UPDATING NUMERICAL SIMULATIONS FOR TSUNAMI FORECASTING DATABASE CONSIDERING SOURCES ALONG THE MANILA TRENCH

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ABSTRACT

We consider a method to update tsunami database in order to enhance the capability of Malaysia National Tsunami Early Warning System. We identify the Manila trench to be the location of potential earthquake sources which can generate a hazardous tsunami in South China Sea region and the surrounding countries including Malaysia. The source points are located along the Manila trench with 4 depths (0, 10, 20 and 30 km). Fault parameters are set using a scaling law for 3 magnitudes (M_w7.5, 8.0 and 8.5). Numerical simulations of tsunami propagation for 108 cases are performed using a software called TUNAMI-N2. Our target area is the coastal region of the east part of Malaysia, and forecast points are set along this area. There are two groups of forecast points; forecast points with a fixed distance of 5 arc-minutes and forecast points along the bathymetry contour depth of 50 m. The Green's law is applied in order to estimate reliable tsunami heights for the coastal area. The results of the tsunami simulation showed similar tsunami waveforms pattern between the source points with the same earthquake scenario. In terms of tsunami amplitude, the results indicate that higher tsunami heights is originated from the source point with larger magnitudes. The factor of depth at the source point also could contribute to the amplitude of tsunami height. This can be explained by the condition of ocean bottom deformation. Finally, all the results will be additional information for the purpose to update tsunami database.

Keywords: Tsunami height, source points, tsunami simulation, arrival time.

1. INTRODUCTION

Malaysia is located relatively close to the boundary between the Eurasian plate in the northern side and the Australian plate in the southern side. Although the Malay Peninsula is located on a stable part of the Eurasian plate (Balendra et al., 2008), tremors are still felt due to large earthquakes from the active seismic area of Sumatra and Andaman Sea. The Malaysia National Tsunami Early Warning System, (MNTEWS) was established as national monitoring centre for all earthquake activities and tsunami around Malaysia. The implementation of tsunami database for the Malaysia National Tsunami Early Warning system (MNTEWS) is needed to ensure a proper dissemination of tsunami warning. Thus, updating the tsunami database has to be one of the purposes of this study. The numerical simulation for the computation of tsunami propagation will be carried out and the results of the simulation will be used as input data to be stored in tsunami database.

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2. DATA AND METHODOLOGY

2.1 Location of potential rupture area

We choose the Manila trench as a potential rupture area which can generate a hazardous tsunami in South China Sea region. According to the study by Kirby et al. (2006), there are 6 fault segments identified along the Manila trench which are shown in Figure 1. According to the study, the coastal regions of Malaysia are significantly affected by tsunamis generated from the fault plane segment E5. Therefore we decided to choose the segment E5 as the location of source point. The fault parameters for the segment E5 suggested by Kirby et al. (2006) are listed in Table 1.

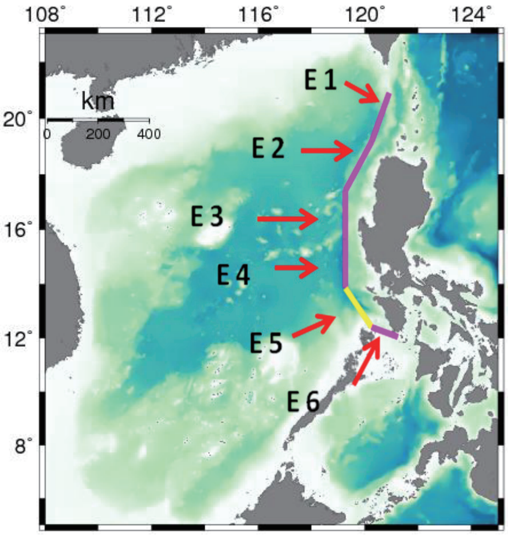

Figure 1. Suggested fault plane segments along the Manila Trench (Kirby et al., 2006).

