Tsunami simulation in Puger Beach considering the combination of earthquake source in South Java

Cite as: AIP Conference Proceedings **2278**, 020037 (2020); https://doi.org/10.1063/5.0014684
Published Online: 26 October 2020

Raden Denisio Edwin Rikarda, Retno Utami Agung Wiyono, Gusfan Halik, et al.

Tsunami Simulation in Puger Beach Considering the Combination of Earthquake Source in South Java

Raden Denisio Edwin Rikarda[1, a)], Retno Utami Agung Wiyono[2, b)], Gusfan Halik[2], Entin Hidayah[2], Munawir Bintang Pratama[3]

[1]*Master Student of Civil Engineering, University of Jember, Indonesia*
[2]*Lecturer of Civil Engineering Department, University of Jember, Indonesia*
[3]*Institute for Energy Systems, The University of Edinburgh, United Kingdom*

[a)]181920301007@students.unej.ac.id,
[b)]retnoutami@unej.ac.id

AbstractTsunami occurred on June 3, 1994, as a result of the earthquake in Banyuwangi at 10,477° South Latitude and 112,835° East Longitude with magnitude 7.2 SR. Tsunami in Banyuwangi causes 122 victims, 15 missing persons, 450 houses completely ruined, over 250 heavily damaged in Pancer village and 6 fishermen disappear. In 2006, The Pangandaran Tsunami also attacked coastal area in South Java. This study aims to model tsunami in Puger Beach using Delft3D with the combination of earthquake source characteristics in South Java. Bathymetry data and topography were taken from The General Bathymetric Chart of the Oceans (GEBCO). Delft3D Dashboard was utilized as a first step to create a model domain and simulation grid. Bathymetric interpolation to the simulation grid and initial surface elevation were also created from earthquake fault parameters using Delft3D Dashboard. After setting parameters, numerical simulation was carried out using Delft3D-FLOW. To conduct model validation, the data observation of the 1994 Banyuwangi tsunami from the previous research was utilized. The locations used for validation in this study were Cape Pelindu, Puger and Watu Ulo Beaches with the maximum water level 3.2 m, 4.88 m - 5.85 m and 6.5 m - 7.5 m, respectively. Simulations were divided into three scenarios. Scenario 1 was a simulation of the 1994 Banyuwangi tsunami. Scenario 2 was a simulation to represent the characteristic of fault from The 2006 Pangandaran Earthquake in Puger Beach. Scenario 3 was a combination between Scenario 1 and Scenario 2 which represented tectonic plate fault simulation. Based on the results of the simulation 3, the time of maximum tsunami height reached the study area at the 40 minutes and back to normal at 170 minutes. The greatest impact was created from Scenario 3 with tsunami heights of 10.91 meters to 22.34 meters.

INTRODUCTION

Jember Regency is a district which is the center of fishermen selling fish community located in Puger Beach. Jember has an area of 3,3293.34 km^2, with a coastline of approximately 170 km in length and is included in the EEZ (Exclusive Economic Zone) [1]. On June 3, 1994, a tsunami occurred in 10.477 ° south latitude and 112.835 ° east longitude with a magnitude of 7.2 SR known as the 1994 Banyawangi earthquake and the impact of the tsunami spread in 3 districts namely Jember, Banyuwangi, and Bali. The impact of the tsunami waves was felt in three places in Jember, namely Cape Pelindu, Puger and Watu Ulo Beach with tsunami height data 3.2 m, 5.85m, and 7.5m respectively [2].

Earthquakes are a trigger for tsunamis when their position is at sea and there are faults or land rises due to shifting soil rock or tectonic plates. The vulnerability of the tsunami area is influenced by the source of the earthquake,

Climate Change and Sustainability Engineering in ASEAN 2019
AIP Conf. Proc. 2278, 020037-1–020037-9; https://doi.org/10.1063/5.0014684
Published by AIP Publishing. 978-0-7354-4008-1/$30.00

proximity to the coast, the strength of the earthquake, location to the subduction trench, the morphology of the coast and the shape of the coast near the peninsula as well as the steep bathymetry conditions [3]. Based on the earthquake catalog book, there were two tsunami events due to the earthquake on the south coast of Java, namely the 1994 Banyuwangi Tsunami and the 2006 Pangandaran Tsunami [4].

