Reclamation Effect of Tsunami Height and Velocity in the Shoreline

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ABSTRACT
Indonesia is a country flanked by 3 active plates and has many active volcanoes. This condition makes Indonesia susceptible to tsunami disaster. In 2018 Indonesia was hit by two tsunamis. The cause is plate friction and volcanic activity. Tsunami waves have a unique characteristic, the height of a tsunami wave in the middle of the sea is the same as ordinary waves, but when it reaches the shoreline the height gets higher. The reason is the increasingly sloping coastal contours. Coastal contours in Indonesia generally changes, either naturally due to abrasion and erosion, or artificially like reclamation. Reclamation clearly impacts the slope of the coast, causing different tsunami heights. This study discusses the impact of Reclamation on tsunami heights. Using the TUNAMI Mathematical Model, the results obtained are the height of the tsunami at the shoreline before Reclamation of 0.80 and the speed of 63.4 km / h, while the height of the tsunami after Reclamation is 0.87 and the speed is 70.5 km / h, so that the impact of Reclamation on the height and speed of the tsunami increases 8% and it can be concluded that the effect of Reclamation on tsunamis is to increase the risk of damage.

Keywords: *Tsunami, Reclamation, Slope, Mathematical models, TUNAMI.*

I. INTRODUCTION

Indonesia as a maritime country has the fourth longest coastline in the world after the United States, Canada, and Russia with a coastline length reaching 95,181 km [1]. The coastline is often used for residential, tourism, and industrial. For cities that have large population and close to the coast, the coastline is one of the targets used to expand its territory, one of the ways to expand is by Reclamation.

Reclamation is basically an activity or effort made by a person / group or developer by changing wetlands (in the form of swamps, coastal areas, river banks, lake banks, etc.) by drying or stockpiling, so that they are produced land or dry land used for development activities [2].

This renewal will obviously change the basic shape of the contour of the coast, so that the height and speed of the resulting waves are different. This of course also has an impact on tsunamis that produce different speeds and heights when on the shoreline.

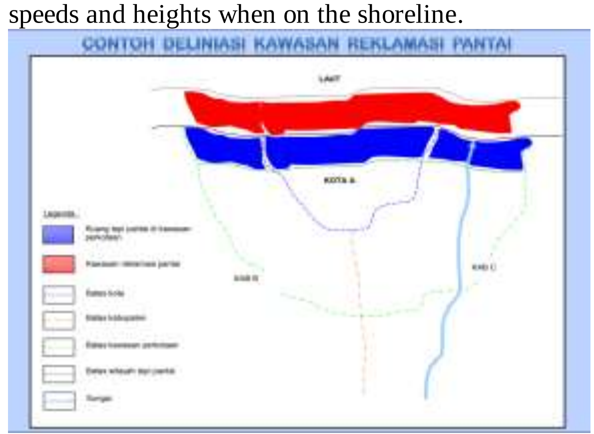

Fig. 1. Reclamation

How to carry out reclamation depends on the system used. According to the Reclamation Guidebook in Coastal Areas [3] the implementation is divided into 4 systems, namely the Pile system, the Polder system, the combination system between the Polder and the Pile, and the Drainage system. The pile system is suitable for tropical areas that have very high rainfall and this method is the most popular in Indonesia.

Java Island is a strategic place to do reclamation because it is supported by rapid industrial growth, so reclamation is one option that can be used, one of which is reclamation carried out in the Jakarta area which is used for the construction of new housing areas. One of the negative effects of this reclamation is the occurrence of sedimentation.

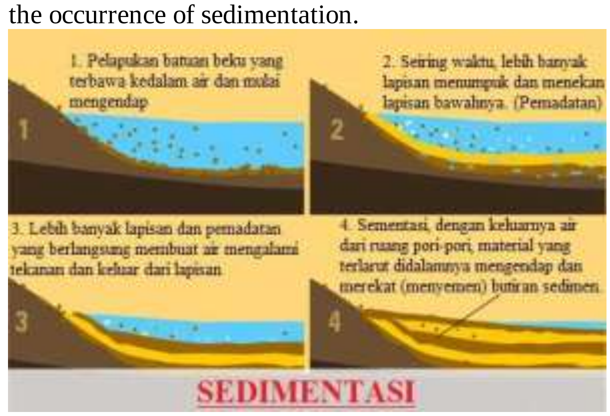

Fig. 2 Sedimentation Process

Sedimentation is the process of deposition of material transported by water as a result of erosion. So that this causes changes in the contour of the slope of the coast become increasingly sloping due to the influence of sedimentation, so that if a tsunami occurs it will have an impact on the height of the tsunami.

