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TSUNAMI WAVE HEIGHT MODELLING USING COMCOT SOFTWARE BASED ON MAXIMUM EARTHQUAKE SCENARIO IN BALI ISLAND

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Abstract. Indonesia has the highest tsunami hazard potential, ranking first out of 265 countries. Bali Island is one of the areas in Indonesia that is categorised as a tsunami-prone area due to the existence of the Java Megathrust in the southern segment of Bali, which holds a maximum magnitude of up to M 9.0, which can trigger a tsunami. This study aims to model tsunami wave heights and wave arrival times based on the maximum earthquake scenario in the southern Bali megathrust zone. The modelling is done using COMCOT (Cornell Multi-grid Coupled Tsunami Model) software. The data used in the tsunami modelling consists of earthquake parameter data from the Global CMT Catalogue, as well as bathymetry and topographic data from GEBCO, BATNAS and DEMNAS. The simulation results show that the tsunami generated can reach a maximum height of up to 18 metres in southern Bali. From the tide gauge points that have been made, the point located at the Nusa Penida location shows a maximum amplitude of up to 5 metres. In addition, the simulation of tsunami wave propagation also shows that the waves take about 15-20 minutes to reach the mainland of the south coast of Bali and Nusa Penida after an earthquake. Therefore, a rapid early warning system and the creation of effective evacuation routes are needed to reduce the risk and impact of tsunamis on the island of Bali.

Keywords: wave height, tsunami modelling, COMCOT, Bali

Abstrak. *Indonesia memiliki potensi bahaya tsunami tertinggi, menempati peringkat pertama dari 265 negara. Pulau Bali merupakan salah satu wilayah di Indonesia yang dikategorikan sebagai wilayah rawan tsunami karena keberadaan Java Megathrust di segmen selatan Bali, yang memiliki magnitudo maksimum hingga M 9.0, yang dapat memicu tsunami. Penelitian ini bertujuan untuk memodelkan tinggi gelombang tsunami dan waktu tiba gelombang berdasarkan skenario gempa maksimum di zona megathrust Bali selatan. Pemodelan dilakukan dengan menggunakan perangkat lunak COMCOT (Cornell Multi-grid Coupled Tsunami Model). Data yang digunakan dalam pemodelan tsunami terdiri dari data parameter gempa dari Katalog CMT Global, serta data batimetri dan topografi dari GEBCO, BATNAS dan DEMNAS. Hasil simulasi menunjukkan bahwa tsunami yang dihasilkan dapat mencapai tinggi maksimum hingga 18 meter di Bali selatan. Dari titik-titik tide gauge yang telah dibuat, titik yang terletak di lokasi Nusa Penida menunjukkan amplitudo maksimum hingga 5 meter. Selain itu, simulasi perambatan gelombang tsunami juga menunjukkan bahwa gelombang tersebut membutuhkan waktu sekitar 15-20 menit untuk mencapai daratan pesisir selatan Bali dan Nusa Penida setelah gempa bumi. Oleh karena itu, sistem peringatan dini yang cepat dan* *pembuatan jalur evakuasi yang efektif diperlukan untuk mengurangi risiko dan dampak tsunami di Pulau Bali.*

Kata kunci: *gelombang tinggi, pemodelan tsunami, COMCOT, Bali*

1. Introduction

Indonesia has the highest tsunami hazard potential, ranking first out of 265 countries [1]. According to information from the National Disaster Management Agency (BNPB), this risk is higher when compared to Japan. Tsunamis are large ocean waves that result from vertical changes in water masses and are mostly triggered by earthquakes on the seabed due to sudden plate subduction activity [2]. In addition, tsunamis can also be caused by several other factors such as underwater landslides, volcanic activity of volcanic eruptions and others [3].

One of the areas in Indonesia that has the potential for a tsunami disaster is Bali Island. Bali is known as an area with a high level of seismicity. When viewed from the region, Bali is located between the meeting of the Indian and Pacific Oceans and very close to the subduction zone between the Eurasian plate and the Indo-Australian plate [4]. Based on the Meteorology, Climatology and Geophysics Agency through the Tsunami Hazard Map Book Edition 1, it is stated that Bali Island is one of the areas in Indonesia that is categorized as a tsunami-prone area [5]. The subduction zone is the main source area for tsunami disasters, especially in the southern area of Bali Island.

