1. Introduction

Tsunami is one of the most severe natural disasters faced by regions around the rim of oceans, usually generated by submarine earthquakes (usually with magnitude larger than 7.0), volcano eruptions and large landslides. Submarine earthquakes are the most common tsunami sources. As we know, the prediction of an earthquake is still not satisfactory with today's technologies, in fact, for most earthquakes, unsuccessful. However, when an earthquake capable of tsunami generation, occurs, it is possible to send out an early warning of tsunami impact, especially for far-field regions.

To release a tsunami early warning, two types of information are important, tsunami arrival time and tsunami wave height. For most of existing numerical models of tsunami simulation, given detailed fault information, both arrival time and tsunami wave height can be predicted fairly accurately. Therefore, real time numerical simulation may provide a possibility for tsunami warning which is described as follows. When a submarine earthquake occurs, the fault parameters, once available, are fed immediately into a numerical model to start a simulation. Then based on the numerical results, an early warning about the arrival time and possible wave heights will be released to affected regions. Unfortunately, shortly after an earthquake, detailed information about the source region is often not available for a simulation to get started. Moreover, numerical simulations and result processing will take considerable amount of time before getting a forecasting ready. Considering the high travel speed of tsunamis, usually several hundreds of miles per hour in deep ocean, real time numerical simulations may be helpful for a tsunami warning, particularly, for near-field regions.

Although many factors may limit the use of real time numerical simulation for a tsunami early warning, it seems more feasible to do numerical simulations before an earthquake. Based on past seismic records and tectonic activities, hazardous tsunami sources can be outlined and pre-studied can be performed to identify possible affected regions. Once an earthquake occurs, an early warning can be quickly released from these pre-studies.

In this document, by constructing a series of hypothetical fault planes along Manila Trench and Ryukyu Trench, which are considered the most hazardous tsunami sources around Taiwan in the future, a preliminary numerical study is carried out to evaluate arrival time and possible tsunami wave heights corresponding to each hypothetical fault. For a future tsunami generated along these regions, the arrival time and tsunami wave heights may be quickly estimated from these preliminary analyses.
2. Hypothetic Fault Planes

Two regions can be identified with higher probability of earthquakes and will generate tsunamis affecting Taiwan. One is along Manila Trench, where Eurasian Plate sub-ducting the Philippine Sea Plate at a speed of 70mm/yr (Lin, 2000 [1]) and the other one is Ryukyu Trench where the Philippine Sea Plate sub-ducting the Eurasian Plate (See Figure 1). Manila Trench is classified as the highest earthquake tsunami source region in the USGS Tsunami Sources Workshop 2006. Earthquake records show that the largest earthquake activity in Taiwan and the Manila Trench region in the past 100 years is about Mw=7.5 (1999 Chi-Chi is 7.6 and the 1934 (Feb. 24) earthquake offshore from the northern Luzon is 7.5), making this region the most hazardous in the future (Willie, personal communication).

![Figure 1 Tectonics in the Taiwan region [1]](image)

Along Manila Trench, six hypothetical fault planes are assumed based on the trench azimuth and the fault geometries outlined in USGS Tsunami Sources Workshop 2006. Each fault plane is assumed to be 20km wide, 10km deep and with 3-meter dislocation (slip). The slip angle is assumed 90 degree. Parameters for these hypothetical fault planes are given in Table 1.

![Table 1 Hypothetical Fault Planes along Manila Trench](image)

The Ryukyu Trench is considered less hazardous than the Manila Trench, but still has higher possibilities of earthquakes than other regions. Along the Ryukyu Trench, five hypothetical fault planes are deployed. Similar to the Manila Trench, Each fault plane is assumed to be 20km wide, 10km deep and with 3-meter dislocation (slip). The slip angle (Rake) is assumed 90 degree. Parameters for these hypothetical fault planes are given in Table 2.
For the assumed 3-meter dislocation, the magnitude of an earthquake the scalar moment required rupturing each hypothetical fault plane can be calculated by

\[ M_w = \frac{2}{3} (\log_{10} M_0 - 9.1) \]  

where \( M_0 \) is the scalar moment of the earthquake evaluated as

\[ M_0 = \mu D L W \]  

and \( \mu \) is the rigidity of earth mantle, \( D \) is the dislocation (slip) and \( L \) is the length of the fault plane and \( W \) is the width of the fault plane. The rigidity, \( \mu = 3.0 \times 10^{10} N/m^2 \), is taken for this calculation. The earthquake magnitude corresponding to each hypothetical fault plane is, thus, calculated in the following tables.