Tsunami is a disaster that often occurs in Indonesia, in 2018 the tsunami struck the hammer and offerings [4]. The main cause is volcanic activity and plate friction, because Indonesia is a country that is crossed by a ring of fire and flanked by 3 active tectonic plates [5], so that Tsunami is prone to occur in Indonesia. Tsunamis are waves that have unique characteristics, where tsunami heights in the middle of the sea look like ordinary waves when on the shoreline, the height can increase many times [6], this is due to the shape of the seabed, the sloping the contours of the seabed the higher tsunami heights produced [7]. This research discusses the effect of reclamation on tsunami velocity and height on the coast

II. PRELIMINARIES

A. Tunami Mathematica Model

The mathematical model of the tsunami is based on the shallow water equation, because the wavelength of the tsunami is longer than the depth of the water. In this study using the TUNAMI mathematical model which has 2 equations, height equation and the flux equation [8]:

Height Equation :

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

Flux equation:

$$\frac{\partial M}{\partial t} + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{\frac{7}{3}}}M|M| = 0 \qquad (2)$$

where,

η = waves height

D = Total depth $(\eta + h)$

g = Acceleration due to gravity

M = flux in x axes $(u * h)$

u = Velocity in x axes

n = Coefficient of Bottom Friction

where the value of n is

Table. 1. The value of n of various types of material [9]

Channel Material	n	Channel Material	n
Neat cement smooth metal	0.01	Natural channels in good conditions	0.025
Rubble masony	0.017	Natural channels with stones and weeds	0.035
Smooth earth	0.018	Very poor natural channels	0.060

The following is a scheme of the Tunami Mathematical Model based on the swallow water model in 1-D [10]:

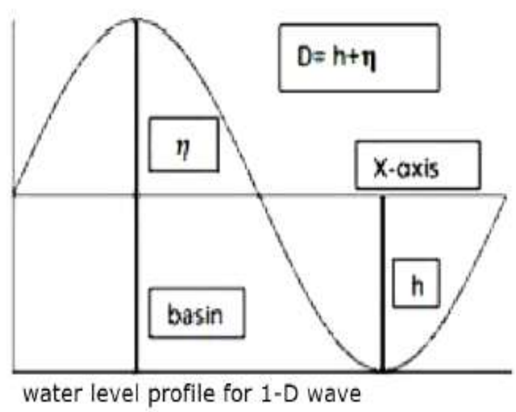

Fig. 3. 1-D Shallow water model

Figure 3 is a tsunami propagation in 1-D. The vertical axis is the change in sea level and the horizontal axis is the distance from the source of the tsunami to the coast, where at each distance the depth varies, and this has an influence on the height and velocity of the tsunami. When the shoreline is reclaimed, the depth becomes more gentle because of the influence of sedimentation. This research discusses the effect of reclamation on the height and velocity of the tsunami at the shoreline.

Based on the mathematical model a numerical process is carried out so as to produce heights and speeds that occur at the seashore

B. Finite Difference Method

Finite-difference methods are numerical methods for approximating the solutions to differential equations to approximate derivatives [11].

