Vietnam Academy of Science and Technology

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APPLICATION OF COMCOT MODEL IN TSUNAMI DANGER LEVEL RESEARCH IN COASTAL AREA OF DA NANG, VIETNAM

SCIENTIFIC RESEARCH

Ha Noi - 2023

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Scientific Research Instructor: Ms . Vu Van Phong

Ha Noi - 2023

Thanks to

My deepest appreciation to Pro. Vu Van Phong who supplied me with research material and helped me understand the complex science behind earthquakes and tsunamis.

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Ha Noi, 13th of August 2023

Executor: Nguyen Tuan Quang

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M	:	Earthquake magnitude
M_0	:	Seismic moment magnitude
M_w	:	Earthquake magnitude on the moment magnitude scale
M_{max}	:	Maximum Earthquake magnitude
H_{max}	:	Maximum tsunami heights
Tp	:	City
PTWC	:	Pacific Tsunami Warning Center (USA)

OPENING

A tsunami is a disaster of nature. It came suddenly and was devastating. Many coastal countries have suffered heavy damage from the tsunami but Vietnam with a coastline of more than 3200 km has not suffered those effects due to the topography of the South China Sea for many years.

Although there are no official documents on tsunami damage to Vietnam's coasts and islands, experts have not ruled out the possibility that the tsunami danger could come from within the South China Sea and nearby.

Within the scope of the article, the writer will conduct research on "Simulation of tsunami waves from distant and near sources impacting on Da Nang waters using the COMCOT Model" in order to better understand the dangers of tsunamis affecting Vietnamese waters.

CHAPTER 1: THEORETICAL BASIS OF TSUNAMIN

1.1. Definition

An earthquake is a vibrational movement of the ground. Earthquakes are usually caused by the movement of the Platonic Plates or the fault lines on the Earth's crust. Though very slow, the ground is always moving and earthquakes happen when the stress is higher than what the Earth's crust can handle.

_***focus*** is the location where rupture starts during an earthquake event. Energy is most concentrated and released under the ground.

Epicenter is the projection on the mean surface of the Focus.

Strike angle is the angle measuring clockwise from the local north to the strike direction.

Dip angle is the angle between the mean Earth surface and the fault plane, measured from the mean Earth surface down to the fault plane

Slip angle describes in which direction the hanging block moves relative to the foot block on the fault plane

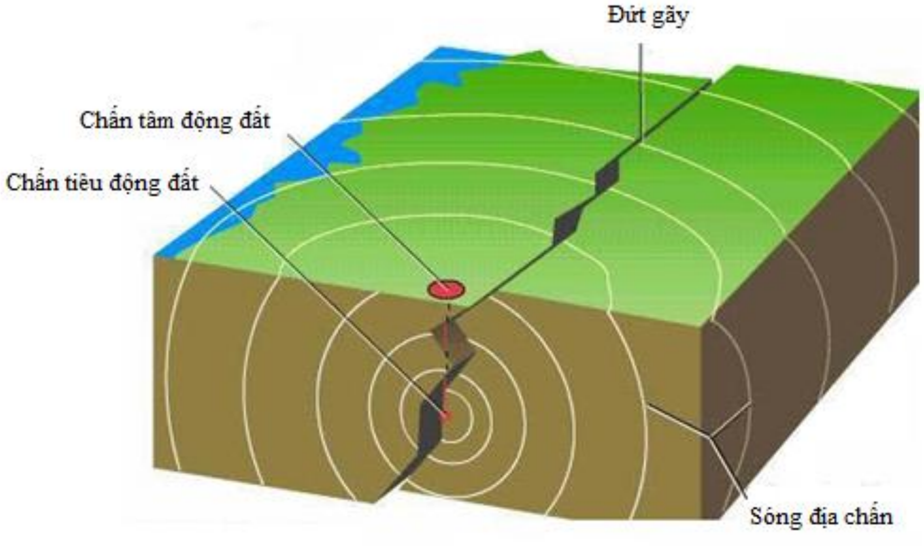


Figure 0.1 An earthquake model

Moment Magnitude Scale, a way to measure the strength of an earthquake, developed in 1979 by Tom Hanks and Kanamori Hiroo is a successor of the Richter scale (used formally in California, USA). It is used by many seismologists to compare the energy caused by an earthquake. The Moment Magnitude Scale (M_w) is calculated by the following equation.[25]:

$$M_w = \frac{2}{3}\left(\log_{10} M_0 - 9.1\right)$$

M_0 is moment magnitude (N.m), denoted explicitly with M_w.

Displacement is qualitatively assessed by studying any drag folding of strata.

The term "tsunami" is a borrowing from the Japanese tsunami 津波, meaning "harbor wave." Tsunamis is a kind of long wave, with high wavelengths and a long life cycle originating by strong geological forces under the sea or near the shores. Normal waves that we usually see in the ocean are caused by the wind blowing onto the surface of the ocean and are usually much weaker and shorter.

1.2. Caused for tsunami

Most tsunamis originate from powerful earthquakes outside the sea. The amount of earth moving leads to the rising or falling of the sea above it. Other activities such as volcanoes or sliding underwater or, in rare cases, meteoroids can be the causes of tsunami

1.3. Spread of tsunami

Tsunamis have some notable differences compared to normal waves caused by wind. While it is easy to recognize a wind-based wave, the highest point of the tsunami is very difficult to spot. Usually, tsunami waves can have a wavelength ranging from a couple of 10 of cms to a couple hundred. [31]

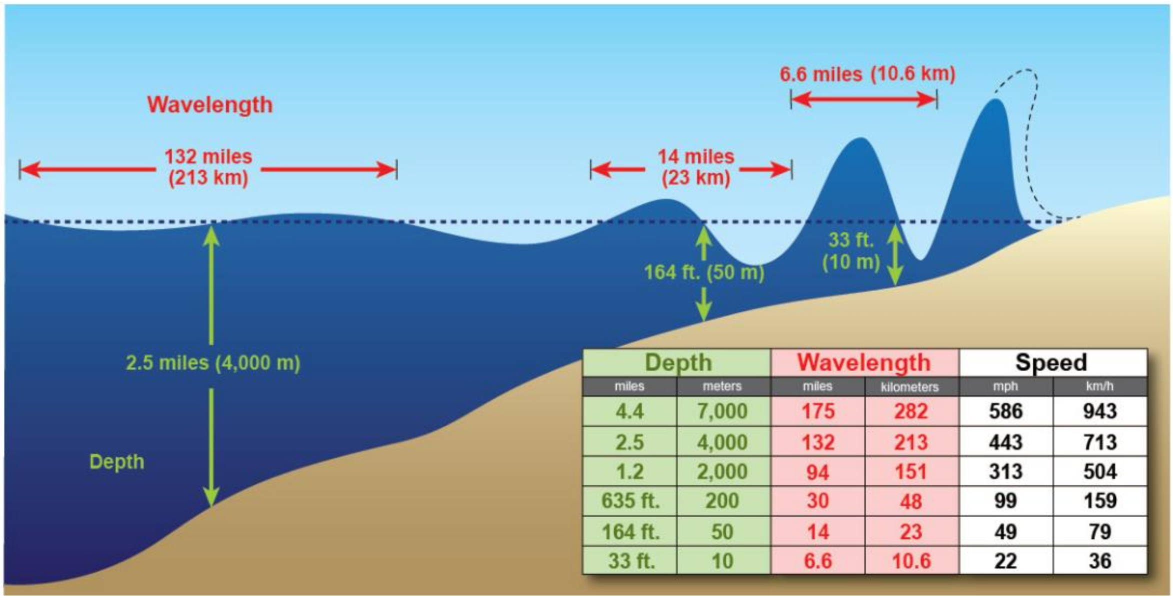
The speed of the tsunami also depends on the depth of the body of water according to the formula:

$$\boldsymbol{v} = \sqrt{\boldsymbol{gH}}$$

In which: g = 9.81 (m/s^2) is the gravitational constant of Earth. H is the depth of the sea.

For example, If H=10km then the speed of the tsunami will be v=313.2 m/s, and if H=1km then v=100m/s. Similarly when H=500 m then v=70m/s.

So, the speed of the wave can become extremely fast in the deep sea, up to 800km/h or equal to that of a commercial plane. Then the speed decreases as it approaches the shore.



Depth		Wavelength		Speed	
miles	meters	miles	kilometers	mph	km/h
4.4	7,000	175	282	586	943
2.5	4,000	132	213	443	713
1.2	2,000	94	151	313	504
635 ft.	200	30	48	99	159
164 ft.	50	14	23	49	79
33 ft.	10	6.6	10.6	22	36

Figure 0.2 Changes in the velocity of tsunamis.

The decrease in depth of the sea also comes with the decrease in speed, but because energy is preserved. So when the speed of the wave decreases then the height of the wave increases, sometimes up to several m or more than 10m. This explains why tsunami is difficult to spot out in the blue. Then suddenly, it crashed to the shore unexpectedly, causing a huge amount of damage. Although this can be mitigated by other factors such as coral reefs, rivers, etc..

1.4. Threat of Tsunami to the East Sea

Based on the maps of SouthEast Asia, (figure 1.3), we can see that the Vietnam Sea is surrounded by mainland China to the North; and a dense chain of Thailand and Malaysia's islands to the South-West side. While the Indonesia and Malaysia'islands shield the sea to the South, and the Philippines peninsula covers the East. All protected by all four sides, VietNam's shore will not be affected by tsunamis starting from outside the East Sea, so Vietnam will only be affected by tsunamis from inside the East Sea.

All the sources that can cause possible earthquakes are already identified in the East Sea region and other possible regions. Further research and analysis of the geological forces in the SouthEast region [1 -3, 5 - 10] has identified the two most dangerous causes: the Manila trench and the 109^0 Meridian Fault system. While the Manila trench is shown to cause much more damaging earthquakes, but the 109 Meridian Fault system are dangerous because of its proximity to the VietNam shores.

Figure 0.3 Maps of South East sea, East Sea is covered by islands and mainland China.

1.4.1. 109^0 Meridian Fault system

Located on the continental shelf and stretching approximately 1,000 km along the Central and Southern Central coasts of Vietnam, from 12^0 N to 6^0 N latitude the 109o Meridian Fault system has long been recognized as seismically active (Figure 1.4). From many results of many authors, the 109^0 Meridian Fault system has both a normal fault and a reverse fault. These fault lines have a connection to the formation of the East Sea and the interaction between the tectonic plates of Indo-Australian and Eurasian [33].

109^0 Meridian Fault system is huge, starting from the southwest Hai-nam island. Then it develops to the West of Borneo island and is divided by Tuy Hoa fault lines near 12^0 latitudes. In VietNam's tectonic regions, the fault lines are many similar lines, distributed across tens of kilometers of width and hundreds of kilometers of length to the North.

Many researchers have also investigated the 109^0 Meridian Fault system's ability to cause powerful earthquakes [8, 22, 9, 43]. Recorded earthquakes from the 109^0 Meridian Fault system aren't a lot and are distributed quite scarcely across the whole system, but it is concentrated on the fault lines South of Tuy-Hoa (figure 1.4). From past earthquake results, seismologists had estimated differing levels of earthquakes by the 109^0 Meridian Fault system. Nguyen Hong Phuong (1991, 2001, 2012) expected an earthquake ranging from 6.6 ± 0.28; Nguyen Dinh Xuyen (2004) expected an earthquake with a maximum energy of 6.1 on MMS; Le Tu Son (2006, 2010) thought that earthquakes had value between 6.4 ± 0.8; and Do Van Linh (2010) expected earthquakes to reach a maximum of 7.9 (fault line 2) [11, 13, 18, 22, 29].