### Table 2 Hypothetical Fault Planes along Ryukyu Trench

<table>
<thead>
<tr>
<th>Fault</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Length(km)</th>
<th>Width(km)</th>
<th>Strike</th>
<th>Dip</th>
<th>Slip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seg#1</td>
<td>121.3</td>
<td>22.8</td>
<td>150km</td>
<td>20km</td>
<td>275</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>Seg#2</td>
<td>122.7</td>
<td>23.0</td>
<td>150km</td>
<td>20km</td>
<td>259</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>Seg#3</td>
<td>124.1</td>
<td>23.4</td>
<td>150km</td>
<td>20km</td>
<td>247</td>
<td>16</td>
<td>90</td>
</tr>
<tr>
<td>Seg#4</td>
<td>125.3</td>
<td>24</td>
<td>140km</td>
<td>20km</td>
<td>240</td>
<td>16</td>
<td>90</td>
</tr>
<tr>
<td>Seg#5</td>
<td>126.4</td>
<td>24.8</td>
<td>140km</td>
<td>20km</td>
<td>233</td>
<td>14</td>
<td>90</td>
</tr>
</tbody>
</table>

### Table 3 Fault Planes along Manila Trench

<table>
<thead>
<tr>
<th>Segment No.</th>
<th>Length (km)</th>
<th>Width (km)</th>
<th>Dislocation (m)</th>
<th>Magnitude (Mw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>20</td>
<td>3</td>
<td>7.55</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>20</td>
<td>3</td>
<td>7.64</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>20</td>
<td>3</td>
<td>7.64</td>
</tr>
<tr>
<td>4</td>
<td>180</td>
<td>20</td>
<td>3</td>
<td>7.61</td>
</tr>
<tr>
<td>5</td>
<td>150</td>
<td>20</td>
<td>3</td>
<td>7.55</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>20</td>
<td>3</td>
<td>7.44</td>
</tr>
<tr>
<td>All segments</td>
<td>980</td>
<td>20</td>
<td>3</td>
<td>8.10</td>
</tr>
</tbody>
</table>

### Table 4 Fault Planes along Ryukyu Trench

<table>
<thead>
<tr>
<th>Segment No.</th>
<th>Length (km)</th>
<th>Width (km)</th>
<th>Dislocation (m)</th>
<th>Magnitude (Mw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>20</td>
<td>3</td>
<td>7.55</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>20</td>
<td>3</td>
<td>7.55</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>20</td>
<td>3</td>
<td>7.55</td>
</tr>
<tr>
<td>4</td>
<td>140</td>
<td>20</td>
<td>3</td>
<td>7.53</td>
</tr>
<tr>
<td>5</td>
<td>140</td>
<td>20</td>
<td>3</td>
<td>7.53</td>
</tr>
<tr>
<td>All segments</td>
<td>730</td>
<td>20</td>
<td>3</td>
<td>8.01</td>
</tr>
</tbody>
</table>

The seafloor displacement is calculated based on elastic finite fault plane theory developed by Mansinha and Smylie (1971). And it is also assumes that the sea surface just mimics the seafloor deformation instantly. This is reasonable since the duration of an earthquake is usually measured in seconds and there is no way for the water above the seafloor deformation to drain out. The seafloor deformation on each hypothetical fault plane is shown in the following figures.
In Figure 2, along the Manila Trench, the seafloor deformations over all the six hypothetical fault planes are shown together. The transect plot of fault segment 3 is also shown in the figure with the maximum amplitude 1.04m and minimum -0.25m and the positive displacement (uplift) faces to the east. The calculated seafloor displacements are very similar for all these six hypothetical fault planes with the maximum amplitudes ranging from 0.97m to 1.05m, due to the slightly difference of dip angles.

Figure 2 Hypothetical fault planes along Manila Trench and associated seafloor deformations
Figure 3 Hypothetical fault planes along Ryukyu Trench and associated seafloor deformations

The calculated seafloor displacement of each hypothetical fault plane along the Ryukyu Trench is also shown in Figure 3. The transect profile of the seafloor displacement is very similar to that of along the Manila Trench. However, the amplitude is a little smaller due to the relatively small dip angle. A transect plot is given in the transverse direction of fault segment 2. The maximum amplitude is 0.96m and the minimum is -0.43m.

