Correlation between Seafloor Topography and Mangrove to High Wave Propagation

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ABSTRACT
In this study, a high wave propagation simulation is conducted with several scenarios that include water's depth or seafloor topography's scenario and mangrove forest. The seafloor topography scenario is included because Indonesia has a quite different seafloor topography. The mangrove scenarios are included in this study because it will be seen how the effects of mangrove forests influence to reduce the height and velocity of waves. After the results of numerical simulations that have been carried out, it is obtained some information that the depth of waters and mangrove forests can contribute to the propagation of waves. Both can play a role to reduce the wave height to arrive at the mainland about 0,02 meters. It also can reduce the speed of the wave. With some results of the analysis obtained, how we provide obstacles can be done to reduce the impact of the risk of high waves, one of which is by planting mangrove forests. Further research is needed to learn the cause of the difference between negative velocity and time to wave that is fast enough even if given obstacles.

Keywords : *high wave, mangrove, seafloor topography, , numerical simulation.*

I. INTRODUCTION

Indonesia is an archipelago country that bordering directly with the ocean for all its islands, both the sea that connects between islands and the ocean. Based on a map of Indonesia, a developing bathymetry pattern shows the morphology of the seafloor following the coastline and the pattern of tectonic results (Figure 1). Around the Sunda Exposure (Malacca Strait, South China Sea and Java Sea), the morphology of exposure develops along the coastline, whereas in Eastern Indonesia, it shows a great depth, starting from 2000 meters to more than 7000 meters. The high area shows the shape of sharp bumps and narrow valleys as the main characteristic of the bedrock. These forms are inseparable from the influence of Australian intra microcontinent collisions with the Banda Islands [1].

Based on the geographical location of Indonesia that has been described, then there is a possibility that high wave disasters can hit the coast of Indonesia at any time. With this possibility, the Indonesian population must always be vigilant and be careful of the high wave disasters. Based on the data obtained, there are many types of high wave disasters that have occurred in Indonesia. High wave disasters that have occurred in Indonesia include storm waves and tsunami waves. A storm surge is an abnormal sea level rise along the coast when a typhoon approaches and crosses it. The main causes of storm surges are high winds and low pressure [2]. While the tsunami waves occur because of several things, including earthquakes, volcanic eruptions on the seafloor, landslides on the seafloor and the meteor that fall into the sea [3].

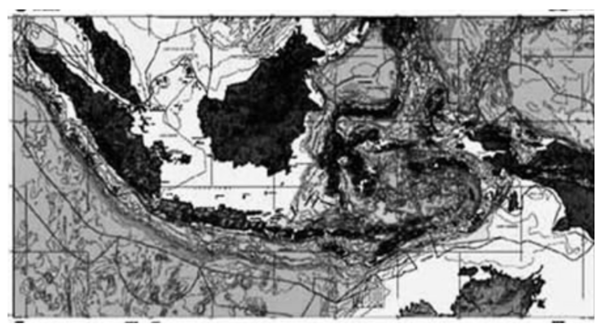

Fig 1. Map of Indonesia

In addition to the two types of high waves mentioned, another high wave disaster is abrasion which can occur at any time. This can occur when a lunar eclipse where the moon's gravity is high enough to cause sea water to rise and head to land. These waves can also move quickly towards the mainland if accompanied by strong wind speeds. Some areas in Indonesia that have been identified as abrasion are the coastal areas of North Sumatra in 2018 and the coast of West Sulawesi in 2017 [4]. Some areas in Indonesia that have been identified as being affected by the tsunami, include Aceh in 2004, Palu, Central Sulawesi in 2018 [4] and the Banten-Lampung region in 2018 [5]. The storm surge and tsunami waves that occurred in Indonesia took many victims, both material and lives.

