# QUICK FORECASTING OF TSUNAMI IN BALI AND NUSA TENGGARA REGIONS, BASED ON THE TSUNAMI DATABASE SYSTEM

**Titi HANDAYANI*** **Supervisor: Yushiro FUJII****
**MEE08174**

## ABSTRACT

Tsunami database in Bali and Nusa Tenggara regions, Indonesia has been created in this study. Two types of bathymetry grids were applied for tsunami simulations, namely finer mesh grid and coarse mesh grid. The intervals of finer and coarse mesh grids are 20 arc-second (~616.67 m) and one arc-minute (~1850 m), respectively. The 1977 Sumbawa earthquake was adopted as a real case study. We compared the simulation results from the both grids in order to investigate the effective way to create a tsunami database. The coarse mesh grid will be used for tsunami simulations of hypothetic earthquakes to construct the tsunami database. We located 21 source points (SP) along the trench axis, surrounding the real case of the 1977 Sumbawa earthquake, with three magnitudes (M 7.0, 7.5 and 8.0) and four depths (0, 20, 40 and 60 km) set for tsunami simulations, in total 252 hypothetic cases. We located 38 coastal points (CP) and 38 forecast points (FP) as target points. We estimated maximum tsunami heights at CPs by applying Green's law to those at FPs. Inverse refraction diagram was used to obtain tsunami arrival times at CPs.

Three kinds of method to retrieve values from the database were applied in this study, namely interpolation methods for epicenter location, magnitude and depth; extrapolation methods for magnitude and depth; and maximum risk methods. Those methods are very useful to pick up data from the database, which are used for issuing tsunami warning. The comparison of tsunami heights from the direct simulation and the retrieved values from the database shows a good agreement for the real case.

**Keywords:** Tsunami Database, Numerical Tsunami Simulation, Green's law.

## 1. INTRODUCTION

Indonesia has a lot of tsunami experiences, almost every 2 years we suffered from an attack of tsunami generated by earthquake. To save many lives from the tsunami impact, Indonesia has an ultimate goal of establishing Indonesia Tsunami Early Warning System (InaTEWS) issuing warning within 5 minutes after an occurrence of earthquake. In order to quickly issue tsunami warning a tsunami database system is necessary. In this study, we create a tsunami database and confirm that database will be applicable to future earthquakes.

## 2. THEORY AND METHODOLOGY

### 2.1. Bathymetry Data

We used GEBCO (The General Bathymetric Chart of the Ocean) 1 arc-minute (~1850 m) bathymetry data to construct the tsunami database. This bathymetry data is processed for calculating tsunami travel times and tsunami heights.

*Meteorological, Climatological and Geophysical Agency (BMKG), Indonesia.
**International Institute of Seismology and Earthquake Engineering, Building Research Institute, Japan.

### 2.2. Scaling Law

The length, width and slip amount of fault plane are determined from empirical formula of scaling law (Utsu et al., 2001), from magnitude of the earthquake, which can be expressed as follows

$$\begin{aligned} LogL &= 0.5M - 1.8 \\ LogW &= 0.5M - 2.1 \\ W &= \frac{L}{2} \\ LogD &= 0.5M - 3.3 \end{aligned} \tag{1}$$

where $L$, $W$, $M$ and $D$ are fault length (km), width (km), magnitude and slip amount (m) of fault, respectively.

### 2.3. Numerical Simulation of Tsunami Propagation

We performed tsunami simulations by using TUNAMI-N2 (Tohoku University's Numerical Analysis Model for Investigation of Near-field tsunamis No.2) with the staggered leap-frog scheme which is applied to shallow water theory in shallow and deep seas for investigating near field tsunami (Imamura et al., 2006).

### 2.4. Tsunami Simulation for Real Case of the 1977 Sumbawa Earthquake

To investigate the effective way to perform tsunami simulation, we used fine mesh (20 arc-second ~616.67 m) and compared it with coarse mesh (1 arc-minute ~1850 m) for the real case of the 1977 Sumbawa earthquake (Mw 8.3) which is located at 11.14° S and 118.23° E with depth of 23.3 km as shown in Figure 2. First, we set 38 coastal points (CP) along coastal lines at minimum sea depth of 1 m and 38 forecast points (FP) just seaward of coastal points at sea depth of 50 m based on bathymetry contour. The total number is 76 for output points in tsunami numerical simulation.

