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Tsunami Propagation in the Gulf of Thailand

Cdr.Pichet Puahengsup

Coastal Engineering Section, Oceanographic Division,

Hydrographic Department

ppuahengsup@yahoo.com

Abstract

The earthquake off the west coast of Thailand on December 26, 2004 and the subsequent tsunami disaster has focused research interests among scientists. The research is not solely focused on the west coast of Thailand, but also the east coast. The reason for the research is that the Thailand's east coast is adjacent to China Sea, a part of the Pacific Ocean where earthquakes and volcanic eruptions are frequent. In addition, coastal elevation on the Thailand's east coast is generally low, thus making it extremely vulnerable to wave inundation with a height of a few meters. The Manila Trench is an excellent candidate to assess the risk of tsunami impact to the east coast of Thailand due to its close proximity. This study creates a hypothetical earthquake tsunami scenario caused by sudden movement of seafloor at the Manila Trench. Tsunami travel time will be strictly observed because it is the most critical information for tsunami warning. The time will be determined by numerically solving the shallow - water equation. The study reveals that tsunami reaches the southern part of Thailand 11.42 hours and reaches Bangkok 17.73 hours after an earthquake. The probability of tsunami generated by the Manila Trench is unlikely to result in loss of human life along Thailand's east coast due to the long travel time of the tsunami wave. The slower wave speed in the Gulf of Thailand allows time to evacuate people away from the coastal zone.

1. Introduction

The great Sumatra earthquake on December 26, 2004 was the second largest earthquake recorded during the last century. It led to the worst tsunami disaster with more than 200,000 lives lost and devastation throughout the Indian Ocean. Thailand was one of the countries impacted by the tsunami. Many questions about the earthquake and tsunami risk have arisen in Thailand. The questions are not solely focused on the west coast of Thailand, but also the east coast. Thailand's east coast stretches along the Gulf of Thailand, where the location of China Sea is linked to the Pacific Ocean and proximal to the Manila trench. It is one of the most active plate boundaries where earthquakes and volcanic eruptions are frequent - commonly referred to as the Pacific Ring of Fire (USGS, 2016). In addition, coastal elevation along the Gulf of Thailand is generally low, thus making it extremely vulnerable to inundation by waves with a height of a few meters.

The Pacific Ocean is bordered by active margin associated with plate subduction, active mountain construction, and earthquakes (Kennett, 1977). Liu et al. (2007) argued that 90 percent of global undersea earthquakes take place around the Pacific Ring of Fire. Recently, the United States Geological Survey (USGS) has assessed the Manila Trench as a high risk zone for tsunami sources (Wu et al., 2009). Implying that the east coast of Thailand could be considered under the tsunami risk.

A tsunami is a water wave generated by the disturbance caused by submarine earthquakes, landslides, explosive volcanisms and meteorite impacts with the ocean (Chadha et al., 2006). Tsunamis around the world occur from many causes, but principally result from shallow earthquakes in subduction zones (Liu et al., 2007). Tsunami generated by earthquakes take place most likely in trench regions with a large tectonic movement during subduction (Fukao, 1979; Liu et al., 2007). Studies on seismic activities in the South East Asia show that the Philippines are seismically active with subduction earthquakes along the Manila Trench (Zhu et al., 2000; Michel et al., 2000; Kreemer et al., 2000; Bautista et al., 2001; Torregosa et al., 2001; Ruangrassamee and Saelem, 2009). It is also argued that there is potential tsunami sources in this region due to the fault rupture along the Manila Trench (Dao et al., 2009). Even though the probability of a great earthquake generated in the Manila Trench is unlikely, it may happen sometimes in the future (Megawati et al., 2009). This paper will discuss the probability of tusanami risk, generated from the Manila Trench, on Thailand's east coast. The trench is close to the Gulf of Thailand, so it is the most likely potential tsunamigenic source in this region.

The Hawaii Tsunami Education Curriculum: Kai E ‘e program reported that there are 113 Tsunamis were recorded on earth from 2000 – 2010 of which 12 resulted in fatalities. That means tsunamis caused the fatality of humans in every year. It is thus important to study the probability of the Tsunami hazard for disaster preparedness.