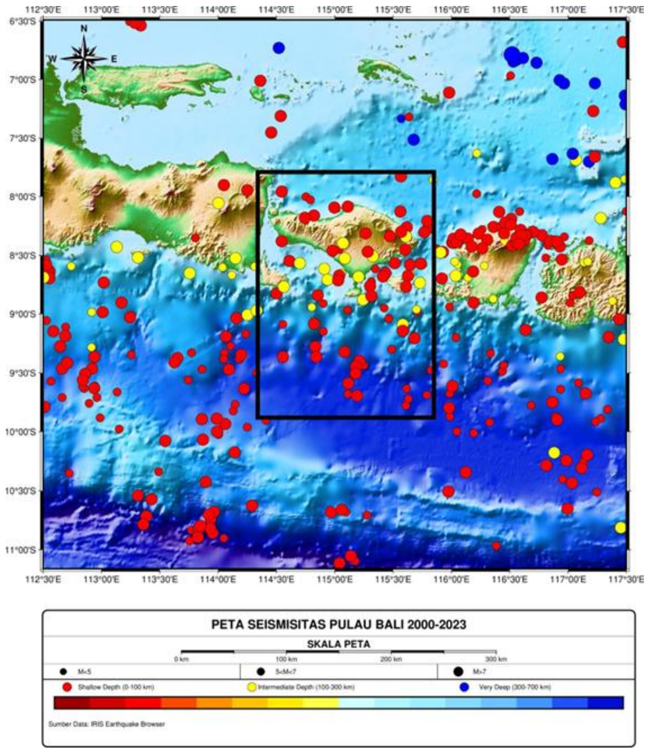

Figure 1. Bali Seismicity Map. The study area is bounded by a black box

Based on the Indonesian Earthquake Hazard and Source Map Book (PuSGeN), the Java Megathrust in the southern Bali segment holds a maximum magnitude of up to M 9.0, which can trigger a tsunami. According to historical records, several tsunamis that have occurred and caused impacts to the island of Bali include the Sumba Tsunami in 1977 and the Banyuwangi Tsunami in 1994 [6].

Mitigation efforts are important on the island of Bali given the high risk of tsunamis [7]. Bali is known for its tourism so that many tourists visit every time. High population activity is also a major factor in the need for good mitigation efforts. The impact of a tsunami disaster will not only harm the economy of the local community, but also the image of Indonesia as a safe tourism destination [8]. Based on this, it is necessary to have a good understanding of the potential tsunami disaster in this region.

To analyze the potential of tsunami in Bali Island, the attenuation and height of tsunami waves were analyzed using COMCOT (Cornell Multi-grid Coupled Tsunami Model). The analysis was conducted by simulating the tsunami wave propagation process using a maximum magnitude earthquake scenario that could occur in southern Bali. With this analysis, the authors identify areas of high vulnerability and predict the maximum tsunami wave heights that could occur. This research aims to provide an understanding of tsunami propagation patterns and impacts in Bali. With this research, it is expected to be one of the references in mitigation-based spatial planning and the preparation of evacuation routes in the Bali region.

2. Research Methods

2.1. Data

This study covers the area around the source of the tsunami-generating earthquake in southern Bali. The data used in tsunami modeling consists of bathymetry data, topographic data in .asc format, and earthquake parameters. Bathymetry data contains information on the sea depth and topographic data contains information on the elevation of the land area of Bali Island under review. Bathymetry data obtained from the General Bathymetric Chart of the Oceans (GEBCO) was used for layer 1, and National Bathymetry data (BATNAS) with better resolution for layers 2 and 3, while for the third layer a combination of bathymetry data from BATNAS and topographic data from DEMNAS provided by the Geospatial Information Agency (BIG) was used. The earthquake parameters in this modeling follow the historical record of the earthquake that generated the tsunami in Bali in 1992. The earthquake parameters are listed in Table 1 below [9, 10]:

Table 1. Earthquake focal mechanism parameters used as reference

Time of Event		Mag	Location		Focus Mechanism			Depth (km)
Date	Hour		Lon	Lat	Strike	Dip	Rake	
12/12/1992	5:29:26	7,7	-8,480	121,89	80	40	95	20,4

2.2. Method

This study uses a quantitative research method, namely the analysis of tsunami wave height attenuation model using Cornell Multi-grid Coupled Tsunami (COMCOT) software. Tsunami modeling was adapted to the worst potential earthquake sources in the southern region of Bali to obtain values of tsunami wave height, tsunami wave arrival time, and damping area in the coastal areas of Bali. Observation points were located on the coast to obtain records of wave arrival times and heights on the coast.

Table 2. Observation points for tsunami wave arrival time and height

Observation Points		
Location	**Longitude**	**Latitude**
Benoa	115.2099	-8.746
Nusa Penida	115.4867	-8.676
Jembrana	114.5733	-8.385

Data preparation included the creation of three layer files to be used in modeling. For the first layer, bathymetry data in .asc format from GEBCO has been obtained which can be used directly. The second layer uses bathymetry data from BATNAS which has a more precise scale than GEBCO data, but because the research area consists of several data grids, it is necessary to merge these grids to be used in the second input layer. Furthermore, for a better land topography, topographic data from DEMNAS was merged with bathymetry data from BATNAS. This data preparation stage was carried out with the help of Global Mapper 20.1.

After the earthquake parameters and data for the three layers are ready, the next step is to modify the comcot.ctl configuration file contained in the COMCOT package. The configuration file contains settings for simulation parameters, fault model parameters, and configuration parameters for each layer. Tsunami modeling in this study was conducted for a duration of one hour or 3,600 seconds, with the earthquake mechanism described above, and a three-layer configuration with input files in .asc file format.

When the parameter configuration settings have been completed, the next step is to run the comcot.exe program. This process takes a while, depending on the number of layers and the size of the modeling area. After the modeling is complete, the output plot can be done using MATLAB to get a visualization of the modeling results. From this modeling, visualization of the initial point, namely the deformation field of the tsunami generator, bathymetry plot, tsunami wave height plot from mean sea level, visualization of tsunami wave height from the location of the observation point, and travel time plot are obtained.

3. Result and Discussion

In tsunami modeling, the process begins with determining the initial model, earthquake location, parameters, and fault plane area, which are the main factors in determining the characteristics of the tsunami waves that will be generated. The initial model refers to the initial model that represents the initial conditions before the earthquake [11]. The modeling in this study uses the worst-case scenario of a 9.0 magnitude earthquake located in the megathrust zone south of Bali. The selection of this scenario refers to the National Center for Earthquake Studies (Pusgen) book, and the calculation process is carried out using MATLAB. From the calculation results, a fault length of 576 km and a fault width of 190 km were obtained. The selection of this scenario is based on the history of seismicity or historical data related to seismic activity that has occurred in the zone. Some studies also explain related to historical records that show that in the Bali region at least several tsunamigenic earthquakes have occurred since 1800 AD [12].

In the early stages of the simulation, the results obtained will show changes in sea level immediately after an earthquake. Based on the modeling carried out, the results show the display of sea water level immediately after an earthquake with a change in sea water level of 1.2 meters. This can occur due to the deformation of the seabed caused by shifting fault planes that will disturb the balance of the sea and trigger the propagation of tsunami waves. Figure 2 shows the initial condition of the sea surface due to the earthquake in the subduction zone south of Bali.