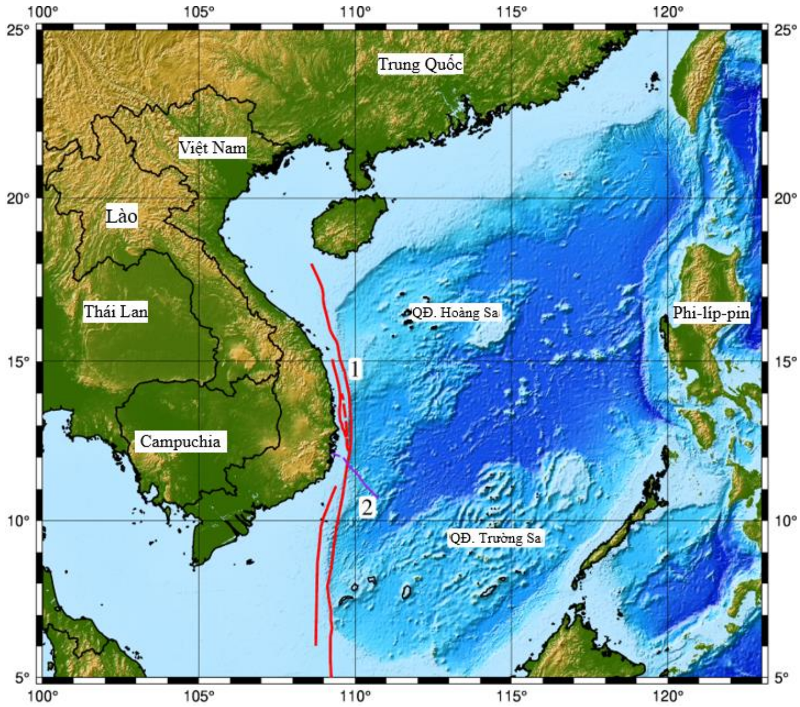


Figure 0.4 Fault zones on the continental shelf of Vietnam: Meridian 109^0 fault zone (red, thick); Suture zone Tuy Hoa (purple, thin)

1.4.2. The Manila Trench.

The Manila Trench is located on the West side of the Philippines peninsula with a length of 1200 km. The fault lines are distributed among the three main directions: From North to South, from 14^0 N to 18^0 N, North-East to South-West from 18^0 N, and North-West to South-East from the South at 14^0 N. Figure 1.5 shows the Manila trench and its recorded distribution of tsunami, volcanic, and earthquake activities in all of the East Sea. Data of earthquakes is taken from NEIC, from 1975 until now and all have a magnitude of 5.0 or above. The color depicts the depth of the sea. We can see that from the maps, the Manila trench's fault lines can be one big earthquake region that can create giant tsunamis. Because it is one of the two most active earthquakes hotspots of the planet, also known as the "Pacific Ring of Fire"

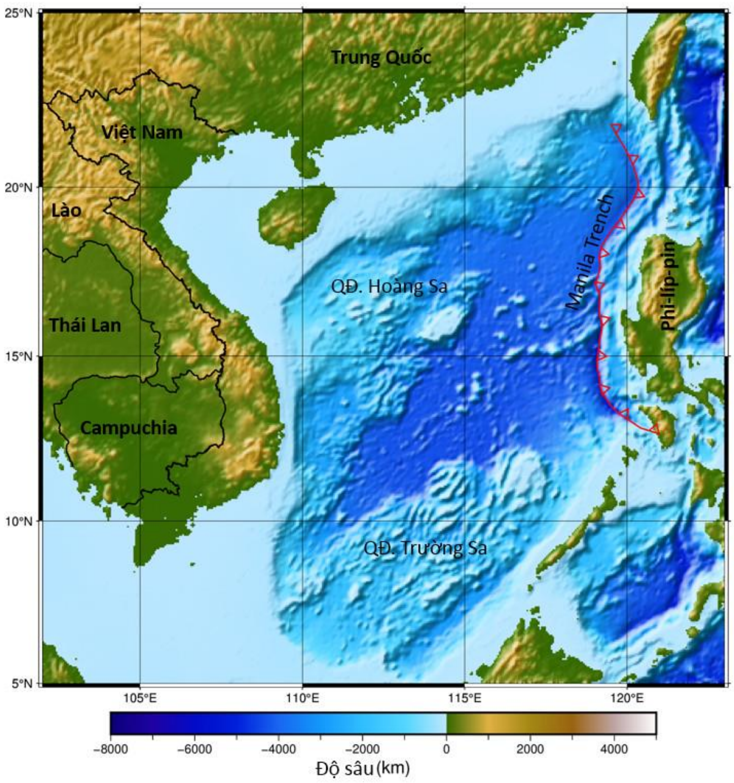


Figure 0.5 Location of the Manila Fault Super Fault Zone in the South China Sea.

The Manila fault lines still have strong seismic activity until now, so it has a high likelihood of making powerful earthquakes. From past seismic activity from Manila, authors Nguyen Hong Phuong and Nnk (2012) speculated the maximum earthquake magnitude, M_{max} = 8.7 by probability sampling and showed that it lies on the North side of the Fault lines [1]. Also, Qiang Qiu and Nnk (2019) used the sliding model to determine the maximum earthquake magnitude in the Manila area. The author had given out the maximum on three segments of the Manila Trench: Segment 1 (From 190^0 N to 220^0 N latitude) with an M_{max} = 9.03 prediction, Segment 2 (From 160^0 N to 190^0 N latitude) with an M_{max} = 9.18 and Segment 3 (From 140^0 N to 160^0 N latitude) with a M_{max} = 8.99 [20]. Furthermore, the Manila fault line is a reverse fault line (from 120^0 N to 180^0 N latitude), so it is very likely to make a big earthquake thus a huge tsunami [2].

1.5. Research content in the report

1.5.1. Research goal

Tsunami is one of the deadliest disasters of nature with a large capacity to cause damage. This research paper will estimate the effects of tsunamis on the shore of Vietnam, specifically damage to DaNang city, by using COMCOT.

1.5.2. Research primary content.

In this research paper, the author used the deterministic method; it helps build different scenarios for maximum tsunami by earthquakes or sliding under the sea.

CHAPTER 2: THEORETICAL BASIS OF TSUNAMI DANGER ASSESSMENT MODEL AND PROCEDURE.

1.6. Research area of interested.

The research area will be Da Nang City (figure 2.1). The geography location of Da Nang city extends from 15°15' to 16°40' N and 107°17' to 108°20' E with a total area of 1,285.4 km². It is adjacent to Thua Thien–Hue province to the north; touches Quang Nam province to the west and south; and meets the East Sea to the East.

Figure 0.6 Da Nang City (sources: Internet).

Da Nang city has a long shoreline,74 km (from the curved shore of Da Nang Bay to Fort Isabelle is 26 km + the shoreline surrounding Son Tra peninsula is 32 km + the shoreline from south of Son Tra peninsula to Dien Ngoc is 16 km).

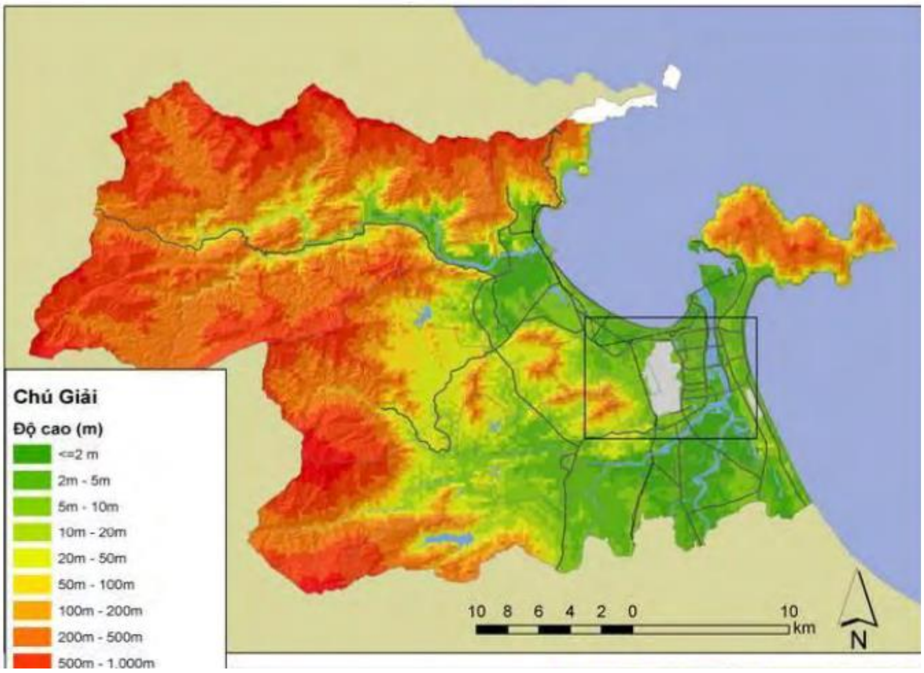


Figure 0.7 The map shows the elevated height from sea level of Da Nang City.

From the above map, we can see that Da Nang has an elevated ground from West to East. The city's geography is quite complex and diverse, with many high mountains, low valleys, and the plain near the sea and the river delta. The lowest part of the city sits 2m below sea level, distributed among Cu De delta, and Vu Gia-Thu Bon, including Cam Le, Vinh Dien, and Co Co River. The plain with an average height of 5m above sea level contributes around a fourth of the area of the city and is concentrated near the main delta and the shoreline. The Son Tra peninsula has a height of 693m

1.7. Research methods.

1.7.3. COMCOT's theoretical side

The study will simulate the tsunami disaster by using COMCOT (COrnell Multi-grid Coupled Tsunami model) first built by Cornell University, USA, and now developed to version 1.7, is one of three models (the other two are MOST and TUNAMI) most widely used to calculate the effects of the tsunami in the world and the South East Asian region write by Fortran with open sources.[2].