2. Scenario Earthquakes for Numerical Modelling

Tsunami modelling in this study is concerned with two areas. The first area is the South China Sea with the adjacent Philippine Sea Plate bordered by the Manila Trench. The second area is the Gulf of Thailand and Thailand’s east coast. The South China Sea is a complex system, bordered by the Manila and Philippine Trenches (Fig. 1a). The South China Sea is the largest marginal sea in the Pacific Ocean. Depth in the South China Sea is generally shallow (< 600 m) in the northwestern and southwestern regions. However, the depth is greater than 5,000 m in the central and eastern basin (Fig. 1b)

Liu et al. (2007) studied tsunami hazards from potential earthquakes in the South China Sea area. The geological and geophysical data in this region were analyzed. They found that the crust in this region is under tremendous tectonic stresses from many directions due to the complex interactions between tectonic plates – the Philippine Sea Plate, Sunda Plate, and Eurasia Plate. The Eurasia Plate moves toward the northwest approximately 10 mm/yr., whereas the Philippine Sea Plate moves from east to west roughly 50 mm/yr. Lin (2000) also proposed that the Manila Trench is where the Eurasian Plate subducts under the Philippine Sea Plate at a rate 70 mm/yr. This information implies that this region is a highly tectonically active.

The Gulf of Thailand is located between latitudes 6° and 14° N and longitudes 99° and 105° E. It is a shallow semi-enclosed basin that is bounded to the east of the South China Sea. Its greatest width is approximately 300 miles. Survey data from “Naga Expedition” undertaken by Scripps Institution of Oceanography shows bathymetry of the Gulf of Thailand (Fig. 2). The Gulf of Thailand is relatively shallow with a mean depth is 45 m, and the maximum depth of only 80 m. The general shape of the Gulf’s bottom bathymetry can be considered as an elliptic paraboloid (Wattayakorn, 2006).

The coasts of Thailand have evolved due to both changing of sea level and accretion (Wattayakorn, 2006). Accretion has occurred in the inner Gulf of Thailand, from approximately 70 km to the present Chao Phraya delta (Siripong A., 2010). The