This study focuses on tsunami simulation Jember district, especially the Puger area because it has developed rapidly into a fisherman crossing area. Houses are also located not far from the Puger coast and river estuaries. There were several studies conducted in Puger Beach. The results of the identification of tsunami vulnerability in Jember Regency showed that Jember coast was divided into 3 tsunami-prone areas, namely high, medium and low areas, where the inundation depth reached 4 meters and the distance of the inundation was as far as 365 meters [5]. The results of the disaster risk map incorporated in the tsunami capacity and risk map showed high hazard risks until the Puger beach evacuation route planning map is provided [6].

Few studies analyzed the effect of combination of earthquake characteristics to tsunami in Puger Beach. Based on PusGen, mega thrust exists in the south of Java Island. It is very important to model tsunami caused by the combination of the earthquake characteristics located in fault plate in the south of Java Island [7]. This research aims to analyze tsunami simulation results for three scenarios. The first scenario is a validation model to model the 1994 Banyuwangi Tsunami. Scenario 2 represents earthquake parameters of The 2006 Pangandaran Tsunami which is located in Puger. Scenario 3 is a combination of Scenario 1 and Scenario 2 which is located in fault plate.

METHODS

This study was conducted in the coastal area of Jember Regency, East Java. Geographically, the coastline in Jember Regency is 170 kilometers in length. Administratively, there are 4 sub-districts along the coastline of Jember regency, namely Gumukmas, Kencong, Ambulu, and Tempurejo.

The hydrodynamic study was carried out with a 2D model using Delft3D version 4.01.01. Bathymetry data used in this study was obtained from GEBCO data available on the Delft3D Dashboard on the coast of Java. Earthquake characteristics of the 1994 Banyuwangi tsunami and the 2006 Pangandaran tsunami are shown in Table 1.

TABLE 1. Characteristics of Earthquake

Tsunami Event	Epicenter		MW	Depth	Strike	Dip	Slip	D	L	W
	Long (°)	Lat(°)		(Km)	(°)	(°)	(°)	(m)	(Km)	(K
Tsunami Bayuwangi 1994	113,14	-10,547	8,0	10	100	15	85	4,7	130	7
Tsunami Pangadaran 2006	108.594	-9.319	7,7	20	290	10	85	15	140	2

D: *Dislocation* (meter)
L: *Length* (km)
W : *Width* (km)

This study was conducted by using the 1994 Banyuwangi tsunami as a validation case. This research was divided into several steps as shown in Figure 1. The research framework consists of: (1) the input process of the location of the fault data; (2) tsunami validation (Scenario 1); and (3) tsunami simulations with several earthquake characteristics (Scenario 2 and Scenario 3). The simulation process was divided into four-stage namely the determination of calibration coordinates, Delft3D Dashboard data input, Delft3D flow process, and output.

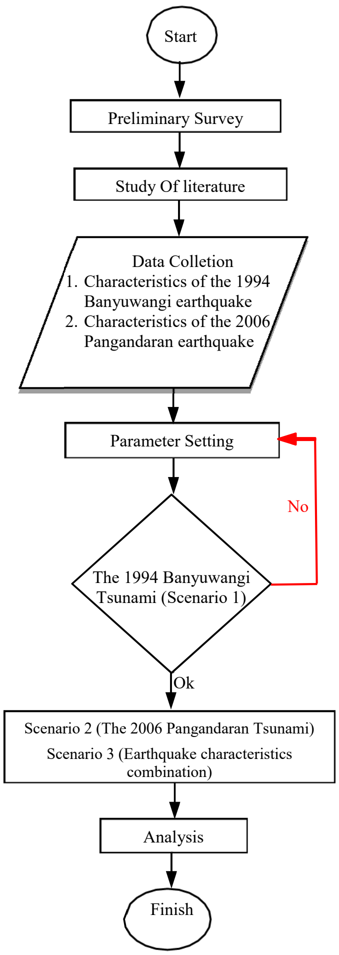

FIGURE 1. Research Framework

Simulations were conducted based on the earthquakes characteristics as shown in Table 2. Scenario 2 has the smallest magnitude and fault width. Scenario 3 is the longest of all scenarios because it is a combination of the lengths of the 2 scenario. Modeling tsunami data based on the same grid and bathymetry data to see comparable results.

