STUDY ON APPROPRIATE MODELING OF TSUNAMIS IN MALAYSIA FOR RISK EVALUATION

Zaty Aktar binti Mokhtar* **Supervisor:** **Fumihiko Imamura****

MEE06025 **Shunichi Koshimura****

ABSTRACT

In order to design a tsunami warning system in a region, there are three major issues in developing the data base or estimating tsunami risk; the first is the assumption of tsunami sources by selecting the potential and past earthquakes and others, the second is accuracy and stability on the numerical model with the computational regions for tsunami propagations, the third is output such as water level and velocities from the model to provide the warning and to estimate the risk. In this study, a numerical simulation of tsunamis in the Sabah coast is conducted. Two types of models are developed in this study: (1) a numerical model of the generation and trans-oceanic propagation of tsunamis using linear theory in spherical coordinate system and (2) a numerical model based on the nested grid system in Cartesian coordinate system using linear and non-linear theory with a two different spatial grid sizes. Six cases of fault ruptures are considered in the Manila trench for the earthquakes with magnitudes of 9.0, 8.5 and 8.0 which are corresponding to the earthquakes with the return periods of 667, 205 and 63 years, respectively. In the nested grid system model, the linear shallow water wave theory in spherical coordinate system is used for tsunami simulation in the large area covering Southeast Asia while the non-linear shallow water wave theory in Cartesian coordinate system is used for tsunami simulation in the Sabah coast region. It is found that the tsunamis arrives the Northern part of Sabah in approximately 2 hours after an earthquake occurred and the maximum tsunami height calculated is more than 1 m for the M_w 9.0 earthquake. Finally, a few computational instability problems are introduced and discussed in this paper.

Keywords: Numerical Model, Tsunami Simulation, Nested Grid System

INTRODUCTION

The Sumatran mega-thrust earthquake on 26 December 2004 has awakened specially the affected countries for the need of an early warning system and re-evaluation of the tsunami hazard map in the region. Malaysia is located in the area which can be affected by the tsunamis generated by the earthquakes in the seismically-active western part of the Philippines. Therefore, further research should be emphasized for this possibility of the future tsunami events in the region. In this study, the simulation of tsunamis in the Sabah coast area using nested grid system method is conducted to investigate the tsunami arrival times, and wave heights at several selected points. The numerical simulation is conducted using TUNAMI codes (Imamura et al., 2006) with modifications to simultaneously solve tsunami propagation in the two regions with using the Leap-Frog Scheme (Goto et al., 1997).

---

* Malaysian Meteorological Department, ** Disaster Control Research Centre, Tohoku University Japan

EARTHQUAKES IN THE PHILIPPINES AND FAULT PARAMETERS

The geometry of subduction slabs in northern Luzon, Philippines has been studied by Bautista et al., (2001), where a new model of the subducting slabs of the Eurasian plate beneath the Manila Trench was proposed. They used the hypocentral and focal mechanism data in order to characterize the tectonic configuration in the Northern Luzon region. Papazachos et al., (2004) have proposed the empirical formulas for estimating the subsurface fault length, L, fault width, W and displacement, u from the moment magnitude, M_w. The equations were developed from global earthquakes classified into strike-slip faults, dip-slip continental faults, and dip-slip faults in subduction regions. Therefore, based on the empirical equations, the static fault parameters for each magnitude which are the length, width, and displacement are predicted and summarized in Table 1 below.

Table 1 Predicted fault parameters estimated using empirical eqs. (Papazachos et al., 2004)

Magnitude (M_w)	**Subsurface rupture length, (L) (km)**	**Subsurface rupture width (W) (km)**	**Displacement, (u) (m)**
8.0	162.2	70.8	2.19
8.5	305.5	101.2	4.57
9.0	575.4	144.5	9.55

In this model, for the dip angle of a fault plane is assumed equal to the one proposed by Bautista et al. (2001); Dip = 30^o and (Strike, Slip) = (0^o, 90^o).