From Taylor Series expansion, we have

$$f(x+\Delta x) = f(x) + \frac{\partial f}{\partial x}(\Delta x) + \frac{1}{2!}\frac{\partial^2 f}{\partial x^2}(\Delta x)^2 +, \ldots, + \frac{1}{n!}\frac{\partial^n f}{\partial x^n}(\Delta x)^n \qquad (3)$$

The grid generation in FDM shown in Fig 3

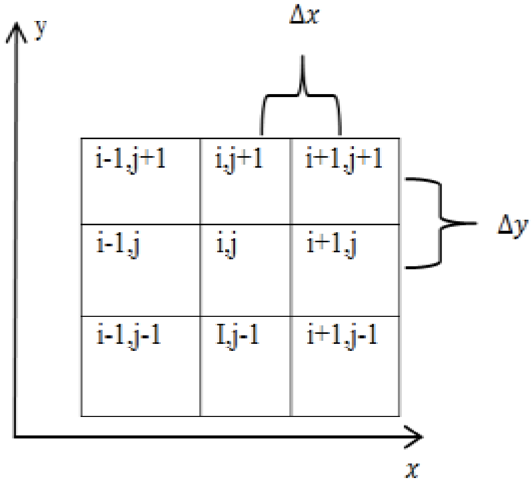

Fig. 4. Grid in Finite Difference Method

Based on figure the forward difference approximation is

$$\left(\frac{\partial f}{\partial x}\right)_i^j = \frac{\left(f_{i+1}^j - f_i^j\right)}{\Delta x} + O(\Delta x)$$

The backward difference approximation :

$$\left(\frac{\partial f}{\partial x}\right)_i^j = \frac{\left(f_i^j - f_{i-1}^j\right)}{\Delta x} + O(\Delta x)$$

and the central difference approximation as :

$$\left(\frac{\partial f}{\partial x}\right)_i^j = \frac{\left(f_{i+1}^j - f_{i-1}^j\right)}{2\Delta x} + O(\Delta x)^2$$

III. NUMERICAL RESULTS

A. Numerical Scheme

To get the numerical solution of the TUNAMI equation, discretion is done on equation (1) and equation (2). In this study the time dimension is carried out by advanced difference discretization, and the space dimension is carried out by discretization of the center, so:

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} = 0$$

$$\Longrightarrow \left[\frac{\eta_i^{t+1} - \eta_i^t}{\Delta t}\right] + \left[\frac{M_{i+1}^t - M_{i-1}^t}{2\Delta x}\right] = 0$$

$$\Longrightarrow [\eta_i^{t+1} - \eta_i^t] = -\frac{\Delta t}{2\Delta x}[M_{i+1}^t - M_{i-1}^t]$$

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

Then, from equation 2, we get :

$$\frac{\partial M}{\partial t} + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{\frac{7}{3}}}M|M| = 0$$

$$\left[\frac{M_i^{t+1} - M_i^t}{\Delta t}\right] + g(\eta_i^t + h_i)\left[\frac{\eta_{i+1}^t - \eta_{i-1}^t}{\Delta x}\right] + \frac{gn^2}{(\eta_i^t + h_i)^{\frac{7}{3}}}M_i^t|M_i^t| = 0$$

$$\left[\frac{M_i^{t+1} - M_i^t}{\Delta t}\right] = -g(\eta_i^t + h_i)\left[\frac{\eta_{i+1}^t - \eta_{i-1}^t}{\Delta x}\right] - \frac{gn^2}{(\eta_i^t + h_i)^{\frac{7}{3}}}M_i^t|M_i^t|$$

$$M_i^{t+1} - M_i^t = -g(\eta_i^t + h_i)\frac{\Delta t}{\Delta x}[\eta_{i+1}^t - \eta_{i-1}^t] - \Delta t\frac{gn^2}{(\eta_i^t + h_i)^{\frac{7}{3}}}M_i^t|M_i^t|$$

$$M_i^{t+1} = -g(\eta_i^t + h_i)\frac{\Delta t}{\Delta x}[\eta_{i+1}^t - \eta_{i-1}^t] - \Delta t\frac{gn^2}{(\eta_i^t + h_i)^{\frac{7}{3}}}M_i^t|M_i^t| + M_i^t$$

B. Simulation Results

Simulations were carried out using various types of depths, the first with a constant depth, the second with a normal depth based on the depth in the south of Java Island [12], and the last with the reclaimed depth

