreline shape and beach slope. Figure 9 and 10 show maximum inundation heights. Maximum inundation height got up to 1.32 m in Nusa Kambangan that is located perpendicular to the fault length.

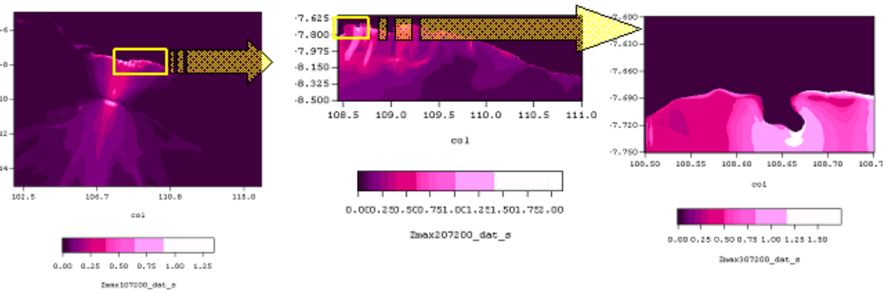

Figure 9. Maximum inundation heights.

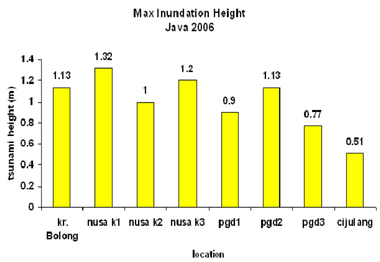

Figure 10. Inundation heights at several villages.

Tsunami Hazard Map

Tsunami hazard map contains information about damages of tsunami, affected area, emergency information, other information and graph, depend on purpose.

In tsunami hazard map, we put some important area that may be inundated, like business center, airport and area with special feature that could be flooded by tsunami wave higher than other area. We also put tsunami waveform and tsunami height in some TGs. Based on simulation data such as, waveform, travel time, inundation height, and another data, such as survey data, photograph, map image, we can make tsunami hazard map (Figure 11).

Some pictures in Pangandaran tsunami hazard map (Figure 11) show interesting places that were attacked by the 2006 tsunami. Pangandaran coast, the most valuable tourism destination in West Java Province is the interesting place that was attacked by tsunamis twice in last hundred years (Tedy Eka Putra, LIPI, personal communication). Based on field survey (Kongko et al., 2006), 2 tsunami deposit layers are found in Cikembulan Village, Pangandaran.

