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Hydrodynamic Model Simulation at the Port of Tanjung Rhu Belitung

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Abstract—**Ports around Belitung Island have an essential role in supporting inter-island shipping activities, which positively impact economic growth. So that predictions to find out the condition of the waters need to be made early to anticipate disruption to the ship's shipping lanes. This study's prediction of these waters was carried out with a hydrodynamic model. Model accuracy (calibration) compares model results with survey data. Based on several iterations, the tidal model and current velocity are obtained with an accuracy rate of 5% and 7%, respectively. These results indicate the model's relatively good level of accuracy because it is below 10%. The model results also found that current velocity and wave height are always higher during high tide conditions than during low tide. In addition, along the Tanjung Rhu shipping channel, the current speed at point A1 experiences a significant difference during high tide conditions, namely 0.285 m/s at high tide, 0.102 m/s at low tide, 0.072 m/s at low tide, and 0.033 m/s s when heading for high tide, because of the narrowing of the water area due to the crush of two landmasses. In addition, areas far from shipping lanes (A1 and A2) have the lowest wave height compared to areas close to shipping lanes (A3). Because the surrounding land slightly covers the two points (A1 and A2), the wave height is smaller than point A3 in more open waters.**

Keywords— hydrodynamic model, model calibration, current velocity, wave

I. INTRODUCTION

Belitung Island is located on the east coast of Sumatra, surrounded by the ocean and 98 small islands. It is part of the province of the Bangka Belitung archipelago (Figure 1). This area is part of the management and development area for the Java Sea and the South China Sea, which covers vast land, coasts, and waters. Because of this position, inter-island shipping activities are a top priority for the community. Therefore, the ferry port is essential in facilitating shipping activities, which will positively impact economic growth. To prevent disruption of shipping activities at the port, it is necessary to monitor the depth of the anchor pool and the ship's shipping lanes.

The problem that usually occurs in ports is sedimentation, which can interfere with sailing and berthing ships. Sedimentation problems generally occur in locations where the sediment transport capacity of the hydraulic system is reduced due to decreased current velocity and ocean wave oscillations and related turbulent motions. Sedimentation occurs when solid materials such as soil, sand, or rocks are carried away by water currents and then accumulate at the bottom of the waters [1]. Sedimentation can change the structure of the shoreline, reduce water depth, and narrow shipping channels. Sedimentation can also cause silting of the ship's mooring pool, disrupting the flow of ships in and out of the port.

Analysis of changing current and wave behavior in Tanjung Rhu waters will affect coastal conditions, impacting seabed morphology changes [2 - 10]. Changes in coastal morphology are closely related to sedimentation in a coastal area [11, 12]. Coastal sedimentation analysis is used to determine and evaluate sediment entering and leaving the beach to identify coastal areas that experience erosion and sedimentation. Sediment transport occurs along the coast and perpendicular to the coast entering the area under review due to mining activities around the coast and rivers. The impact due to waves that usually occur daily and the influence of sediment transport along the coast will reshape the beach, which was previously eroded so that the beach profile will reshape in a short cycle. Many efforts have been made by researchers to reduce wave energy [13-17], so that wave energy reaching the coast can be significantly reduced, and this will reduce worse impacts, for example, in coastal tourism areas [18-21]

Such conditions need immediate proper handling by conducting studies on various alternatives with numerical simulations so that current and wave distribution patterns can be predicted in the area, which is not detrimental to the surrounding environment. This problem can be anticipated early on with hydrodynamic predictions to determine the condition of the waters around Belitung Island (Figure 2). This model simulation was carried out with Delft3D, an integrated 3D modeling program to model various aspects such as ocean currents, sediment

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transport, waves, water quality, development morphology, and ecology in coastal areas, rivers, lakes, and estuaries [22]. This study will examine hydrodynamic models and other physical activities in the waters around Belitung Island so that efficient and effective preventive measures can be taken.