Of course, a possible earthquake may rupture one or more of these hypothetical fault segments. In the worst scenarios, the earthquake will rupture all the six hypothetical fault segments along Manila Trench, totally 850km long, or all the five hypothetical fault segments along the Ryukyu Trench, totally 700km long. Tsunami generated by each hypothetical fault plane, is investigated in the report and, furthermore, the worst scenarios are also considered.

3. Numerical Model

Tsunami propagation is simulated with a validated tsunami simulation model -- COMCOT, which adopts a modified Leap-Frog finite difference scheme to solve Shallow Water Equations [6][7][8]. In this preliminary study, uniform 1-minute grid, interpolating from ETOPO2, is implemented for all the simulations. The simulated domain ranges from 105E to 130E in longitude and 8N to 33N in latitude with a dimension 1501×1501. Vertical wall boundary is assumed along the shorelines (where water depth is less than or equal to 0.5 meters).

4. Results and Analysis

For a tsunami forecast and early warning, two factors are very important. One is the arrival time and the other is tsunami wave height. Based on numerical results, arrival time, tsunami wave
height distribution and the maximum tsunami wave heights along Taiwan shoreline are investigated to identify the fault regions most dangerous to Taiwan. In addition, other regions are also studied, including coastal regions of Southeast China and Vietnam.

4.1 Hypothetical Faults along Manila Trench
4.1.1 Arrival time
Contours of arrival time of a tsunami generated by each hypothetical fault segment are given in Figure 4, 5 and 6. In these plots, the arrival time is defined as when the water surface starts to be elevated more than 1 cm above the still sea level due to the arrival of the leading wave. For near field regions where waves are relatively high, this criterion works well. However, for far field regions where tsunami wave height is very small (close to 1 cm), especially when bathymetry is also complicated (with islands etc), it begins to fail (curves become messy as shown in the following figures).

Figure 4 Arrival time of tsunamis generated by fault segment 1 (left panel) and fault segment 2 (right panel) along Manila Trench
Numerical results show that, for an earthquake occurring in the hypothetical fault segment 1 which is the closest to Taiwan, the generated tsunamis will impact the southern part of Taiwan in 20 minutes. Arrival time plots also indicate that for future earthquakes along Manila Trench, the generated tsunamis will attack coastal regions of Southeast China (Fujian province, Gudong province, Hong Kong, Macao and Hainan Island) in 2 to 3 hours. Shorelines of Vietnam will also be affected in 2 hours.
4.1.2 Distribution of Tsunami Energy

The distribution of maximum tsunami wave heights within the entire simulated region is investigated by plotting the maximum tsunami wave heights within the simulated 5-hour physical duration. The distribution is shown in a gray scale ranging from 0 meter (in white) to 1.0 meter (in black). The max wave height distribution, in fact, indicates the distribution of tsunami energy.

Figure 7 Tsunami wave height distribution (Manila Trench – Segment 1 (left panel) and segment 2 (right panel))

Figure 8 Tsunami wave height distribution (Manila Trench – Segment 3 (left panel) and segment 4 (right panel))
In the above plots, it is obvious that only for earthquakes occurring within hypothetical fault plane segment 1 and segment 2 along Manila Trench, the southern part of Taiwan will be greatly affected. For earthquakes occurring in other segments, the tsunami impacts on Taiwan will be relatively small. The plots also show that a major part of energy of tsunamis generated by earthquakes within hypothetical fault segment 1, 2, 3 and 4 will travel to the west and northwest. As a result, the coastal regions of Southeast China will be threatened by these possible tsunami sources. For regions along Vietnam shoreline, hypothetical fault segment 4 and 5 can be considered as the most hazardous tsunami sources and the generated tsunamis will impact these regions in about 2 hours.

4.1.3 Maximum Tsunami Height along Shorelines
The maximum tsunami heights along shorelines, recorded in the 5-hours simulated physical duration, are also plotted to give a rough estimate of possible tsunami runup heights. It should be noted that vertical wall boundary condition is assumed along the shorelines, the max tsunami wave heights may be exaggerated by a factor 2 due to wave reflection.