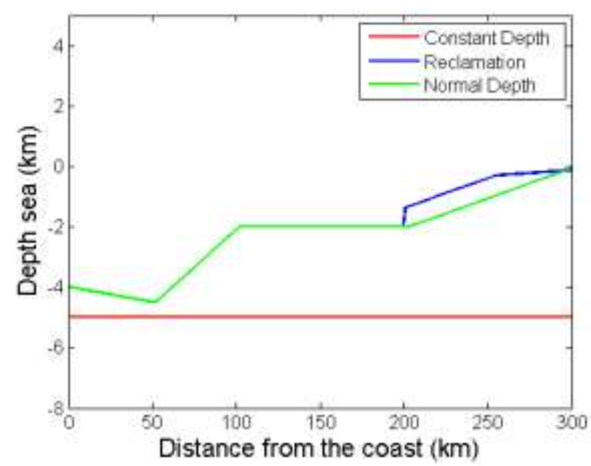

Fig. 5 Varying Depth

The red, blue and green lines are the depth lines, it is assumed that the distance of the tsunami source to the shoreline is 300 km with point 0 being the point of the tsunami source occurring and point 300 km is the shoreline point, the red color line is a constant depth of

5 km along 300 km, the line green color is the normal depth, from a distance of 0 - 50 km the depth is 4 - 4.5 km, from a distance of 50-100 km the depth is 4.5 - 2 km, from a distance of 100 - 200 km the depth is 2 km, and from a distance of 200 - 300 km the depth gradually decreases from 2 - 0.1 km, and the blue line represents the depth line after reclamation, where the depth from 0 - 250 km is the same as normal depth, but from 250 km the depth changes due to the reclamation effect.

- Constant Depth Results

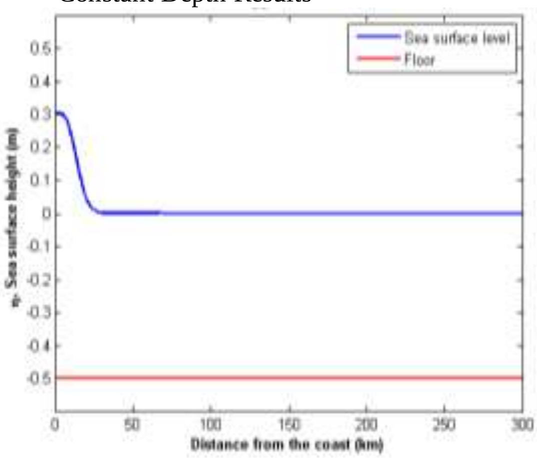

Fig. 6. Tsunami with constant depth at t = 0

Figure 6 is the initial condition when the tsunami was first formed, the distance between the source of the tsunami to the shoreline is 300 km, visible height of the initial tsunami waves is 0.3 m with an initial speed of 0 km / hour

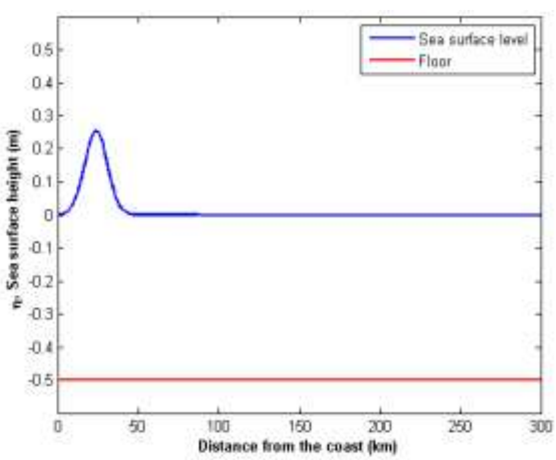

Fig. 7. Tsunami with constant depth at t = 850

Figure 7 is a condition when t = 850 s, at this time the waves have reached 25 km from the tsunami source with an altitude of 0.25 m.

