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Virtual Tide Gauge Observation of the 2006 Pangandaran Tsunami Using COMCOT Version 1.7

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Abstract

The 2006 Pangandaran tsunami was one of the most significant natural disasters in Indonesia, causing major damage to coastal infrastructure and extensive social impacts. This study aims to reconstruct the 2006 Pangandaran tsunami using topographic data from DEMNAS and bathymetry data from BATNAS by applying it to a fine grid size (nested model). The other purpose is to determine the validity of the model that has been made if verified using a comparison with the results of field surveys and calculations of Aida numbers. The research method used is by using topographic data from DEMNAS and bathymetry data from BATNAS as well as using earthquake mechanism data from Global CMT. Furthermore, it is simulated using COMCOT software version 1.7 as well as by creating a nested grid of 4 grids. The obtained simulation results are then verified using field data and Aida numbers. The results of this study show that the earthquake with a magnitude of 7.7 Mw caused the movement of tectonic plates which resulted in a decrease and increase in sea level along the coast of Pangandaran. The simulation results have an Aida K value of 1.48 and an Aida κ value of 1.35 with the K value outside the recommended range but the K value is still within the recommended range indicating a validity level of 72.55%. The simulated tsunami arrival time is 8-12 minutes faster than eyewitness accounts.

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INTRODUCTION

Indonesia ranks 12th out of 35 countries that face a relatively high risk of death from several natural disasters ((World Bank, 2021)). Other sources suggest that Indonesia ranks third globally, in terms of disaster risk (Bündnis Entwicklung Hilft and Institute of International Law of Peace and Armed Conflict, 2022). It should be noted that Indonesia's geographical location on the Pacific Ring of Fire exposes the country to great threats from natural hazards, including earthquakes, tsunamis and volcanic eruptions ((Ulza *et al.*, 2023)). Tsunamis pose a particularly serious threat to Indonesia, second only to Japan ((Parwanto & Oyama, 2014); (Suppasri et al., 2012). Faced with these challenges, it is imperative for Indonesia to prioritize disaster mitigation strategies to reduce the risks posed by natural disasters (Ulza *et al.*, 2023).

The Sunda Strait is one of the areas in Indonesia that is prone to earthquake and tsunami disasters because it is located between the meeting of two active tectonic plates, namely the Indo-Australian plate which continues to subduct under the Eurasian plate (Sugianto, 2019). These plates experience relative motion of about 70 mm per year, which can cause seismic activity, including earthquakes with a maximum magnitude of 8.7 Mw. Such earthquakes can generate tsunamis and are felt across the island of Java with a maximum intensity of VII-VIII MMI in four coastal districts in Central Java (Tim Pusat Studi Gempa Nasional, 2017).

In July 17, 2006 a tsunami struck the southern coast of the Pangandaran region, West Java, Indonesia. The trigger earthquake (7.7 Mw) occurred at a depth of 34 km deep and located 225 km from Pangandaran Beach (Lavigne *et al.*, 2007). According to the Catalog Indonesia Tsunami Catalog 416-2018 (BMKG, 2019) states that the run-up height of the waves of the Pangandaran tsunami reached a range of 3-8 meters.

Tsunami modeling is indispensable for Indonesia, which has tsunami-prone areas. Significant benefits can be generated from tsunami modeling simulations, namely to anticipate the occurrence of a tsunami disaster and to minimize the impact of the tsunami disaster (Hajar, 2006). In this research, tsunami modeling will be conducted using COMCOT software version 1.7 developed by Dr. Xiaoming Wang at the Institute of Geological & Nuclear Science (GNS Science) in New Zealand (Destrayanti *et al.*, 2023). This study aims to reconstruct the 2006 Pangandaran tsunami event and to verify the modeled tsunami height results by comparing the results of field studies along the coast (Lavigne *et al.*, 2007) with the simulation results using Aida number calculations (Aida, 1978).

METHOD

Research Location

The study area to be modeled is Pangandaran Regency which can be seen in Figure 1 below. This geographical layout is very important in the tsunami modeling process, as the shape of the coastline, bathymetry and topography of the area will influence wave propagation and inundation patterns.

