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SIMULATION OF TSUNAMI WAVE PROPAGATION AND RUN-UP AT PANGANDARAN BAY, WEST JAVA

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ABSTRACT

Pangandaran is an area located in Southern of Java Island, which dealing with the Indian Ocean. In the Indian Ocean, there is a subduction zone between the plates that can cause earthquakes and tsunami, as an example earthquakes and tsunami in Pangandaran (2006). The earthquake and tsunami that have occurred in an area, potentially happen again in the future. The purpose of the research is to determine the height of tsunami, tsunami time travel and tsunami wave run-up. This research was conducted on December 29th to 30th, 2015 in Pangandaran Bay with coordinates between 108°20'00" E - 108°47'00" E and 7°36'00" S - 7°48'00" S. The method used is quantitative method and the method that has been used to determine research location is purposive sampling. The data used are the source of earthquake faults, bathymetry data, and slope the beach. Data modeled using COMCOT v1.7 software to determine the height of tsunami and tsunami time travel. The height of tsunami wave by simulation model used to determine tsunami wave run-up. The simulation result known tsunami wave height range from 2 to 9 meters with run-up between 0 to 510 meters. The highest tsunami wave at observation point 3 and the lowest at observation point 1. The highest run-up tsunami at observation point 3 and the lowest at observation point 6. Time required for tsunami waves reach land between 39 to 48 minutes. Based on the result can be concluded that the highest tsunami wave located in sloping morphology, while the lowest tsunami located in high area or behind the cape area.

Key words: *The tsunami, Pangandaran, Comcot, Run – up*

INTRODUCTION

Tsunami wave is one of the natural disasters caused significant damage. Tsunami waves are the most common due to tectonic or earthquake activity (Suppasri et al., 2017; Raby et al., 2016; Leelawat et al., 2015; Sorensen, 2000). Earthquakes that occur in the middle of the sea with a depth of less than 30 km and earthquake strength of more than 6.5 mw, it changes into a tsunami wave. In open seas, tsunamis move with high speeds and it come to the beach with a decrease in its velocity. The basic condition of the hoop can increase the wavelength so as to produce vertical walls that move towards the mainland and cause major damage on land in coastal areas with topography ramps (Chaeroni et al., 2013; Muhari et al., 2007).

Indonesia is flanked by 3 actively moving plates of Eurasian, Indo-Australian and Pacific plate plates. The movement of these three plates makes Indonesia vulnerable to major earthquakes. Areas that are considered as a danger is the area through which the plate encountering, especially in areas along the west of Sumatra Island, the southern part of Java Island to Nusa Tenggara and northeastern part of Papua (Istiyanto et al., 2011; Triatmadja, 2010).

Pangandaran Regency is one of the areas included in tsunami prone areas. Pangandaran Beach is located in the southern part of this area directly with the Indian Ocean where there is a subduction zone or zone plate planking between continental plates and oceanic plates that can cause earthquakes. There were occurred twice the tsunami with major damage due to tectonic activity in southern Java region Banyuwangi tsunami in 1994 and Pangandaran tsunami in 2006. The occurrence of earthquake and tsunami that ever happened in the future, so it is necessary study to know the condition of tsunami wave propagation (Latief et al., 2012; Mori et al., 2007).

This assessment of tsunami height, travel time and run-up of tsunami waves can be used as preliminary data in mitigation planning to reduce the casualties and losses caused by the tsunami. The data obtained can be used as an Early Warning System or as a basic data in the preparation of tsunami disaster mitigation maps.

MATERIAL AND METHOD

Materials of Research

There are several parameter abbreviations used in this research including moment magnitude, length in kilometers (L), width in kilometers (W), dislocation in meters (D), angle (α), maximum tsunami wave height in meters (H), run-up range in meters (RH), tsunami time travel in minutes (TTT), and maximum tsunami wave height on land in meters (Tmax).

The research material is divided into two main material and supporting material. The main material is coastal slope and coastal elevation value. Supporting material is RBI map of 30 arc second scale, earthquake fault data and tsunami disaster data of Pangandaran area.

The research used case study research method which analyzed with quantitative analysis, that is data analysis using model or numerically. Research location was established using purposive sampling method at 6 point which have been considered to represent research area. The 6 points include cliffs, slopes, river estuaries and cliffs-sloping mix.