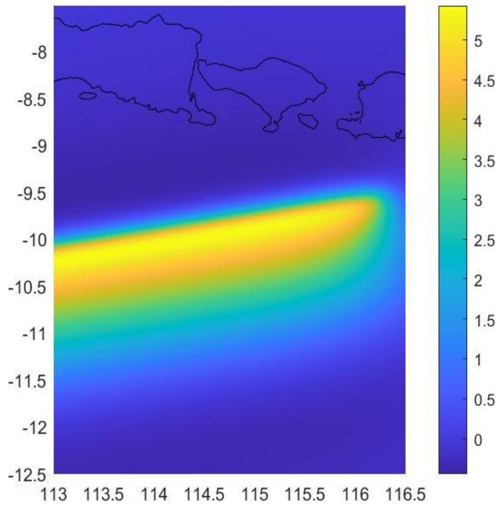

Figure 2. Initial sea level conditions shortly after the earthquake

Next, the maximum height of tsunami waves at the tide gauge points created in the tsunami modeling was analyzed. These tide gauge points were created as reference monitoring points in observing changes in sea level caused by tsunami waves. The simulation results show that the maximum height of tsunami waves varies when they reach the tide gauge points in Benoa, Nusa Penida and Jembrana. At the Nusa Penida tide gauge point, the maximum height of tsunami waves was recorded to reach 5 meters, indicating that this area experienced the most significant impact compared to other points. In contrast, for the other two locations, the Benoa and Jembrana tide gauges, there were no significant changes in the sea water level, indicating that the tsunami impact at these locations was relatively small. Figure 3 shows the results of the tsunami modeling amplitude and velocity values at each tide gauge point.

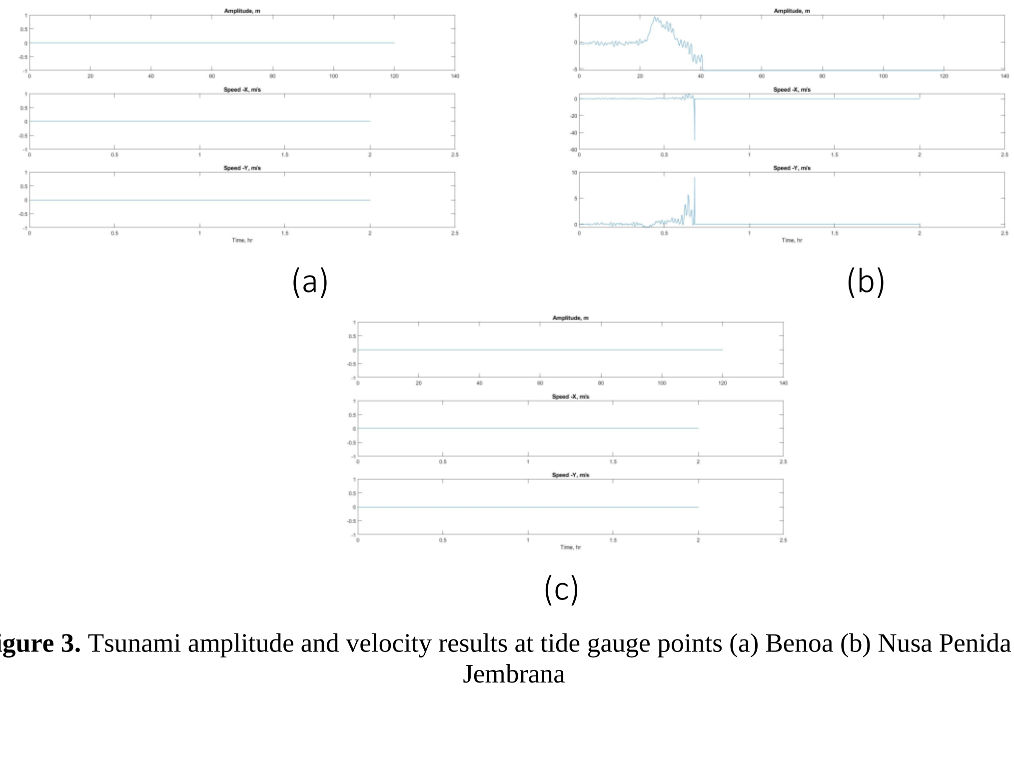

Figure 3. Tsunami amplitude and velocity results at tide gauge points (a) Benoa (b) Nusa Penida (c) Jembrana

The phenomenon of different tsunami wave heights can occur due to several factors, such as bathymetry, the shape of the coastline, and the depth of the sea around the tide gauge point. The topographical configuration of the sea and land greatly influences the characteristics of tsunami waves [13]. In addition, the distribution of tsunami energy is strongly influenced by the geometry of the earthquake source and the sea depth around the subduction region, which explains the variation in tsunami heights at each tide gauge point [14].