The setting of fault parameters for the real case is based on the Global (Harvard) CMT catalog, the strike angle of 260° which is parallel to the trench axis, dip angle of 24° and slip (rake) angle of -73°, represented as a normal fault. The length of the fault of 223.872 km, width of 111.936 km and slip amount of 7.08 m were determined by the scaling law using equation (1). We obtained detail of tsunami heights at each coastal area (blue rectangle) by pairing 1 coastal point and 1 forecast point.

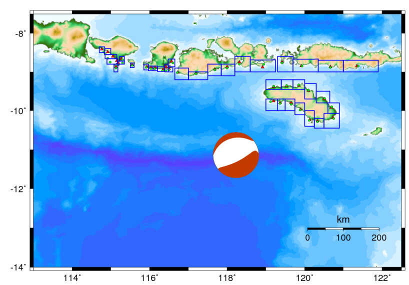


Figure 1. The location and focal mechanism of the 1977 Sumbawa earthquake (Mw 8.3). Red triangles and green circles denote coastal and forecast points, respectively.

### 2.5. Green's Law Application

When tsunami reaches the coast, the calculation is not applicable if we are still using a coarse mesh grid. Therefore, to estimate tsunami heights at the coast, Green's law (energy conservation law) is applied. The equation of Green's law is as follows

$$H = \sqrt[4]{\frac{h_1}{h}} H_1 \tag{2}$$

where $H$ and $H_1$ are tsunami height at the coastal and forecast point and $h$ and $h_1$ are sea depth at coastal and forecast point, respectively (Kamigaichi, 2009).

## 2.6. Construction of Tsunami Database

We assume that an earthquake is a pure reverse fault for database creation. The reverse fault could generate severe tsunami with slip angle of 90°, dip angle of 45° and strike angle parallel to the trench axis. We used coarse mesh grid (1 arc-minute ~1850 m) for tsunami simulations. We divided the region into 19 coastal blocks for issuing tsunami warning purpose (Figure 2). Each coastal block is defined by taking into account the administrative district of local government, in which one coastal block corresponds to one prefecture. Especially for two coastal blocks of the Sumba Island whose the locations are opposite with each other, that condition could be a problem for issuing tsunami warning. Because location of coastal blocks facing the source points will be affected by tsunami with higher amplitude than the opposite side. Therefore in this case we divided them into 2 sub coastal blocks.

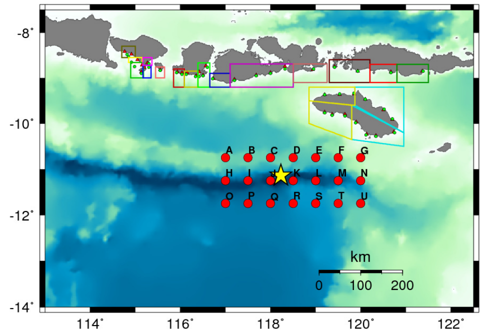

Figure 2. Source points (red circles) and coastal blocks (rectangles). Yellow star denotes the 1977 Sumbawa earthquake (Mw 8.3).

We set 21 Source Points (SP) along the trench axis, surrounding the real case of the 1977 Sumbawa earthquake with three magnitudes (M 7.0, 7.5 and 8.0) and four depths (0, 20, 40 and 60 km) set for tsunami simulations (see Figure 2). Each source point is located on the grid with distance interval of 30 arc-minutes (~55.5 km). The dimension of computation area is 570 grid-points for longitude and 390 grid-points for latitude which covers the region from 113°E – 122.5°E in longitude and 7.5°S – 14°S in latitude. The time step was set to 3 s which satisfy the Courant Friedrics Lewy (CFL) stability condition. The calculation time was set to 3 hours. The deformation area on the ocean bottom is computed for each fault by using the elastic dislocation theory (Okada, 1985). Deformation area of source point C with magnitude 8.0, depth of 0 km, fault length of 158.489 km, width of 79.245 km and slip amount of 5.01 m, which were determined by the scaling law using equation (1), is shown in Figure 3.