TABLE 2. Index of earthquake fault scenario data used

Name	longitude (°)	latitude (°)	Magnitude (Mw)	Depth (Km)	Strike (°)	Dip (°)	Slip	Fault Length (Km)	Fault Width (Km)
Scenario 1	112.835° 113.706°	-10.477° -10.627°	8	10	100	15	85	130	70
Scenario 2	112.835° 111.657°	-10.477° -10.055°	7,7	20	290	10	90	140	20
Scenario 3	111.657° 113.706°	-11.006° -10.586°	8	10	285	15	85	270	70

NUMERICAL MODEL

Numerical model has been widely used by researchers in the formulation and making of hazard determination in coastal areas. Tsunami modeling can be done with several models such as GeoClaw, FVCOM, ANUGA, Delft3D and other software. This study utilized Delft3D for tsunami modeling. It is chosen because it provides an open ware version for research activities and Delft3D has become one of the leading tools in multi-purpose hydrodynamic modeling. In this study, numerical modeling is utilized to show the effects of earthquake characteristics and the different tsunami models with the provisions that have been determined.

Delft3D is one of the leading tools capable of performing hydrodynamic modeling for coastal, river and estuary areas. This tool has many advantages that can simulate wave phenomena, determining the direction of flow caused by salinity or temperature gradients, adjusting water levels caused by wind waves, tidal propagation, transport of sand and mud, water quality and changes in bathymetry (morphology). The Delft3D Dashboard and Delft3D Flow were used in this study.

This study aimed to perform tsunami hazard simulation which is a result of earthquake characteristics in the South of Puger Beach. First, validation was carried out using the 1994 Banyuwangi tsunami. Second, tsunami simulation was performed using the 2006 Pangandaran earthquake characteristics located in the South of Puger Beach (Scenario 2). The third case was a simulation which combined earthquake characteristics of the 1994 Banyuwangi and the 2006 Pangandaran case (Scenario 3). The simulation domain consisted of 1091 cells on M direction and 740 cells in N direction. The size of each cell was 0.005 x 0.005degrees. Delft3D flow was then used for tsunami simulation. Delft3D Dashboard input data such as water density data, simulation time, and tsunami wave generation data were prepared. Bathymetry data was assumed by positive (+) value for area below water level and negative (-) values for area above water level (See Figure 2).

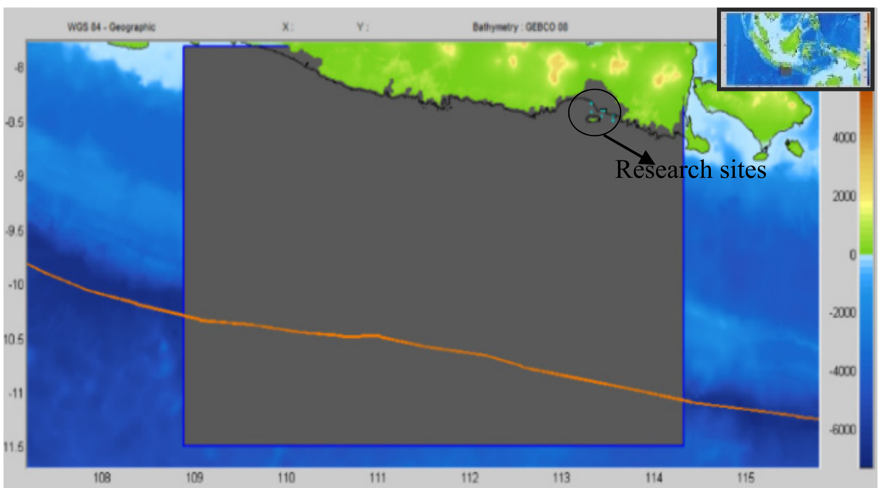

FIGURE 2. Research domain area

Delft3D The Green Formula [8] was utilized to obtain the height of tsunami at the observation point.

$$\frac{\eta_2}{\eta_1} = \left(\frac{h_1}{h_2}\right)^{\frac{1}{4}} \tag{1}$$

Information: η_1= Tsunami height in the sea (m)
η_2= Tsunami height in coastal area (m)
h_1= Water Depth in the sea (m)
h_2= Water Depth in coastal area (m)

In this study, it was assumed that there was no change in the width of the bay as the research location was not a bay.