Linear and nonlinear shallow water equations in both Spherical and Cartesian Coordinates are implemented in COMCOT. For tsunamis in deep ocean, tsunami amplitude is much smaller than the water depth and linear shallow water equations in Spherical Coordinates can be applied

$$\frac{\partial\eta}{\partial t}+\frac{1}{Rcos\varphi}\left\{\frac{\partial P}{\partial\psi}+\frac{\partial}{\partial\psi}(cos\varphi Q)\right\}= -\frac{\partial h}{\partial t}$$

$$\frac{\partial P}{\partial t}+\frac{gh}{Rcos\,\phi}\frac{\partial\eta}{\partial\psi}-fQ=0$$

$$\frac{\partial Q}{\partial t}+\frac{gh}{R}\frac{\partial\eta}{\partial\psi}+fP=0$$

where η is the water surface elevation; (P, Q) denote the volume fluxes in X (West-East) direction and Y (South-North) direction, respectively; (ϕ, ψ) denote the latitude and longitude of the Earth; R is the radius of the Earth; g is the gravitational acceleration and h is the water depth. And the term − reflects the effect of transient seafloor motion, and can be used to model landslide-generated tsunamis. f represents the Coriolis force coefficient due to the rotation of the Earth and Ω is the rotation rate of the Earth.

$$f=\Omega\sin\varphi$$

Since the tsunami propagates over a continental shelf and approaches a coastal area, linear shallow water equations are no longer valid. The wavelength of the incident tsunami becomes shorter and the amplitude becomes larger as the leading wave of a tsunami propagates into shallow water. Therefore, the nonlinear convective inertia force and bottom friction terms become increasingly important, while the significance of the Coriolis force and the frequency dispersion terms diminishes. The nonlinear shallow water equations including bottom friction effects adequately describe the coastal zone's flow motion (Kajiura and Shuto, 1990; Liu et al., 1994). Furthermore, along the shoreline, where the water depth becomes zero, a special treatment is required to properly track shoreline movements

In COMCOT, the following nonlinear shallow water equations are implemented in Spherical Coordinates as

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\varphi}\left\{\frac{\partial P}{\partial \psi} + \frac{\partial P}{\partial \varphi}(\cos\varphi Q)\right\} = -\frac{\partial h}{\partial t}$$

$$\frac{\partial P}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left\{\frac{P^2}{H}\right\} + \frac{1}{R}\frac{\partial}{\partial \varphi}\left\{\frac{PQ}{H}\right\} + \frac{gH}{R\cos\varphi}\frac{\partial \eta}{\partial \psi} - fP + Fy = -\frac{\partial h}{\partial t}$$

$$\frac{\partial Q}{\partial t} + \frac{1}{R\cos\varphi}\frac{\partial}{\partial \psi}\left\{\frac{PQ}{H}\right\} + \frac{1}{R}\frac{\partial}{\partial \varphi}\left\{\frac{Q^2}{H}\right\} + \frac{gH}{R}\frac{\partial \eta}{\partial \varphi} - fP + Fy = -\frac{\partial h}{\partial t}$$

in which H is the total water depth and H = η + h; Fx and Fy represent the bottom friction in X and Y directions, respectively. And these two terms are evaluated via Manning's formula

$$Fx = \frac{gn^2}{H^{\frac{7}{3}}}Q(P^2 + Q^2)^{1/2}$$

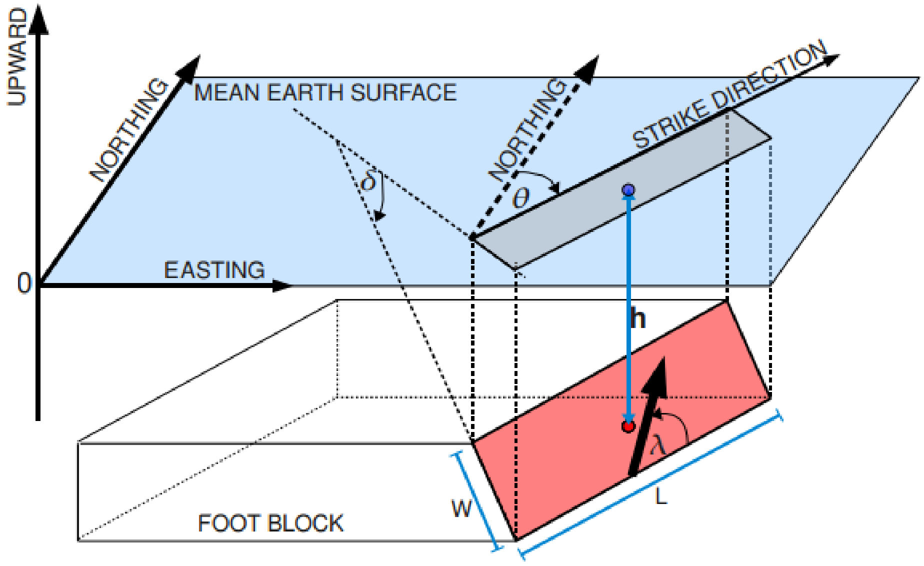
1.7.4. Instantaneous seafloor rupture

For instantaneous seafloor rupture, the seafloor displacement caused by an earthquake event is computed via elastic finite fault plane theory proposed originally by Mansinha and Smylie (1971) and then improved by Okada (1985). Both models are available in COMCOT. The theory assumes a rectangular fault plane being buried in semi-infinite elastic half-plane. This plane is an idealized representation of the interface between two colliding tectonic plates where violent relative motion (i.e., dislocation) occurs during an earthquake event (see Figure 3.1). The dislocation (or slip motion) occurring on the fault plane will then deform the surface of the semi-infinite medium, which is considered as the seafloor displacement during the earthquake event. To compute the deformation, the following fault parameters are necessary. The definition of these parameters can be seen in the table below

Table 0.1. Parameters and units of the Elastic Plane Model.

Variables	Units
Epicenter (Lat, Lon)	Degrees
Focal depth	Meters
Length of Fault Plane	Meters
Width of Fault Plane	Meters
Dislocation (slip)	Meters
Strike direction (θ)	Degrees
Dip angle (δ)	Degrees
Rake (slip) angle (λ)	Degrees

. In elastic fault plane theory, ***fault plane*** is where violent relative motion occurs in an earthquake event. Specifically, fault plane is assumed as a rectangular area of plate interface on the foot block and the top and bottom edges of the fault plane are parallel to the mean Earth surface. The orientation and position of this fault plane are 22 prescribed by its center location (ϕ0, ψ0), strike direction, and dip angle. The center of the fault plane is called ***focus*** and is the location where rupture starts during an earthquake event. Its projection on the mean surface of the Earth is called ***epicenter***. ***Focal depth*** is defined as the vertical distance between the focus and the epicenter. ***Strike direction*** is defined as the facing direction when someone stands on the top edge of a fault plane with foot block on his left-hand side and the fault plane on his right-hand side. Then ***strike angle***,θ, is the angle measuring clockwise from the local north to the strike direction. ***Dip angle***, δ, is the angle between the mean Earth surface and the fault plane, measured from the mean Earth surface down to the fault plane. The size of the fault plane is described by its length and width. The ***length*** of a fault plane, L, is defined as the length of its top edge or bottom edge (the edges parallel to the strike direction) and the ***width*** of the fault plane, W, refers to the length of one of the other two edges. The above parameters describe the size, location, and orientation of a fault plane. The rupture occurring on this fault plane is described by slip direction (i.e., rake) and dislocation (amount of slip motion). ***Slip Direction (rake)*** describes in which direction the hanging block moves relative to the foot block on the fault plane. ***Strike angle***, λ, is the angle measured counter-clock-wise from the strike direction to slip direction on the fault plane. ***Dislocation (slip amount)*** is the distance of motion of hanging block relative to the foot block along the strike direction on the fault plane.



MEAN EARTH SURFACE

FAULT PLANE (A RECTANGULAR SURFACE ON FOOT BLOCK)

PROJECTION OF FAULT PLANE ON MEAN EARTH SURFACE

SLIP DIRECTION ON FAULT PLANE (RELATIVE TO FOOT BLOCK

FOCUS OF AN EARTHQUAKE (CENTER OF FAULT PLANE)

EPICENTER (PROJECTION OF FOCUS ON EARTH SURFACE)

δ DIP ANGLE OF FAULT PLANE

λ SLIP DIRECTION ON FAULT PLANE (RAKE ANGLE)

θ STRIKE ANGLE

H FOCAL DEPTH

L LENGTH OF FAULT PLANE

W WIDTH OF FAULT PLANE

Figure 0.8 Sketch of a Fault Plane and Fault parameter definitions.

Since the floor displacement is evaluated over a plane, special handling is required to map it onto the mean Earth Surface (i.e., Ellipsoidal surface). Oblique Stereo-graphic Projection (Snyder, 1987) is implemented in COMCOT to map the surface of 23 an Ellipsoid (the Earthquake) onto a plane by taking the epicenter as where the plane is tangential to the Earth's surface. For this projection in COMCOT, the Earth is described by WGS84 Datum (i.e., semi-major axis a = 6378137.0m and semi-minor axis b = 6356752.3142m with scaling factor k0 = 0.9996). With this projection method, each location (ϕ, λ) on the Earth surface (Ellipsoidal surface), corresponds to a point (x, y) on the plane tangential to the Earth surface at the epicenter (ϕ0, λ0), whose displacement can be computed via either Mansinha and Smylie’s method or Okada’s approach

Apply the COMCOT module to stimulate different scenarios where the tsunami, due to earthquakes and sliding, hit the coastal areas of VietNam, originating from the South-East Sea. Specifically, the author used 3 different levels of detail stimulation. Level 1 will cover the whole South Sea (from 98^0E to 125^0E longitude and from 2^0S to 25^0N latitude) with a stimulation time is 1 minute of runtime for every second. Level 2 zone is for the Coastal South areas of Vietnam with 0.5 (minute/s), and level 3 will cover the coastal area of Da Nang city with 0.025 (minute/s) (from 15.80^0E to 16.30^0E longitude and 108.0^0N to 108.6^0N latitude).

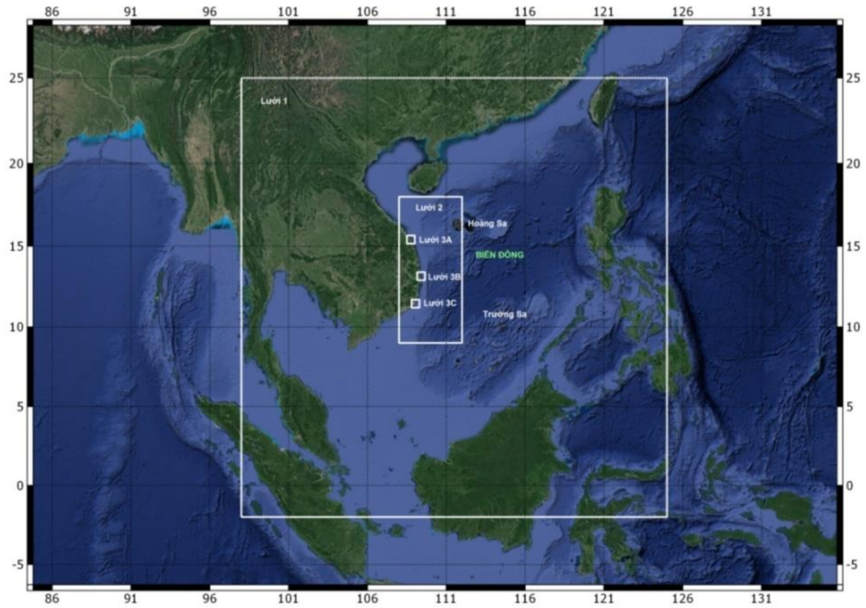


Figure 0.9 The level systems

These levels have different details that correspond negatively to the area of the levels, or the less the area of the levels is the more detailed results it can have. These results of levels 1,2 and 3 are usually in the form of maps and graphs displaying the highest wave heights and time. Data was used from the Web(: *https://www.gebco.net*) to stimulate the tsunami.

1.8. Tools and web used

In the research, the author used COMCOT to module different tsunami scenarios, in the South-East sea that can have an impact on the coastal area of VietNam, caused by earthquakes or sliding under the sea. Matlab, Excel, … was used to help draw graphs and maps. So, we can have a more overall look at the results from COMCOT.

1.9. Steps taken to evaluate the danger of tsunami

Step to evaluate the danger of tsunami for the south-coastal area of Vietnam.

Step 1: Locate the sources of earthquakes and underground sliding in the Southeast Sea. In this research, I am going to look at the Manila trench and the 109 fault lines.

Step 2: Pick tsunami scenarios due to earthquake or sliding for the simulation

Step 3: For every scenario, apply COMCOT to stimulate the sources and the aftermath.

Step 4: Calculate the value for the maximum wave heights at every instance of the levels covering the VietNam coastal area.