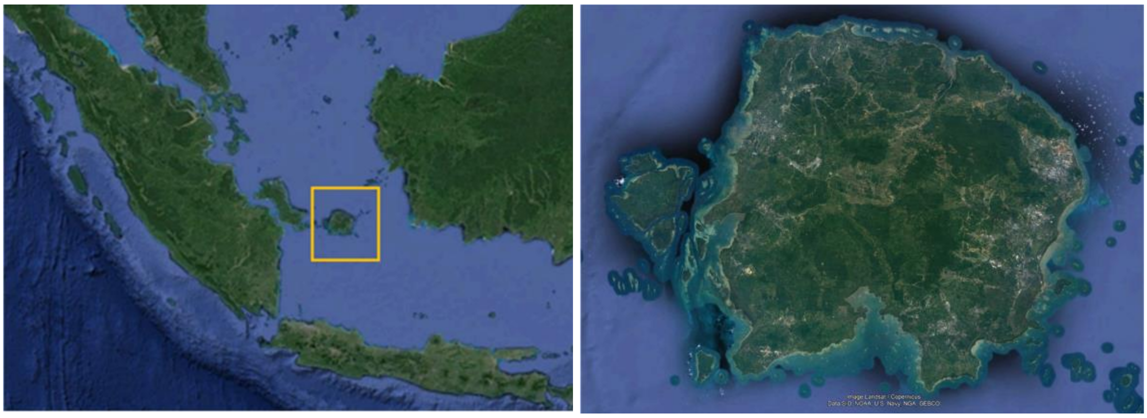

Figure. 1. Belitung island

Figure. 2. Tanjung Rhu port.

II. METHOD

2.1 Hydrodynamic Model

The Delft3D program was used to obtain current and tidal models. Delft3D is a program simulating various aspects of coastal and marine areas. Delft3D practices depth-averaged (2D) or three-dimensional (3D) approaches to derive current and tidal models.

In hydrodynamic modeling, the depth-average continuity equation is fundamental to obtaining information about water flow in a body of water. This equation can calculate the speed of water flow and changes in water level due to the influence of waves and ocean currents. In addition, the depth-averaged continuity equation can also help researchers and professionals in the marine field to understand sedimentation patterns and sediment movement in coastal and oceanic waters. This equation can be expressed as [22]:

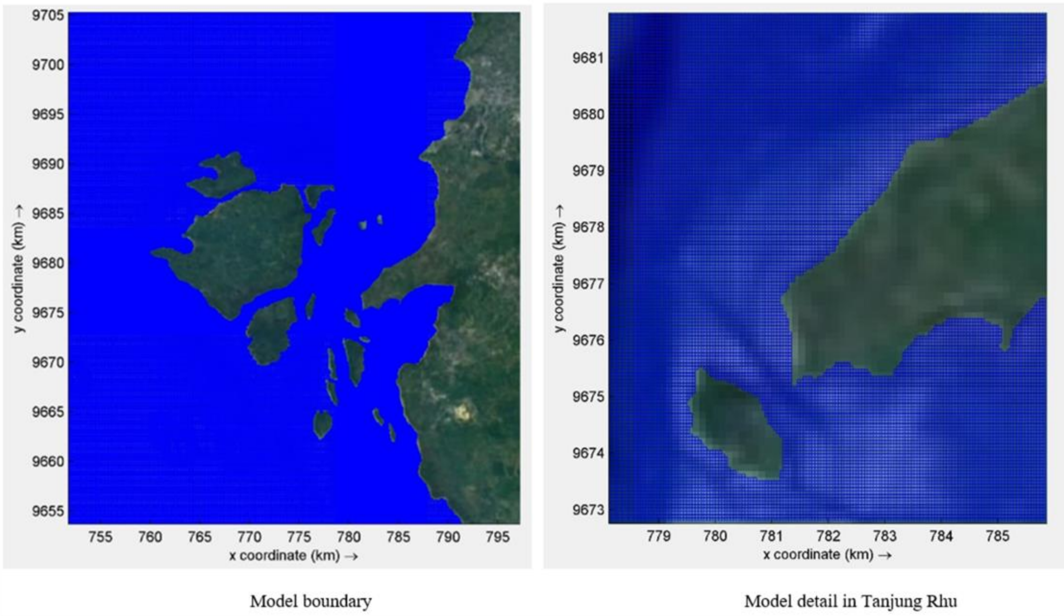

Figure. 3. The boundaries of the hydrodynamic model area

$$\frac{\partial \zeta}{\partial t} + \frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \frac{\partial (d + \zeta) U \sqrt{G_{\eta\eta}}}{\partial \xi} + \frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}} \frac{\partial (d + \zeta) V \sqrt{G_{\xi\xi}}}{\partial \eta} = (d + \zeta) Q \quad (1)$$

d	= water depth (m)
ζ	= water level elevation (m)
$G_{\xi\xi}$, $G_{\eta\eta}$	= the coefficient used to convert curved coordinates into rectangles (m)
Q	= global sources or sinks per unit area (1/sec)
q_{in}	= local source per unit volume (1/sec)
q_{out}	= local sinks per unit volume (1/sec)
U, V	= depth average velocity in the ξ and η direction (m/s)
u, v	= flow velocity in the y direction, ξ (m/s) and in the x or η direction (m/s)
ξ, η	= horizontal and curved coordinates