As the initial condition in this model, I assumed that the vertical displacement of water surface is instantaneous as the same as vertical displacement of the sea bottom which is calculated by using Mansinha and Smylie (1971) theory. Six cases of fault ruptures are considered for the earthquakes with magnitudes of 8.0, 8.5 and 9.0. The return periods of earthquakes with the magnitude M_w 9.0, 8.5 and 8.0 are 667, 205, 63 years, respectively (Ruangrassamee, 2007). Top depth of the fault is assumed 25 km. The fault planes for all six cases are located on the subducting slab in the Manila Trench as shown in Figure 1.

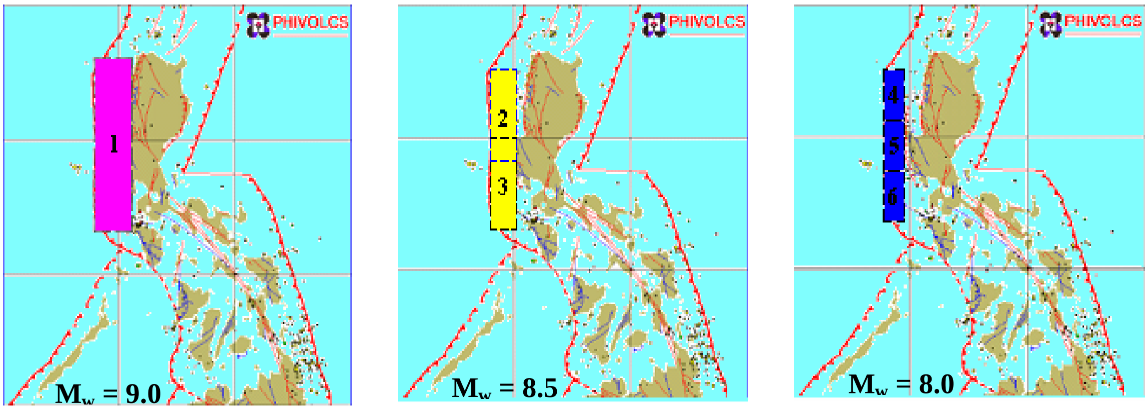

Figure 1 Location of fault plane models for six cases in the Manila Trench area (Sources: *Philippine Institute of Volcanology and Seismology*, http://www.phivolcs.dost.gov.ph/).

ANALYTICAL SCHEME AND CONDITIONS

Figure 2 depicts the area of computation considered in the analysis. In this paper, the nesting grid system method is introduced where there are two different grid size regions which are considered in this model. In order to calculate the trans-oceanic tsunami propagation in the long distance (region 1) , the linear long wave equations with Coriolis force in spherical coordinate system are used in this model which is numerically solved by using finite difference method. Meanwhile, the domain of computation for region 2 covering the Sabah coast area is in Cartesian coordinate system which used the non-linear shallow water wave equations in numerical computation. The sea depth off the shore of the Philippines is about 4 km to 5 km, while the depth around Sabah coast area is less than 2 km and quite shallow. The digital global bathymetry grid data are extracted from (British Oceanographic Data Centre, 1997) for both regions with spatial grid size 1-arc-minute (about 1850 m) for trans-oceanic tsunamis calculation (region 1). As for region 2, I used modified GEBCO data with a resolution of 20 sec (about 616.67 m).

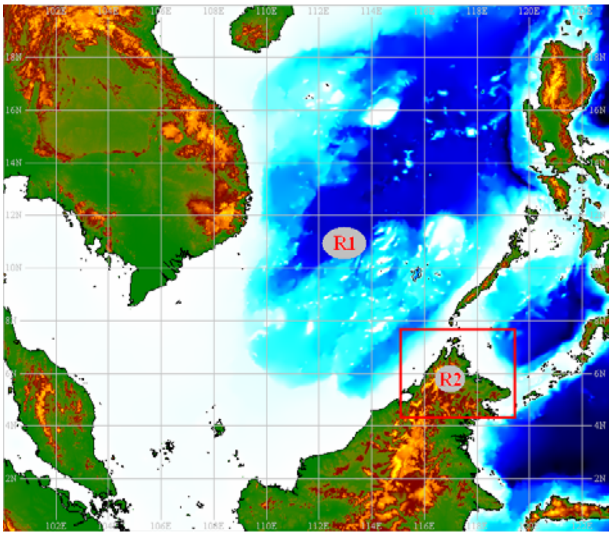

Figure 2 Computational areas in numerical model.