Table 1: List of fault parameters suggested by Kirby et al. (2006)

Fault	E5
Longitude center of fault (deg)	119.6
Latitude center of fault (deg)	13.7
Length (km)	140
Width (km)	35
Strike (deg)	320
Dip (deg)	22
Rake (deg)	90
Slip(m)	7.63
Magnitude (Mw)	8.0

2.2 Data

We used the bathymetry data from the General Bathymetric Chart of the Oceans (GEBCO) with a spatial grid size of one arc-minute which is equivalent to 1850 m. A source point is defined as a center of tsunami source. The area of source points covers from 12.67°N to 14.83°N and 118.33°E to 120.67°E (Figure 2). The source points are set on the grid with a distance interval of 40 arc-minute ~ (74 km). In Figure 2, there are 9 source points (red circle) with three magnitudes (M_w 7.5, 8.0, and 8.5) and 4 depths of center fault (DCF) (0, 10, 20, 30 km) for each source point. A location of buoy is set up as the buoy point for this study which is located at longitude of 113.78°E and latitude of 7.37°N (yellow triangle). The purpose of setting up the buoy point is to observe early passing of tsunami waves. Then for the forecast points, we decided to form 2 groups; one is located parallel to coastal point with a fixed distance of 5 arc-minute ~ 9.25km (purple circle) and forecast points which located along the bathymetry contour depth of 50 m (green circle).

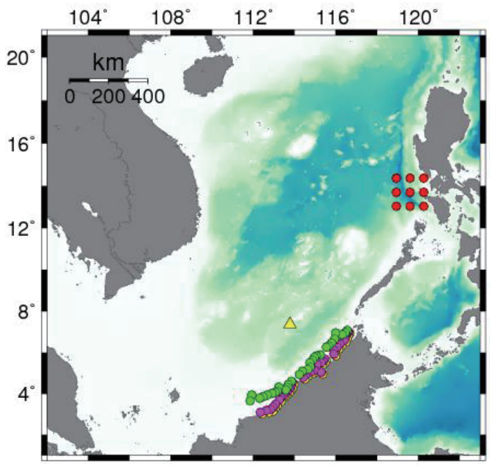

Figure 2. Locations of 9 source points (red circles), 1 buoy point (yellow triangle), forecast points with distance 5 arc-minute (purple circle) and forecast points of contour depth of 50 m (green circle)

2.3 Initial condition

In tsunami numerical simulations, fault parameters are parts of the inputs of a tsunami source. Fault parameters consist of the values of strike angle $(\emptyset)$, dip angle (δ), slip angle (λ), length (L), width (W) and slip amount (U). According to Satake (2008), the slip amount (U) has the largest effect on the vertical seafloor deformation and the tsunami amplitude. The dip angle and fault depth also contribute to control the size of a tsunami. The fault parameters were set up at the top left corner (TLC) in Figure 3. In setting the strike angle, we need to consider the direction of the trench axis. We put the strike of 350° and 300° at source points parallel to the trench axis. We set up the dip angle of 22° for a purpose to update the information in a database system and the slip angle is 90° considering the severest case for tsunami generation.

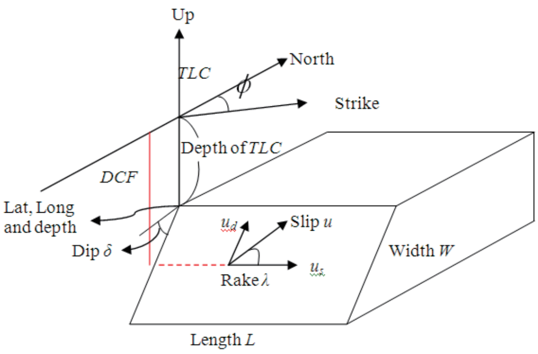

Figure 3. Fault plane parameters. Dotted line in red indicates the depth of fault center (DCF) (Chai, 2008)

In this study, we also categorized the magnitude and depth into several cases for each source point. The magnitude and the depth were assumed based on historical earthquake records from the Global Centroid Moment Tensor (CMT) catalog and the study by Liu et al. (2008) about the potential tsunami hazards in the South China Sea region. The lists of magnitude and depth with fault parameters are shown in Tables 2 and 3.