Data on coastal slope and beach elevation were obtained from field measurements using Global Positioning System (GPS) and hoses functioned as water-pass. At each location, the observation was made 3 times the measurement with the distance of each measurement 20 meters horizontally. Field data was analyzed and obtained by coastal slope value (α).

The earthquake fault data parameter is divided into 5 different scenarios. The scenarios used consisted of the 2006 earthquake pangandaran and 4 earthquake fault parameters based on the history of the earthquake that once occurred in the island of Java.

Bathymetry data and earthquake fault parameters were simulated using COMCOT v1.7 to determine the height and travel time of wave propagation at each observation point. The simulation is done within 2 hours after the earthquake. Calculation of the run-up range of tsunami waves can be done taking into account the maximum height of tsunami waves on land and coastal slope values.

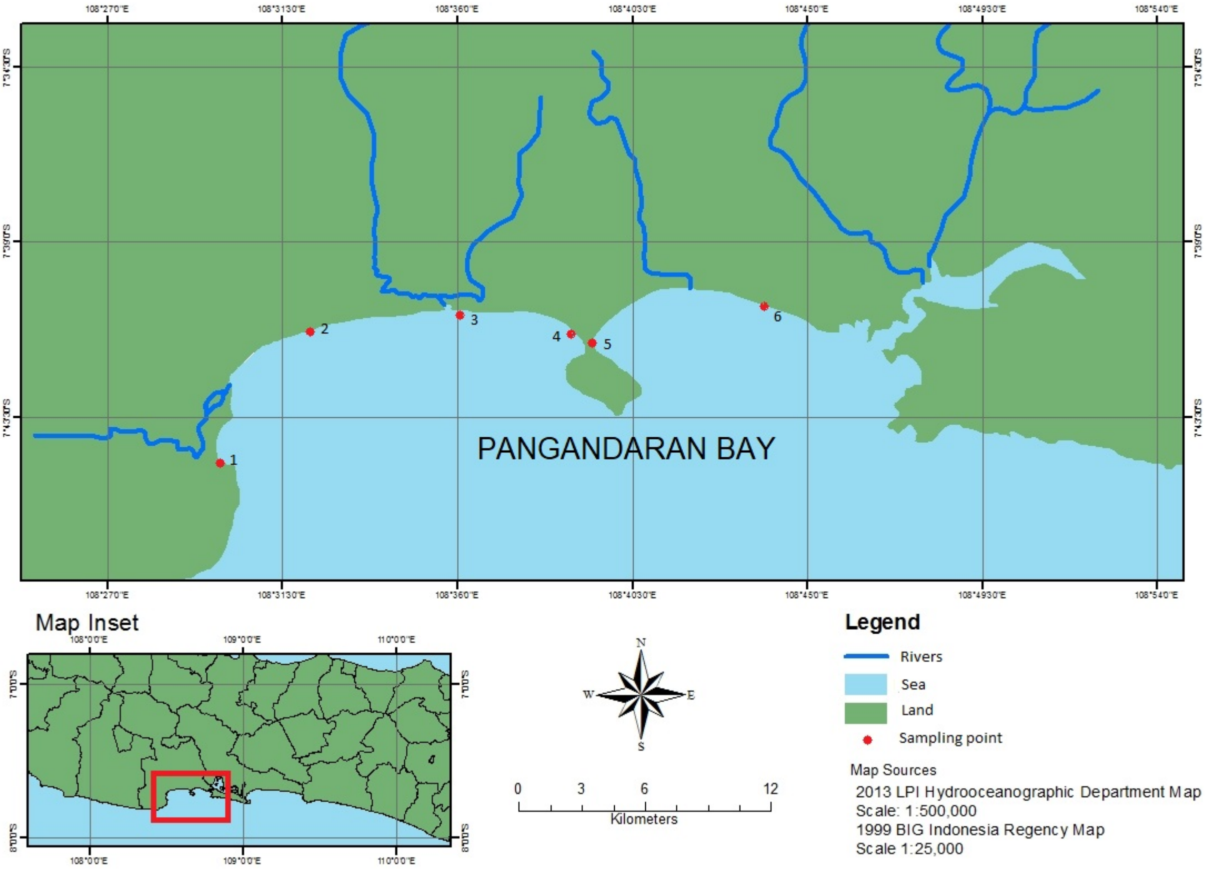
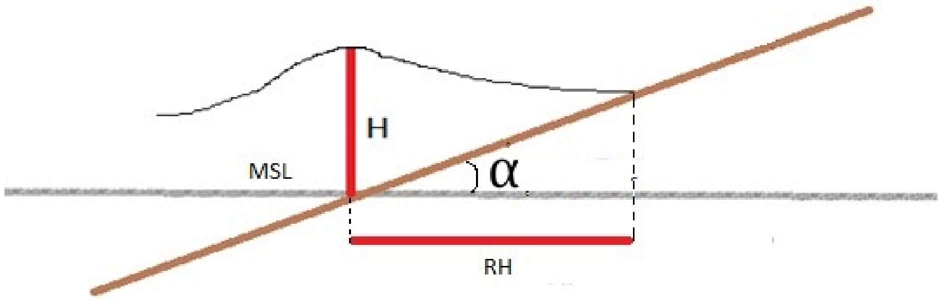