Figure 1. Map of Pangandaran Regency Research Area

Data Source

Bathymetry data used in this study is from Batimetri Nasional (BATNAS) with data spatial resolution of 6 arc-second or equivalent to 180 meters using Mean Sea Level (MSL) datum and topographic data from the Digital Elevation Model Nasional (DEMNAS) which has a spatial resolution of 0.27 arc-second or equivalent to 8 meters provided by the Badan Informasi Geospasial (BIG) using EGM2008 datum. The data used is 4 grids (nested model) as shown in Figure 2.

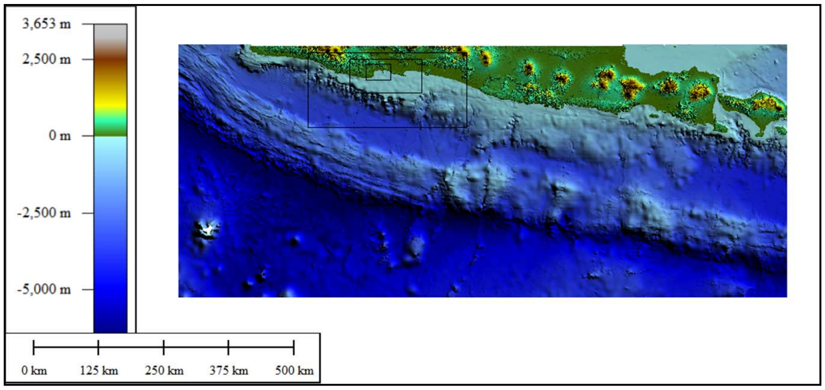

Figure 1. Grid Used in Simulation

Table 1 shows the four grids with varying coverage areas and resolutions, designed to enhance tsunami propagation and inundation simulations in Pangandaran, with finer resolutions focusing on smaller areas.

Table 1 Location and Area of the Grid Used

Location	Model Area	Total Area (km^2)	Coordinates
Pantai Selatan, Pulau Jawa dan Bali	Grid 1	568.544	105°E - 115°E 11°S - 7°S
Jawa Barat	Grid 2	44.126	107°E - 110°E 8°S - 7°S
Tasikmalaya, Pangandaran, Cilacap	Grid 3	9.024,6	108°E - 109°E 8°S - 7°S
Pangandaran	Grid 4	1.300,8	108°24'E - 108°51'E 7°50'S - 7°36'S

This research requires input parameters from the earthquake source that will generate tsunami waves. These parameters are based on the earthquake source mechanism solution data from the Global CMT listed in Table 2 as follows.

Table 2 Earthquake Source Mechanism Solution (Global CMT)

Strike (degree)	290/98
Dip (degree)	10/80
Slip (degree)	102/88
Seismic moment (Nm)	$4{,}61 \times 10^{27}$
Moment magnitude (Mw)	7,7
Duration (sec)	13,9 (half)
Depth (km)	20
Latitude (°LS)	-10,28
Longitude (°BT)	107,78

Model Validation Method

Model results from simulations are important to verify to determine validity, namely using a comparison of simulation results with field data. In this study using field data conducted by Lavigne, *et al.* (2007) can be seen in Figure 3.