One effort that can be done to reduce the risk of high waves is to provide obstacles during the propagation of high waves from the ocean to the mainland. This can reduce wave energy, such as the wave height and wave velocity to the land is reduced. One of effort is the preservation of mangrove forests. Based on research that has been done, mangrove forests can reduce wave heights. Wave height reduction depends on mangrove area, mangrove morphology and water depth topography [6]. With the mangrove forest, the height and speed of the waves when arriving on land can be reduced. In addition, in 2012, laboratory test were carried out related to the influence of mangroves that were able to reduce tsunami waves. In the study, information was obtained that mangrove roots were more effective in reducing run-up compared to stems and canopies [7]. In addition, in 2015, a simulation was also conducted on laboratory-based wave propagation by providing mangrove forests as obstacles. From the results of this simulation, it was also found that mangrove forests were able to reduce wave velocity and height [8].

In this study, a simulation of high wave propagation will be carried out with several scenarios which include a combination of scenarios between seafloor topography and mangrove barriers. The seafloor topography scenario was chosen because Indonesia has a very different seafloor topography. The mangrove scenario was chosen in this study aims to see how the effect of the influence the mangroves for reducing the height and velocity of the waves. So with this research, it is hoped that information can be obtained to optimize mangrove forests in coastal conditions in Indonesia with certain seafloor topography.

II. MATHEMATICAL MODEL

In this section, we will explain the mathematical models used in simulations. The mathematical model used is a combination of the wave mathematical model on the sea and the mathematical model of the wave on the mangrove forest. Then in this section, the two models will be discreted with finite difference methods.

A. Mathematical Model before Mangrove

The wave propagation mathematical model iused is a tsunami wave mathematical model derived by Imamura [9]. In this study, the wave propagation simulation used is a simulation with a one-dimensional mathematical model. In the simulation, wave propagation is observed along the x direction. The x direction referred to in this study is the direction of wave propagation from the sea to the mainland. Equation 1 is the wave height equation and equation 2 is the horizontal wave velocity equation in the x-axis direction. Equation 1 and Equation 2 are used to simulate waves from sea to land, precisely to the mangrove forest area.

- Wave height equation :

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} = 0 \quad (1)$$

- Discharge fluxes in x – direction :

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2 M\,|M|}{D^{7/3}} = 0 \quad (2)$$

with the variable description as follows:

x : coordinates
M : wave discharge on the x-axis
η : wave height
D : depth of water above the source field
n : manning roughness coefficient
g : acceleration due to gravity

D is the total height or the sum of h (depth) and η (wave height above sea level). M is the wave discharge fluxes, which is the product of D and u where u is the wave velocity in the direction of the x axis.

B. Mathematical Model on Mangrove

As the wave reaches the location of mangrove forests, the mathematical models in equations 1 and 2 are constrained in the form of friction coefficients, which are the result of calculating the characteristic density of trees in the mangrove forest. Equation 3 is the flux equation by entering the friction coefficient and the inertia coefficient when the sea water wave passes through mangrove forests [10].

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2 M\,|M|}{D^{7/3}} + \frac{C_d A_0 M\,|M|}{2D^2} + C_M \frac{V_0}{V}\frac{\partial M}{\partial t} = 0$$

(3)

with additional information as follows :

C_d : drag coefficient
C_M : inertia coefiicient
V_0 : volume of trees in underwaters
V : control volume that chosen
A_0 : area of trees in under water

To get the A_0 and V_0 values, it needs to be considered in relation to mangrove forests planted on the beach. To determine the two values, a survey was first carried out related to the diameter of mangrove trunks (D_T), diameter of mangrove roots (D_R) and diameter of leaves of mangrove trees (D_L). In addition, surveys were carried out related to mangrove trunks (H_T), height of mangrove roots (H_R) and height of the crowd of leaves on mangrove trees (H_L). The information needed to calculate the values of A_0 and V_0 is information related to the many roots owned by mangrove trees (N_R) and the many mangrove trees planted per square meter (N_T).