U and V depth average speed:

$$U = \frac{1}{d + \zeta} \int_{d}^{\zeta} u \, dz \text{ to } \int_{1}^{0} u \, d\sigma \quad (2)$$

$$V = \frac{1}{d + \zeta} \int_{d}^{\zeta} v \, dz \text{ to } \int_{1}^{0} v \, d\sigma \quad (3)$$

Hydrodynamic model settings used in DELFT3D-Flow are as follows: Model configuration = 2D (depth-averaged), Time Step = 60, Seawater density = 1025 kg/m3, and roughness (Chezy coefficient) = 5.

2.2 Boundary Conditions

The domain is the modeling area considered for simulation. The Domain parameter data group contains several sub-data, namely the grid parameter and bathymetry.

- Sub data grid parameter is used to enter grid data created in Delft3D-RFGRID and to determine the type of coordinates to be used. The type of coordinates used in cartesian coordinates.
- The Bathymetry sub-data is used to enter depth data that has been entered into Delft3D-QUICKIN and is valid for simulation purposes.

The boundary conditions for the modeling area are presented in Figure 3.

2.3. Environmental Data

Field measurements with various parameters such as depth, wave height, flow rate, and changes in water level were carried out around the ports of Tanjung Rhu and Batu. Bathymetry data were obtained by measuring, processing, and visualizing the seabed in January 2023. The data from this survey is used better to understand the hydrodynamic model of the area under study. The bathymetry data used results from interpolation between the survey and Dishidros bathymetry data (Figure 4).

The wind data used is secondary data from BMKG for 2011-2021 (Figure 5). The wind rose method analyzes wind direction and speed at a specific location, usually by comparing the wind from each direction. Other data is tidal data obtained from measurements at the Tanjung Rhu pier location. From the results of these measurements, it can be seen that the type of tide is diurnal tide, with a Formzahl number of F=1.05, and the tidal component is stated in Table 1.

III. RESULTS AND DISCUSSION

3.1 Model Calibration

Model calibration is performed to evaluate the level of accuracy of the model against the measurement data. This calibration process involves several iterations by adjusting the model parameters so that the model results agree with the field survey data. In the tidal model, a relatively high level of accuracy is obtained with an error value of 5% for the measurement data (Figure 6) using the Root Mean Square Error method. These results indicate that the model built with Delft3D accurately predicts tides in the Tanjung Rhu area.

After calibrating the tide model, the next step is to calibrate the current model. Currents are an essential factor affecting coastal hydrodynamic conditions, so a numerical model to predict currents is needed. The flow calibration process is carried out in the same way as the tide calibration. The model results are mapped and validated with a previously measured flow survey (Figure 7). The validation results are then used to calculate the error value to determine the model's accuracy level. In this case, the current model calibration results show an error of 7% (Figure 8) against the survey data for ocean current velocity in Tanjung Rhu.