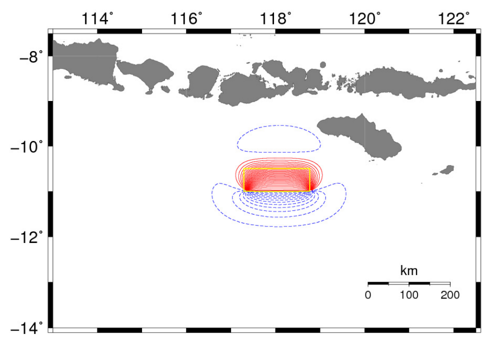

Figure 3. Deformation area of source point C with magnitude 8.0, depth of 0 km. The red contours show uplift area with contour interval of 0.1 m, blue contours show subsidence area with contour interval of 0.05 m.

## 2.7. Inverse Refraction Diagram to obtain Tsunami Travel Time (TTT)

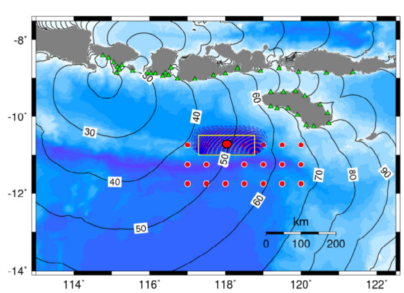

Figure 4. Inverse refraction diagram from a coastal point to the source points.

We used TTT Software Package (ver. 2.21) which is provided by NGDC (National Geophysical Data Center) and ITIC (International Tsunami Information Center) to calculate inverse refraction diagrams. In this software we can calculate tsunami travel times on all the geographic latitude and longitude grid points using Huygen's principle. Figure 4 shows inverse refraction diagram from a coastal point to the source points. The tsunami arrival time is obtained as a minimum value within the travel times from the grid points inside the deformation area to the coastal point. All results from inverse refraction diagrams will be stored into a database as tsunami arrival times at coastal points.

### 2.8. Retrieve Values from the Tsunami Database

Three kinds of method to retrieve values from the database were applied in this study, namely interpolation methods for epicenter location, magnitude and depth; extrapolation methods for magnitude and depth; and maximum risk methods (JMA, 2007). Those methods are very useful to pick up data which is already prepared in the database and will give recommendation for issuing tsunami warning at each coastal block. The data points surrounding the supposed hypocenter are used with interpolation methods of epicenter location, magnitude and depth. Extrapolation method is applied if no data is available in database such as lower and upper magnitude. The maximum risk methods 1 and 2 are applied by using circle and rectangle area, respectively, for target searching as the database output. In order to test these methods, we used the magnitude and depth of the real case, the 1977 Sumbawa earthquake.

## 3. RESULTS AND DISCUSSION

### 3.1. Tsunami Simulation for Real Case of the 1977 Sumbawa Earthquake using Finer Mesh

In tsunami simulation of the 1977 Sumbawa earthquake, we compared the result of tsunami heights by the finer mesh and the coarse mesh and found that mean and median of tsunami heights with finer mesh are higher than ones with coarse mesh at most areas. The tsunami heights at forecast points applying Green's law generally agree with the range of minimum and maximum tsunami heights of finer mesh at coastal areas (Figure 5). In some areas, however, tsunami heights at coastal points using the finer mesh were lower than using the coarse mesh. These may be because the complexity of bathymetry data caused difficulty of selecting coastal and forecast points as output points. Based on these results and examined computation times for both grids, we decided to use coarse mesh grid and apply Green's law for constructing a tsunami database.