After the value is obtained, then the calculation of the A_0 and V_0 values is performed in equation (4) and (5) :

$$A_0 = A_T + A_R + A_L \tag{4}$$

$$V_0 = V_T + V_R + V_L \tag{5}$$

With each value of $A_T, A_R, A_L, V_T, V_R, V_L$ are obtained in equation 6 through equation 11 :

$$A_L = P_L H_L \left(D_L \frac{N_T}{100} \right) \tag{6}$$

$$A_T = H_T \left(D_T \frac{N_T}{100} \right) \tag{7}$$

$$A_R = H_R \left(D_R \frac{N_T N_R}{100} \right) \tag{8}$$

$$V_L = P_L H_L \left(\pi \frac{D_L^2}{4} N_T \right) \tag{9}$$

$$V_T = H_T \left(\pi \frac{D_T^2}{4} N_T \right) \tag{10}$$

$$V_R = H_R \left(\pi \frac{D_R^2}{4} N_T N_R \right) \tag{11}$$

P_L is the porosity value of mangrove trees or the density of mangrove trees per unit area. The value of P_L can be obtained from equation (12) [11] :

$$P_L = \left(1 - \pi \frac{D_T^2}{4} N_T \right) \tag{12}$$

When the wave flow enters the mangrove forest, the calculation of the value of the manning coefficient is as equation 13 [8] :

$$n = \sqrt{\frac{C_d A_0 D^{1/3}}{2 g \Delta x}} \tag{13}$$

After getting the mathematical model used, the next step is numerical simulation. Before doing simulations, mathematical models are discreted with finite difference methods.

C. Discretization

In this section, the results of the discretization from equation 1, equation 2 and equation 3 will display and will be used in the numerical simulation process.

- Wave height equation :

$$\eta_i^{t+1} = \left(- \frac{M_{i+1}^t - M_{i-1}^t}{2\Delta x} \right) \Delta t + \eta_i^t \tag{14}$$

- Discharge fluxes in x – direction :

$$M_i^{t+1} = 2M_i^t \left(\frac{M_{i+1}^t - M_{i-1}^t}{2\Delta x D_i^t} \right) \Delta t + M_i^t \left(\frac{D_{i+1}^t - D_{i-1}^t}{2\Delta x} \right) \Delta t - gD_i^t \left(\frac{\eta_{i+1}^t - \eta_{i-1}^t}{2\Delta x} \right) \Delta t - \frac{gn^2 M_i^t \left| M_i^t \right|}{\left(D_i^t \right)^{7/3}} \Delta t + M_i^t \tag{15}$$

- Discharge fluxes in x – direction on mangrove forest :

$$M_i^{t+1} = 2M_i^t \left(\frac{M_{i+1}^t - M_{i-1}^t}{2\Delta x D_i^t} \right) \frac{\Delta t}{\left(1 + C_M \frac{V_0}{V} \right)} + M_i^t \left(\frac{D_{i+1}^t - D_{i-1}^t}{2\Delta x} \right) \frac{\Delta t}{\left(1 + C_M \frac{V_0}{V} \right)} - gD_i^t \left(\frac{\eta_{i+1}^t - \eta_{i-1}^t}{2\Delta x} \right) \frac{\Delta t}{\left(1 + C_M \frac{V_0}{V} \right)} - \frac{gn^2 M_i^t \left| M_i^t \right|}{\left(D_i^t \right)^{7/3}} \frac{\Delta t}{\left(1 + C_M \frac{V_0}{V} \right)} - \frac{C_d A_0 M_i^t \left| M_i^t \right|}{\left(D_i^t \right)^2} \frac{\Delta t}{\left(1 + C_M \frac{V_0}{V} \right)} + M_i^t \tag{16}$$

III. ALGORITHM

In this section, a simulation location is explained. In the simulation, the first plan is to determine the sea and land plan. In this study, observational were taken in general, with the category of coastal areas planted with mangrove and not planted with mangroves. In Figure 2, a simulation about location is presented. *Lx* is the length of the wave propagation area, where the left endpoint is the location where the waves appear high in the middle of the sea. Then the waves flow inland (from left to right) to the mangrove forest for the beach planted with mangrove forests. In Figure 2, mangroves are planted along *Ls* km.