The simulations conducted in this study also include tsunami inundation analysis, i.e. the process of tsunami wave propagation until it reaches land and the extent to which seawater can inundate coastal areas. The simulation results show that the maximum inundation value occurs in the third layer, where the maximum height reaches 18 meters in most of the southern coastal areas of Bali and Nusa Penida. Based on the simulation results, the most significantly affected areas are coastal areas with flat topography and located closer to the earthquake source in the subduction zone. These high-risk areas are shown in Figure 4.

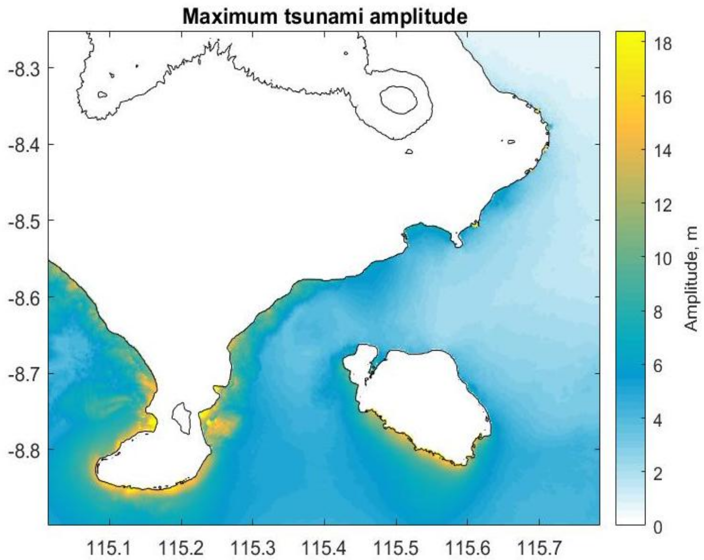

Figure 4. Maximum tsunami height

In this study, the authors modeled tsunami wave propagation for 2 hours or 120 minutes to analyze the dynamics of wave propagation from the earthquake source until it reaches land. The simulation of tsunami wave propagation is shown in Figure 5, which displays changes in the wave pattern at every 30-minute interval to observe the evolution of wave amplitude and velocity at various stages of propagation. The simulation results are visualized in the form of snapshots showing the movement of tsunami waves in two main mechanisms, namely uplift and subsidence. The uplift tsunami wave movement is shown in red snapshots indicating a rise in sea level due to seafloor deformation generated by the earthquake, while the subsidence tsunami wave movement is shown in blue representing a decrease in sea level in response to the pressure release mechanism in the fault zone.