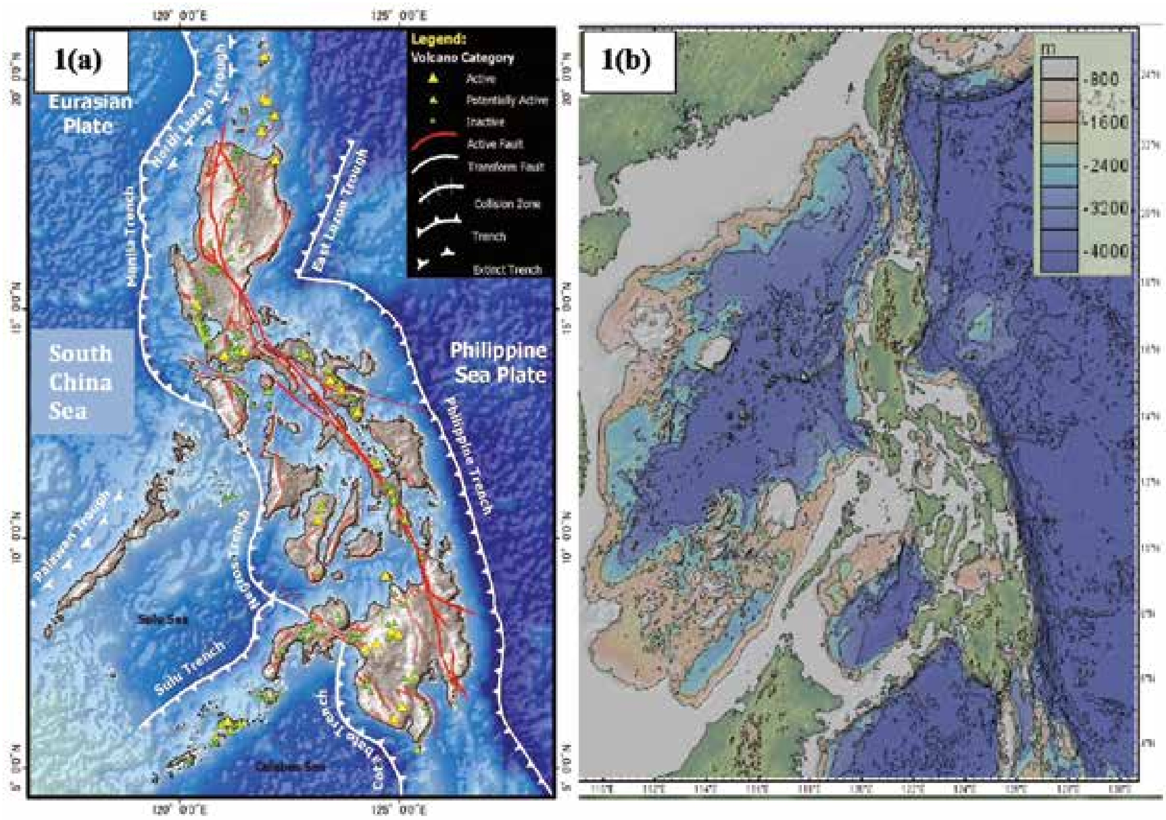

__Figure 1__ (a) The South China Sea with Philippine Sea Plate bordered by the Manila Trench. Available from: http://drrcca.blogspot.com/ Viewed November 5, 2016. (b) Bathymetry of the South China Sea generated by Global – Multi – Resolution (GRMT) on GeoMapApp.

east coast of Thailand stretches along the Gulf of Thailand. Its total coastline length is about 1,700 km. Cross section of coastal elevation at observation points along the Gulf of Thailand, including Prachuap Khiri Khan, Nakhon Si Thammarat, and Pattani provinces are illustrated in Fig. 3 illustrates that the east coastal plain is wide and flat, with heights of a few meters above mean sea level (M.S.L.) with widths of about 30 to 80 km landward.

3. Method

3.1 Determination of Epicenter

Earthquakes around the Manila Trench and the Philippines from 1900 – 2012 were compiled from the USGS database to determine earthquake probability in this study. A return period, which is an estimated time for the likelihood of an event for each magnitude, will be discovered to confirm the probability of earthquakes generated in

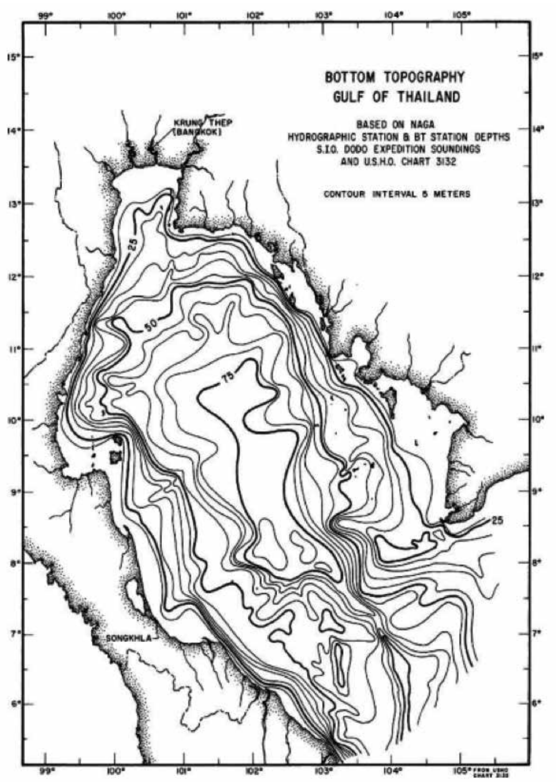

Figure 2 *Bathymetry of the Gulf of Thailand based on data from the Naga Expedition, Cruise S11, Scripps Institution of Oceanography. Available from: http://escholarship.org/uc/item/4mf3d0b7#page-2 Viewed November 5, 2016.*

