Effect of Rupture Velocity, Ocean Current and Initial Sea Level on the Transoceanic Propagation of Tsunami

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1. Introduction: Numerical simulation of a tsunami is one of the most effective methods to reproduce what occurred in the past or even to predict what will occur in a future for many tsunamis related research aspects. However, some real phenomena were neglected during an original transoceanic tsunami simulation such as fault dynamics of rupture velocity, ocean current and initial sea level.

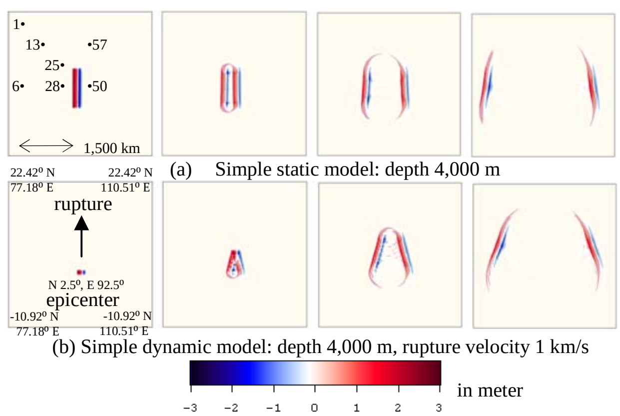
Once an earthquake occurred, fault propagated from the start to the end point with some velocity. Thus, the assumption for an original tsunami simulation that the sea bottom is lifted or deformed at the same time is not realistic. In case of large fault length, this will directly affect to the tsunami arrival time, wave height and should be included in a simulation of tsunami for a forecast or warning purpose. On the other hand, though it is quite complicate to simulate all natural forces resulted in a different current direction and velocity by location, but this study will simplify the phenomena and apply to example these effects. Also, a typical tsunami wave is much shorter than astronomically driven tidal waves. Therefore, the tidal range was usually neglected during tsunami modeling, and the computed sea level dynamics is superimposed with the tidal one after the computations. However, this study will illustrate the nonlinear effect from a simple initial sea level by using a numerical experiment.

2. Objectives: This paper will carry out the numerical experiments to examine the effects on the tsunami propagation over the ocean, which tend to be neglected without detailed consideration for each condition; those are the dynamic effect of the fault rupture velocity, current velocity in the ocean and initial variation of sea level. In conventional and original tsunami-simulation techniques, simplifications have been employed by neglecting the dynamic seabed displacement resulting from fracturing of a seismic fault and considering only the static contribution. The water layer is also assumed to be incompressible, regardless of its acoustic effects.

3. Methodology: TUNAMI (Tohoku University's Numerical Analysis Model for Investigation of Far-field tsunamis) code (IUGG/IOC TIME Project, 1997) was modified in order to dynamically run the tsunami simulation. A segment of the fault will be calculated by Mansinha and Smylie equation (1971) and generate segment by segment toward a fault rupture direction and velocity. Then the computational program will receive the segment's parameter one by one as an initial condition for a tsunami propagation program. However, the dynamic effect from the rising time of each segment is not included in this study. This study attempts to propose a simply non-dimensional parameter in which easy to obtain and calculate. So that after knowing this value, whether the dynamic effect is able to be neglected can be judged. The proposed parameter is a ratio between the fault rupture velocity, V_R and the tsunami wave celerity, C. The experiment was adapted from Aida (1969) and using a simply tsunami source model by varying the considered effect and constant bathymetry depth. Output locations for wave height and arrival time are located as 500 km from the source. Some are shown in Fig. 1(a). The initial parameters adopted from the 2004 Indian Ocean tsunami for a generation of bottom deformation, rupture velocity, current velocity and initial sea level are given in Table 1.

Table 1 Parameters used in the model

Parameter	Value
Length / Width (km)	1000 / 150
Strike / Dip /Slip (degree)	0 / 10 / 90
Depth (km)	10
Dislocation (m)	10
No. of sub-segment	10
Bathymetry depth (m)	100 ~ 4,000
Rupture velocity (km/s)	1.0 ~ 2.5
Current velocity (m/s)	0.1 ~ 0.9
Initial sea level (m)	±1.0 ~ ±3.0



(a) Simple static model: depth 4,000 m
(b) Simple dynamic model: depth 4,000 m, rupture velocity 1 km/s

Figure 1 Comparison between static and dynamic model

4. Results and discussion:

4.1. Rupture velocity effect: In principle, the tsunami propagation characteristic will become more static in shallow water and fast rupture velocity. Snapshots (Fig. 1 (a) and (b) illustrate the waveforms including the effect of spherical earth at the compuational latitude and lontitude. In this case, water depth is 4,000 m for both case. While the rupture velocity of 1.0 km/s was included in the dynamic model case. In Fig. 2, fault generation become more static (wave height and arrival time ratio, H_D/H_S and T_D/T_S are nearly to one) as the V_R/C increase (faster rupture velocity and shallower depth). Slower rupture velocity causes later in arrival time because of the time different in generation time between the first and the last segment. Also the sea depth, as the tsunami propagation velocity is controlled by the equation $C = (gH)^{1/2}$ means that tsunami propagation is

Transoceanic tsunami propagation, fault rupture velocity, ocean current, initial sea level
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mainly depending on the depth. Moreover, it was found that the dynamic effect to both wave height and arrival time is considerable large around the point that located near the tsunami source (500 km surrounding points, point 25) and will gradually reduce when it moves further as the farthest 1,500 km grid point (point 1). Comparison of the waveforms at point 13 and 57 is shown in Fig. 3. The directivity coefficient (Aida, 1969) is defined by the ratio between the heights of waves radiated in along and opposite direction from the bottom deformation. From the results, directivity coefficients obtained from both this study and Aida's study provides the same trend as a higher source generation time (lower rupture velocity) causes higher directivity.