Figure 1. Locations of data collections at Pangandaran Bay, West Java

Table 1. Earthquake fault scenarios

Scenarios	MW	Epicenters		Depth (km)	Strike (°)	Dip (°)	Slip (°)	L (km)	W (km)	D (m)
		Lat	Long							
2006 Tsunami	7,7	-9,319	108,594	20	290	10	90	140	20	15
1	8,3	-9,319	108,594	15	290	15	90	240	20	20
2	8	-9,319	108,594	25	290	15	90	140	17	17
3	8,3	-9,656	108,554	15	290	15	90	240	20	15
4	8	-9,656	108,554	25	290	15	90	140	60	10



From the picture above we get the equation to determine the run-up range of tsunami, that is:

$$\frac{H}{RH} = \tan\alpha \qquad RH = \frac{H}{\tan\alpha}$$

RESULT AND DISCUSSION

Result

The results obtained from simulation of tsunami wave propagation are initial condition, height, travel time and run-up of tsunami wave at beach and time step of tsunami wave.

Pangandaran Tsunami (2006)

The earthquake that caused the Pangandaran tsunami in 2006 occurred at 9,319 LS and 108.594 BT epicenter with the strength of 7.7 Mw, and generated sea condition during earthquake as in Figure 3. At the condition around the epicenter of sea level rise of 3.878 meters and Sea level decrease of -1.541 meters.

The wave height data, wave propagation and the run-up height of tsunami waves at each observation point are obtained from Badan Penanggulangan Bencana Daerah (BPDD) of Ciamis Regency (Table 2). BPBD of Ciamis Regency data is then validated with data from the Processing model (Table 3).

First Scenario

This scenario assumes the earthquake occurs on epicenter 9,319 LS and 108,594 BT with 8 Mw power, so that the result of sea condition during earthquake as in Figure 4. At the condition around the epicenter of sea level rise 4.116 meters and sea level decrease of - 1.9920 meters.

From the model simulation, the height of the tsunami at each observation point is then calculated to determine the value of tsunami run-up (Table 4).

Second Scenario

This scenario assumed the earthquake that occur on epicenter 9,319 LS and 108,594 BT with a strength of 8.3 Mw, resulting in the condition of the Sea around the Center of Earthquake during Earthquake as shown in Figure 5. At the condition around the epicenter of sea level rise of 6.479 meters and sea level decrease of -3.098 meters.