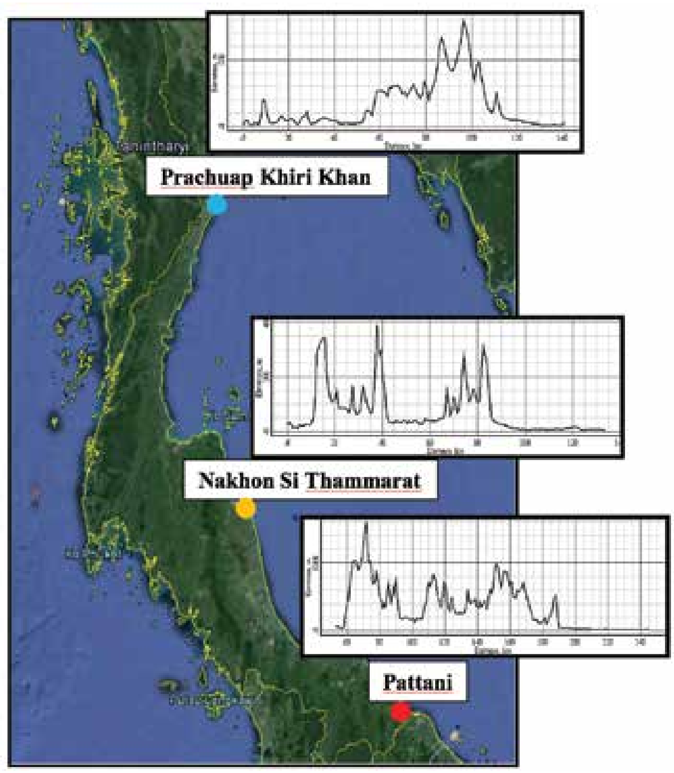

Figure 3 *Coastal elevations above M.S.L along the Gulf of Thailand including Prachuap Khiri Khan, Nakhon Si Thammarat, and Pattani provinces. The cross sections are generated using GeoMapApp.*

this region. To further tsunami modeling, it is important to define an epicenter which is the point on the earth's surface vertically above the focus of an earthquake. In this study, locations of hypothetical fault planes will be sources for tsunami modelling instead of utilizing an exact point of the epicenter. The six hypothetical fault planes, along the Manila Trench, used in this study are suggested by the 2006 Tsunami Source Workshop and then issued by USGS (Kirby et al., 2006; Wu et al., 2009). Water depths along the fault planes are approximately 3,000 – 3,500 m, except fault planes 4 and 6 which have depths of 4,000 and 2,700 m, respectively. The 2006 Tsunami Source Workshop identified these faults based on the trench azimuth and the fault geometry

Figure 4 Faults along the Manila Trench assigned by the 2006 Tsunami Source Workshop. Adapted from Modeling Tsunamis Hazards from the Manila Trench to Taiwan by T.-R. Wu and H.-C. Huang, 2009, Journal of Asian Earth Sciences, 36, p.23.

(Fig. 4 and Table 1). For this reason, Fault characteristics, which determine whether or not a tsunami will form, are not necessary taken into consideration to determine the probability of the earthquake at these hypothetical locations.

3.2 Tsunami Simulation

Numerical simulation using the **WinITDB** model which uses shallow - water equation. Tsunamis behave like shallow water wave in the open ocean because of their wavelengths longer than the ocean depth. When tsunami waves move into shallow water, the wavelength decreases leading to a growth in height. The amount of energy in the wave remains the same even though tsunamis move to shallow water. Hence, simulation of tsunami propagation is related to ocean depth. Shallow water begins when the depth of water is less than 1/20 the wavelength (The Open University, 1999). The velocity of tsunami wave becomes a simple direct proportion function of depth as follows:

$$C = (gd)^{05}$$

Where,

C = wave speed (m s-1)

g = gravitational acceleration (9.81 m s-1)

d = Depth (m)

WinITDB is numerical modelling software used for tsunami travel time calculation. ITDB stands for Integrated Tsunami DataBase. The software is operated

Table 1 Hypothetical fault planes along the Manila Trench issued by USGS.

Fault	Lon.	Lat.	Length (km)	Strike	Dip	Rake
1	120.5	20.2	160	10	10	90
2	119.8	18.7	180	35	20	90
3	119.3	17.0	240	359	28	90
4	119.2	15.1	170	3	20	90
5	119.6	13.7	140	320	22	90
6	120.5	12.9	100	293	26	90

Note: Adapted from Modeling Tsunamis Hazards from the Manila Trench to Taiwan by T.-R. Wu and H.-C. Huang, 2009, Journal of Asian Earth Sciences, 36, p.23.

on a Windows operating system which requires few computational resources. It has been used by the Hydrographic Department of the Royal Thai Navy since tsunami event in 2004. This study will focus on tsunami travel time that is defined as the duration for the first wave hitting on the coast after the initiation of the tsunami. Tsunami travel time is the most critical information required for tsunami warning. Hence, the level of risk could be classified by travel time as well.

Four locations on the east coast along the Gulf of Thailand including Bangkok, Prachuap Khiri Khan, Nakhon Si Thammarat, and Pattani provinces will be nominated to observe the tsunami travel time. The locations of observations are illustrated in Fig. 5 and also summarized in Table 2.

4. Results

Information provided by USGS illustrates that the Pacific Plate is subducting beneath the Philippine Plate. It starts from the south of Japan to the Mariana Island arc, which extend more than 3,000 km along the eastern margin of the Philippine Sea Plate. This subduction zone is characterized by rapid plate convergence and high-level seismicity extending to depths of over 600 km. The plate interface has been associated with a few great (Mw > 8.0) “megathrust” earthquakes. Fig. 6 shows earthquake records in the past 100 years which are mostly about 7.5 – 8.0 Mw.