In order to stabilize the numerical computation, the temporal grid sizes (dt) were set to 3.0 sec for region 1 and 1.0 sec for region 2, which satisfied the stability condition in the analysis. The number of grid points are 1381×1201 and 772×631 for region 1 and 2, respectively. The computation time is about 12 hours.

ANALYTICAL RESULTS AND DISCUSSION

The arrival times and tsunami heights at several selected points in the case study area are investigated for the tsunami warning and risk evaluation. Results of both methods are compared and it is found that the tsunami amplitudes obtained for the linear theory model were larger than the non-linear theory model at the output points. It means that the predictions by the linear model are overestimated but it is safer evaluation. This happened by neglecting bottom friction and convection terms in the calculation of tsunami

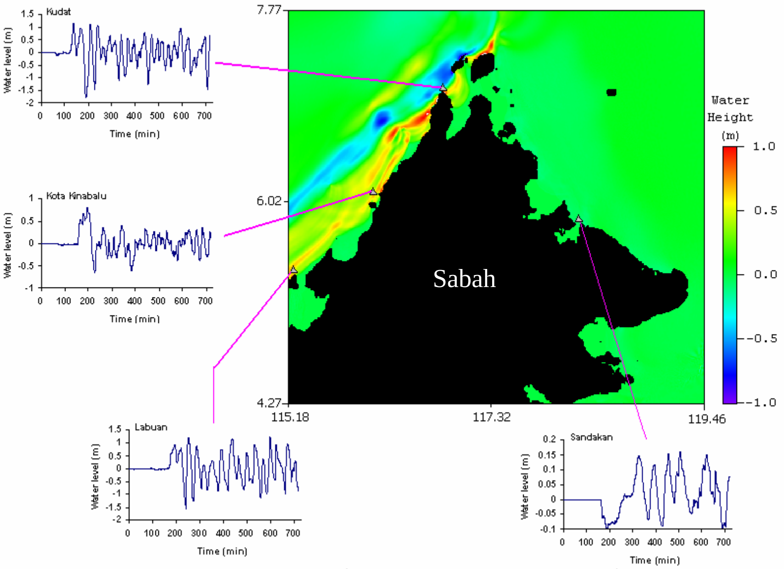

Figure 3 Snapshot of tsunami propagation after 3 hours using the nested grid system method.

propagation. Figure 3 shows the snapshot of tsunami wave 3 hours after the earthquake occurred with the time histories of the water level computed for each output point in the region using nested grid system method. It is noticed that, the tsunamis arrived at the northern part of Sabah approximately in 2 hours after an earthquake M_w 9.0 occurred with the maximum tsunami height of more than 1 m. In this model, it is obvious that the fault rupture occurred off the shore of the Philippines for the M_w 9.0 has generated a strong directivity of tsunami energy to propagate toward Vietnam coast area and a very small affect to the coastline of Sabah (see Figure 4). At the western coast of Sabah, the calculated maximum tsunami height is about 1.25 m at a sea depth of 5 m in Labuan output point. However, it is also noticed that the tsunami height at some other places are likely more than 2 m. Therefore, the characteristic of sea bottom topography is really important and needs to be emphasized, in fact it is one of the major factors determining the influence and severity of the tsunami. The effect of earthquake magnitudes on the tsunami height and arrival time at several output points are presented in Table 2.