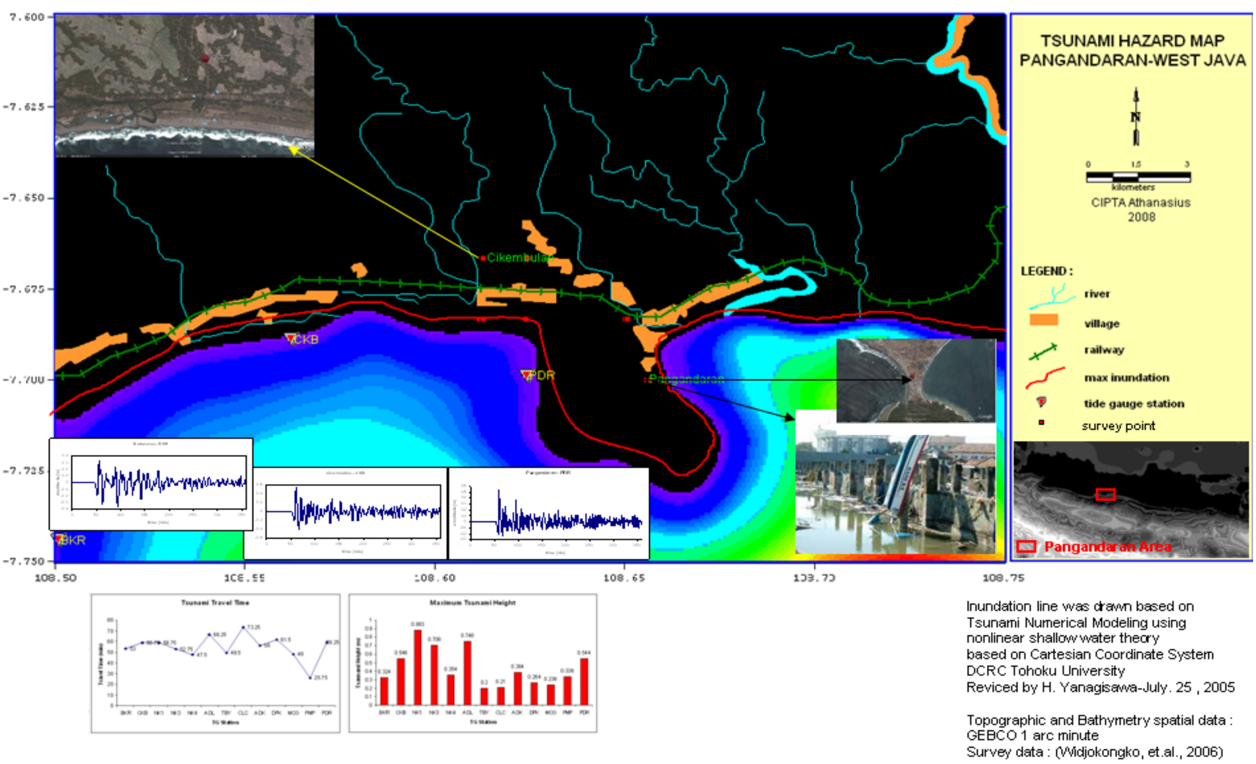

Figure 11. Example of tsunami hazard map, Pangandaran area, West Java Province.

CONCLUSION

In this study non-linear theory model based on nested grid system computations of tsunami propagation is conducted. The precise and finer (< 3 arc seconds) bathymetry and topography data are important as basic input for simulation, especially for complicated shoreline shape.

Tsunami height at tide gauge stations, tsunami travel time, inundation height and inundation area are some of many factors to be considered in making tsunami hazard map. Tsunami hazard map is the first step in effort to minimize tsunami disaster.

FUTURE WORKS

There are still broad possibilities to improve tsunami simulation based on the nested grid system technique in this paper. The important things to be done in the future are:

- Improvement of computed results for tsunami travel times, tsunami heights and inundation heights in the model, the detailed and accurate bathymetry data is essential for tsunami numerical computation.
- Improvement of modeling by using more accurate and effective input source parameters.
- Topography data should be concerned in the numerical computation where interaction with the structure as well as vegetation or buildings should be taken into consideration in calculation of tsunami coastal effect.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to advisor Dr. Y. Fujii of IISEE, BRI for continuous support, valuable suggestion and guidance during study.

REFERENCES

Imamura, F., et al., 2006, Tsunami Modelling Manual (TUNAMI model).

Mofjeld H.O., 2000, Analytic Theory of Tsunami Wave Scattering in the Open Ocean with Application to the North Pacific, NOAA Technical Memorandum OAR PMEL-116.

Kongko, W., et al., 2006, Rapid Survey On Tsunami Jawa 17 July 2006, BPDP-BPPT & ITS.

Koshimura, S., 2008, Lecture Note on Theory of Tsunami Propagation and Inundation Simulation, IISEE/BRI.

Nagano, O., et al., 1991, Natural Hazards 4, 235-255.

Papazachos B.C., et al., 2004, Bulletin of the Geological Society of Greece vol. XXXVI, 2004, Proceedings of the 10th International Congress, Thessaloniki.

Yukselme D., 2006, July 17, 2006 Indonesia Java Tsunami, Middle East Technical University, Civil Engineering Department, Ocean Engineering Research Center, Ankara.