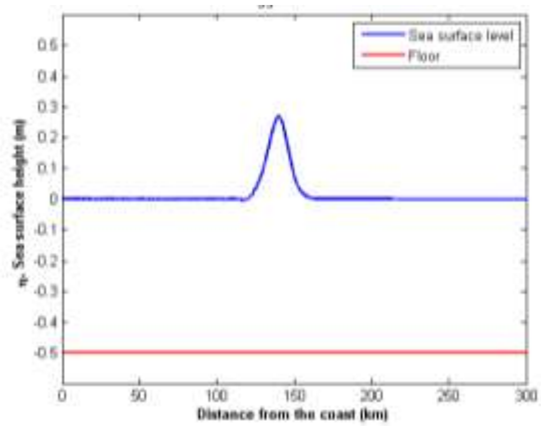

Fig. 8 Tsunami with constant depth at t = 5000

Based on Figure 8, the waves have reached a distance of 150 km from the tsunami source with the height reached is 0.26 m

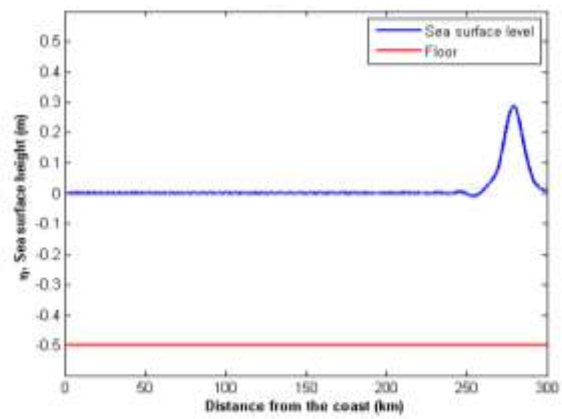

Fig. 9. Tsunami with constant depth at t = 10000

Based on the picture 9 waves have reached a distance of 280 km from the tsunami wave or 20 km before the shoreline with an altitude of $\eta = 0.29$ m

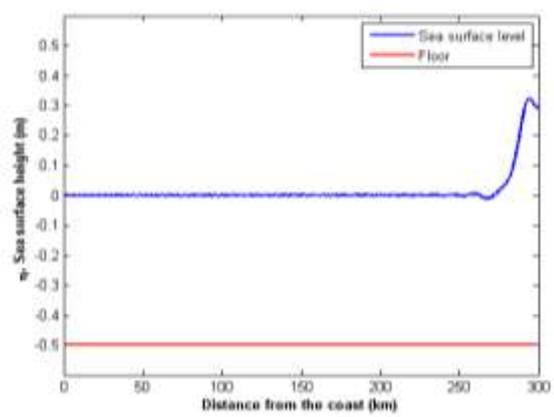

Fig. 10. Tsunami with constant depth at t = 10500

Figure 10 is a condition where the tsunami has reached the coast, within 10500 s height at the coast is 0.32 m with a speed of 45 km / h

The following is a table of heights and speeds of tsunami heights with constant depth

Table 2. Increased tsunami heights

No	Distance form the coast	Height (η)
1	300 km before coastline	0.30 m
2	275 km before coastline	0.25 m
3	150 km before coastline	0.26 m
4	25 km before coastline	0.28 m
5	In shoreline	0.32 m

Based on the table it can be seen that the height of the tsunami did not increase significantly, with a distance of 300 km the increase in wave height was only 28%, this was due to the constant depth

- Results of tsunami height with normal depth

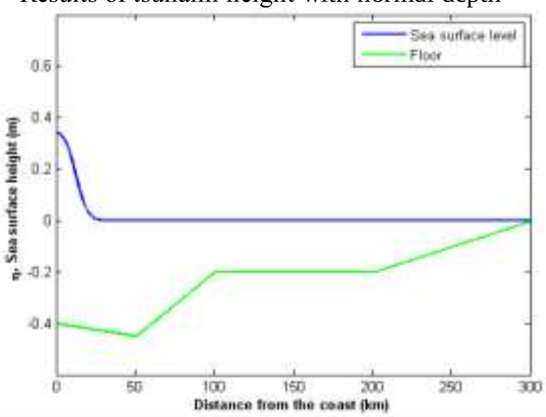

Fig. 11. Tsunami with normal depth at t = 0

Figure 11 is an initial condition when a tsunami occurs, where the initial height is 0.36 m, and the initial velocity is 0, the distance from the tsunami source to the coast is 300 km, with varying depths.