Hypothetical Fault Segment 1 (along Manila Trench)
Figure 11 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 12 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)

**Hypothetical Fault Segment 2 (along Manila Trench)**

Figure 13 Max Tsunami Heights along shoreline of Taiwan (Manila Trench-Segment 2)
Figure 14 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 15 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)

**Hypothetical Fault Segment 3**

Figure 16 Max Tsunami Heights along shoreline of Taiwan (Manila Trench-Segment 3)
Figure 17 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 18 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)

Hypothetical Fault Segment 4 (along Manila Trench)

Figure 19 Max Tsunami Heights along shoreline of Taiwan (Manila Trench-Segment 4)
Figure 20 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 21 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)

**Hypothetical Fault Segment 5 (along Manila Trench)**

Figure 22 Max Tsunami Heights along shoreline of Taiwan (Manila Trench-Segment 5)
Figure 23 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 24 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)

**Hypothetical Fault Segment 6 (along Manila Trench)**

Figure 25 Max Tsunami Heights along shoreline of Taiwan (Manila Trench-Segment 6)
In the above plots, it is obvious that only for earthquakes occurring within hypothetical fault plane segment 1 and segment 2 along Manila Trench, the southern part of Taiwan will be greatly impacted (tsunami wave heights may be up to 0.9 meters along the shoreline of southern part of Taiwan, see Max tsunami height plots). If earthquakes occur in other hypothetical fault segments along Manila Trench, the generated tsunamis won't affect Taiwan greatly. The impact can be neglected (tsunami heights less than 0.3 m along the shoreline). This is consistent with tsunami energy distribution patterns.

In addition to the above six hypothetical fault planes, a worst scenario, in which an earthquake rupturing all the 6 hypothetical fault planes along Manila Trench, is also simulated by assuming that the dislocation is 3 meters everywhere along the trench. The arrival time, tsunami height distribution and maximum tsunami wave heights along shorelines of Taiwan, Southeast China and Vietnam are shown in the following plots.
Figure 28 Tsunami arrival time (left panel) and wave height distribution (right panel) for an earthquake rupturing all segments along Manila Trench.

Figure 29 Max tsunami heights along shorelines of Taiwan (Left panel: western shoreline; right panel: eastern shoreline).
4.2 Hypothetical Faults along Ryukyu Trench

4.2.1 Arrival time

Similar to possible tsunami sources along Manila Trench, the arrival times of tsunamis generated by hypothetical faults along Ryukyu Trench are plotted as contours in the following figures.
Numerical analysis shows that, for an earthquake in hypothetical fault segment 1 along Ryukyu Trench, the generated tsunamis will affect the eastern shoreline of Taiwan in 5 minutes. Therefore, practically, there is not enough time to send out a warning for the latter scenario.

4.2.2 Distribution of Tsunami Energy

The distribution of maximum tsunami wave heights within the entire simulated region is investigated by plotting the calculated maximum tsunami wave heights within 5-hour simulated physical duration. The distribution is shown in a gray scale ranging from 0 meter (in white) to 1.0 meter (in black).
4.2.3 Maximum Tsunami Heights along Shorelines

For a tsunami generated by each hypothetical fault plane, the maximum tsunami wave heights along the eastern and western shorelines of Taiwan are also plotted to check the tsunami impacts along these regions. It should be noted that vertical wall boundary condition is assumed along the shorelines, the max tsunami wave heights may be exaggerated by a factor 2 due to wave reflection.
Hypothetical Fault Segment 1 (along Ryukyu Trench)

Figure 38 Max Tsunami Heights along shoreline of Taiwan (Ryukyu Trench - Segment 1)

Figure 39 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 40 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)

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Hypothetical Fault Segment 2 (along Ryukyu Trench)

Figure 41 Max Tsunami Heights along shoreline of Taiwan (Ryukyu Trench- Segment 2)

Figure 42 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 43 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)
Hypothetical Fault Segment 3 (along Ryukyu Trench)

Figure 44 Max Tsunami Heights along shoreline of Taiwan (Ryukyu Trench - Segment 3)

Figure 45 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 46 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)
Hypothetical Fault Segment 4 (along Ryukyu Trench)

Figure 47 Max Tsunami Heights along shoreline of Taiwan (Ryukyu Trench- Segment 4)

Figure 48 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 49 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)
Hypothetical Fault Segment 5 (along Ryukyu Trench)

Figure 50 Max Tsunami Heights along shoreline of Taiwan (Ryukyu Trench- Segment 5)

Figure 51 Max Tsunami Heights along shorelines of Southeast China (left panel) and Hainan, China (right panel)