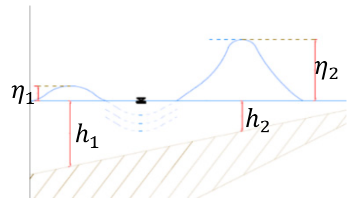

FIGURE 3. Overview of calculation

RESULT AND DISCUSSION

Tsunami validation was conducted for three observation points according to the 1994 Banyuwangi tsunami survey [2], namely in the Cape Pelindu, Puger Beach and Watu Ulo Beach. (Fig. 4).

TABLE 3. Validation of tsunami simulation result of the 1994

number	Location	Coordinates		Observed data	Simulation Result
		latitude	longitude		
1	Cape Pelindu	-8.32	113.32	3.2 m	3.42 m
2	Puger Beach	-8.38	113.47	4.88-5.85 m	5.96 m
3	Watu Ulo Beach	-8.44	113.56	6.5 - 7.5 m	7.15 m

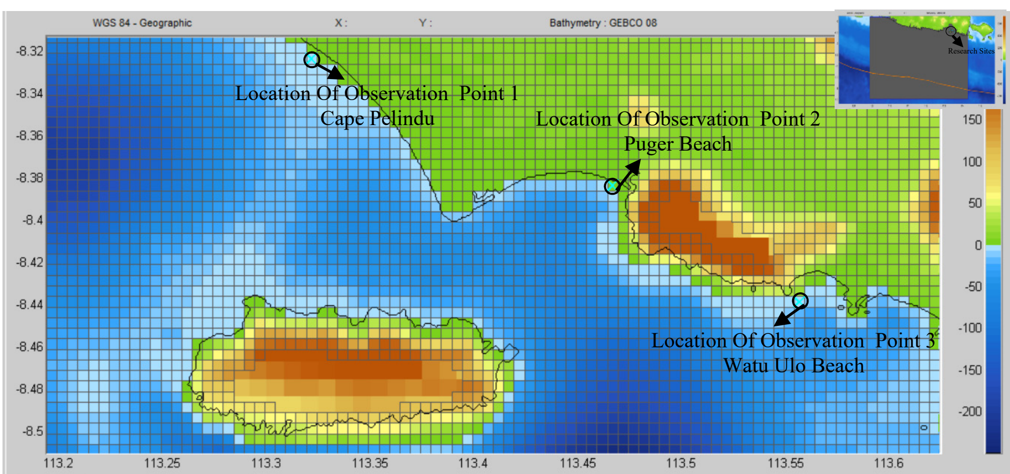

FIGURE 4. Location of Observation Point

The simulation results (Table 3) showed that tsunami heights reached 3 meters to 7.15 meters at the observation points. In Cape Pelindu, the simulation result (3.42 m) slightly overestimated the observation result (3.2 m) with error value of 6.88% between both results. In Puger Beach, the simulation result reached 5.96 m while the maximum value of observation result was 5.85 m. The difference between both results was 1.88%. In Watu Ulo Beach, the simulation result (7.15 m) was inside the observation results range (6.5 – 7.5 m).

It was found that the discrepancy value for the location close to the fault model was more accurate (Watu Ulo Beach) than the locations far from the fault model locations (Puger Beach and Cape Pelindu). The closer the observation point to the fault model, the more accurate the simulation result is. The discrepancy between simulation results and observation results may due to the lack of bathymetry data. Additionally, there were several conditions that may affect the observation results that were not included in the modeling such as tides and seasonal winds. In this study, the propagation simulations were conducted using Delft3D Flow while the inundations were estimated using Green Equation. Although several methods were used, the simulation result values were still acceptable.