The most recent tsunami in the South China Sea was generated by an earthquake magnitude of 7.6 Mw in 1986 (Wang and Zhang, 2005). This earthquake magnitude

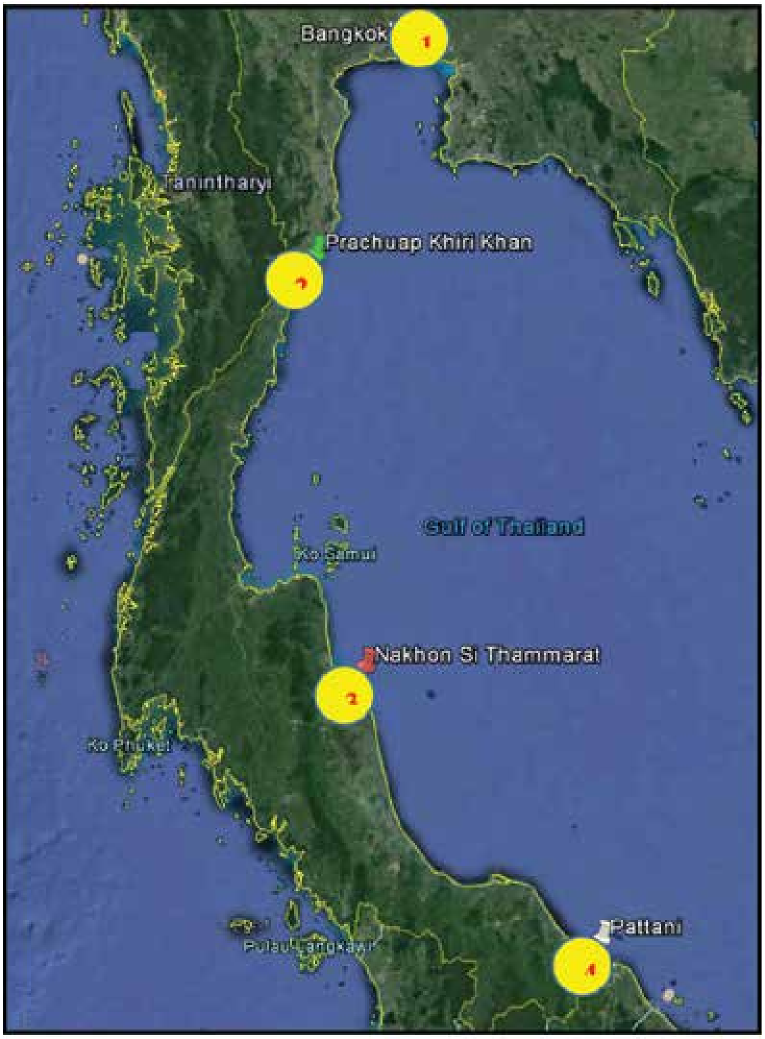

Figure 5 *The locations of observations points on the east coast along the Gulf of Thailand. The locations in longitude and latitude for all observation points are also provided in Table 2.*

has a return period of about 19 years, which is a short period. It implies that the earthquake magnitude 7.5 Mw is likely occur in this region. The earthquake return periods, which is an estimated time for the likelihood of an earthquake in the China Sea, is summarized in Table 3 (Ruangrassamee and Saelem, 2009).

In order to determine tsunami travel time on the east coast of Thailand, locations of the six hypothetical fault planes along the Manila Trench, suggested by the 2006 Tsunami Source Workshop, are assigned as epicenters for WinITDB. Fig. 7 presents simulations of tsunami waves

Table 2 *Locations of observation points along the Gulf of Thailand*

No.	Name (Provinces)	Lon.	Lat.
1	Bangkok	100.5	13.5
2	Prachuap Khiri Khan	99.8	11.8
3	Nakhon Si Thammarat	100.2	8.5
4	Pattani	102.1	6.3