CHAPTER 3: TSUNAMI HAZARD ASSESSMENT FOR COASTAL AREA OF DA NANG

1.10. Earthquake scenario

1.10.5. 109^0 meridian fault

Based on the structural characteristics of the 109^0 meridian fault source zone and using deterministic methods to construct maximum earthquake scenarios arising on the source zone of the 109^0 meridian fault tsunami, with the initial assumption that the scenario earthquake magnitude is Mw = 8.0. This earthquake magnitude value is the upper bound of the maximum earthquake magnitude predicted by Vietnamese seismologists for this source. In addition, the depth of seismic focus is assumed to be H = 15 (km), the destruction zone is considered to be rectangular with a length of L (km) and a width of W. The location of the destruction zone is to the north of Tuy Hoa - Phu Yen suture zone). This scenario was chosen so that the impact of the tsunami on the South Central region, Vietnam was the greatest.

Intial Variables inputs for the stimulation such as width, length and displacement of the fault depends on MM (moment magnitude)(M_w). To calculate this variable, this paper had used theoretical formula by Wells and Coppersmith (1994) [24]. These are the steps for the input variables.

*Step 1: Determined the length of the fault **L (km)**, by MM, M_w.*

$$\text{Log}_{10}L = -2.86 + 0.63\,M_w \quad \text{with } H = 15\ (\text{km})$$

*Step 2: Determined the width of the fault **W (km)** and areas **A (km^2)** through MM, M_w.*

$$\text{Log}_{10}A = -3.99 + 0.98\,M_w$$

*Step 3:, Determined the displacement **D (m)** through MM, M_w.*

$$\text{Log}_{10}D_{tb} = -4.80 + 0.69\,M_w$$

Step 4: verify the likeliness of the earthquakes variables by Hanks and Kanamori formula (1979) [25].

$$M_w = 2/3\log_{10}M_0 - 10.7$$

with $M_0 = \mu DLW$ and $\mu = 3 \times 10^{10}$ (N/m); μ is sideway magnitude of the rock.

Table 0.2. Defined source parameters for two earthquake-induced tsunami scenarios arising on the 109^0 meridian fault source zone (M_w = 8.0).

	Longitude	**Latitude**	**Mw**	**Length (km)**	**Width (km)**	**Displacement (m)**	**Depth (km)**	**Strike Direction (degrees)**	**Dip Angle (degrees)**	**Slip angle (degrees)**
01	109.519	14.989	8.0	151.356	46.774	5.25	15	345.00	45.00	90

1.10.6. The Manila Fault

The Manila Fault is thought to be more likely to produce earthquakes than the 109th meridian fault, but the distance of the Manila Fault is farther. Use deterministic methods to construct scenarios of maximum earthquakes arising on the source zone of the Manila meridian fault where the tsunami occurred, with the initial assumption with a scenario earthquake magnitude of M_w = 9.0. This earthquake magnitude value is the upper bound of the maximum earthquake magnitude predicted by Vietnamese seismologists for this source. In addition, the depth of seismic focus is assumed to be H = 30 (km), the destruction zone is considered to be rectangular with a length of L (km) and a width of W. The location of the destruction zone is at 119.18 Longitude and 16.43 Latitude. This scenario was chosen so that the impact of the tsunami on the South Central region, Vietnam was the greatest. The method for calculating L and W will be the same as for the 109th meridian. These are the inputs for the Manila Fault

Table 0.3. Defined source parameters for two earthquake-induced tsunami scenarios arising on the Manila Fault source zone (M_w = 9.3).

	Longitude	Latitude	Mw	Length (km)	Width (km)	Displacement (m)	Depth (km)	Strike Direction (degrees)	Dip Angle (degrees)	Slip angle (degrees)
01	**119.182**	**16.430**	**9.0**	**645.654**	**104.713**	**25.70**	**30**	**355.99**	**8.46**	**90**

1.11. Tsunami Hazard Assessment.

1.11.1. The earthquake created a Tsunami at the 109^0 Meridian Fault.

In this section presents tsunami danger assessment for the South Central coastal strip region in the event of a tsunami arising from an earthquake in the 109th meridian with M_w = 8.0 The theoretical parts of the COMCOT Model were used Instantaneous Deformation Elastic Fracture Module for earthquake scenario simulation. The results obtained by the simulation include: maps of the distribution of maximum wave height, tsunami propagation time from the source of the tsunami to virtual sea-level monitoring stations (or measuring stations for short).

Below are tsunami propagation images of earthquake scenarios over the South China Sea and surrounding areas.

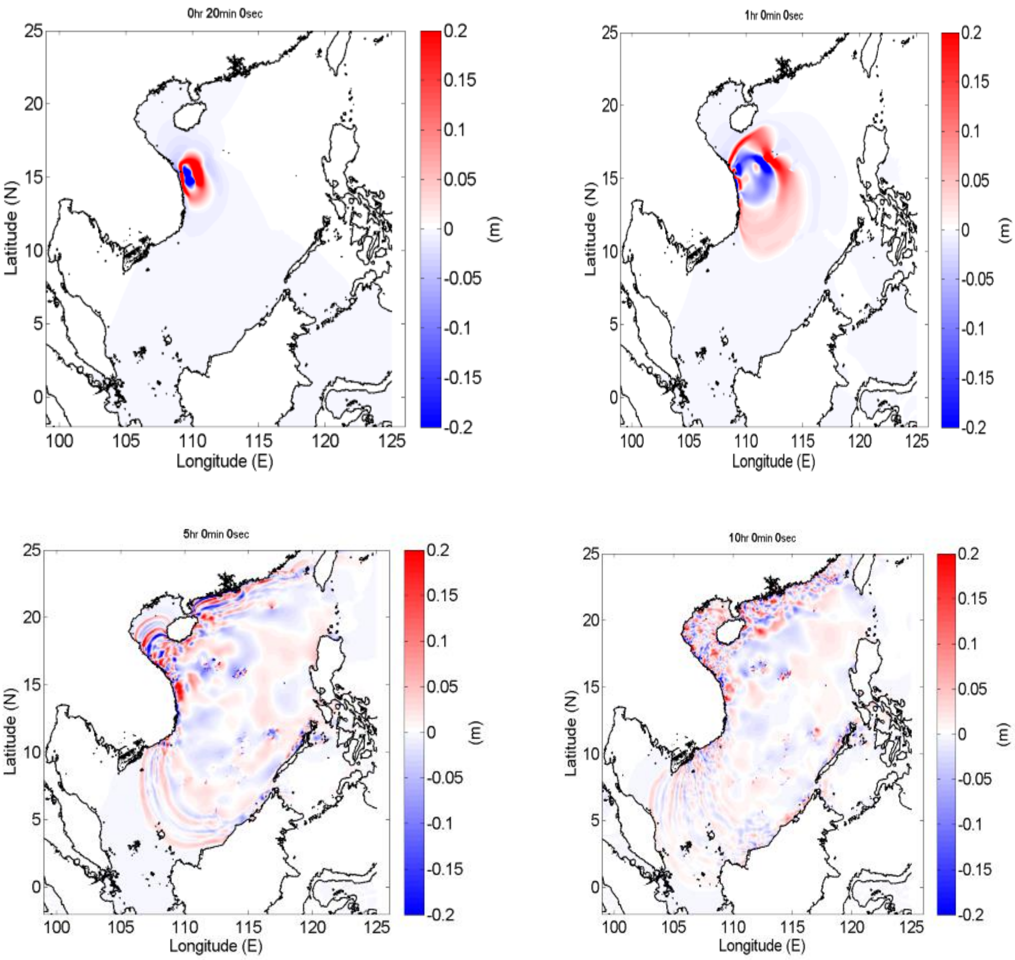


Figure 0.10 The images spread tsunami waves caused by earthquakes at the 109^0 meridian fault over time over the South China Sea and nearby.

Within the scope of the thesis, maps of the maximum tsunami altitude distribution will be established with a standard color scale developed by the Pacific Regional Tsunami Warning Center (PTWC) [32]. Specifically, the division of wave height and corresponding color is as follows: The maximum tsunami height corresponds to H_{max} = 0.0 - 0.3 m (white, not dangerous); 0.3 - 1.0 m (blue, attentive to information intake and readiness for action)); 1.0 - 3.0 m (yellow, danger level, stay away from coastal areas); from 3.0 m or more (red, very dangerous level, urgent evacuation is required).

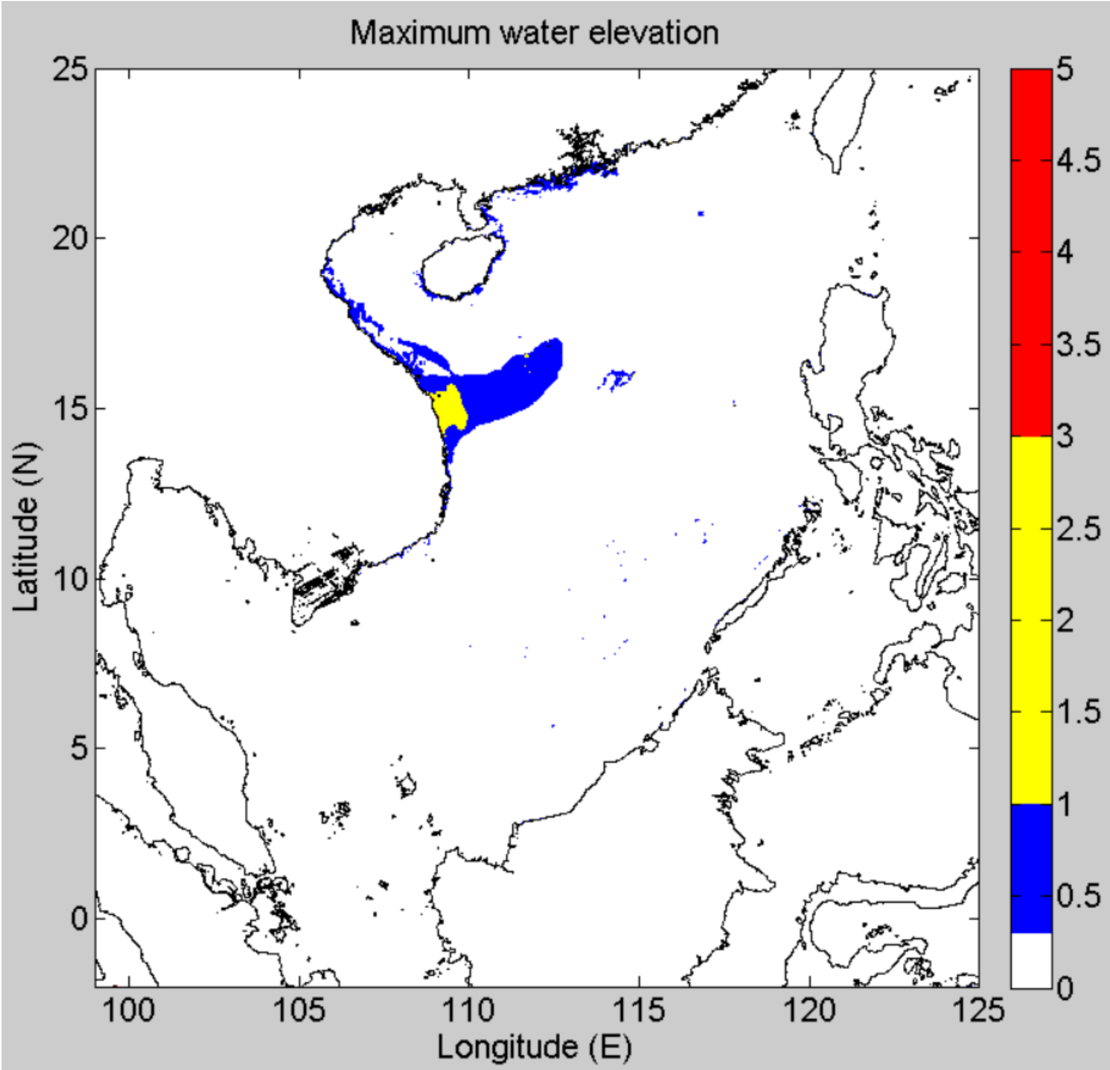


Figure 0.11 Maximum tsunami height over the East Sea of Vietnam according to the meridian fault scenario 109^0, M_w = 8.0.