2.5 Scaling law

A scaling law is used to determine the fault parameters such as length L, width, W and slip amount, U. The formula of the scaling law by Tatehata (1997) is used for calculating the fault parameters. The parameters of earthquakes can be determined by the moment magnitude, M_w and the scaling law formulas are expressed as follows:

$$Log\ L(km) = 0.5M_w - 1.9$$

$$W(km) = L/2$$

$$\log U(m) = 0.5\ M_w - 1.4$$

Table 2. Fault parameters with strike angle of 350° and dip angle of 22°.

M_w	DCF (km)	Depth of TLC (km)	Slip (cm)	Length (km)	Width (km)	Strike (deg)	Rake (deg)
7.5	0	0.000 *	223.9	70.8	35.4	350	90
7.5	10	3.369	223.9	70.8	35.4	350	90
7.5	20	13.37	223.9	70.8	35.4	350	90
7.5	30	23.37	223.9	70.8	35.4	350	90
8.0	0	0.000 *	398.1	125.9	62.9	350	90
8.0	10	0.000 *	398.1	125.9	62.9	350	90
8.0	20	8.219	398.1	125.9	62.9	350	90
8.0	30	18.219	398.1	125.9	62.9	350	90
8.5	0	0.000 *	708.0	223.9	111.9	350	90
8.5	10	0.000 *	708.0	223.9	111.9	350	90
8.5	20	0.000 *	708.0	223.9	111.9	350	90
8.5	30	9.041	708.0	223.9	111.9	350	90

*Depth of TLC had negative value and was forced to. zero

Table 3. Fault parameters with strike angle of 300° and dip angle of 22°.

M_w	DCF (km)	Depth of TLC (km)	Slip (cm)	Length (km)	Width (km)	Strike (deg)	Rake (deg)
7.5	0	0.000 *	223.9	70.8	35.4	300	90
7.5	10	3.369	223.9	70.8	35.4	300	90
7.5	20	13.37	223.9	70.8	35.4	300	90
7.5	30	23.37	223.9	70.8	35.4	300	90
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*Depth of TLC had negative value and was forced to zero

2.4 Numerical simulation by using TUNAMI-N2

TUNAMI-N2 (Tohoku University's Numerical Analysis Model for Investigation of Near-field tsunamis, No.2) is used as a tsunami numerical simulation tool for this study, applying the shallow water theory with the Cartesian coordinate system for calculating tsunami propagation. The process of the simulation requires several steps described by Fujii (2011). The area of computation covers from 102°E to 123°E in longitude and 1°N to 21°N in latitude with the grid points of 1260 and 1200 respectively. To stabilize the numerical computation, the temporal interval (Δt) is set to 3s, satisfying the C.F.L (Courant Friedrics Lewy) condition for stability criteria. The computation time is 8 hours and the total number of simulation is 108 for all the source points.

2.5 Green's law

The Green's law is used to estimate the height of tsunami at the coastal point from the forecast point at the sea. The Green's law is derived from the conservation of potential energy along the ray (e.g. Satake, 2008):

$$h_0 = \left(\frac{d_1}{d_0}\right)^{\frac{1}{4}} h_1$$

where d_0 and d_1 are the water depth at the coastal and the forecast point, h_0 and h_1 are the height of tsunami at the coastal and the forecast point respectively.