Figs. 5-8 showed the simulation results of the 1994 Banyuwangi Tsunami. Figure 5 showed the initial surface elevation of tsunami which reached 1.2 meters. The wave height was generated by the fault dislocation which occurred around the fault location. Figure 6 showed the water level at 10 minutes. The wave was propagated to surrounding area and reached 0.5 m. Figure 7 showed the waves were propagating to the coastal area and reached 2.5 meters at 35 minutes. The maximum wave height was higher than before due to the shoaling process of the wave. Figure 8 showed the surface elevation at 150 minutes after the wave returned to normal condition.

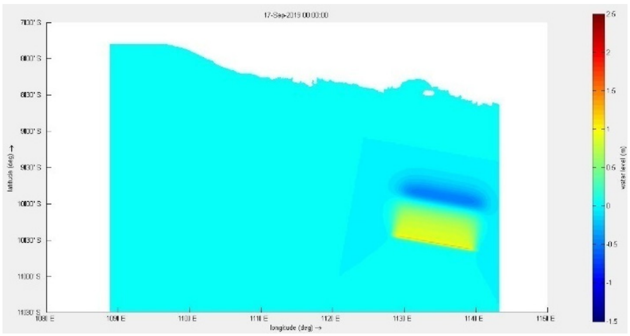

FIGURE 5. Spatial surface elevation of scenario 1 at 0 minute

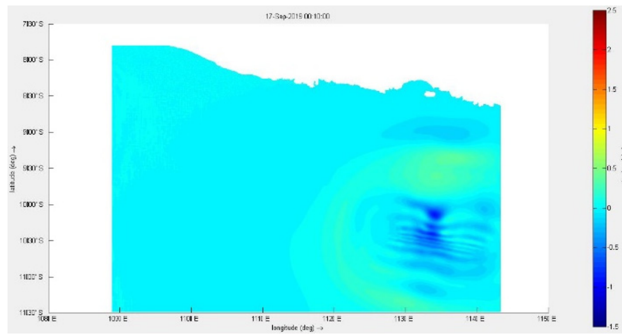

FIGURE 6. Spatial surface elevation of scenario 1 at 10 minutes

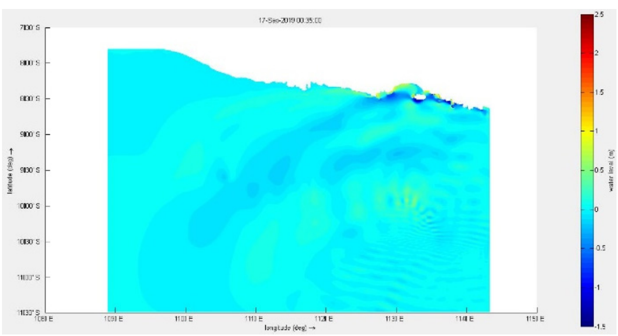

FIGURE 7. Spatial surface elevation of scenario 1 at 35 minutes

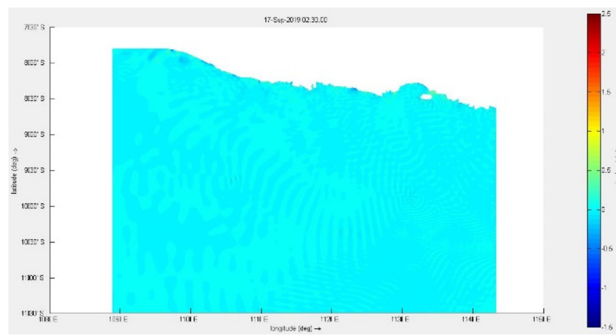

FIGURE 8. Spatial surface elevation of scenario 1 at 150 minutes

After the simulation of the 1994 Banyuwangi Tsunami (Scenario 1 showed in Fig.9), two scenarios were simulated. Fig.10 (Scenario 2) showed the initial surface elevation of the tsunami that was generated by earthquake characteristics of The 2006 Pangandaran Tsunami which was located in the South of Puger Beach. Fig.11 (Scenario 3) showed the initial surface elevation which was generated using a combination between two earthquake characteristics from Scenario 1 and Scenario 2.