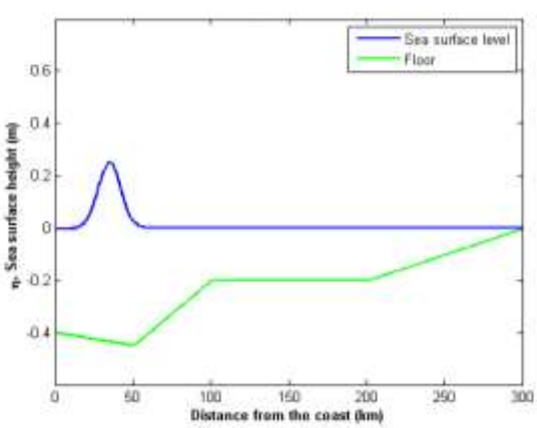

Fig. 12. Tsunami with different depth at t = 1700 s

Figure 12 is a condition where the waves reach 35 km after the tsunami source, the wave height is 0.25 m.

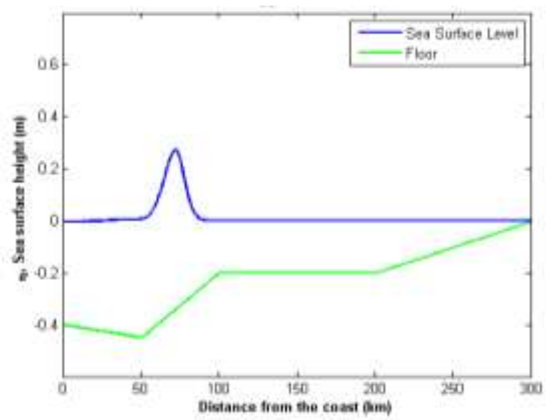

Fig. 13. Tsunami with different depth at t = 3500 s

Figure 11 is a wave condition when time to 1500, obtained wave height is 0.27 m, at this time the waves reach 80 km from the tsunami center

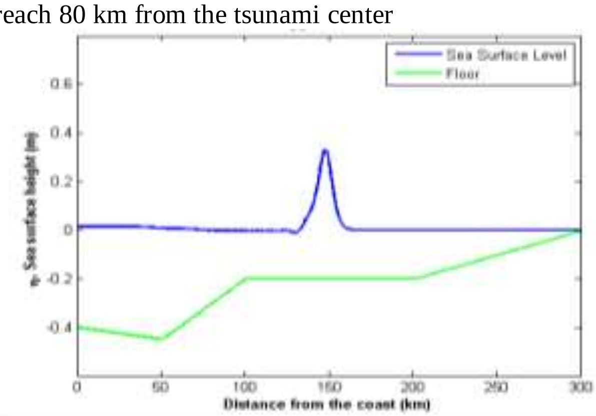

Fig. 14. Tsunami with different depth at t = 9000 s.

Figure 14 is a wave condition when the 9000th time, obtained wave height is 0.33 m, at this time the waves reach 150 km from the tsunami source

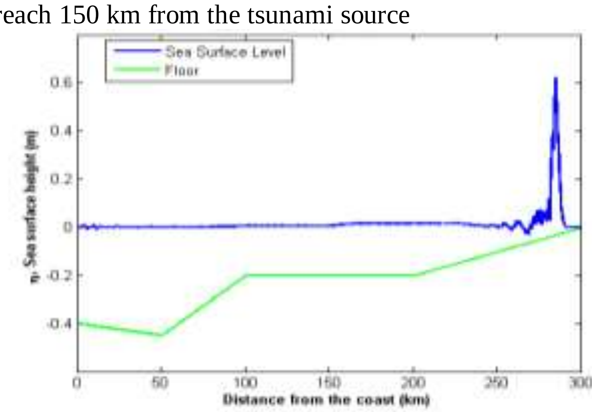

Fig. 15. Tsunami with different depth at t = 20000 s.

Figure 15 is a wave condition when time to 20000 s, obtained wave height is 0.62 m, in this iteration the waves reach 280 km from the tsunami wave or 20 km before the shoreline.