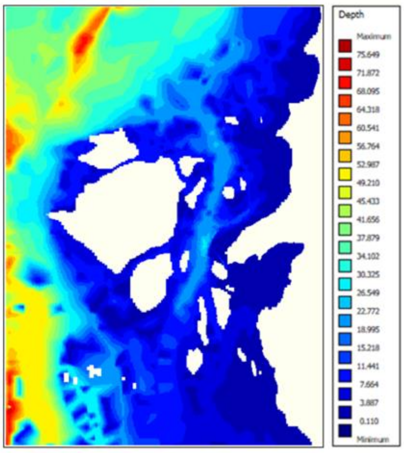

Figure 4. Bathymetric data interpolation results in the model area

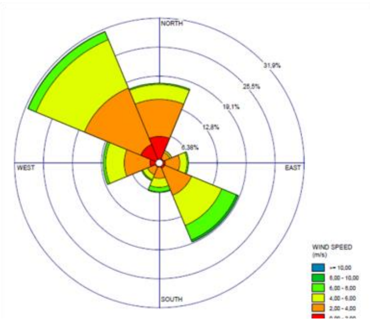

Figure 5. Wnd rose in Tanjung Rhu for 10 years

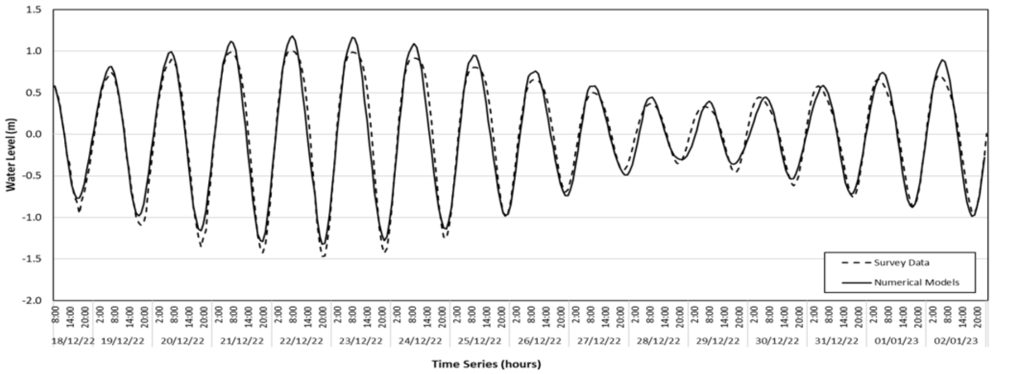

Figure 6. Calibrate the tidal model with survey data for 2022

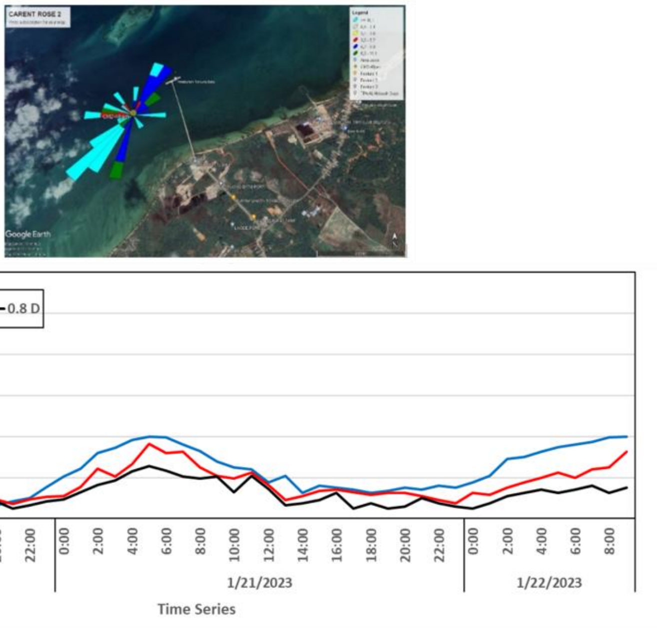

Figure 7. The results of current velocity measurements in the waters of Tanjung Rhu

3.2 Simulation of Current and Wave Models

Current and wave model simulations are carried out with a large model to illustrate the water area. Furthermore, based on the large model, it is analyzed in the small model domain so that the simulation results of the current and wave models can be analyzed in detail. The simulation results for the two domains can be seen in Figure 9. The wave model simulation was carried out only in the dominant direction according to the 10-year wind data (Figure 4), and the results are shown in Figure 10. The effect of tidal conditions on current speed and wave height was analyzed by comparing current speed and wave height at high tide, toward ebb, at low tide, and toward tide. The observations were made at three observation points (Figure 11), and the results are shown in Figures 12 and 13 and Tables 2 and 3.).