3. RESULTS AND DISCUSSION

3.1 Different types of forecast points with Green's law

Based on Figure 4, the tsunami heights at coastal point between both forecast points are different. The tsunami heights at coastal points from the forecast points with depth of 50 m depth are higher than the results from forecast points at 5 arc-minute off shore. The distribution of tsunami heights along the coastal points depend on the variation of bathymetry. Thus, application of Green's law for an evaluation of tsunami height at coastal points is required instead of computations with finer bathymetry in order to obtain reliable results. In this study, we selected a group of forecast points at depth of 50 m for an estimation of tsunami height at coastal points using the Green's law calculation. Then the results will be stored into the database.

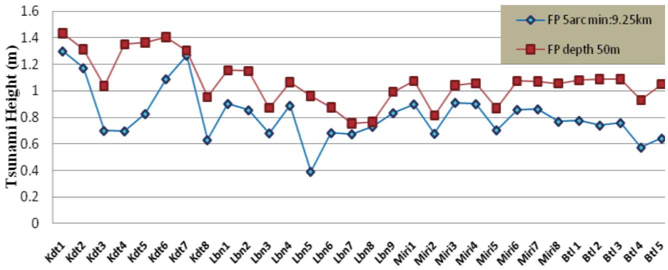

Figure 4. Tsunami heights from the coastal points obtained from Green's law at source point 4, M_w8.0, depth (DCF) of 0 km with different types of forecast points

3.2 Tsunami heights of different magnitudes and depths

A comparison between the results from tsunami simulation and calculation using Green's law with different magnitudes and depths (DCF) at the fixed source point 4 is shown in Figure 5. Tsunami heights are mainly controlled by the earthquake's magnitude (Tatehata, 1997). The larger magnitude contributes to larger tsunami heights. The value of tsunami heights calculated using Green's law for coastal points is higher than the results from direct tsunami simulation. The calculation using Green's law produces a significant value as tsunami height increases as the magnitude becomes larger. The factor of depth can give different values of tsunami heights at coastal points. From the result of analysis on Figure 5, the tsunami heights from the deeper depth are higher than the shallow depth with the same magnitude.

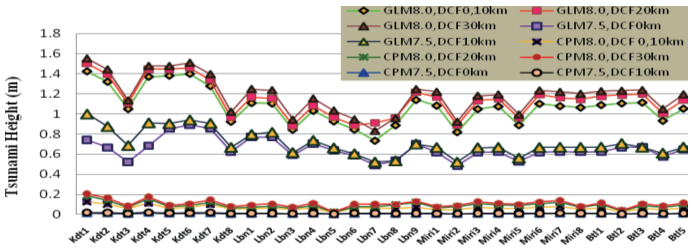

Figure 5. Tsunami heights at coastal point are obtained directly from tsunami simulation (CP) and calculation using Green's law (GL) by different magnitudes and depths of center of fault (DCF) at source point 4.

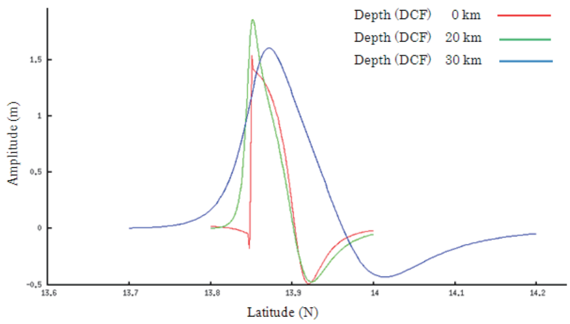

Figure 6. Vertical cross section of ocean bottom deformation for magnitude 8.0 with DCFs of 0 (red line), 20 (green line) and 30 km (blue line)

An inspection for this condition was carried out on the ocean bottom deformation at the source point 4. The vertical cross section across the center of fault with depth of center of fault (DCF) of 0, 20 and 30 km are shown in Figure 6. DCFs of 0, 20 and 30 km correspond to 0, 8.219, 18.219 km in depth of top of left corner (d_{TLC}). Based on Figure 6, the cross section of fault with depth of 30 km represented by blue line is wider than the cross section of fault with depth of 0 km (red line).