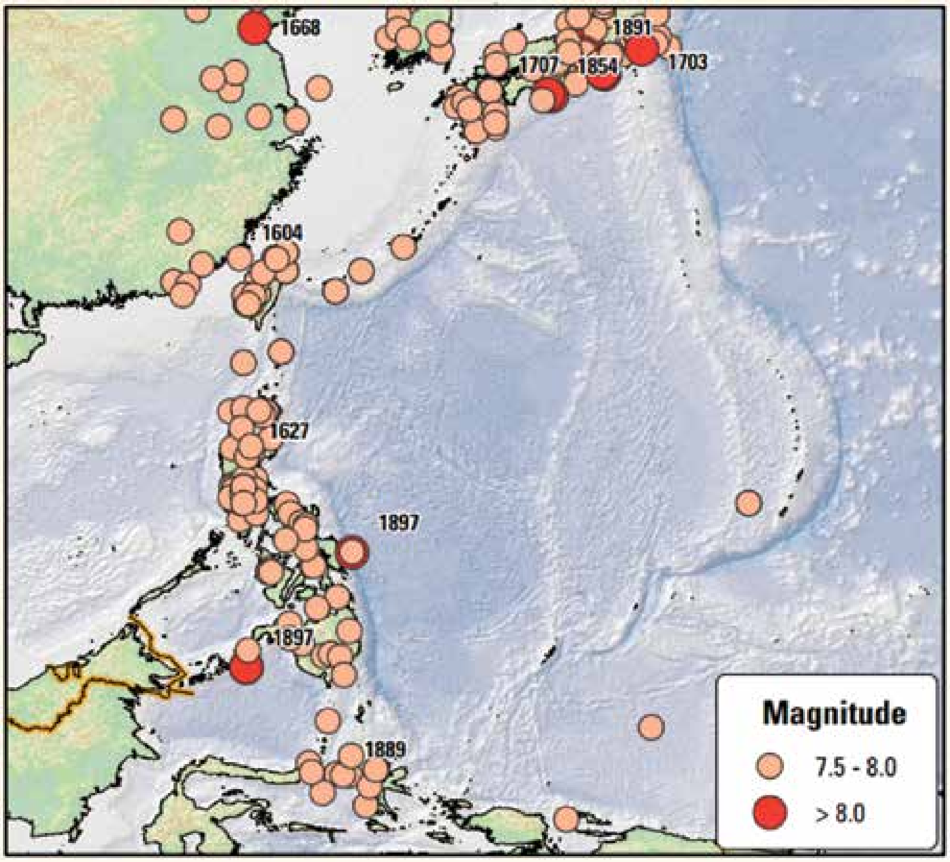

Figure 6 *Seismicity of the Philippine Sea Plate and vicinity during 1900 – 2012. Available from http://pubs.usgs.gov/of/2010/1083/m/pdf Viewed November 6, 2016.*

generated from Fault 1 and 6, respectively. The red dot presents the epicenter at the Manila Fault that triggered tsunami event. The spacing between each contour presents 600 seconds time interval. Thus, each color, either red or green, represents a one hour time interval. Arrival times of the first wave peak at all observation points on the east coast along the Gulf of Thailand are summarized in Table 4.

The shortest time before a tsunami wave reaches the southern part of Thailand at the Pattani location is 11.42 hours, and arriving in Bangkok 17.73 hours after an earthquake. The waves travel very fast in the South China Sea, but slowdown in the Gulf of Thailand. This comes from observation of contours presented in Fig. 7. The contours are close together in the Gulf of Thailand whereas more widely spaced in the South China Sea. The details will be described in the next section.

Table 3 Return period for each magnitude

Magnitude (M_w)	Return Period (Years)
7.0	6
7.5	19
8.0	63
8.5	205
9.0	667

Note: Adapted from Effect of Tsunamis generated in the Manila Trench on the Gulf of Thailand by Ruangrassamee A. and Saelem N., 2009, Journal of Asian Earth Sciences 36, p.55-56.

Fault	Bangkok	Prachuap Khiri Khan	Nakhon Si Thammarat	Pattani
1	19.03	16.65	15.01	12.53
2	18.21	16.28	14.18	11.96
3	18.05	15.85	14.01	11.75
4	17.80	15.65	13.76	11.53
5	17:73	15.38	13.72	11.42
6	18.32	15.98	14.47	12.23

Table 4 Arrival times (hour) of the first wave peak at observation points on the east coast along the Gulf of Thailand.