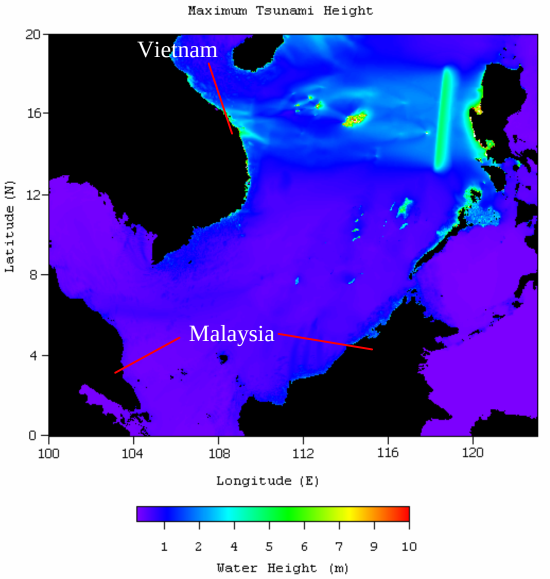

Figure 4 Directivity of the tsunami front towards Vietnam (linear model).

Table 2 Maximum tsunami heights and tsunami arrival times at selected output points

M_w	Case	Max. Tsunami Height (m)				Tsunami Arrival Time (min)			
		Kdt	KK	Lbn	Sdkn	Kdt	KK	Lbn	Sdkn
9.0	1	1.15	0.79	1.25	0.16	120	156	170	165
8.5	2	0.34	0.19	0.39	0.05	141	172	184	336
	3	0.51	0.19	0.51	0.08	126	158	170	301
8.0	4	0.16	0.05	0.10	-	157	187	201	-
	5	0.11	0.06	0.13	0.03	143	174	187	511
	6	0.18	0.07	0.12	0.03	130	162	175	458

Kdt: Kudat, KK: Kota Kinabalu, Lbn: Labuan, Sdkn: Sandakan

COMPUTATIONAL PROBLEMS

There are some computational problems occurred during this study effort and some existing approaches can be used to solve the problems. One example of major instability occurred in the computation as shown in Figure 5. We can notice that three sources of instability at the bottom right corner of the boundary are indicated with the red circles (see Figure 5(a)). Since the depth at these three sources is estimated around 1 m ~ 2 m and the equation used to calculate the water level at this boundary is a linear equation theory, thus, it was impossible to calculate the water level at the boundary in this case. A large dislocation between depth in region 1 (linear theory –the minimum depth is set up to 10 m only) and region 2 (non-linear theory – 1 m ~ 2 m minimum depth) yields unrealistic results of water level at the boundary region. This is the main cause of the instabilities and demolishes the whole computation as shown in Figure 5(b).

There are many ways to eliminate this kind of instability, for example I have created a bit wider new bathymetry data. However, I have to make sure that the depth around the boundary of region 2 is more than 10 m in order to make appropriate the linear equation used in the boundary of region 1 and to avoid the same problem of instability.