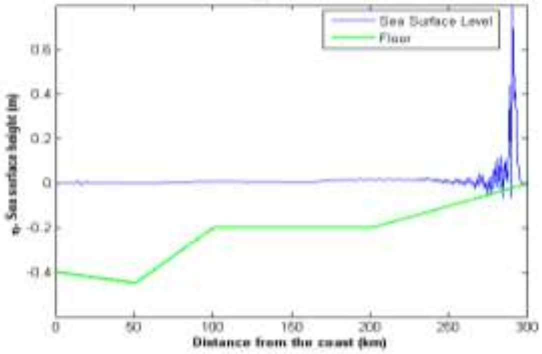

Fig. 16. Tsunami with different depth at t = 21000 s.

Figure 16 is a wave condition when time to 21000, obtained wave height is 0.80 m and the value u = 63.4 km / h in this iteration the wave has reached the shoreline.

The following is a table of heights and speeds from tsunami heights with normal depth.

Table 3. Increased tsunami heights

No	Distance form the coast	Height (η)
1	300 km before coastline	0.36 m
2	275 km before coastline	0.25 m
3	150 km before coastline	0.33 m
4	25 km before coastline	0.62 m
5	In shoreline	0.80 m

Based on the table it can be seen that the height of the tsunami increased significantly, with a distance of 300 km the increase in wave height was 122%, this is because the depth of the sea is getting smaller and smaller.

• Results of tsunami heights with Reclamation

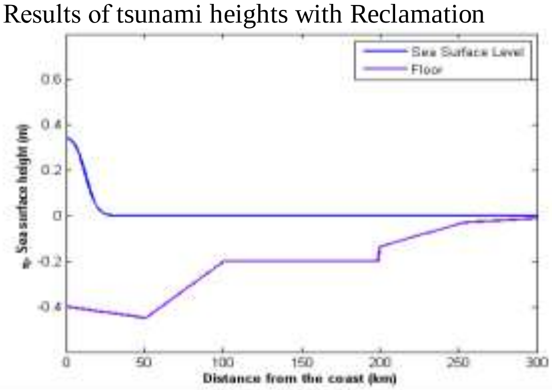

Fig. 17. Tsunami with reclamation depth at t = 0

Figure 17 is the initial condition when a tsunami occurs, where the initial height is 0.36 m, and the initial velocity is 0, the distance from the tsunami source to the shoreline is 275 km, with the reclamation depth.

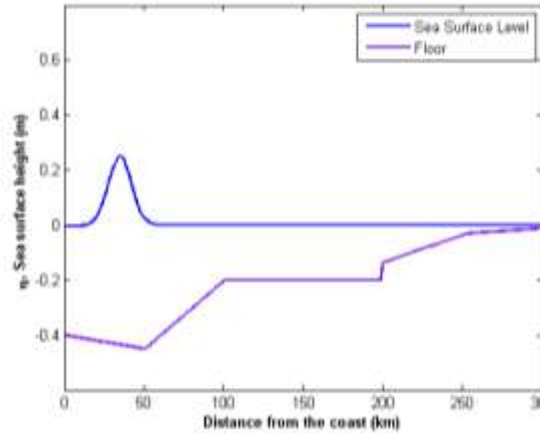

Fig. 18. Tsunami with reclamation depth at t = 1700 s

Figure 18 is a wave condition when time to 1500, obtained wave height is 0.27 m, in this iteration the waves reach 25 km from the tsunami source.

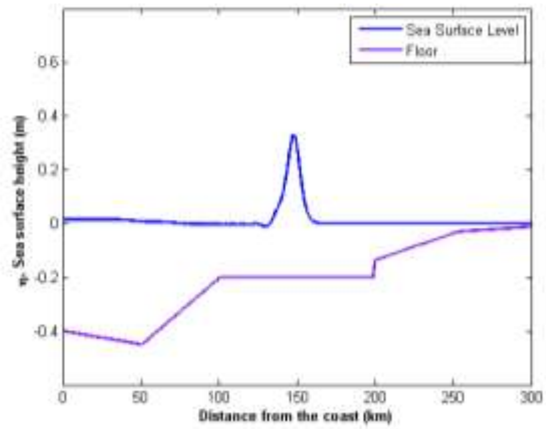

Fig. 19. Tsunami with reclamation depth at t = 9000 s.