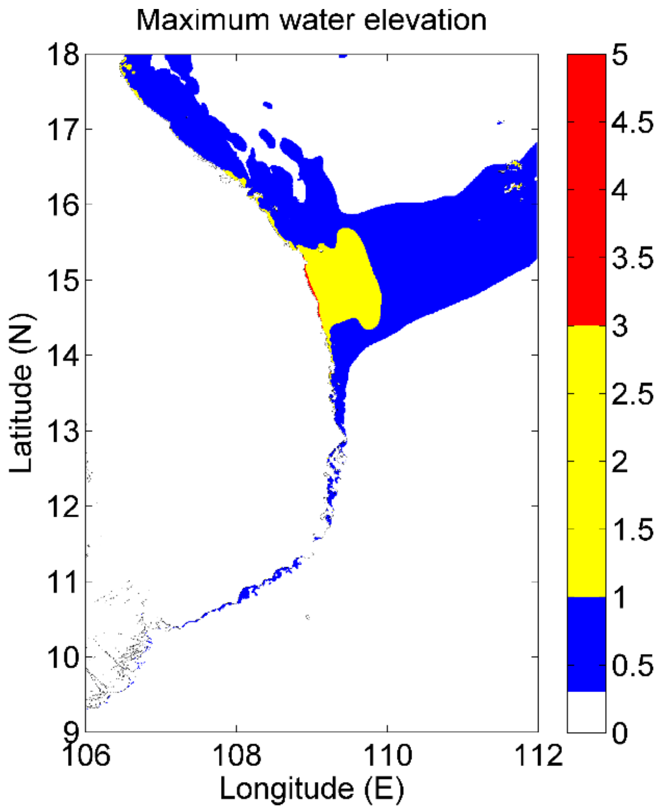


Figure 0.12. Maximum tsunami height over the South Central coastal area under the 109^0 meridian fault scenario, $M_w = 8.0$.

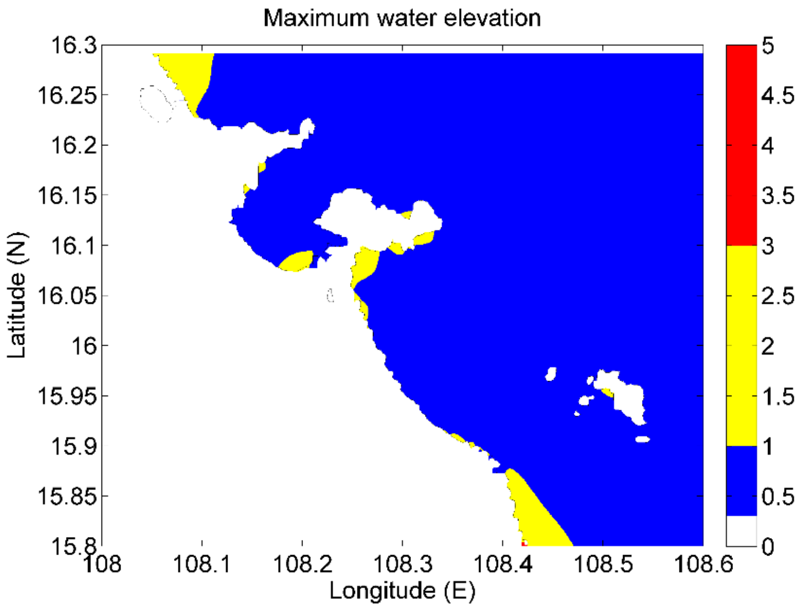


Figure 0.13. Maximum tsunami height over the coastal area of Da Nang according to the meridian fault scenario 109^0, $M_w = 8.0$.

Based on the maps of the maximum tsunami height distribution corresponding to the earthquake scenario arising from the source zone of the 1090th meridian fault, it can be seen that the impact of the tsunami on the coastal strip of Da Nang is mainly at a non-dangerous level. Similar to the Da Nang area, the Paracel Islands have the maximum tsunami height recorded at some monitoring points as follows: H_{max} = 1.423 m (Hoang Sa 4 station), Da Nang has H_{max} = 0.822 m (Da Nang 5 station), with the above tsunami height, although not dangerous, must still be ready for action.

The results of virtual water level measuring stations are also graphically represented corresponding to the tsunami amplitude values that change over time. The maximum tsunami height corresponding to the propagation time when reaching each measuring station is listed in the value table.

Figure 3.5 High-level tsunami variable through virtual measuring stations in coastal areas of Da Nang and Paracel Islands (Vietnam) for the 109^{0} meridian fault scenario, $M_w = 8.0$.

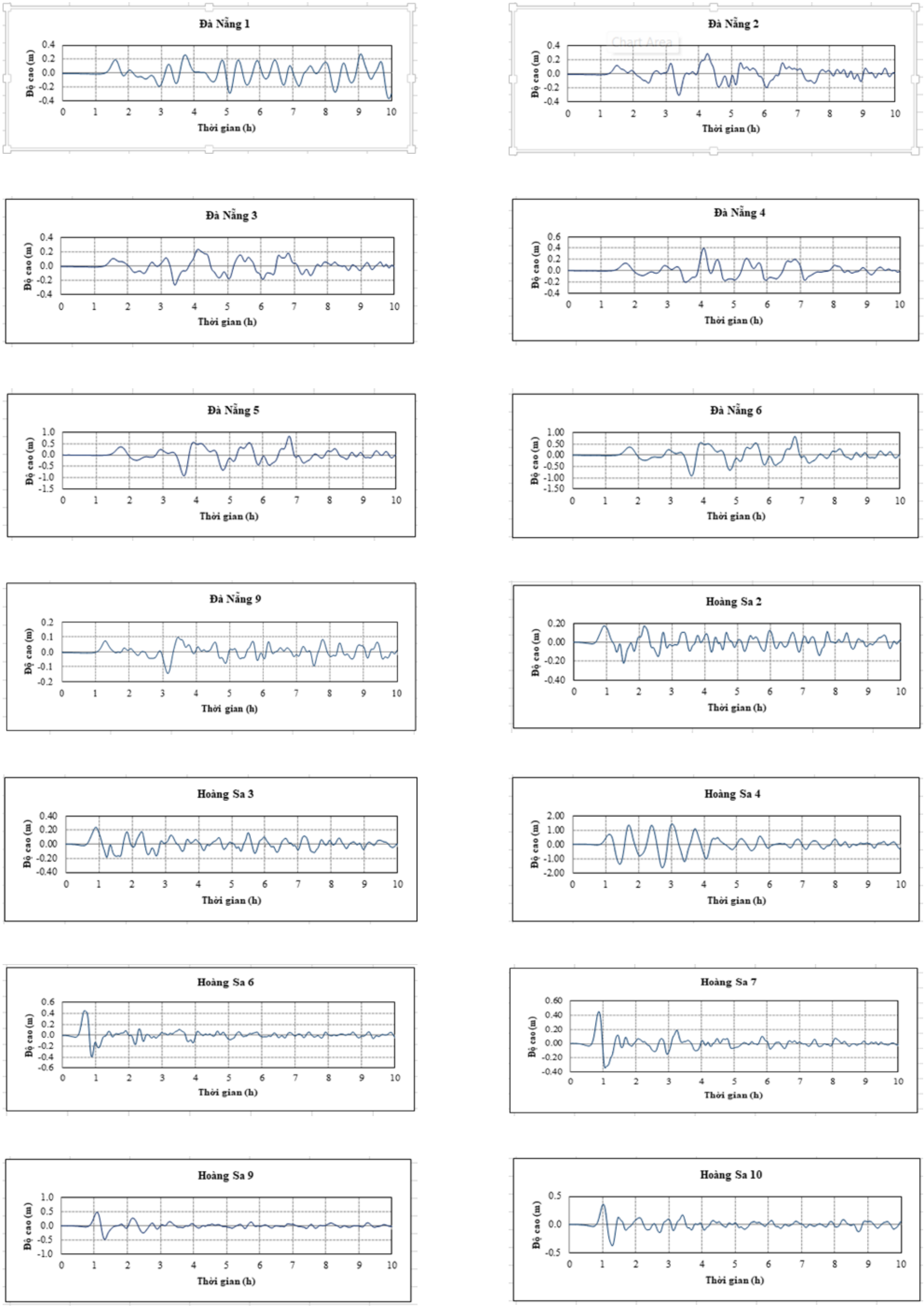


Table 0.4. Location and tsunami danger parameters at virtual sea-level monitoring stations calculated from the maximum tsunami scenario (M_w = 8.0) arising on the source zone of the 109^0 meridian fault.

No.	Region	Station's name	Longitude	Latitude	Meridian Scenario 109	
					Wave heights (m)	Travel time (hh:mm)
1	Viet Nam	Da Nang 1	108.18	16.08	0.275(*)	09:05(*)
2	Viet Nam	Da Nang 2	108.21	16.09	0.289(*)	04:17(*)
3	Viet Nam	Da Nang 3	108.22	16.14	0.237(*)	04:07(*)
4	Viet Nam	Da Nang 4	108.3	16.14	0.395(*)	04:06(*)
5	Viet Nam	Da Nang 5	108.33	16.11	0.822(*)	06:48(*)
6	Viet Nam	Da Nang 6	108.26	16.08	0.431(*)	04:17(*)
7	Viet Nam	Da Nang 9	108.250	16.075	0.793(*)	03:42(*)
8	Viet Nam	Da Nang 10	108.269	16.012	0.135(*)	03:46(*)
9	Viet Nam	Hoang Sa 2	111.58	16.24	0.239	00:55
10	Viet Nam	Hoang Sa 3	111.26	15.83	0.576	00:53
11	Viet Nam	Hoang Sa 4	111.83	16.02	1.423(*)	03:02(*)
12	Viet Nam	Hoang Sa 6	112.04	16.39	0.449	00:52
13	Viet Nam	Hoang Sa 7	112.45	16.09	0.543	00:58

14	Viet Nam	Hoang Sa 9	112.292	16.920	1.095	01:55
15	Viet Nam	Hoang Sa 10	112.450	16.093	0.361	01:02

(Cases marked (*) are the highest wave to the first.)

After analyzing the tsunami height variable graph, we can see that the maximum tsunami height at the measuring stations is usually less than 1m. Specifically, the highest maximum tsunami height at 3 stations: Da Nang 5 (H_{max} = 0.822 m), Hoang Sa 4 (H_{max} = 1,423 m), Hoang Sa 9 (H_{max} = 1,095 m). The comparison of these results is quite similar to the study that authors Vu Thanh Ca and nnk., previously published. The author simulated earthquake-induced tsunami scenarios (M_w = 7.0) arising over the source region of the 109^0 meridian fault using the MOST model. These results include that the maximum altitude in the coastal area of South Central Vietnam, Vietnam has an H_{max} of < 1.0 m and the shortest propagation time from the source of the tsunami to the coast of this area is less than 1 hour [8]. Based on the calculation and simulation results, the impact of the tsunami caused by the source zone of the 1090th meridian fault on the waters of Da Nang and the Paracel Islands is not large. However, this is still one of the two source areas assessed by experts as potentially dangerous to Vietnam's coastal areas.