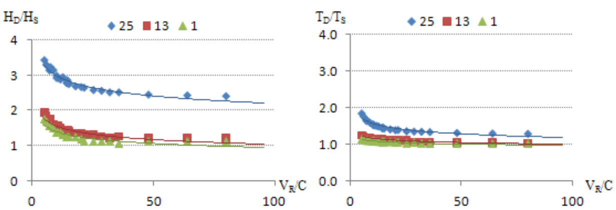

Figure 2 Non-dimensional V_R/C with wave height and arrival time ratio at point 1, 13 and 25

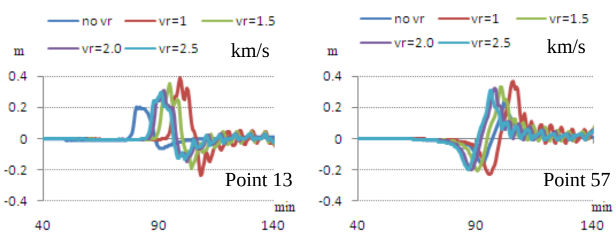

Figure 3 Waveforms of 4,000 m depth at point 13 and 57

4.2. Ocean current effect: In the real phenomena, ocean current alters in both direction and magnitude monthly and current magnitude varies from 0.1 to 1.5 m/s. However, exact magnitude and direction are different location by location. Thus, to apply all exact magnitude and direction for all locations are seemed to be impossible. Assumed the same one current direction moving from the left to the right at 4,000 m depth with the velocity from 0.1 to 0.9 is used in the study of static model as shown in Fig. 1(a). The results show that most of the wave height ratio is about one exept in some location. This means ocean current has not much effect to a tsunami propagation even the depth and current velocity is changed. Aslo, it can be clearly seen when the waveform is compared (Fig. 4) since the first wave height and arrival time is nearly the same. However, it causes some difference in wave height for a later following wave.

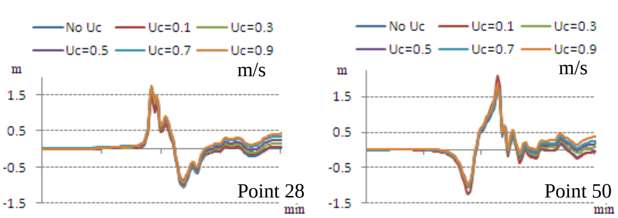

Figure 4 Waveforms of 4,000 m depth at point 28 and 50

4.3. Initial sea level effect: Typical tidal range in the open ocean is about 0.6 m. As when get closer to the coast, however, this range gets much greater. Coastal tidal ranges vary globally and can differ anywhere from 1.8 m to 3.0 m. This study focuses only on the effect from initial sea level just after the earthquake of the static model as shown in Fig. 1(a). In the study, the tidal range between ±1.0 and ±3.0 is used together with the constant depth of 100 m to 4,000 m. It can be seen from the result (Fig. 5) that the initial sea level has no effect to the wave height but only arrival time. Closer point from the source of 500 km (point 28) show less effect compared to the point that located at 1,500 km (point 6). Furthermore, the most effective parameter regarding to the arrival time is the water depth. For example, in case of 4,000 m depth, the ratio of the tidal height over the depth is 0.025 percent if the tidal high is order of 1 m. In contrast, if the tidal height remain the same as one m but the depth reduce to 100 m, the ratio will become one percent or 40 times. Thus, the different can be clearly seen when the ratio is high as velocity produce from the total depth water (depth plus tide) follow the equation $C = (gH)^{1/2}$ means that the propagation is mainly depending on the depth. This is the reason why later of arrival time is high in shallow depth.

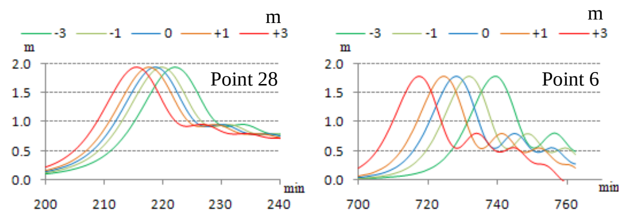

Figure 5 Waveforms of 100 m depth at point 28 and 6

5. Conclusion: This study conducted the numerical experiment with a simple tsunami generation source and constant depth so as to illustrate the effect for each phenomenon and can be conclude again as follow.

5.1. Rupture velocity effect: The effect will be high if the rupture velocity is slow. Also, tsunami propagates faster in deep sea causing high dynamic effect. Besides, distance from the tsunami source also affect both arrival time and wave height as large effect occur in the near-source area and reduce when it goes further. If V_R/C is smaller than 40, the effect of directivity on the wave height and arrival time cannot be neglected.

5.2. Ocean current effect: Results show that deep sea and faster current velocity will cause slightly effect to the first wave height but not clear in arrival time. In brief, effect from ocean current with one flow direction is not significant.

5.3. Initial sea level effect: It was found that longer distance from tsunami source lead to higher effect in arrival time but not the wave height. In addition, sea depth also has an effect to arrival time as deep sea has less effect since the ratio between tidal level and sea depth is small.

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