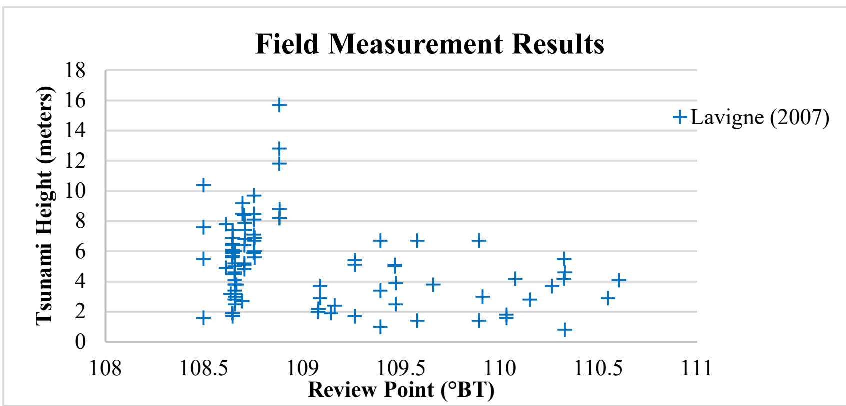

Figure 3. Tsunami Height from Field Measurements

After comparison with field data, the accuracy of the simulation results was calculated using Aida's K and κ parameters. (Aida, 1978) introduced the parameters K which indicates the relative size of observed and simulated tsunami heights, and κ which indicates the precision of simulated tsunami heights (Gusman et al., 2014). To evaluate the accuracy of the model, the geometric mean value of Aida's number K and its variance κ are used, which can be written in equations (1) and (2) below:

$$log\ K = \frac{1}{n}\sum_{i=1}^{n} logK_i \tag{1}$$

$$log\ \kappa = \left[\frac{1}{n}\left\{\sum_{i=1}^{n}(logK_i)^2 - n(logK)^2\right\}\right]^{\frac{1}{2}} \tag{2}$$

Description n is Amount of data; K_i is $\frac{R_i}{H_i}$; R_i is Tsunami height from field measurement; H_i is Model-simulated tsunami height; K_i is the ratio between the field measured tsunami height (R_i) and the modeled tsunami height H_i. If the ratio between the mean value of K = 1.0 or close to "1" and the calculated standard deviation is smaller, the tsunami height value is said to be close to the actual event (Komata, 2019). The range of K values and standard deviation κ for evaluating the application of tsunami simulation models has been widely applied, and the Japan Society of Civil Engineering (JSCE) recommends a range of values of $0.95 < K < 1.05$ and $\kappa < 1.45$.

RESULT AND DISCUSSION

This reconstruction simulation of the 2006 Pangandaran tsunami generates tsunami wave heights and tsunami wave arrival times. The tsunami wave height is marked with blue to red colors. Blue color indicates a decrease in sea level and red color indicates an increase in sea level. Grid 1 shows the tsunami wave propagation from the epicenter to Pangandaran Regency, while grid 4 shows the tsunami wave propagation in the coastal area of Pangandaran Regency more clearly and focuses on the research area. Snapshots of the Pangandaran tsunami wave propagation pattern of grid 1 simulation results at minutes 0, 3, 7, 15, 30, and 40 are presented in Figure 4.