1.11.2. Tsunami created by Earthquaked in Manila Fault.

In this section, a tsunami hazard assessment is presented for the South Central coastal strip region in the event of a tsunami arising from an earthquake in the Manila Meridian with M_w = 9.0. Using the COMCOT model, the results obtained by the simulation include: maps of maximum wave height distribution, tsunami propagation time from the tsunami source to virtual sea level monitoring stations (or measuring stations for short).

Below are tsunami propagation images of earthquake scenarios over the South China Sea and surrounding areas.

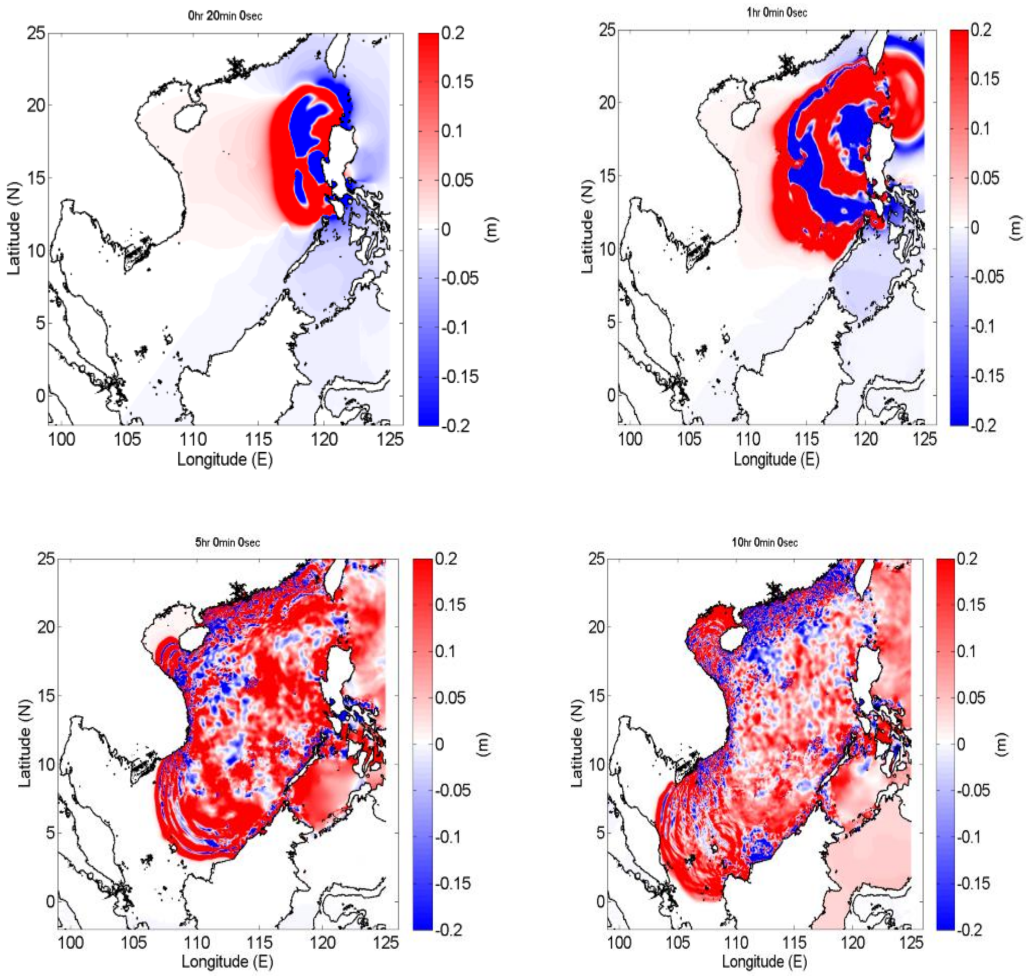


Figure 0.14. Images spread tsunami due to earthquakes at the Manila Fault over time over the South China Sea and surrounding waters.

Within the scope of the thesis, maps of the maximum tsunami altitude distribution will be established with a standard color scale developed by the Pacific Regional Tsunami Warning Center (PTWC) [32]. Specifically, the division of wave height and corresponding color is as follows: The maximum tsunami height corresponds to H_{max} = 0.0 - 0.3 m (white, not dangerous); 0.3 - 1.0 m (blue, attentive to information intake and readiness for action)); 1.0 - 3.0 m (yellow, danger level, stay away from coastal areas); from 3.0 m or more (red, very dangerous level, urgent evacuation is required).

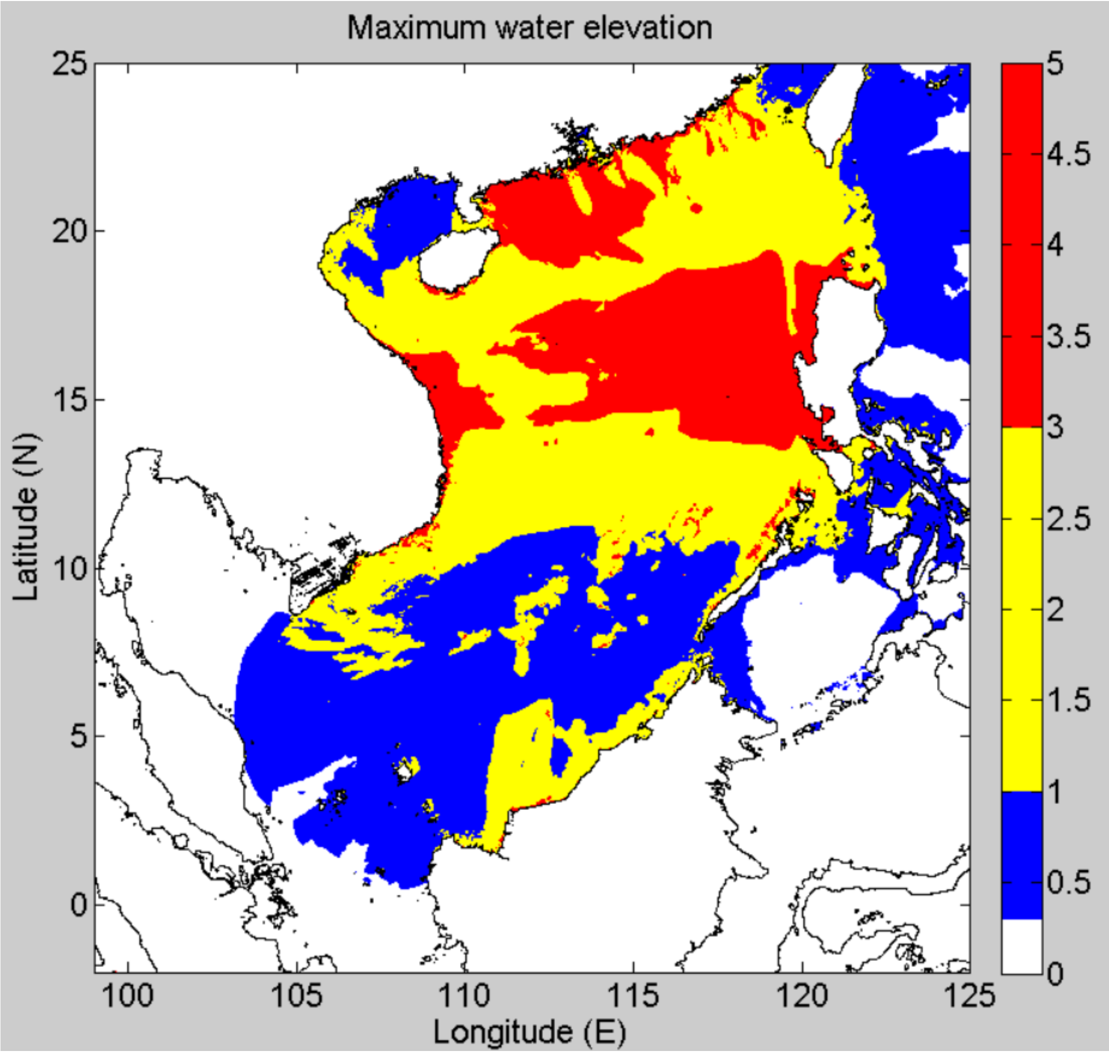


Figure 0.15 Maximum tsunami height over the East Sea of Vietnam under the scenario of the Manila Super Fault, $M_w = 9.0$.

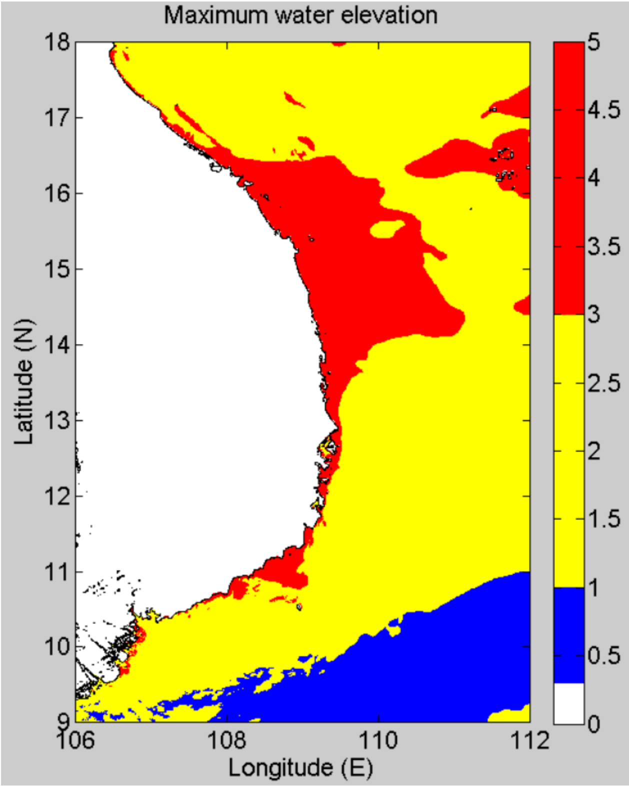


Figure 0.16. Maximum tsunami height over coastal area of Da Nang according to Manila Super Fault scenario, M_w = 9.0.

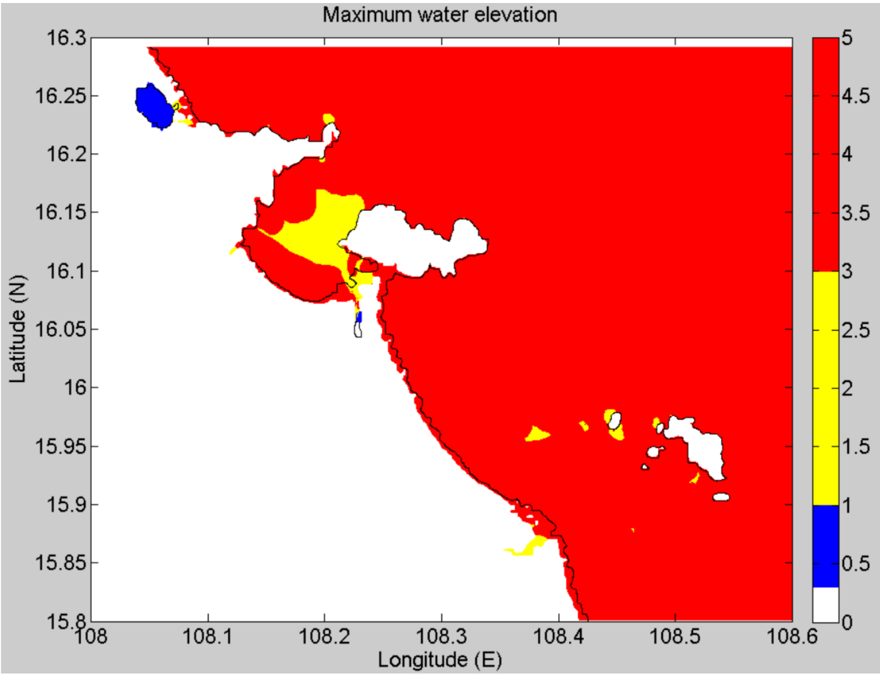


Figure 0.17. Maximum tsunami height over coastal area of Da Nang according to Manila Super Fault scenario, M_w = 9.0.