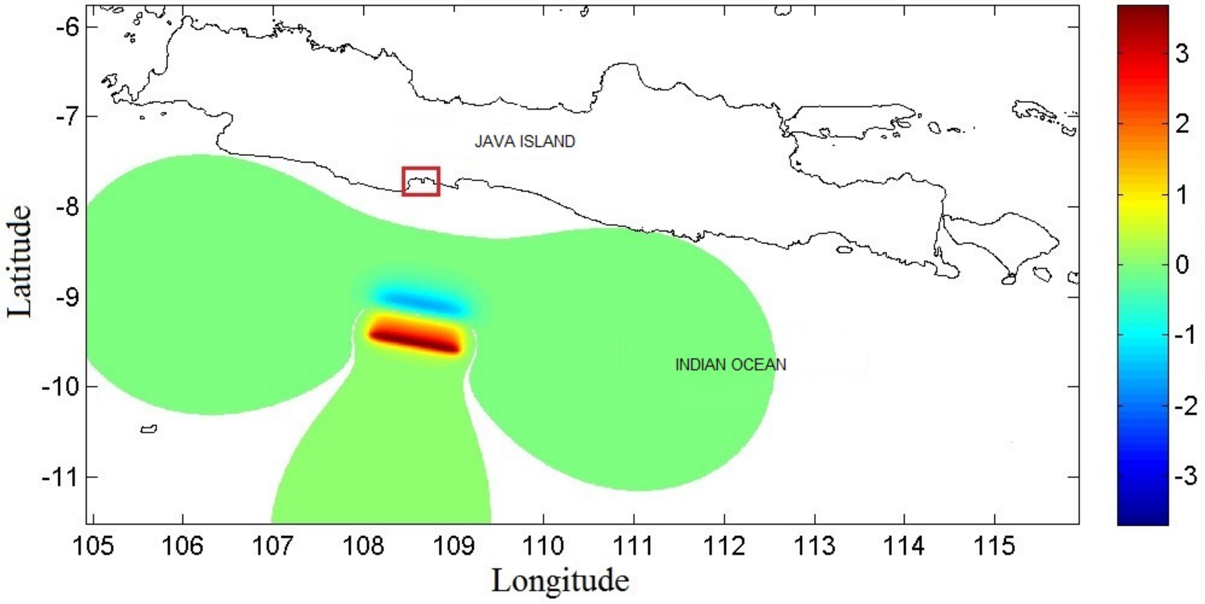


Figure 3. Ocean condition when tsunami waves occurred

Table 2. Tsunami wave height, tsunami travel time and tsunami *run-up* (source : 2006 BPBD Ciamis Regency)

Location	**TTM(minutes)**	**Tmax(meters)**	**Time(minutes)**	**RH(meters)**
1	35	2,0	39	25
2	37	3,5	40	90
3	40	5,0	43	250
4	37	4,0	40	200
5	38	3,0	42	95
6	45	3,2	48	0

Table 3. Tsunami wave height, tsunami travel time and tsunami run-up (model result)

Location	**TTM(minutes)**	**Tmax(meters)**	**Time(minutes)**	**RH (meters)**
1	38,9	2,52	41	29
2	41,3	3,25	44	85
3	43,5	4,25	47	236
4	42,6	3,04	45	190
5	41	2,84	44	93
6	42,3	3,19	44	0

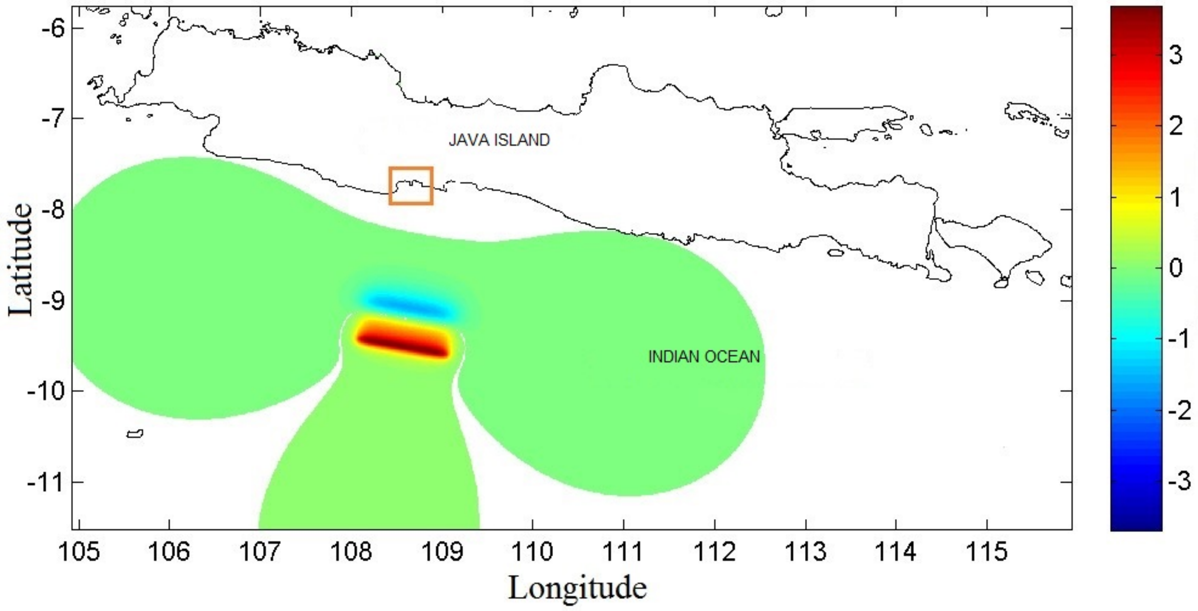


Figure 4. Ocean condition in first scenario when tsunami waves occurred

Table 4. Tsunami wave height, tsunami travel time and tsunami run-up first scenario model result