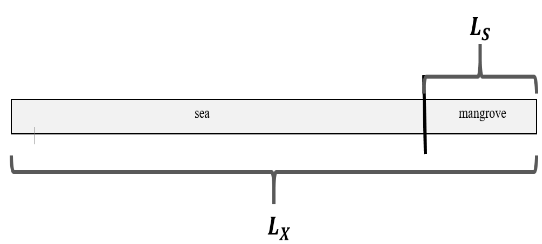

Fig 2. Simulation Location

In Figure 2, it is explained that there are seas and land. Where at a few meters from the mainland fortified by Mangrove forests. From Figure 2, the simulation algorithm performed on figure 3.

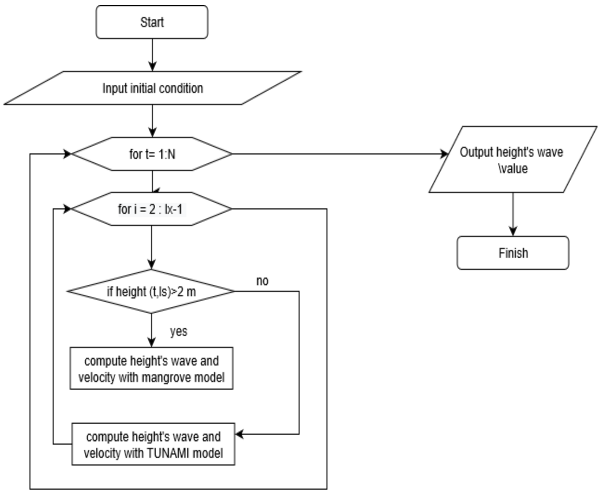

Fig 3. Simulation Algorithm

In the simulation algorithm presented in Figure 3, it can be seen that the simulation looping process with a mathematical model of mangrove forests will be carried out when the wave height at the mangrove forest landline reaches a certain wave height. So that under these conditions, a simulation with a mathematical model of mangrove forest is carried out. Whereas before the wave height reaches a certain height at position ls, the simulation is carried out with the TUNAMI mathematical model.

IV. NUMERICAL SIMULATION

In the simulation process, the initial wave conditions are determined with the following specifications:

- Wave height: 5 m
- Distance from land: 50 km

In determining the initial height value, because the value is ignored (it can be considered due to an earthquake, sea landslide or whatever). Figure 4 is displayed of the initial wave conditions with a height of 5 m and a distance of 50 km from the mainland.

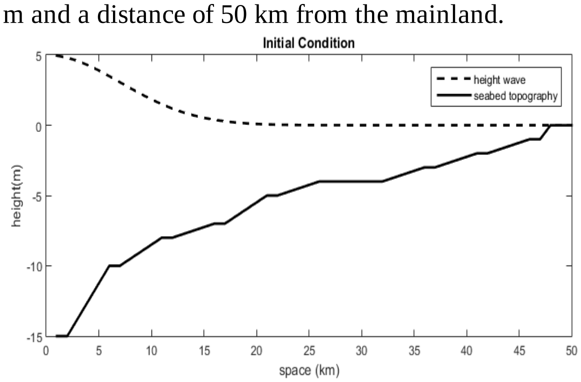

Fig 4. Initial Condition

Furthermore, the simulation process is carried out divided into several scenarios with differences in the seafloor topography and the long existence of mangrove forests crossed by high waves. Each scenario is divided into two conditions, namely the condition of high waves that go directly to the mainland without passing through the mangrove forest (there is no mangrove forest at that location) and passing through the mangrove forest. This aims to see how much influence the mangrove forest has to reduce the height and velocity of the waves. In each scenario, the high wave performance will be compared to the mainland through the mangrove forest or not through the mangrove forest.