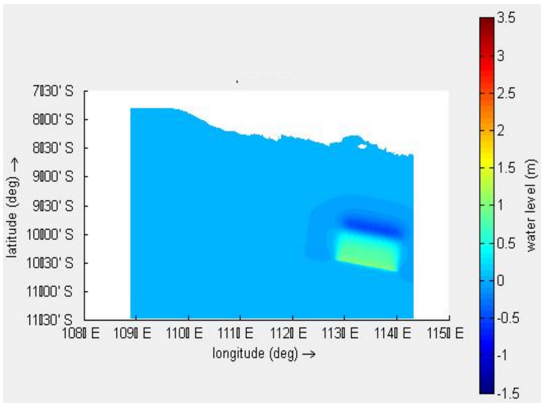

FIGURE 9. Initial surface elevation of Scenario 1

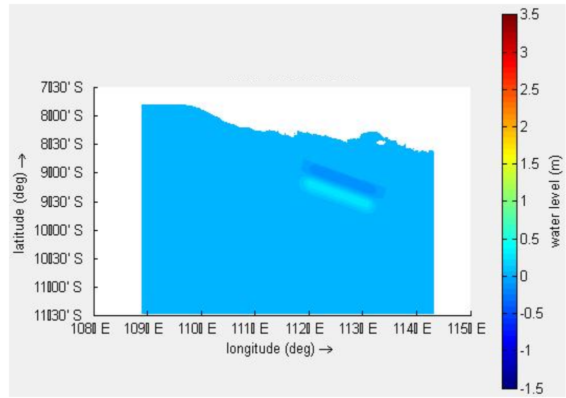

FIGURE 10. Initial surface elevation of Scenario 2

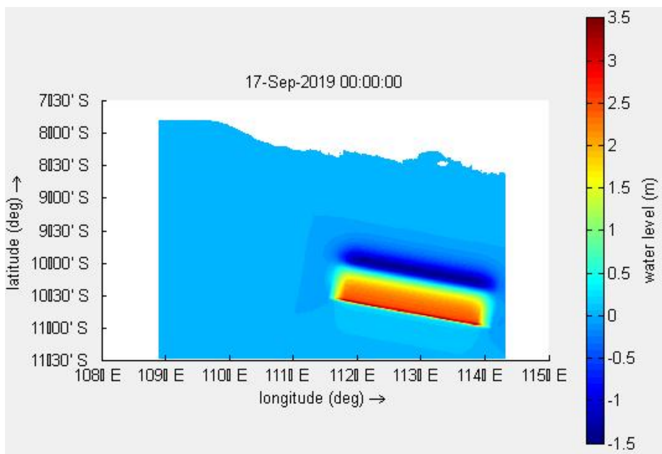

FIGURE 11. Initial surface elevation of Scenario 3

Scenario 2 was caused by a fault model with the smallest width (20 km) and the smallest magnitude among the three scenarios. Therefore Scenario 2, which represented the 2006 Pangandaran fault model in Puger Beach, showed the smallest tsunami height among all scenarios. Scenario 3 that was generated by a combination of two fault models showed the highest initial surface elevation (3.5 m) among all scenarios.