Location	**TTM(minutes)**	**Tmax(meters)**	**Waktu(minutes)**	**RH(meters)**
1	40,1	2,98	43	34,65
2	41,9	3,79	44	99,74
3	44,4	5,09	45	282,78
4	41,9	4,32	44	190
5	43,5	3,04	47	98,43
6	43	3,25	45	0

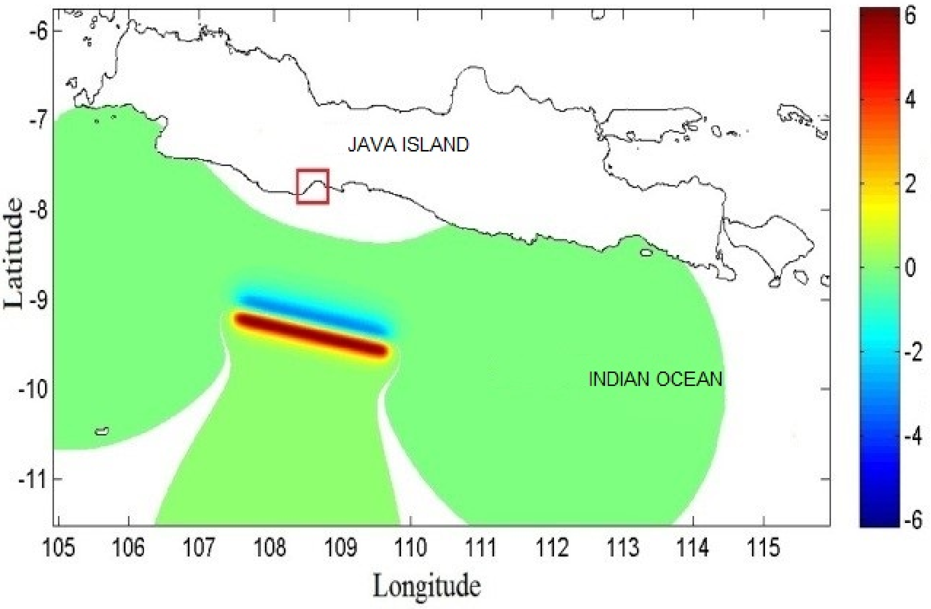


Figure 5. Ocean condition in second scenario when tsunami waves occurred

From the model simulation, the height of the tsunami at each observation point is then calculated to determine the value of tsunami run-up (Table 5).

Third Scenario

Third scenario assuming the earthquake occurred at epicenter 9,656 LS and 108,554 BT with power 8 Mw, so that marine condition resulted during earthquake as shown in Figure 6. At that condition, around the epicenter happened sea level rise 1,9430 meter and decreasing of water level the sea of -0.81 meters.

From the model simulation, it is known that the height of the tsunami at each observation point is then calculated to determine the value of tsunami run-up (Table 6).

Table 5. Tsunami wave height, tsunami travel time and tsunami *run-up* second scenario model result.

Location	TTM(minutes)	Tmax(meters)	Time(minutes)	RH(meters)
1	39,92	5,60	43	65,15
2	42	5,98	44	157,33
3	44,5	9,13	47	507,22
4	41,9	5,93	44	370,41
5	43,7	4,86	47	113,76
6	43,1	7,01	45	0