- Scenario 1

The following from the 1st scenario has specification linear depth and mangrove forest is 5 km from the mainland. Furthermore, the first scenario will be simulated wave propagation with a height of 5 m with a distance of 50 km from the coast. In Figure 5, a wave propagation is displayed from the origin of the waves to the mainland without going through the mangrove forest at all and in Figure 6 a wave propagation is displayed from the origin of the waves to the land by passing the mangrove forest along the 5 km located on the coast.

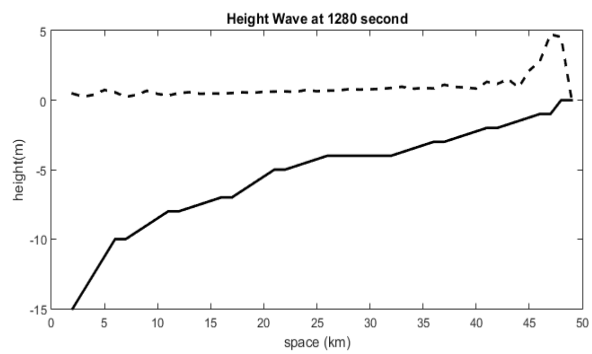

Fig 5. Wave's Propagation on Scenario 1 without Mangrove

In Figure 5 a wave propagation is displayed when it reaches the edge of the mainland without going through the mangrove forest.

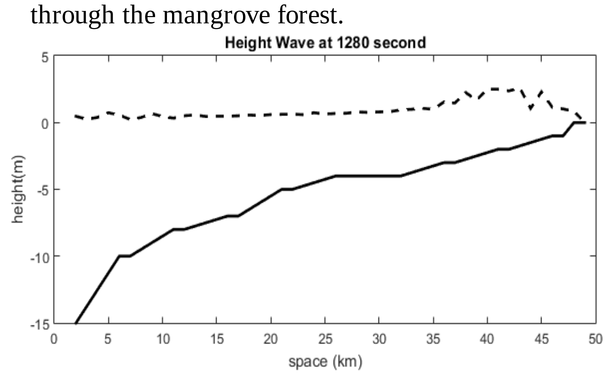

Fig 6. Wave's Propagation on Scenario 1 with Mangrove

In Figure 6 a wave propagation is displayed as it reaches the edge of the mainland through the mangrove forest.

- Scenario 2
  The following from 1st scenario have specification steep depth and the length of mangrove forest is 5 km from the mainland. Furthermore, the first scenario will be simulated wave propagation with a height of 5 m with a distance of 50 km from the coast. In Figure 7 a wave propagation is displayed from the origin of the waves to the mainland without going through the mangrove forest at all and in Figure 8 a wave propagation is displayed from the origin of the waves to the land by passing the mangrove forest along the 5 km located on the coast.

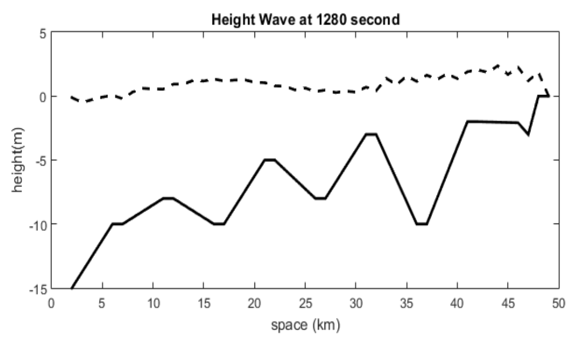

Fig 7. Wave's Propagation on Scenario 2 without Mangrove

In Figure 7 a wave propagation is displayed when it reaches the edge of the mainland without going through the mangrove forest.

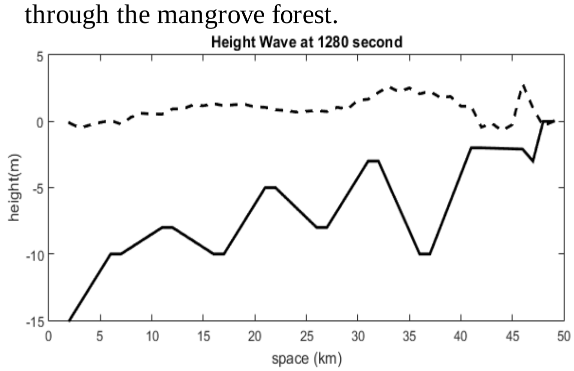

Fig 8. Wave's Propagation on Scenario 2 with Mangrove

In Figure 8 a wave propagation is displayed as it reaches the edge of the mainland through the mangrove forest.