Figure 52 Max Tsunami Heights along Shorelines of Vietnam (left panel) and Luzon (right panel)
From the tsunami wave height distribution and max wave heights along shorelines, we can see that if an earthquake ruptures hypothetical fault plane segment 1 along Ryukyu Trench, the entire eastern shoreline of Taiwan will be seriously affected (tsunami wave heights along eastern shoreline may be up to 0.90m). If an earthquake occurs within hypothetical fault plane segment 2, the entire eastern shoreline of Taiwan will also be affected. However, the wave height will be much less than that of segment 1 (reduced to below 0.60m). For future earthquakes in other hypothetical fault regions, the impact of generated tsunamis on Taiwan can be neglected since the tsunami wave heights along the eastern shoreline is very small (less than 0.2 meters).

A worst scenario is also simulated, which refers to an earthquake rupturing all the 5 hypothetical fault planes along Ryukyu Trench with a uniform 3-meter dislocation being assumed. The arrival time, tsunami height distribution and maximum tsunami wave heights along shorelines of Taiwan, Southeast China and Vietnam are shown in the following plots.

Figure 53 Tsunami arrival time (left panel) and wave height distribution (right panel) for an earthquake rupturing all segments along Ryukyu Trench

Figure 54 Max Tsunami Heights along shoreline of Taiwan (Ryukyu Trench-All Segments)
BRIEF COMMENTS

From the above numerical results, we can see that for the hypothetical faults assumed above, regions north to Taiwan, won't be seriously impacted by tsunamis triggered by these hypothetical earthquakes no matter they occurs along Manila Trench or Ryukyu Trench since these regions are sheltered by Taiwan and Ryukyu Islands and most of tsunami energy is reflected back to the south and the east. Shorelines along Southeast China and Vietnam will only be slightly affected by tsunamis generated by earthquakes along the Ryukyu Trench. However, if hypothetical earthquakes occur along Manila Trench, coastal regions of Southeast China and Vietnam will be attacked by tsunamis in about 2 to 3 hours with wave heights up to 0.5 meters. Luzon will also be seriously affected with a possible tsunami height up to 1.0 meter high (western and northern parts) for hypothetical earthquakes along Manila Trench and up to 0.6 meters high (Northern part) for hypothetical earthquakes along Ryukyu Trench.

For Taiwan, the hypothetical fault segment 1, 2 and 3 along Manila Trench (Northern part of Manila Trench) and the hypothetical fault plane 1 and 2 along Ryukyu Trench (Western part of Ryukyu Trench) will be the most hazardous. If tsunami-generated earthquakes occur within the
former region, Taiwan will be attacked in about 20 minutes. However, for earthquakes in the latter region, the generated tsunamis will impact Taiwan in 5 minutes, leaving no time for sending out an early warning.

The hazardous tsunami sources for each region are summarized in Table 5.

<table>
<thead>
<tr>
<th>Shorelines</th>
<th>Hazardous tsunami sources Along Manila Trench</th>
<th>Along Ryukyu Trench</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philippine</td>
<td>All segments</td>
<td>Segment 1 and 2</td>
</tr>
<tr>
<td>Southeast China</td>
<td>Segment 1, 2, 3 and 4</td>
<td>None</td>
</tr>
<tr>
<td>Taiwan</td>
<td>Segment 1, 2 and 3</td>
<td>Segment 1 and 2</td>
</tr>
<tr>
<td>Vietnam</td>
<td>Segment 3 and 4</td>
<td>None</td>
</tr>
</tbody>
</table>

4.3 Tsunami Early Warning?
The above preliminary results may be used for an early warning of tsunamis triggered by a future earthquake along Manila Trench or Ryukyu Trench.

Numerical studies show that for a fixed fault plane, a far field tsunami is not very sensitive to the change of fault plane angles (i.e., strike, dip and slip (rake)) and the most important fault parameter is dislocation between two fault walls [5]. Especially, when we're looking at a specific tsunami source region, the fault plane angles and the width of the fault plane are almost fixed. If the length of the fault plane is also known, given the earthquake magnitude, the dislocation can be immediately obtained from Equations (1) and (2). Furthermore, by using elastic finite fault plane theory (Mansinha and Smylie, 1971), the seafloor displacement can be easily calculated, which is also assumed the initial sea surface displacement. Taking the hypothetical fault segment 2 along Manila Trench as an example, the relationship between the fault dislocation (slip) and the initial sea surface displacement is plotted in Figure 57 (based on Mansinha and Smylie's theory (1977)).