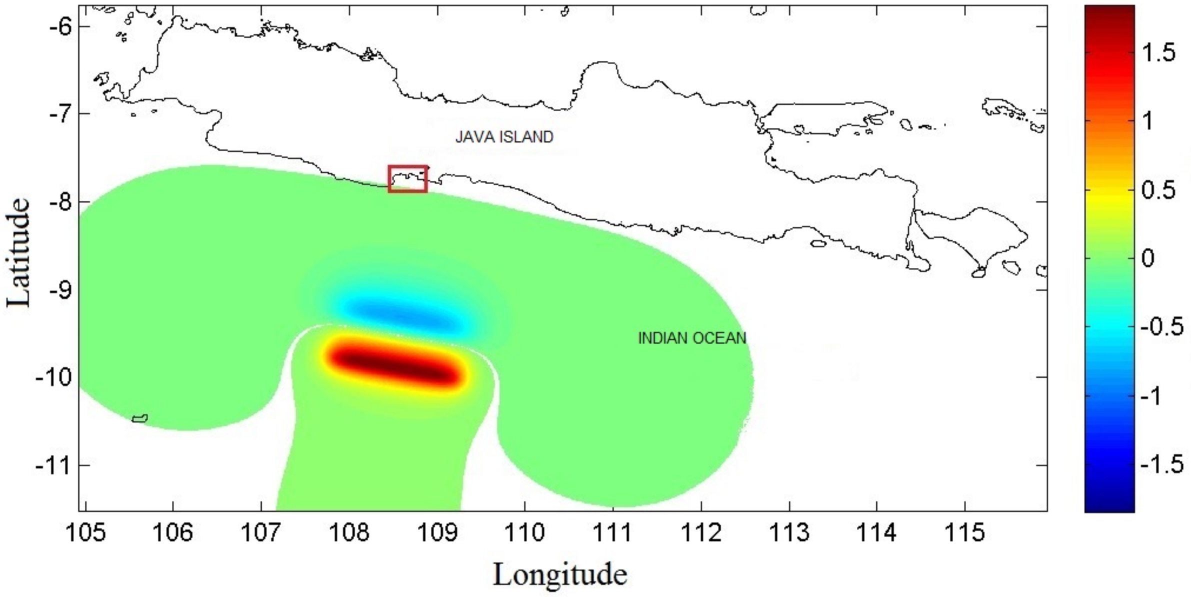


Figure 6. Ocean condition in third scenario when tsunami waves occurred

Tabel 6. Tsunami wave height, tsunami travel time and tsunami *run-up* third scenario model result.

Location	TTM(minutes)	Tmax(meters)	Time(minutes)	RH(meters)
1	42,2	1,69	44	15.92
2	44,6	2,66	48	65.98
3	46,7	3,8	49	169.2
4	44,2	2,06	47	113.67
5	46,1	2,79	50	70.05
6	45,7	2,51	50	0

Fourth Scenario

The scenario assumes the earthquake occurred at epicenter 9,656 LS and 108,554 BT with power 8,3 Mw, so that the result of sea condition during earthquake as shown in Figure 7. At that condition, around the epicenter of sea quake happened 2,882 meters and decreasing of water level the sea of -1.202 meters.

From the model simulation, the height of the tsunami at each observation point is then calculated to determine the value of tsunami run-up (Table 7).

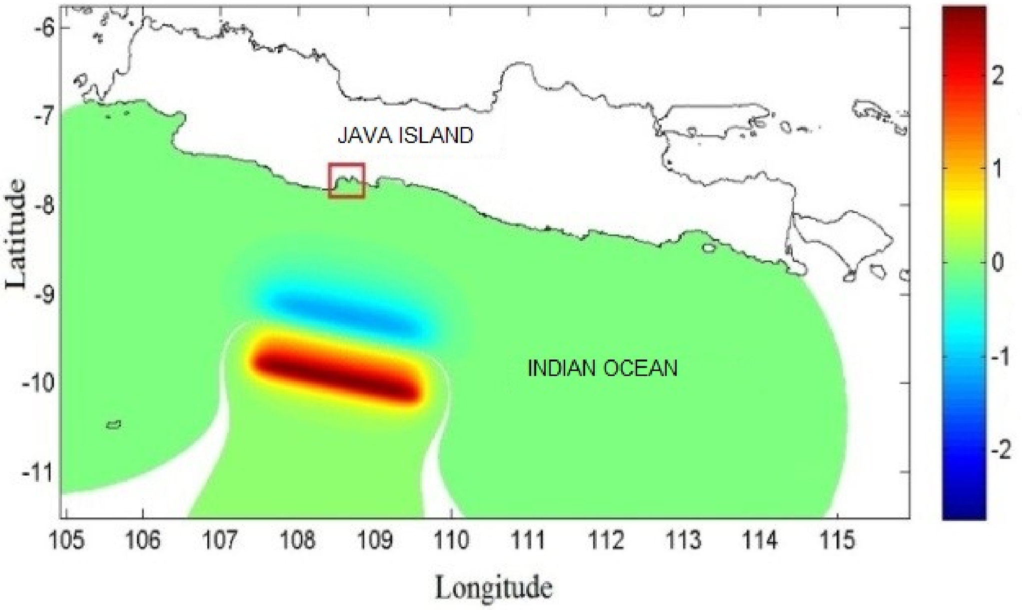


Figure 7. Ocean condition in fourth scenario when tsunami waves occurred

Tabel 7. Tsunami wave height, tsunami travel time and tsunami *run-up* fourth scenario model result.