V. ANALYSIS RESULTS

This section explains the analysis of simulation results that have been carried out. In the simulation that has been done, used two scenarios with various types of water depth. With each type of wave propagation simulation carried out with mangroves and without mangroves. The first analysis was carried out to determine the time of high waves to the coast with the provisions of waves $\geq$ 2 meters. In Table 1, it is presented when high waves arrive at the beach. Location 45 is the initial location of waves entering the mangrove forest area and location 48 is the location of mangrove forests that are already near the mainland. In tables 1 to table 3, η nm is the description of wave height without passing through the mangrove forest at all and η m is the description of wave height with a propagation path through the mangrove forest.

Table 1 . Time of Arrival of High Waves on the Coast

Location	Scenario 1		Scenario 2	
	η nm	η m	η nm	η m
45	943 unit time	945 unit time	876 unit time	625 unit time
48	1078 unit time	1602 unit time	811 unit time	880 unit time

In Table 1 it can be seen that the waves are faster until the waters are steeper and there are mangrove forests. Next to see the efficiency of mangrove forests, the average wave height and wave velocity will be seen at each location (location 45 to location 48) for each scenario. The results of the comparison are presented in Table 2 and Table 3.

Table 2. Average Wave Height

Location	Scenario 1		Scenario 2	
	η nm	η m	η nm	η m
45	0.956146	0.936612	0.937294	0.933294
46	0.956384	0.936851	0.937818	0.933818
47	0.6864	0.667736	0.6596	0.6556
48	0.778299	0.759235	0.802882	0.798882
average	0.844307	0.825109	0.834399	0.830399

Table 3 . Average Wave Speed

Location	Scenario 1		Scenario 2	
	u nm	u m	u nm	u m
45	0.956146	0	0	-0.004
46	0.956384	0.007768	0.006602	0.002602
47	0.6864	0.000672	0.000418	-0.003582
48	0.778299	-0.017318	-0.014956	-0.018956
average	0.844307	-0.00222	-0.001984	-0.005984

In Table 2, the information is obtained that the average wave height generated by the propagation of waves through the mangrove forest is lower than through the mangrove forest. Likewise with the speed of the wave. Even, based on Table 3, information can also be obtained that the wave velocity is positive or leads to land for scenario 1 with a propagation path without passing through mangrove forests. Whereas for other conditions the wave velocity is negative or can be said to slow down because physically, if it is negative, it has the opposite direction. The correlation between progress and mangrove forests also provides orientation. Can be seen as scenario 1 without mangrove conditions is different from scenario 2 with scenario 1 and mangrove. Based on the results of the simulation conducted, information can be obtained that the more obstacles are given in the wave propagation path, the wave velocity will decrease and the average wave height will be smaller. However, based on Table 1, information can be obtained that the more obstacles, the faster the propagation of waves towards the shoreline. With some results of the analysis obtained, the provision of obstacles can be done to reduce the impact of the risk of high waves, one of which is by planting mangrove forests.

VI. CONCLUSION

Based on the results of simulations that have been carried out, it is obtained some information that the depth of waters and mangrove forests can contribute to the propagation of waves. Both can play a role to reduce the wave height to arrive at the mainland and also reduce the speed of the wave. Further research is needed to find out the cause of the difference between negative velocity and time to wave that is fast enough even if given obstacles. In addition, further surveys are needed in determining the parameter values associated with Mangrove trees. Adding scenarios is also very necessary to determine the relationship between the length of mangroves and the depth of the waters. This aims to be a consideration to be alert to the future conditions. Moreover, many things that make the depth of the waters change, such as reclamation and sea floor dredging.

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