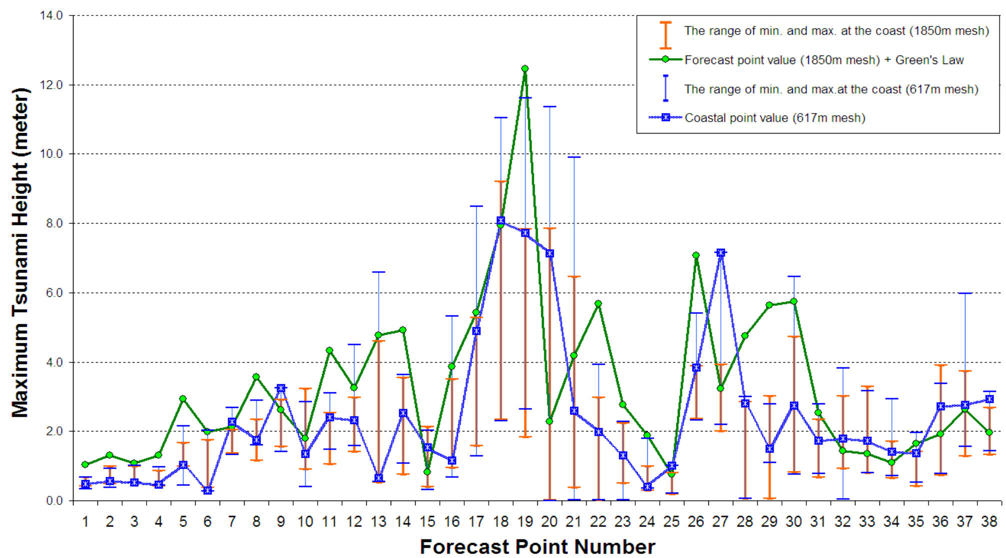


Figure 5. Comparison of tsunami heights by using finer mesh and coarse mesh.

### 3.2. Construction of Tsunami Database

After we completed the tsunami simulations for 252 cases, we calculated the maximum tsunami heights of forecast points applying Green's law, equation (2). Figure 6 shows comparison of tsunami heights at coastal points and those from Green's law application for source point E with magnitude 8.0 and different depths.

We found that tsunami heights at the coastal points get higher as depth becomes shallower. Tsunami heights at coastal points which were obtained from application of Green's law calculations showed higher values than the results obtained directly from tsunami numerical simulation for most cases.

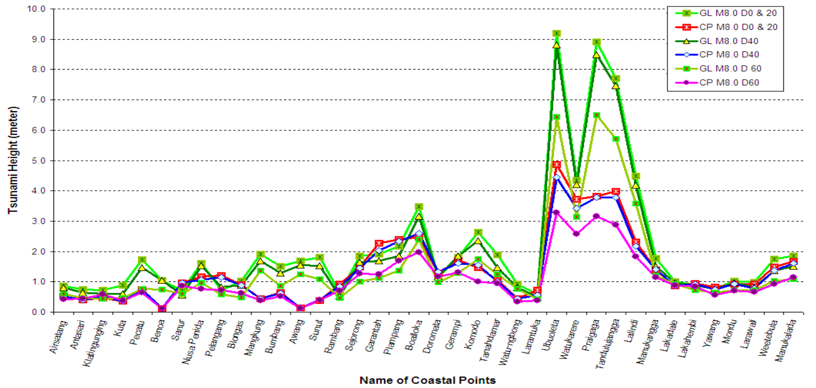


Figure 6. Tsunami heights of Green's law calculation at coastal points.

### 3.3. Retrieving Values from Tsunami Database

The results of maximum risk methods 1 and 2 for the real case are shown in Figure 7. Before we applied the maximum risk methods, first we interpolated the location and depth as shown in blue line. Then we extrapolated of the magnitude as shown in purple line. All source points inside the target area will be searched to find the highest value as the database outputs.

For maximum risk method 1, we calculated half length of the fault (~111.936 km) which is determined from the scaling law, equation (1), and then the maximum tsunami height at coastal point was searched within the circle with the radius, the half length of fault of the supposed hypocenter, as shown in orange line. It was the combination of all maximum values at source points inside the circle. In the maximum risk method 2, the maximum tsunami height at coastal point was searched inside the maximum extent of the possible fault of the supposed hypocenter. The maximum risk method 2 shows highest tsunami heights (red line) because it was the combination of all maximum values at source points inside the rectangle area.

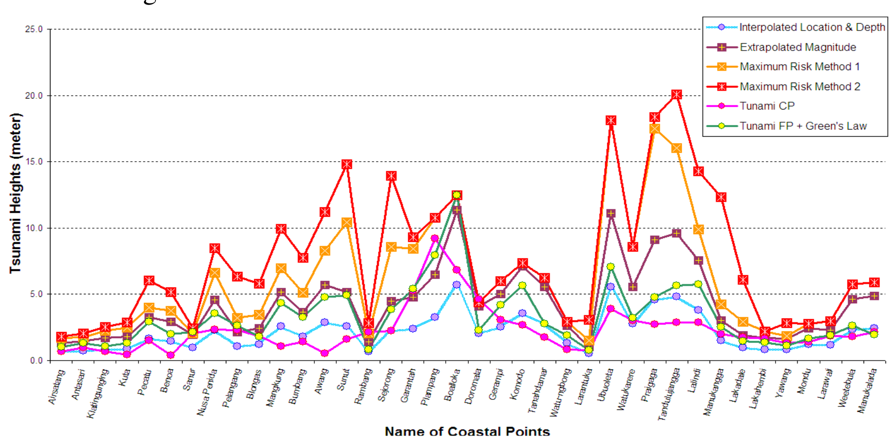


Figure 7. Tsunami heights at coastal points retrieved by maximum risk methods 1 and 2.