Location	TTM(minutes)	Tmax(meters)	Time(minutes)	RH(meters)
1	41,8	3,61	45	19.65
2	44,3	4,96	49	70
3	46,5	6,31	50	188.89
4	44,1	3,56	49	128.75
5	45,9	3,40	51	86.37
6	45,5	5,69	50	0

Discussion

The condition of sea around the epicenter depend on earthquake generating or hypocentrum and dislocations or plate shifts that can lead to sea level rise and decline. The biggest sea level change occurred in scenario 2 because the dislocation value of the earthquake is bigger than other scenarios. While in scenario 3 and 4 with the same depth of earthquake but different dislocation value, it can be seen that the fluctuation of water level in scenario 4 is bigger. The greater the dislocation value of the earthquake that occurs, the sea level changes around the epicenter will be greater. The larger the width of the dislocation compared to the depth of the waters, the greater the magnitude of the earthquake moment and its effect on the waters around the epicenter.

Tsunami Time Travel is the time it takes tsunami waves to reach the mainland first. Tsunami Time Travel is calculated from the time the high wave reaches the mainland. The differences in tsunami travel time is due to the differences in distance between the observation point and the epicenter. The farther the distance between the observation point and the epicenter, the time to reach the land will be longer

Tsunami waves that reach the land will change shape due to water conditions and bathymetry of the sea floor. Point 3 where the highest wave occurs is the region with the most sloping bathymetry among other observation points. This location is also an open area that is not blocked by cliffs and facing directly with the epicenter. Such conditions cause the tsunami waves to break near the land and the waves will be higher. Points 1 and 5 where the lowest wave forms are locations blocked by cliffs and headlands. Point 1 has a relatively steep topography. This location is covered by cliffs. Point 5 is an unobstructed location by Pangandaran Cape. The bathymetry conditions on the cliffs and headlands tend to be steep, so that the incoming waves will experience diffraction. The diffraction process leads to deflection of the wave direction at the edge of the cliff and cape thus causing the waves to enter the area protected by cliffs and headlands. This type of wave will affect the wave height decrease. Points 2, 4 and 6 are sloping locations but not face-to-face with the epicenter so the tsunami maximum height is not as high as at point 3.

Run-Up tsunami waves are conditions where there is a change in energy that causes the waves to rise to the mainland. The run-up value of the tsunami waves at each observation location is different. Point 3 is an open area with a very sloping coastal slope. At the time of the tsunami, there will be the highest run-up wave because at this point there is no barrier that can reduce the height of tsunami waves. At point 6, it can be said that there is no run-up of the wave because the point is a cliff area with a higher land height than the tsunami. Points 1 and 5 have low run-up range values because they are in an area blocked by cliffs and headlands. These cliffs and headlands lead to waves undergoing diffraction processes resulting in deflection of the waves and the protected areas will remain exposed to waves but with relatively smaller heights. The existence of cliffs and headlands is able to reduce the height of tsunami waves. Reduced tsunami heights will result in reduced tsunami run-up range. Points 2 and 4 have relatively high run-up values but are not as high as point 3. Points 2 and 4 are mixed areas between slopes and cliffs with vegetation.

CONCLUSION

The highest tsunami wave height occurred at point 3 with the coordinates of 07 ° 40 '02.02 "LS and 108 ° 36' 06.17" BT in the 8.3 MW magnitude earthquake is 9.13 meters, whereas the lowest height occurred at point 1 with coordinates 07 ° 44 '27.50 "LS and 108 ° 29 '48.41" BT in an 8.0 MW magnitude quake that is 0.83 meters.

Tsunami wave travel time to reach the land ranged between 39 minutes - 43 minutes with a time of maximum tsunami height in the range of 44 minutes - 47 minutes.

The highest run-up range of tsunami waves occurs at point 3 with the coordinates of 07 ° 40 '02.02 "LS and 108 ° 36' 06.17" BT between 150 - 510 meters at the slopes range of 1 ° - 5 ° and the lowest run-up range in Point 6 with coordinates 07 ° 40 '42.79 "LS and 108 ° 42' 32.81" BT is 0 meters on a cliff area with a cliff height of 8 meters.

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