![Figure 57 Dislocation vs. Seafloor displacement](image-url)
It is clear that there is linear relationship between fault plane dislocation and the seafloor displacement (since the fault theory is linear elastic theory). This relationship holds for other fault planes along Manila Trench and Ryukyu trench since the differences due to slightly different dip angles can be neglected.

Therefore, for a fixed fault plane along Manila Trench or Ryukyu Trench, once the magnitude of an earthquake is given, the dislocation will be able to calculate from Equation (1) and (2). Then, immediately, the initial seafloor displacement can be obtained from the above plot (figure 57). Then the far field tsunami heights will be determined from the above preliminary results if linear theory holds.

Based on the above analysis, if an earthquake of magnitude 8.0 occurs and ruptures the fault plane segment 1 along Manila Trench, from Equation (1) and (2), the dislocation is calculated to be 13.99 meters. Immediately, we know that the initial sea surface displacement will be 4.7 (=14.0/3.0) times larger than the hypothetical fault plane we calculated in Table 3. Thus, the max tsunami heights will also be 4.7 times higher if linear theory holds (In fact, it holds for tsunami). And the arrival time won't change since it is solely determined by the location of fault plane.

To confirm this argument, numerical simulations are also performed with an earthquake magnitude 8.0 instead for hypothetical fault plane segment 1, 2 and 3 along Manila Trench and fault segment 1 and 2 along Ryukyu Trench. The dislocation for each fault plane is given in Table 6.

<table>
<thead>
<tr>
<th>Magnitude</th>
<th>Manilla Trench</th>
<th>Ryukyu Trench</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Segment 1</td>
<td>Segment 2</td>
</tr>
<tr>
<td>Dislocation(m)</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Ratio to 3.0 m</td>
<td>4.7</td>
<td>3.5</td>
</tr>
</tbody>
</table>

The max tsunami wave heights are also plotted (in black) together with the previous results (in green).

Figure 58 Max tsunami heights for Fault segment 1 along Manila Trench (Black: Mw=8.0; Green: Mw=7.55)
Figure 59 Max tsunami heights for Fault segment 1 along Manila Trench (Black: Mw=8.0; Green: Mw=7.55)

Figure 60 Max tsunami heights for Fault segment 2 along Manila Trench (Black: Mw=8.0; Green: Mw=7.64)
Figure 61 Max tsunami heights for Fault segment 2 along Manila Trench (Black: Mw=8.0; Green: Mw=7.64)

Figure 62 Max tsunami heights for Fault segment 3 along Manila Trench (Black: Mw=8.0; Green: Mw=7.64)

Figure 63 Max tsunami heights for Fault segment 3 along Manila Trench (Black: Mw=8.0; Green: Mw=7.64)
Figure 64 Max tsunami heights for Fault segment 1 along Ryukyu Trench (Black: Mw=8.0; Green: Mw=7.55)

Figure 65 Max tsunami heights for Fault segment 2 along Ryukyu Trench (Black: Mw=8.0; Green: Mw=7.55)

Figure 66 Max tsunami heights for Fault segment 3 along Ryukyu Trench (Black: Mw=8.0; Green: Mw=7.55)
Apparently, the max tsunami heights along shoreline show almost the same ratio as that of dislocation no matter which fault plane is adopted. This can also be seen on time history plots (Figure 66).

![Figure 66 Time history plots at Hua-lien and Kao-hsiung, Taiwan (fault segment 1 along Manila Trench)](image)

Obviously, linear theory holds. Therefore, for a future earthquake within the studied regions, the arrival time and possible tsunami heights can be estimated quickly from the above preliminary simulations and an early warning may be sent out very soon after the main shock. Of course, practically, an earthquake may rupture one or more fault planes, linear combination may be used.

5. Conclusions
Based on earthquake hazard analysis, hypothetical fault planes are constructed along Manila Trench and Ryukyu Trench to study possible tsunami threatens. Numerical results show that, Taiwan will be seriously affected by tsunami-triggering earthquakes occurring within north half of Manila Trench or eastern half of Ryukyu Trench. Southeast China and Vietnam will be only affected by earthquakes along Manila Trench. Except for mega tsunamis like the 2004 Indian Ocean one, impacts of tsunamis triggered by earthquakes along Ryukyu Trench can be neglected for these regions. For future tsunamis generated in these regions, the preliminary study will be helpful to quickly estimate the arrival time and tsunami heights.

References