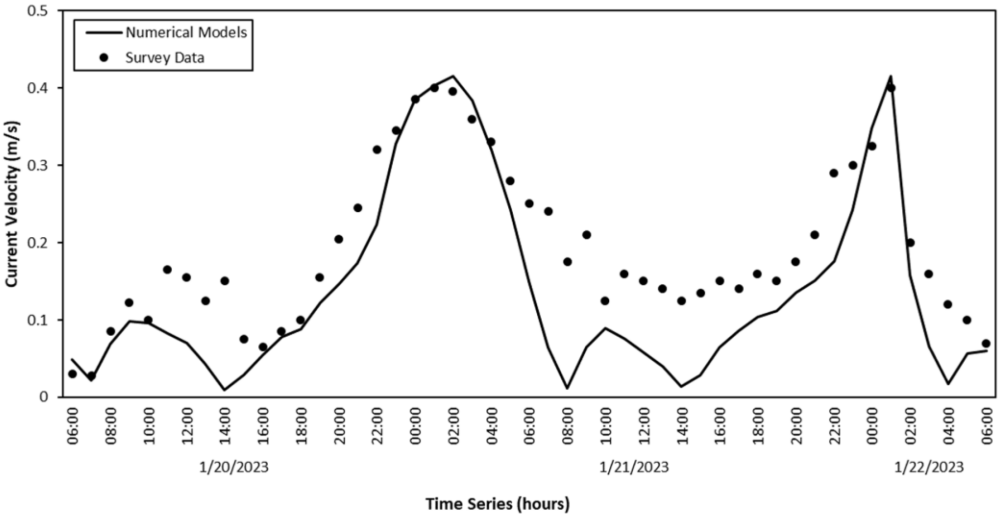

Figure 8. Calibrate the average current velocity model with survey data for 2022

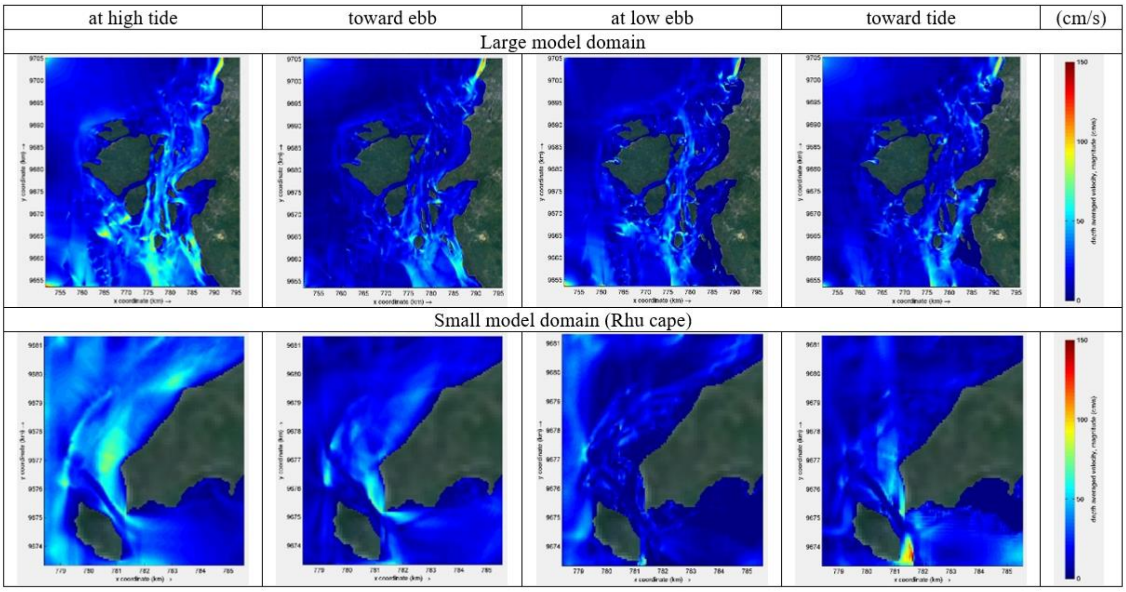

Figure 9. Model simulation of speed distribution pattern and current direction in various conditions