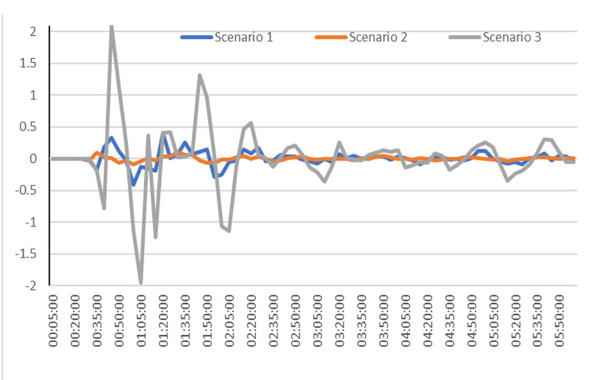

FIGURE 12. Time series of tsunami simulation results

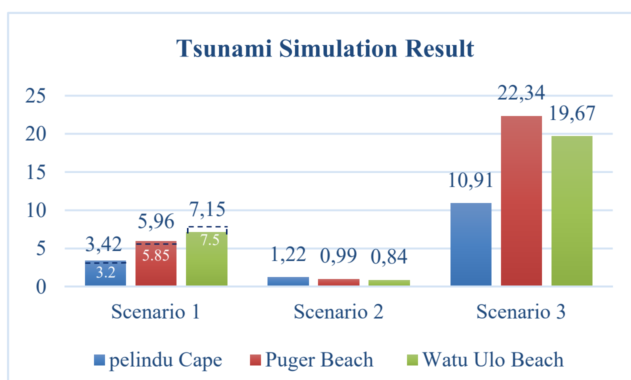

FIGURE 13. Tsunami simulation results at observation points

Fig. 12 showed time series of tsunami simulation for three scenarios in Puger Beach. Fig. 13 showed comparison between simulation results of the three scenarios. Among three scenarios, Scenario 3 showed the highest wave height (10.91-22.34 m). Based on Fig.12, Scenario 2 showed the fastest tsunami travel time among three scenarios. Although the wave height caused by Scenario 2 was the lowest tsunami height among all scenarios (Fig. 13), but the tsunami from Scenario 2 reached the Puger Beach faster than other scenarios were.

TABLE 4. Time of maximum tsunami height

Number	Location	Scenario 1	Scenario 2	Scenario 3
1	Cape Pelindu	01:06	00:42	00:55
2	Puger Beach	00:36	00:30	00:45
3	Watu Ulo Beach	00:35	00:32	00:40

Table 4 shows the time of maximum tsunami height of Scenario 1, 2, and 3. Among all scenarios, the shortest time of maximum tsunami height was resulted by Scenario 2. This occurred because the fault model of Scenario 2 was located in the South of Puger Beach, while the fault models of Scenario 1 and 3 were located in the fault plate in the south of Java Island (further from Puger Beach than that of Scenario 2).

CONCLUSION

Three simulations were performed in this study. Scenario 1 was a validation case which compared the simulation results of the 1994 Banyuwangi Tsunami with the observation results from previous study. Tsunami height at three observation points namely Cape Pelindu, Puger Beach and Watu Ulo Beach were compared to observation results.

Scenario 2 was simulated to represent the 2006 Pangandaran Tsunami in south of Puger Beach. Although the fault model width for this simulation is the smallest among all scenarios, tsunami travel time to Puger Beach for this scenario is the fastest among all because the location of fault model is close to the Puger Beach. Scenario 3 was executed to model the combination of fault model from Scenario 1 and Scenario 2. The highest maximum tsunami heights (10.91-22.34 m) were resulted from this scenario.

This study can be used as initial study to create tsunami hazard information. It will increase the understanding and alertness of the surrounding community to the risk of tsunami hazards especially in the observation areas: Cape Pelindu, Puger Beach and Watu Ulo Beach.

ACKNOWLEDGMENTS

This research is partially supported by Deltares as the developer of the DELFT3D software and it was funded by Master's Thesis Research from the Ministry of Research, Technology and Higher Education of the Republic of Indonesia.

REFERENCES

1. BAPPEDA Jawa Timur. 2013. *Potensi dan Produk Unggulan Kabupaten Jember*. Surabaya.
2. Maramai, A. and Tinti, S. 1997. *A post-event survey of the coastal effects*. Natural Hazards 15:31-49. Italy.
3. Pribadi, S., etc. 2016. *Earthquake source characterization for tsunami zoning(case study of the Bengkulu 12 September 2007 tsunami and the 2 june 1994 Banyuwangi tsunami).*The 5th International Symposium on Earthhazard and Disaster Mitigation. Amerika.

4. BMKG. 2019. *Katalog Gempa Bumi signifikan dan merusak 1821-2018.* ISSN 2477- 0582. Jakarta.
5. Maemunah, I., Sulaeman, C., & Robiana, R. (2011). *Identifikasi potensi kerawanan tsunami di wilayah Kabupaten Jember* , Jawa Timur, *2*(2), 141–152.
6. Martyasari I. K., Turniningtyas A. R., Nindya S. (2012). *Pengurangan Risiko bencana tsunami pesisir : studi kasus pantai Puger*, Jember.
7. Pustlitbang PUPR. (2017). *Buku Peta Gempa 2017*.
8. Dean, R. G., & Dalrymple, R. A. (1991). *Water wave mechanics for engineers and scientists (Vol. 2). World Scientific Publishing Company*.