Comparison of tsunami heights for the real case with the retrieved values from the database is shown in Figure 8. Red line is the result of retrieved values from the database which were obtained from interpolation of location and depth (M 8.0 and depths of 20 and 40 km), then extrapolation of magnitude (from M 8.0 to M 8.3) by multiplying the coefficient value of 2.0. Green line was obtained directly from numerical simulation by the coarse mesh with Green's law application. Blue line was obtained directly from numerical simulation with finer mesh. Red line and green line are close each other and show similar pattern. It was confirmed that the retrieved values from the database has good agreement with the simulation by Green's law application and the tsunami database would be applicable to future earthquakes.

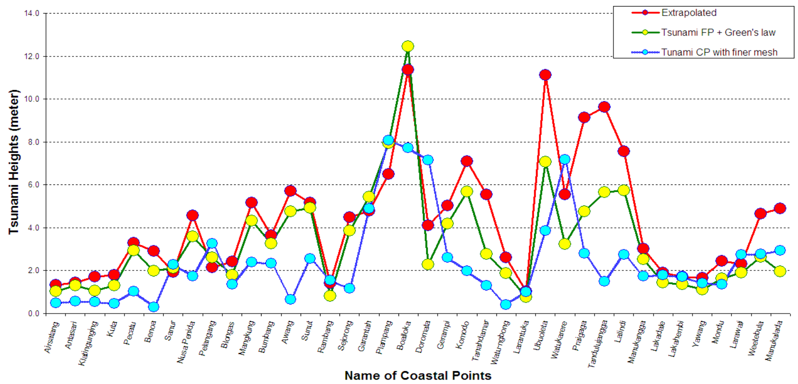

Figure 8. Comparison results from real case with the retrieved values from database.

## 4. CONCLUSIONS

The tsunami database in Bali and Nusa Tenggara regions was successfully constructed for quick tsunami forecasting. We performed the tsunami simulations by using TUNAMI-N2 from Tohoku University and TTT Software Package (ver. 2.21). The maximum tsunami heights and arrival time are calculated and the results are stored in the database for issuing tsunami warning.

In tsunami simulation of the 1977 Sumbawa earthquake as a real case, we compared the result of tsunami heights by finer mesh and coarse mesh and found that mean and median of tsunami heights with finer mesh are higher than ones with coarse mesh at most areas. The tsunami heights at forecast points applying Green's law generally agree with the range of minimum and maximum tsunami heights of finer mesh at coastal areas. In some areas, however, tsunami heights at coastal points using finer mesh were lower than using coarse mesh. These may be because the complexity of bathymetry data caused difficulty of selecting coastal and forecast points as output points. In tsunami database creation, we applied Green's law for the tsunami heights at forecast points to estimate the ones at coastal points. In order to obtain the tsunami arrival time, inverse refraction diagram was used from each coastal point to the deformation area of the source point.

In retrieving values from the database, the data points surrounding the supposed hypocenter are used with interpolation methods of epicenter location, magnitude and depth. Extrapolation method is applied if no data is available in database such as lower and upper magnitude. Comparison of the tsunami heights for the real case with the retrieved values from the database showed good agreement. Maximum risk methods could be applied to search the most severe case of a tsunami event. Through the test cases, we confirmed that the tsunami database system would be applicable to future earthquakes. The retrieved values from database will give us recommendation for issuing tsunami warning at each coastal block.

## AKNOWLEDGEMENT

I would like to express my deepest gratitude to Dr. Bun'ichiro Shibazaki as tsunami course leader of IISEE who helped me a lot, guided and supported me during my individual study in IISEE/BRI.

## REFERENCES

Imamura, F., et al., 2006 Revision, Tsunami Modeling Manual, Asian Inst. Tech, 1-72.
JMA, 2007, Presentation of Database Searching Process, Japan.
Kamigaichi, O., 2009, Encyclopedia of Complexity and Systems Science, JMA.
Okada, Y., 1985, Bulletin of the Seismological Society of America (BSSA), 75, 1135-1154.
Utsu, T., et al., 2001, Encyclopedia of Earthquakes (the second edition), Asakura, pp.657.