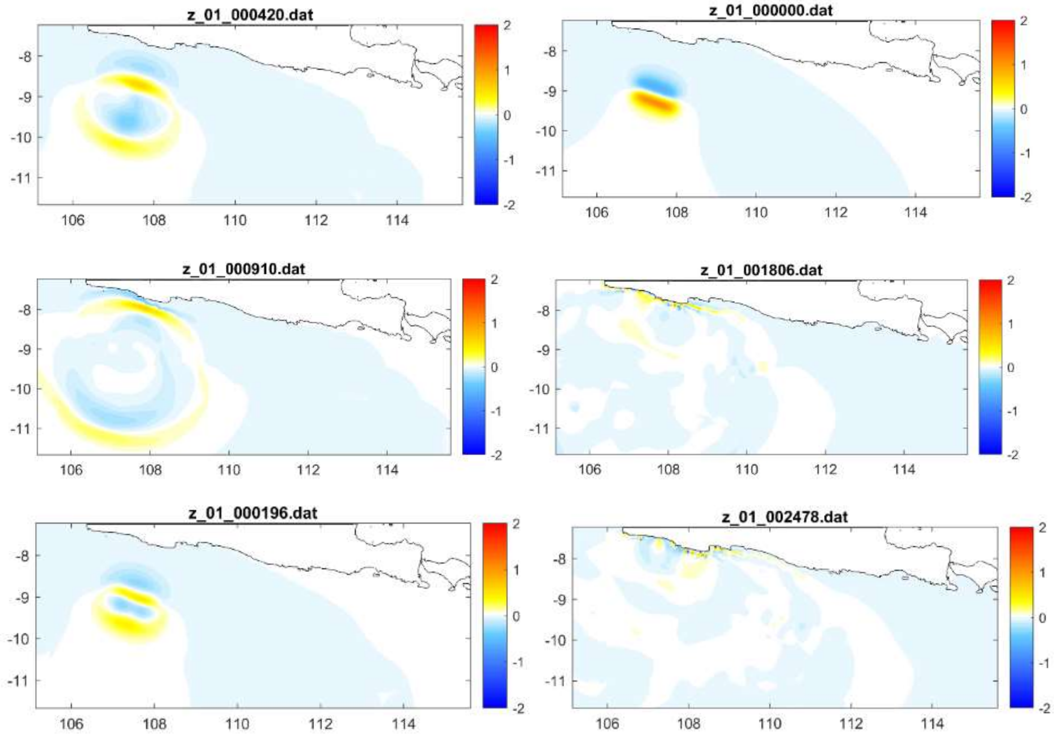

Figure 4. Snapshots of Tsunami Wave Propagation Grid 1 at minutes 0, 3, 7, 15, 30, and 40

The transmission pattern shows that the tsunami wave at the 3rd minute was characterized by low tide and high tide which began to spread to the coastal area of Pangandaran Regency. At around the 40th minute, it then inundated the Pangandaran Regency area. In grid 4, the simulation results focus more on the research area, namely Pangandaran Regency. Snapshots of the Pangandaran tsunami wave propagation pattern of grid 4 simulation results at minutes 0, 27, 30, 33, 40, and 50 are presented in Figure 5.