5. Discussions

This paper answers the question about tsunami risk on the east coast along the Gulf of Thailand. The South China Sea is under tremendous tectonic stresses from many directions due to the complex interactions among tectonic plates. Studies on seismic activities in the South East Asia reveal that there are seismically active with subduction earthquakes along the Manila Trench. The trench is close to the Gulf of Thailand, so it is the most likely tsunamigenic source making it an excellent candidate to assess the risk of tsunami impact to the east coast of Thailand. Information from the USGS illustrates those earthquakes with magnitude 7.5 Mw, which have a return period of about 19 years, are likely to occur in this region. The magnitude is great enough to trigger a tsunami event. The

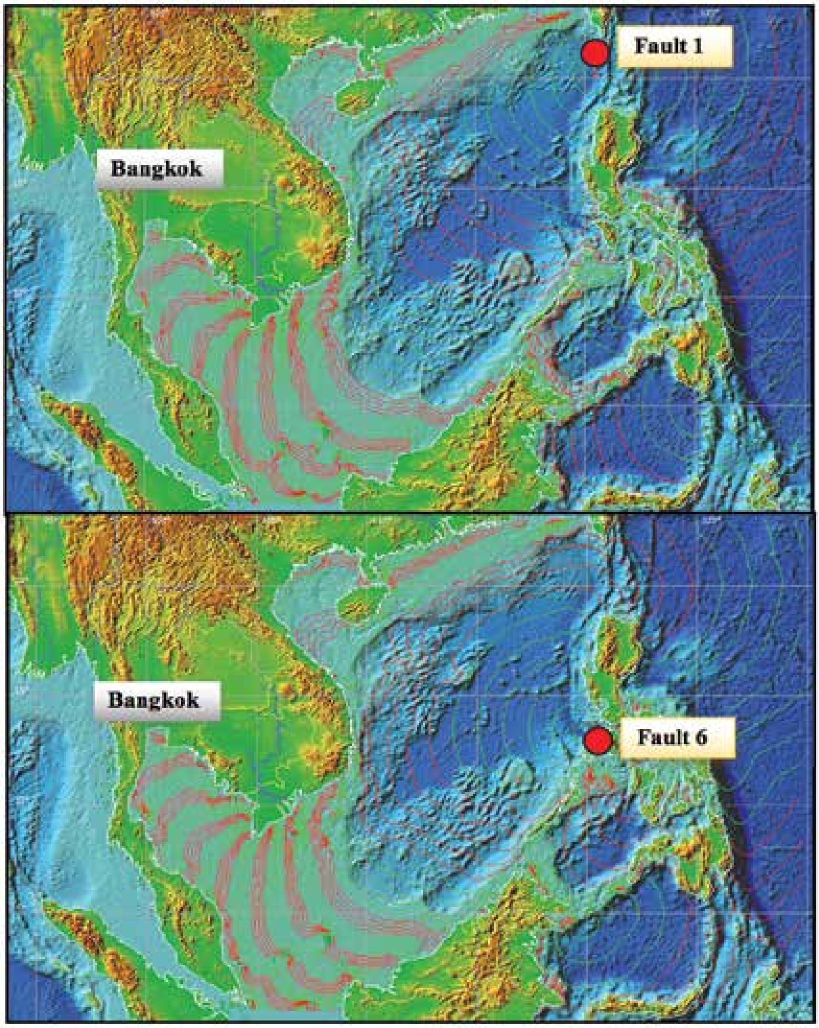

Figure 7 *Tsunami waves generated from Fault 1 (Upper) and Fault 6 (Lower) travels across the South China Sea to the Gulf of Thailand. The red dot presents the epicenter at the Manila Fault that triggered tsunami event. The spacing between each contour presents 600 seconds time interval. Each color, either red or green, represents a one hour time interval.*

probability of earthquakes in this region is therefore confirmed.

The tsunami numerical modelling software "WinITDB", based on the shallow - water equations, allows determination of tsunami travel times. Four observation points are defined along the Gulf of Thailand including Bangkok, Prachuap Khiri Khan Nakhon Si Thammarat, and Pattani provinces. The cross sections at these observation points show that the coastal elevation along the Gulf of Thailand is generally low with a height of a few meters, thus making it extremely vulnerable to wave inundation. Six locations, suggested by the 2006 Tsunami Source Workshop, are assigned as sources of earthquakes at the Manila Trench for utilizing WinITDB. Tsunami waves propagate from earthquake sources whose water depth varies from 2,700 – 4,000 m depending on their locations. Travel speed of tsunami waves depends on water depth as a tsunami waves is considered as a shallow wave that satisfies shallow water equation.