Figure 19 is a wave condition when the 9000th time, obtained wave height is 0.33 m, in this iteration the waves reach 150 km from the tsunami source.

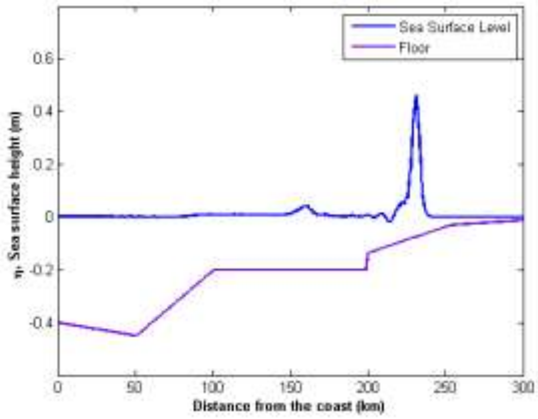

Fig. 20. Tsunami with reclamation at t = 15000 s.

Figure 20 is a wave condition when time to 15000, obtained wave height is 0.46 m, in this iteration the waves reach 225 km from the tsunami source or 50 km before the shoreline.

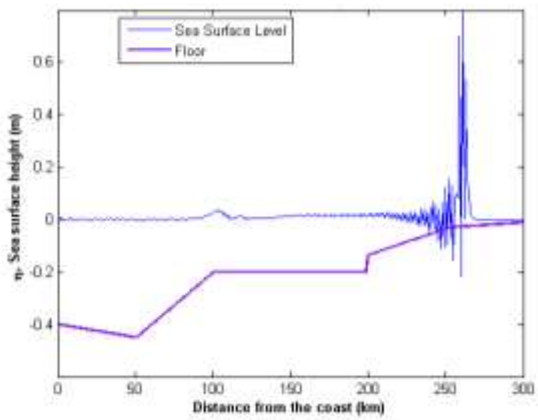

Fig. 21. Tsunami with reklamation at t = 19500

Figure 21 is a wave condition when time to 19500, obtained wave height is 0.87 m and the value u = 70.4 km / h in this iteration the wave has reached the shoreline.

The following is a table of elevations and velocities from tsunami heights with normal depths that have been reclaimed.

Table 4. Increased tsunami height with reclamation

No	Distance form the coast	Height (η)
1	300 km before coastline	0.36 m
2	275 km before coastline	0.25 m
3	150 km before coastline	0.33 m
4	50 km before coastline	0.46 m
5	In shoreline	0.87 m

Based on the table it can be seen that the height of the tsunami did not increase significantly, with a distance of 275 km the increase in wave height was only 141%, this was due to the constant depth

Based on the results of simulations of constant depth, different depths, and depths that have been reclaimed, the following comparisons are obtained:

Table. 5. Comparison of tsunami conditions on the coast

No	Parameter	In the shoreline		
		Constant Depth	Normal Depth	Reclamation Depth
1	Time	10.500 s	21.000 s	19.500 s
2	Height	0.26 m	0.80 m	0. 87 m
3	Velocity	45 km/h	63.4 km/h	70.4 km/h

Based on table 5 it is found that the height and velocity of the tsunami due to the reclamation effect is higher than the others, so this proves that one of the negative effects of the reclamation against the tsunami is the possible deterioration in height and velocity that occurs, the height of the tsunami due to the reclamation effect increases by 8% compared normal depth, and tsunami speed due to the effect of reclamation increases 8% compared to normal depth

IV. CONCLUSION

Based on the simulation results of TUNAMI's mathematical model, it can be concluded that:

1. The height of the tsunami at the reclaimed coastline increased by 8% from normal depth.
2. The speed of the tsunami on the shoreline due to the influence of reclamation increased by 8% than the speed of the tsunami with normal depth.

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