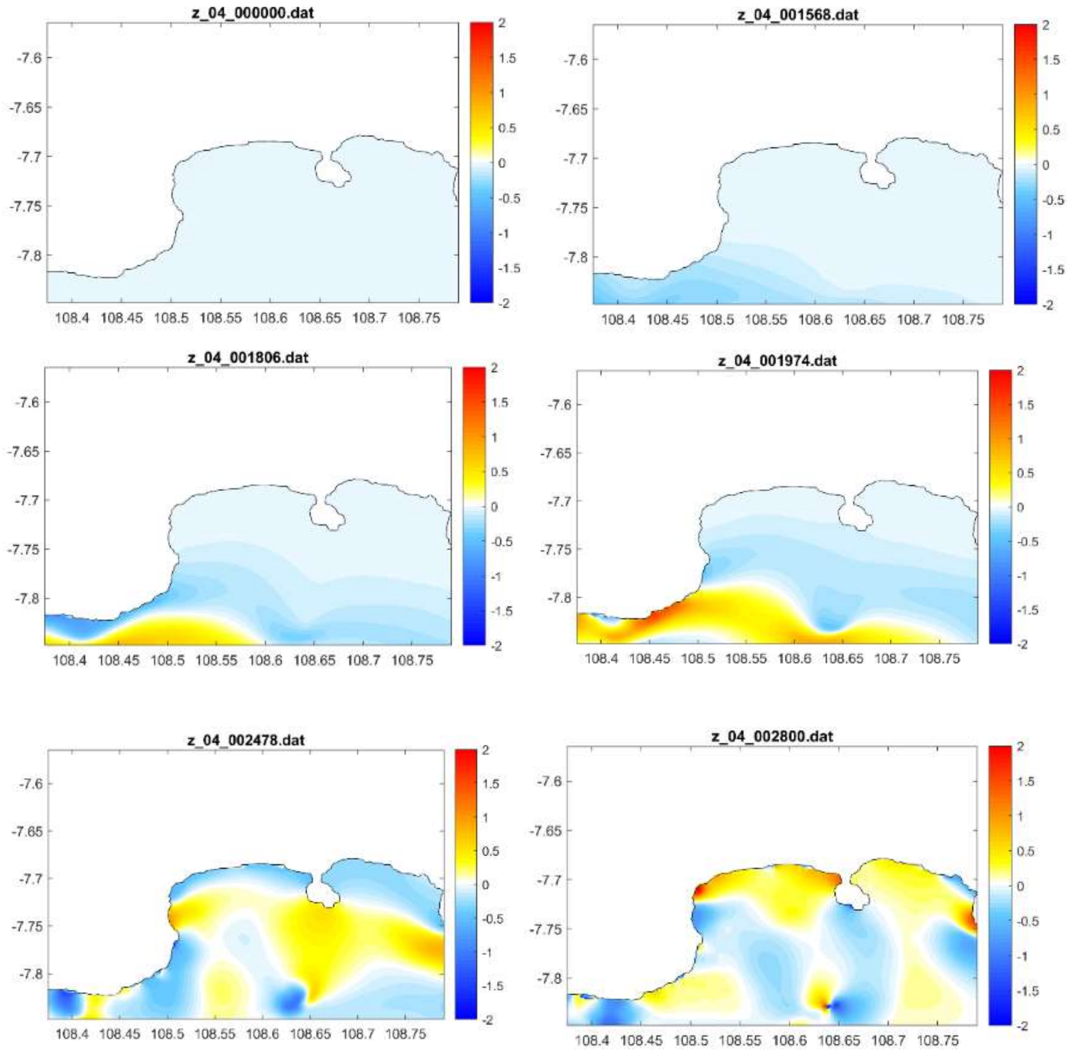

Figure 5. Snapshot of Tsunami Wave Propagation Grid 4 at minutes 0, 27, 30, 33, 40, and 50

The propagation pattern at the 27th minute began to approach the coast of Pangandaran Regency marked by a decrease in sea level later. At the 30th minute, the sea level began to rise and approached the Pangandaran Regency area. At the 33rd minute, the tsunami wave began to rise and hit the southwest area of Pangandaran Regency. At the 40th minute, the tsunami waves began to hit all coastal areas of Pangandaran Regency, and at around the 50th minute, the tsunami waves had reached all coastal areas of Pangandaran Regency. In 2006, the tsunami hit the western part of the peninsula and traveled about tombolo, and hit the eastern part of the peninsula about 1 minute later (Reese *et al.*, 2007). The tsunami height comparison between the field survey by Lavigne, *et al*. (2007) and the simulation model can be seen in Figure 6. Overall, the simulated tsunami height is 1.65-2 meters while the observed tsunami height is 1.6-4.9 meters. The simulated tsunami height still has a slight difference compared to the field survey, but it already shows a similarity in the distribution pattern of tsunami wave heights. The range of K values and standard deviation κ to evaluate the application of tsunami simulation models has been widely applied and recommended with a range of values of $0.95 < K < 1.05$ and $\kappa < 1.45$ (Gusman *et al.*, 2014; Pakoksung *et al.*, 2018). This reconstruction simulation shows significant results with an Aida K value of 1.48 which indicates a validity level of 72.55%. In addition, the resulting Aida κ value is 1.35. Although the K value is slightly outside the recommended range, the κ value remains within the limits recommended by JSCE. The tsunami arrival time at each of these locations is still in accordance with the range generated by the simulation as shown in Figure 7 below.

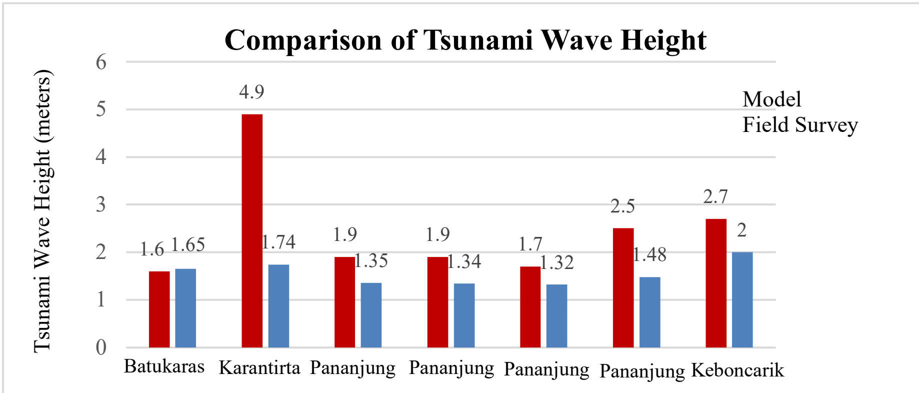

Figure 6. Comparison of Tsunami Wave Height between Model Results and Field Survey Results at Several Measurement Points