This study reveals that tsunami can reach the southern part of Thailand in 11.42 hours and reach Bangkok 17.73 hours after an earthquake. Tsunami travel times to observation points on the Thailand's east coast descend from Faults 1 – 5 whereas the time generated from Fault 6 becomes longer. The reason is that the travel time depends on distance to the epicenter and depth. The location of Fault 6 is further to the east and depth is only 2,700 m which is least among other faults. The probability of tsunami generated by the Manila Trench is unlikely to result in loss of human life along Thailand's east coast due to the long travel time of the tsunami wave. The slower wave speed in the Gulf of Thailand allows time to evacuate people away from the coastal zone. In addition, the slow wave speed in the Gulf of Thailand implies that Thailand's east coast would confront waves with a height of a few centimeters due to strong wave attenuation. The velocity of tsunami wave is a simple direct proportion function of depth, so the attenuation is predominantly caused by shape of the Gulf's bottom bathymetry and shallow depth. As stated, the general shape of the Gulf's bottom bathymetry is considered as an elliptic paraboloid with a mean depth is 45 m, and the maximum depth only 80 m.

6. Conclusions

The probability of the earthquakes with magnitude greater than 7.5 Mw is occurring in the vicinity of the Manila Trench is high. Even though coastal elevation on Thailand's east coast is generally low, tsunamis generated by the Manila Trench is unlikely to result in loss of human life along Thailand's east coast due to the long travel time of the tsunami wave. The slowdown of wave speed in the Gulf of Thailand will allow time to evacuate people away from the coastal zone. The slower wave speed in the Gulf of Thailand also implies that Thailand's east coast would confront waves with a height of a few centimeters due to strong wave attenuation. The strong wave attenuation is predominantly caused by shape of the Gulf's bottom bathymetry and shallow water depth.

References

[1] Chowdhury Shyamal, et al., 2005. Tsunami Hazards, FEMA Coastal Flood Hazard, Analysis and Mapping Guidelines, Focused Study Report, 42p.

[2] Chadha, R.K. 2006. Tsunami Sources in the Indian Ocean: Factors and Impact on the Indian Landmass. The Indian Ocean Tsunami, p.33-38.

[3] Geoffrey Blewitt, et al., 2006. Rapid Determination of Earthquake Magnitude using GPS for Tsunami Warning Systems. Retrieved October 31, 2016 from http://www.earth.northwestern.edu/individ/seth/Texts/gpswarning.pdf

[4] Integrated Tsunami Database for the World Ocean (WinITDB Project): Tsunami Laboratory. Retrieved November 5, 2016 from http://tsun.sscc.ru/tsun_hp.htm

[5] Kirby, S., Geist, E., Lee, W.H.K., Scholl, D., Blakely, R., 2006. Tsunami Source Characterization for Western Pacific Subduction Zones: a preliminary report. In: USGS Tsunami Sources Workshop 2006. Houston, TX.

[6] Robinson, Margaret K., 1974. The physical oceanography of the Gulf of Thailand, Naga Expedition; Bathythermograph (BT) temperature observations in the Timor sea, Naga Expedition, Cruise S11, Scripps Institution of Oceanography, 125p.

[7] Ruangrassamee A. and Saelem N., 2009. Effect of Tsunamis generated in the Manila Trench on the Gulg of Thailand, Journal of Asian Earth Sciences 36, p.55-56

[8] Susan L. Bilek, Kenji Satake and Kerry Sieh, 2007. Introduction to Special Issue on the 2004 Sumatra – Andaman Earthquake and the Indian Ocean Tsunami. Bulletin of the Seismological Society of America, Vol.97, No. 1A, doi: 10.1785/0210050633, p. s1-s5

[9] Siripong A., 2010. Detect Coastline Changes in Thailand by remote sensing, International Archives of the Photogrammetry, remote Sensing and Spatial Information Science, Volume XXXVIII, Part 8, Kyoto, Japan. P.992-995.

[10] The Open University, 1999. Waves, Tides and Shallow – Water Processes, second edition, Butterworth – Heinemann, Oxford, 227 p.

[11] The Accident Investigation Board Finland, 2004. Investigation Report (A 2/2004 Y): The Natural Disaster in Asia on 26 December 2004, 226 p.

[12] United States Geological Survey (USGS): Earthquake Facts. Retrieved November 1, 2016 from https://earthquake.usgs.gov/learn/facts.php

[13] Wattayakorn, G., 2006. Environmental Issues in the Gulf of Thailand, ResearchGate, Ch.16, doi: 10.1007/1-4020-3655-8-16, 12 p. Retrieved November 8, 2016 from https://www.researchgate.net/publication/227211647_Environmental_Issues_in_the_Gulf_of_Thailand

[14] Wu, T.-R., Huang and H.-C., 2009. Modeling Tsunamis Hazards from the Manila Trench to Taiwan, Journal of Asian Earth Sciences 36, p.21-28