The vertical sea floor deformation on depths of 30 km and 20 km (green line), create uplifts higher than the source depth of 0 km. In this case, the vertical displacement of water surface affects the tsunami height at the coastal point. The larger amount of uplift will cause the higher amplitude of tsunami height.

3.2 Tsunami arrival time with different magnitudes and depths

The information of arrival time can be used for time estimation of incoming tsunami reaching to the land. An analysis of tsunami arrival time at the buoy points and coastal points from the source point 4 (SP4) with different scenarios of magnitude and depth are shown in Figure 7. The pattern of arrival time is almost similar for every case. The arrival time at coastal points for the case of $M_w 8.0$ is a slightly earlier than the case of $M_w 7.5$. Tsunami arrival time depends on the size of earthquake slightly. The larger earthquake causes, a little faster tsunami arrivals. The analysis in cases of the same M_w 8.0 showed that the tsunami arrival time was slightly earlier in the case with the source depth of 30 km than the cases of the source depths of 0 and 10 km. The initial waves can be detected at the buoy point and this information is needed in order to estimate the tsunami waves approaching to the coast.

Based on the analysis, the initial tsunami waves from source point 4 (SP4) reached to the buoy point in 103.1 min after the earthquake, while the arrival time at coastal point Kudat 1 is after 119.9 min. Therefore, it can be estimated that travel time of tsunami from the buoy point to the land is approximately 17 min.

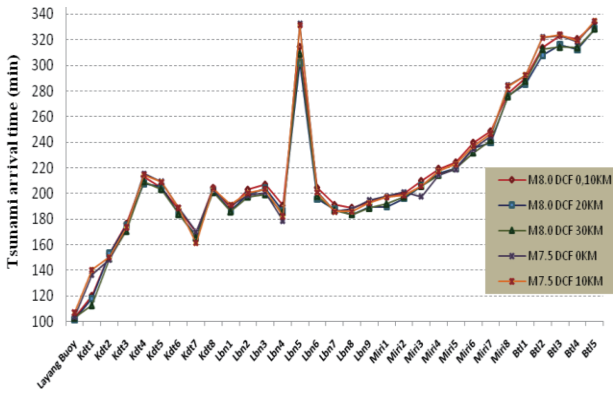

Figure 7. Tsunami arrival time at coastal points according to different magnitudes and depths (DCF) at a fixed source point 4 (SP4).

5. CONCLUSIONS

In this study, an effort to update the tsunami database was carried out. The initial attempt was to find on potential rupture locations. A part of the Manila Trench, located from 12.67°N to 14.83°N and 118.33°E to 120.67°E was chosen as a source points region considering the potential as highly hazardous tsunamigenic earthquake source region (Liu et al., 2008) and the target location is at the east part of Malaysia. A simulation of tsunami using the software TUNAMI-N2 was conducted with total of 108 cases as the initial conditions.

The results of simulation were analysed and the variation of tsunami waveforms in terms of tsunami heights and tsunami arrival times were discussed. To predict any possible tsunami amplitude at the coast, the Green's law was applied. A comparison between the tsunami heights obtained by application of the Green's law and those obtained directly from tsunami simulation indicates an inconsistency. An inaccuracy of sea depth data of GEBCO could affect the result. Therefore, the use of an accurate bathymetry data is essential in numerical computation. Based on the result of analysis, the distribution of tsunami height in the coast depends on magnitude, depth and location of the sources. The amplitude of tsunami height at coast is higher as the earthquake size increases. An analysis on tsunami arrival time was performed and the data from the buoy point is important as we can estimate the incoming tsunami from offshore.

A concept of tsunami database is exposed with the methods of retrieving the database. Hopefully, all the obtained tsunami information can be the additional data to be stored in the existing tsunami database.

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