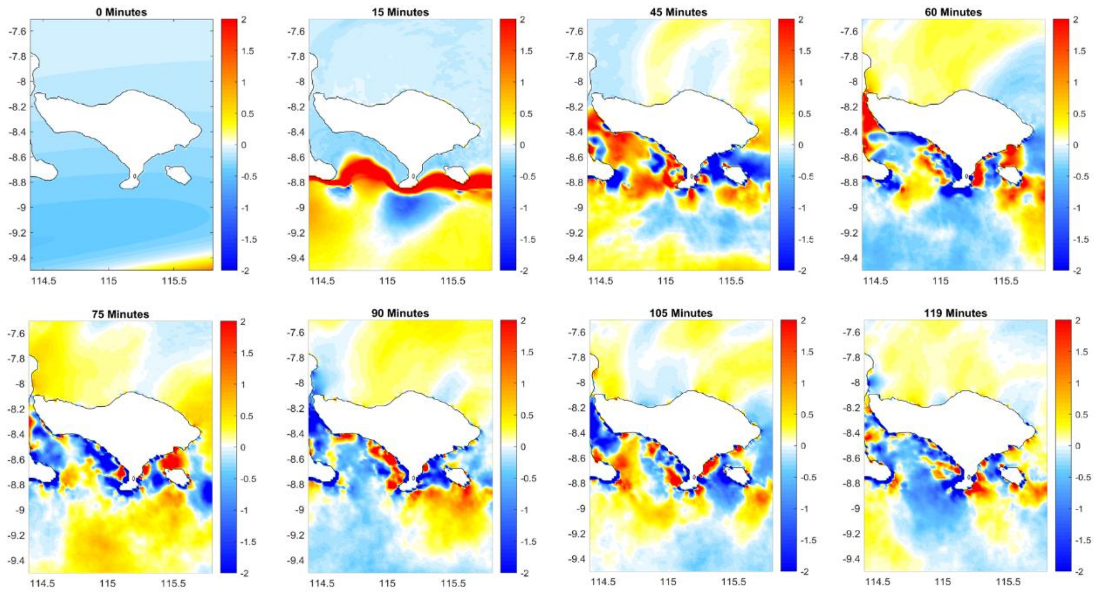

Figure 5. Simulated tsunami wave propagation at minutes 0, 30, 45, 60, 75, 90, 105, and 119

Figure 5 shows the estimated tsunami wave propagation after an earthquake in southern Bali with a maximum magnitude of 9.0 that triggered significant changes in sea level. From the modeling that has been carried out, it can be seen in the results that at the 0th minute there is an initial deformation of the sea surface due to fault movement in the subduction zone. This deformation causes differences in sea level, where some areas experience subsidence, while others experience uplift, shown in red. This subsidence is the initial phase before tsunami waves form and begin to propagate away from the earthquake source. The sea level rise that occurs in the uplift area will be the main source of energy for tsunami wave propagation towards the nearest coast.

From the plots of simulated tsunami wave propagation as well as the analysis of tsunami amplitude and velocity at the tide gauge points, it can be concluded that the average travel time for tsunami waves to reach coastal areas, both in southern Bali and in Nusa Penida, ranged from 15 to 20 minutes after the earthquake. This can be confirmed by plotting the tsunami travel time in Figure 6 below.

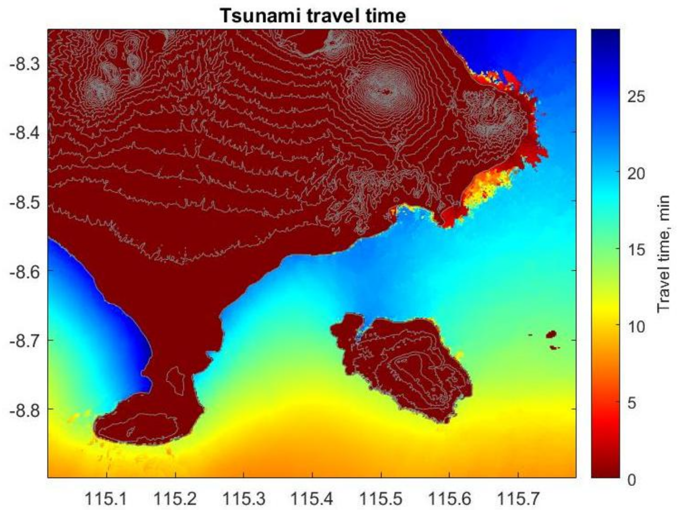

Figure 6. Travel time tsunami scenario on Bali Island

The travel time shown in Figure 6 provides an overview of the estimated travel time of tsunami waves from the earthquake source to the coastal areas of Bali. This result confirms that tsunami waves are expected to arrive in less than 20 minutes after the earthquake occurred.These travel time results provide important information related to tsunami disaster mitigation efforts, which require the development of a good early warning system in the coastal areas of Bali.With a relatively short tsunami travel time, it is necessary for local communities to respond to mitigation efforts to reduce the risk of casualties.

4. Conclusions

Based on the results of past research, this study models the worst-case scenario of a tsunami that could occur in the megathrust zone south of Bali with a magnitude of 9.0. The simulation results show that the resulting tsunami can reach a maximum height of up to 18 meters in southern Bali. From the tide gauge points that have been created, the point located at the Nusa Penida location shows a maximum amplitude of up to 5 meters. In addition, the tsunami wave propagation simulation also shows that the waves take about 15 - 20 minutes to reach the mainland of the southern coast of Bali and Nusa Penida after an earthquake. From this, it is necessary to have a fast early warning system and the creation of effective evacuation routes so as to reduce the risk and impact of tsunamis on the island of Bali.

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