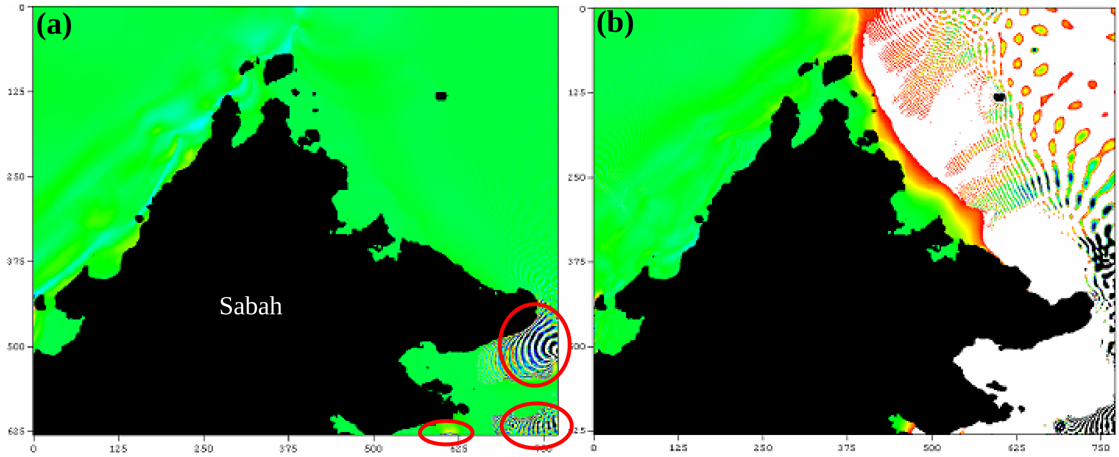

Figure 5 Initiation of an instability at a bottom right corner of the boundary (left panel) which demolished the whole computation (right panel).

CONCLUSIONS

In this study, both linear theory and non-linear theory model based on nested grid system computations of tsunami propagation are conducted in the case study area. The simulations of tsunamis are conducted appropriate with some conditions, where the results of both methods are compared. It is noticed that the fault ruptures occurred off the shore of the Philippines will generate a strong directivity of tsunami energy to propagate toward Vietnam coast area and a very small affect to the coastline of Sabah.

The tsunami arrival time and maximum wave amplitude for case 1 to 6 are analyzed at each selected output points. It is noticed that, the tsunamis arrived earlier at each output point in case 1 compared with another cases 2 to 6. The calculated maximum tsunami heights is 1.25 m in Labuan for case 1, 0.39 m in Labuan for case 2, 0.51 m in Kudat for case 3, 0.16 m in Kudat for case 4, 0.13 m in Labuan for case 5, and 0.18 m in Kudat for case 6.

However, there are some important points that need to be taken into account after conducted these simulation. In order to get much more consistent and better results for tsunami computation, the use of detailed and accurate bathymetry data is essential with a small grid size and is much more effective in the numerical computation.

In this paper, I have examined the computational instability problem that occurred during my study effort. A better knowledge is required to modify the existing program which can minimize the error and to avoid instability in the computation.

On the whole, the tsunami heights are larger in the western part of Sabah than the eastern part. The lifeline facilities and the residents living near the coastal zone should be well prepared for the disaster.

Finally, the structural counter measures using natural protection method (soft structure) such as mangrove plantation or green belt along the coasts is a good protection in order to reduce the tsunami threat in the case study area.

ACKNOWLEDGEMENTS

I wish to express my special gratitude to all of Graduate School of Engineering, Tohuku University and Professor Nobuo Shuto (Research Adviser of ARISH) of Nihon University for their helpful discussions and valuable comments on the manuscript as well as their guidance during this study. I wish to thank members of DCRC, particularly Mr. Hideaki Yanagisawa and Mr. Ikuo Abe for their numerous helps and assistances during the study effort. I am grateful to acknowledge Dr. Bunichiro Shibazaki (Tsunami Course Leader) and Dr. Yushiro Fujii for their guidance, suggestions and encouragements during my study in Japan. I thank all the staff and lecturers in IISEE for providing me very valuable knowledge and materials that are really useful for my future needs.

REFERENCES

Bautista, B. C., et al., 2001, Tectonophysics, 279-310.

British Oceanographic Data Centre, 1997, “The Centenary Edition of the GEBCO Digital Atlas (CD-ROM)”

Goto, C., et al., 1997, IOC Manual, UNESCO, No.35.

Imamura, F., et al., 2006, Tsunami modeling Manual (TUNAMI model), 72p.

Mansinha, L. and D. E., Smylie, 1971, Bulletin Seismological Society America, 61, 1433-1440.

Papazachos B. C., et al., 2004, Bulletin of the Geological Society of Greece, 36, 1482-1489.

Ruangrassamee, A. and N., Saelem, 2007, Fourth International Conference on Urban Earthquake Engineering, 447-452.