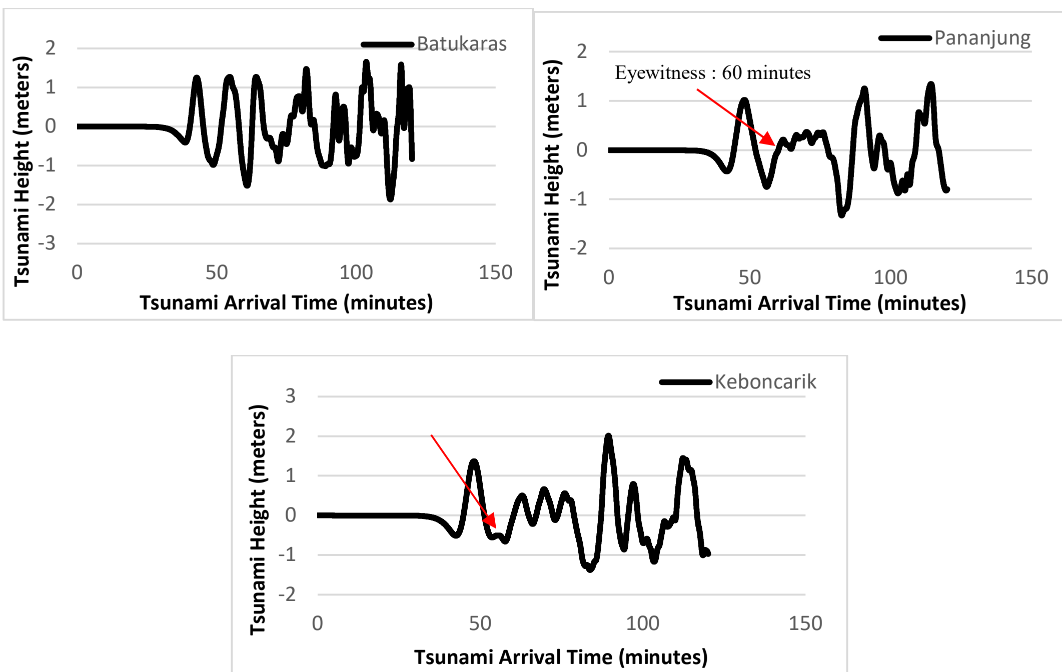

Figure 7. Comparison of Eyewitness Arrival Time and Simulation Results in Batukaras, Pananjung, Keboncarik

The simulated tsunami arrival time at Batukaras was 43 minutes after the earthquake, a difference of 8 minutes from eyewitness accounts (Lavigne, et al. 2007). The simulated tsunami arrival time at Pananjung was 48 minutes after the earthquake, a difference of 12 minutes from the eyewitness accounts. The simulated tsunami arrival time at Keboncarik was 47 minutes after the earthquake, a difference of 9 minutes from the eyewitness accounts. From this time comparison, it can be seen that the simulated arrival time was faster than that of the witnesses. This could be caused by several factors, such as the fact that eyewitnesses often observed the tsunami waves from a position several meters down the beach. This may cause a delay in the direct observation of the tsunami waves when they reach the shoreline, as the waves may have already propagated before being seen by the eyewitnesses. Furthermore, while the simulation has a validity of about 72.55%, this indicates that there is room for improvement and enhancement in the simulation to achieve a higher level of accuracy.

CONCLUSION

The reconstruction simulation of the 2006 Pangandaran tsunami shows that the earthquake with a magnitude of 7.7 Mw caused the movement of tectonic plates which resulted in a decrease and increase in sea level along the coast of Pangandaran. The simulation results have an Aida K value of 1.48 and an Aida κ value of 1.35 with the K value outside the recommended range but the κ value is still within the recommended range indicating a validity level of 72.55%. The simulated tsunami arrival time is 8-12 minutes faster than eyewitness accounts.

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