Based on the maps of the maximum tsunami height distribution of the Manila Fault source zone scenario, it can be seen that the impact of the source zone on the coastal area of Da Nang is at a great danger level. Paracel Islands have H_{max} = 6.539 m (Hoang Sa 3 station), Da Nang has H_{max} = 5.794 m (Da Nang 9 station).

The results of virtual water level measuring stations are also graphically represented corresponding to the tsunami amplitude values that change over time. The maximum tsunami height corresponding to the propagation time when reaching each measuring station is listed in the value table.

Figure 3.10.High-level tsunami variable through virtual measuring stations in coastal areas of Da Nang and Paracel Islands (Vietnam) for Manila Fault scenario, M_w = 9.0.

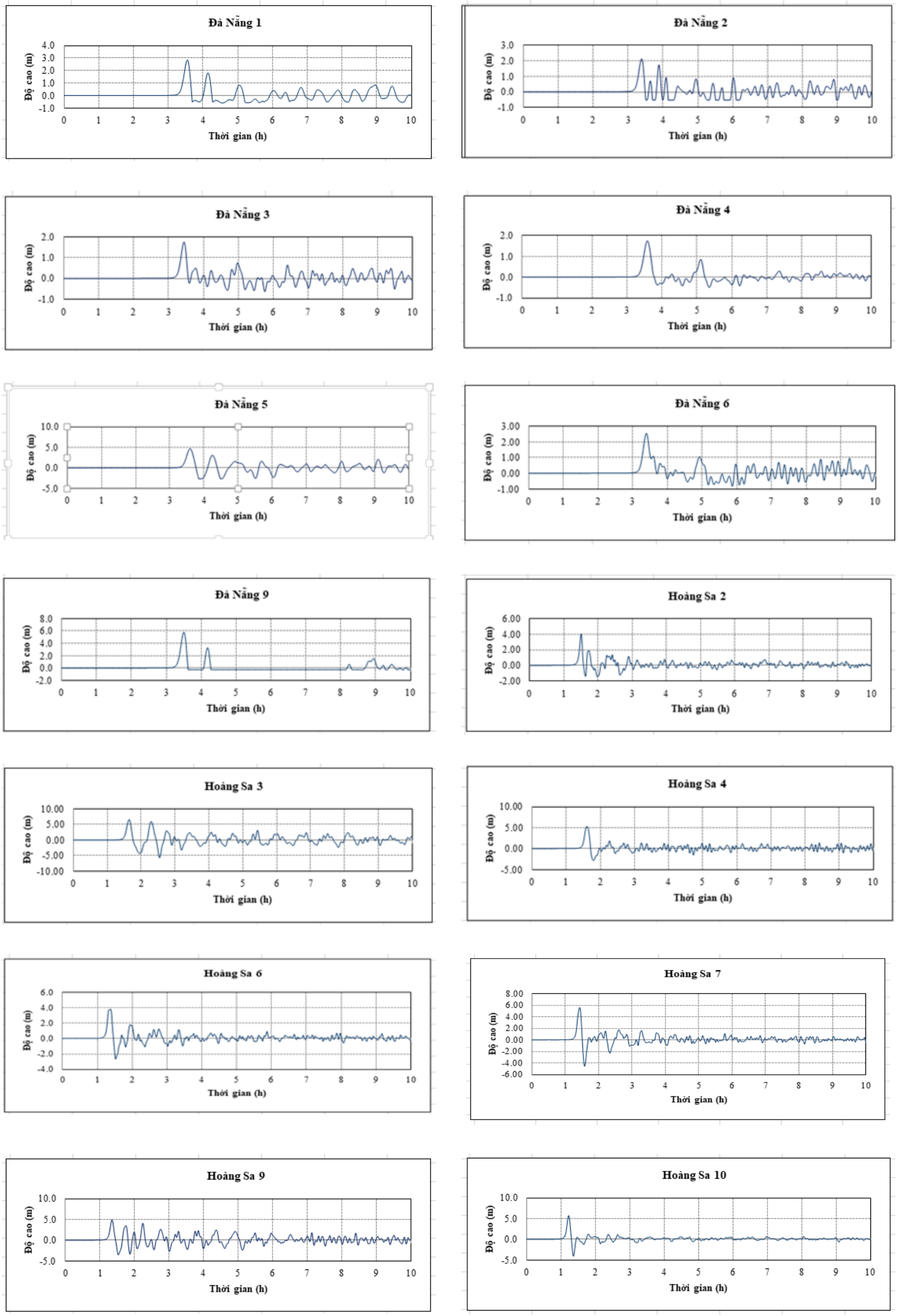


Figure 0.18. Transforming high-level tsunami through virtual measuring stations in the Paracel Islands coastal area for Manila Fault scenario, M_w = 9.0.

Table 0.5. Location and tsunami danger parameters at virtual sea level monitoring stations calculated from the maximum tsunami scenario (M_w = 9.0) arising over the Manila Fault source zone.

No.	Region	Station's name	Longitude	Latitude	Meridian Scenario 109	
					Wave heights (m)	Travel time (hh:mm)
1	Viet Nam	Da Nang 1	108.18	16.08	2.847	03:33
2	Viet Nam	Da Nang 2	108.21	16.09	2.117	03:24
3	Viet Nam	Da Nang 3	108.22	16.14	1.746	03:27
4	Viet Nam	Da Nang 4	108.3	16.14	1.744	03:36
5	Viet Nam	Da Nang 5	108.33	16.11	4.684	03:36
6	Viet Nam	Da Nang 6	108.26	16.08	2.544	03:24
7	Viet Nam	Da Nang 9	108.250	16.075	5.794	03:31
8	Viet Nam	Da Nang 10	108.269	16.012	1.307	03:31
9	Viet Nam	Hoang Sa 2	111.58	16.24	4.067	01:31
10	Viet Nam	Hoang Sa 3	111.26	15.83	6.539	01:39
11	Viet Nam	Hoang Sa 4	111.83	16.02	5.300	01:37
12	Viet Nam	Hoang Sa 6	112.04	16.39	3.831	01:23
13	Viet Nam	Hoang Sa 7	112.45	16.09	5.618	01:26
14	Viet Nam	Hoang Sa 9	112.292	16.920	4.910	01:21
15	Viet Nam	Hoang Sa 10	112.450	16.093	5.726	01:14

(Cases marked (*) are the highest wave to the first.)

After analyzing the tsunami height variable graph, we can see that the maximum tsunami height at the measuring stations is usually less than 7 m. Specifically, the highest maximum tsunami height at 3 stations: Hoang Sa 3 (H_{max} = 6,539 m), Da Nang 9 (H_{max} = 5,794 m), Hoang Sa 10 (H_{max} = 5,726 m).

Comparing these results is quite similar to the study published by Nguyen Hong Phuong and NNK [2]. The author simulates an earthquake-induced tsunami scenario (M_w = 9.3) arising over the Manila Fault source zone using the COMCOT model. In particular, the maximum tsunami height in Da Nang reached 10.2m and the propagation time was 3 hours and 26 minutes [2, 30].

Thus, it can be seen that the tsunami generation capacity of the Manila Fault is extremely large compared to the source of the 109^0 Meridian Fault. With a wave height greater than 7m, tsunamis from the Manila Fault source can cause high damage not only to the city of Da Nang or the South Central Sea, Vietnam but also the entire South China Sea.

CHAPTER 4: CONCLUSION AND RECOMMENDATION

CONCLUSION

From the results obtained on the basis of simulations of two earthquake-induced tsunami scenarios from the 109^0 Meridian fault zone and the Manila Fault source zone, the following conclusions can be drawn:

From the simulation results of the model, the tsunami scenario arising on the 109^0 meridian fault has not too high results. For Da Nang city, this is the nearest tsunami source area. The maximum altitude is 0.822 m (Da Nang 5 station) for Da Nang city and 1.423 m (Paracel 4 station) for Paracel Islands. The shortest time for a tsunami to travel is 53 minutes (Paracel 3 station). According to the results of previous studies, in the South Central and Southern Vietnam, there are some coastal provinces with wave heights of up to 4m when there is a tsunami at the 109^0 meridian fault.

For the tsunami scenario arising over the Manila Fault, the tsunami height in Da Nang reaches 5,794 m (Da Nang 9 station) and 6,539 m (Paracel 3 station). The shortest propagation time from the source of the tsunami takes 01 hour 14 minutes with a wave height of up to 5,726 m (Paracel 10 station). With the maximum tsunami height, the forecast above will cause great damage to Da Nang city, Paracel Islands and the coastal strip of Vietnam. Although there has never been an earthquake as large as $M_w = 9.0$ as in the scenario, there is still a need for evacuation plans and structures to minimize wave height as much as possible to respond to this scenario.

RECOMMENDATION

In this Thesis, the author has simulated maximum tsunami scenarios due to earthquakes, underground slides on the seabed. The results provide certain assessments of tsunami danger for the South Central coastal strip region of Vietnam from these two causes. In order to assess the danger to this area in more detail, it is necessary to simulate many tsunami scenarios arising on tsunami source zones close to the coast of Vietnam (source zone of meridian fault 109^0 and source zone of undersea slides in the South Central Sea area, Vietnam). In addition, it is necessary to assess the tsunami danger from other tsunami source areas such as the North source area of the East Sea, the source area of Pa la oan, ... there is a possibility of a tsunami affecting the coastal strip area of Vietnam in general, South Central Vietnam, Vietnam in particular.

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ADDENDUM

1. Earthquake catalogue table

List of earthquakes in the study area (within R = 300 (km) from the site of Ninh Thuan).

N⁰	Year	Month	Day	Hour	Mins	Sec	Lat	Long	Depth (km)	M	I_o	Noted
1	1715	3		0	0	0	13.5	109.2	0	4.1	V	Historic earthquakes
2	1877			0	0	0	10.56	108.05	0	5.1	VII	
3	1882			0	0	0	10.56	108.2	0	5.1	VII	
4	1918	8	16	14	22	20	9	110	0	0		
5	1923	2	15	0	0	0	10.1	109	0	5.1	VII	
6	1923	5	2	0	0	0	10.1	109	0	6.1	VIII	
7	1924	12	27	6	40	30	14	109	0	0		
8	1926	8	15	16	53	45	14	109	0	0		
9	1928	6		0	0	0	13.32	108.52	0	5	VI+	
10	1935	2	21	1	0	0	10	111	0	0		
11	1950			0	0	0	13.1	109.3	0	4.8	VI+	
12	1955			0	0	0	11.1	108.4	0	3.4	IV	
13	1960	2	29	3	13	40	11.1	109.1	0	4.1	V+	
14	1960	7	3	8	17	5	9.1	108.3	0	5.1	VII	
15	1963	5	7	6	17	42	11.4	109.6	0	3.9	VI	
16	1963	7	5	6	41	35	12	109	0	0		Weak earthquake recorded at Nha Trang seismic measuring station
17	1963	8	22	3	25	15	11.9	109.8	0	0		
18	1963	12	7	21	59	20	11.9	109.4	0	0		
19	1964	2	2	18	0	6	11.6	109.6	0	0		
20	1964	2	3	18	42	51	11.7	109.6	0	0		
21	1964	2	4	1	1	25	11.3	109.6	0	0		
22	1964	5	2	5	19	1	11.8	109.7	0	0		
23	1964	8	3	3	1	49	11.2	109.6	0	0		
24	1964	8	6	7	6	23	11.8	109.9	0	0		
25	1964	8	7	5	54	46	11.1	109.6	0	0		

N^0	Year	Month	Day	Hour	Mins	Sec	Lat	Long	Depth (km)	M	I_o	Noted
26	1964	8	8	10	35	40	11.7	109.8	0	0		
27	1964	8	8	22	16	49	10.3	106.8	0	0		
28	1964	9	12	22	52	16	11.4	109.6	0	0		
29	1964	9	19	8	38	17	10.8	109.6	0	0		
30	1964	9	21	8	51	9	11.5	109.6	0	0		
31	1964	10	1	2	43	20	10.6	109.6	0	0		
32	1964	10	5	9	59	9	9.6	108.9	0	0		
33	1965	1	17	1	41	42	11.8	109.8	0	4.8	VI+	
34	1965	1	24	5	22	26	9.9	108.9	0	4.8	VI+	
35	1966	2	21	7	43	0	12.8	109.9	18	3.3		
36	1966	2	22	7	27	0	12.8	109.9	16	3.3		
37	1967	3	13	6	16	20	12	108.7	0	4	V+	
38	1970	4	12	12	37	21.8	13.39	108.9	13	5.3	VII	ISC 13.4 108.9
39	1970	4	18	23	8	13	8.9	108	0	4.9	VII	
40	1972	5	24	20	18	30.3	13.64	108.82	13	5.3	VII	
41	1990	10	15	14	51	0	10.4	107.48	0	3.7		
42	1991	6		0	0	0	10.6	107.9	5	4	VI	
43	1992	2	2	2	17	13.2	13.62	108.15	0	3		
44	2005	3	6	1	40	1.6	10.374	109.087	0	3.5		
45	2005	3	22	14	12	8.9	10.225	108.559	10	3.3		
46	2005	5	10	22	0	42	9.875	108.819	0	3.6		

N^0	**Year**	**Month**	**Day**	**Hour**	**Mins**	**Sec**	**Lat**	**Long**	**Depth (km)**	**M**	**I_o**	**Noted**
47	2005	8	5	13	35	13.1	9.907	108.741	0	4.4		
48	2005	8	5	18	7	12.8	9.953	108.701	0.6	4.5		
49	2005	8	8	16	56	57.9	9.975	108.675	0.1	3.1		
50	2005	8	11	14	3	8	10.356	108.7	0	3.9		
51	2005	9	19	19	29	8.7	9.969	108.559	0	4		
52	2005	9	26	21	34	26.7	9.89	108.974	0	3.4		
53	2005	10	5	21	52	52.9	9.967	108.549	0	3		
54	2005	10	17	1	28	18	10.321	108.855	0	4		
55	2005	11	8	7	54	36.6	9.896	108.855	0	5.3		
56	2005	12	5	20	21	26.7	9.984	108.655	0	3.5		
57	2005	12	7	17	56	22.5	10.478	110.094	4.3	3		
58	2005	12	15	19	3	48.6	10.062	109.009	1.3	3.4		
59	2005	12	16	9	47	25.9	9.988	108.48	1	3.6		
60	2005	12	16	18	20	46.6	10.025	108.533	6	3.4		
61	2005	12	18	13	20	9.6	10.017	108.513	4.7	3.2		3.3Mb
62	2005	12	27	10	55	28.1	10.557	109.121	10	3.3		
63	2005	12	27	14	18	24	9.965	108.739	0	3.1		
64	2007	1	20	10	35	8.7	10.087	108.229	4.2	3.1		3.2Mc

N^0	Year	Month	Day	Hour	Mins	Sec	Lat	Long	Depth (km)	M	I_o	Noted
65	2007	1	21	0	44	21.2	10.425	108.264	10	3		
66	2007	2	15	10	54	17.4	10.075	108.286	1	3.4		3.5Mc
67	2007	3	12	13	51	45.7	10.498	108.286	10	3.2		
68	2007	4	29	12	24	5.3	9.594	107.494	12.2	3.2		
69	2010	6	23	1	55	0	10.5	109	0	4.7		
70	2011	1	26	7	24	30	9.94	108.33	10	4.7		
71	2011	3	6	14	59	41	9.46	108.37	10	4.75		

<u>Note:</u> M_b - Earthquake magnitude in bulk waves; M_s - Earthquake magnitude in surface waves; M_c - Earthquake magnitude in terms of the tail of the wave band.

2. Terrain data (*.xyz file format)

A_MienTrung.xyz

```
107.0041666667,18.9958333329,-53
107.0041666667,18.9874999996,-53
107.0041666667,18.9791666662,-53
107.0041666667,18.9708333329,-53
107.0041666667,18.9624999996,-53
107.0041666667,18.9541666662,-54
107.0041666667,18.9458333329,-54
107.0041666667,18.9374999996,-54
107.0041666667,18.9291666662,-54
107.0041666667,18.9208333329,-55
107.0041666667,18.9124999996,-55
107.0041666667,18.9041666662,-55
107.0041666667,18.8958333329,-56
107.0041666667,18.8874999996,-56
107.0041666667,18.8791666662,-57
107.0041666667,18.8708333329,-57
107.0041666667,18.8624999996,-58
107.0041666667,18.8541666662,-58
107.0041666667,18.8458333329,-58
107.0041666667,18.8374999996,-59
107.0041666667,18.8291666662,-59
107.0041666667,18.8208333329,-59
107.0041666667,18.8124999996,-60
```

3. Setting the parameters of tsunami scenarios in the COMCOT Model

3.1. Set simulation time of earthquake tsunami scenarios (comcot.ctl)

```
#################################################
#                                               #
# Control file for COMCOT program (v1.7)        #
#                                               #
#################################################
#--+-----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
#===============================================:===============================
# General Parameters for Simulation             : Value Field                  |
#===============================================:===============================
#Job Description: Manila Trench 9.3, Spherical Coordinates for code testing
 Total run time (Wall clock, seconds)           :   36000.000
 Time interval to Save Data     ( unit: sec )   :   300.0
 Output Zmax & TS (0-Max Z;1-Timeseries;2-Both) :     2
 Start Type (0-Cold start; 1-Hot start)         :     0
 Resuming Time If hot start (Seconds)           :  1000.00
 Specify Min WaterDepth offshore  (meter)       :     0.00
 Initial Cond. (0:FLT,1:File,2:WM,3:LS,4:FLT+LS):     0
 Specify BC  (0-Open;1-Sponge;2-Wall;3-FACTS)   :     0
 Specify Input Z filename (for BC=3, FACTS)     :
 Specify Input U filename (for BC=3, FACTS)     :
 Specify Input V filename (for BC=3, FACTS)     :

```

3.2. Set the parameters of earthquake tsunami scenarios with earthquake magnitude (Mw = 9.0) (comcot.ctl)

```
#===============================================:===============================
# Parameters for Fault Model (Segment 01)       :Values E1                     |
#===============================================:===============================
 No. of FLT Planes (With fault_multi.ctl if >1) :   1
 Fault Rupture Time (seconds)                   :   2.0
 Faulting Option (0: Model; 1- Data;)           :   9
 Focal Depth                             (meter):  30000.000
 Length of source area                   (meter): 645654.000
 Width of source area                    (meter): 104713.000
 Dislocation of fault plate              (meter):   25.7
 Strike direction (theta)               (degree):   355.99
 Dip  angle       (delta)               (degree):   8.46
 Slip angle       (lamda)               (degree):   90.00
 Origin of Comp. Domain (Layer 01) (Lat, degree):  -2.0
 Origin of Comp. Domain (Layer 01) (Lon, degree):  99.000
 Epicenter Location: Latitude           (degree):   16.430
 Epicenter Location: Longitude          (degree):  119.182
 File Name of Deformation Data                  :
 Data Format Option (0-COMCOT; 1-MOST; 2-XYZ)   :     2

```

3.3. Set up the calculation grid level 1, 2, and 3 (comcot.ctl)

```
#===============================================:================================
# Configurations for all grids                  :Values                         |
#===============================================:================================
# Parameters for 1st-level grid -- layer 01     :Values                         |
#===============================================:================================
 Run This Layer ?       (0:Yes,       1:No     ):     0
 Coordinate System    (0:spherical, 1:cartesian):     0
 Governing Equations  (0:linear,    1:nonlinear):     0
 Grid Size  (dx, sph:minute, cart:meter)        :     1.0
 Time step                            ( second ):     1.0
 Bottom Friction Switch? (0:Yes,1:No,2:var. n ) :     1
 Manning's Roughness Coef. (For fric.option=0)  :     0.0
 Layer Ouput Option? (0:Z+Hu+Hv;1:Z Only;2:NONE):     1
 X_start                                        :   99.0
 X_end                                          :  125.0
 Y_Start                                        :  -2.0
 Y_end                                          :   25.0
 File Name of Bathymetry Data                   :   A_BienDong_2.xyz
 Data Format Option (0-OLD;1-MOST;2-XYZ;3-ETOPO):     3
 Grid Identification Number                     :    01
 Grid Level                                     :     1
 Parent Grid's ID Number                        :    -1

```

```
#===============================================:================================
#  Parameters for Sub-level grid -- layer 02    :Values                         |
#===============================================:================================
 Run This Layer ?       (0:Yes,       1:No     ):     1
 Coordinate           (0:spherical, 1:cartesian):     0
 Governing Eqn.       (0:linear,    1:nonlinear):     0
 Bottom Friction Switch? (0:Yes,1:No,2:var. n ) :     0
 Manning's Roughness Coef. (For fric.option=0)  :     0.025
 Layer Ouput Option? (0:Z+Hu+Hv;1:Z Only;2:NONE):     1
 GridSize Ratio of Parent layer to current layer:     2
 X_start                                        :   106.0
 X_end                                          :   112.0
 Y_start                                        :     9.0
 Y_end                                          :    18.0
 FileName of Water depth data                   :    A_MienTrung.xyz
 Data Format Option (0-OLD;1-MOST;2-XYZ;3-ETOPO):     3
 Grid Identification Number                     :    02
 Grid Level                                     :     2
 Parent Grid's ID Number                        :     1

#===============================================:================================
```

```
#===============================================:===============================
#   Parameters for Sub-level grid -- layer 03    :Values                        |
#===============================================:===============================
 Run This Layer ?        (0:Yes,       1:No      ):      1
 Coordinate            (0:spherical, 1:cartesian):      0
 Governing Eqn.        (0:linear,     1:nonlinear):      1
 Bottom Friction Switch? (0:Yes,1:No,2:var. n ) :      0
 Manning's Roughness Coef. (For fric.option=0)  :      0.025
 Layer Ouput Option? (0:Z+Hu+Hv;1:Z Only;2:NONE):      1
 GridSize Ratio of Parent layer to current layer:     20
 X_start                                        :   108.0
 X_end                                          :   108.6
 Y_start                                        :    15.80
 Y_end                                          :    16.30
 FileName of Water depth data                   :  A_DaNang.xyz
 Data Format Option (0-OLD;1-MOST;2-XYZ;3-ETOPO):      3
 Grid Identification Number                     :     03
 Grid Level                                     :      3
 Parent Grid's ID Number                        :     02
```