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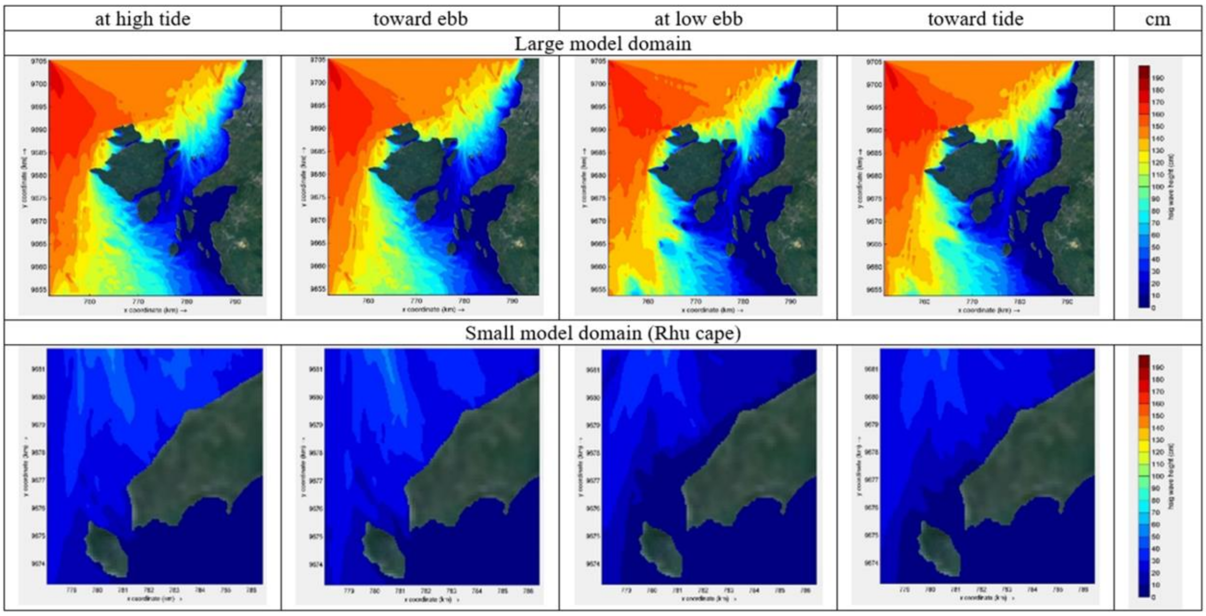

Figure 10. Simulation of wave transformation modes under various conditions

To make it easier to observe the results of these observations, they are described in graphical form to illustrate the differences that occur in current speed and wave height due to the influence of differences in tidal conditions.

Based on these results, it can be seen that differences in tidal conditions significantly impact current speed and wave height, whereas, at high tide conditions, the current speed and wave height are always higher than at low tide.

In addition, we can also see that along the Tanjung Rhu shipping lane, the current speed at point A1, where there is a narrowing of the water area due to the crush of 2 landmasses, causes a significant difference during high tide conditions.

In planning coastal structures, consideration is needed regarding how long the structure can last and how much

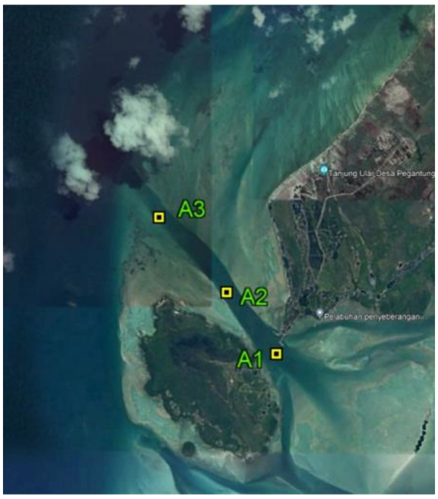

Figure 11. Location of three-point observation

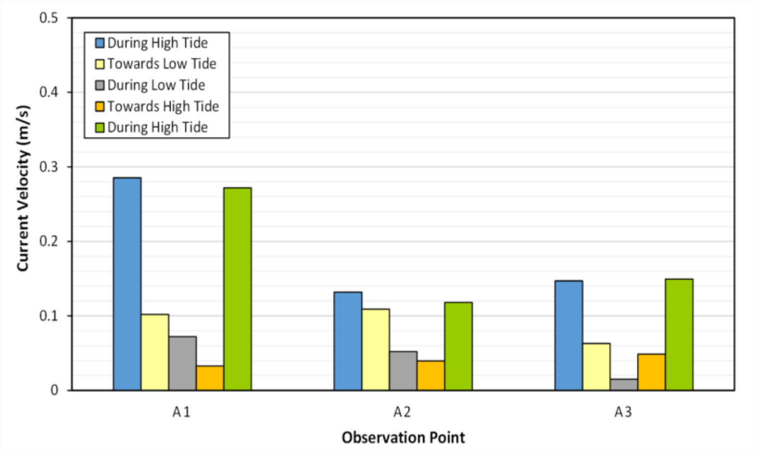

Figure 12. Current velocity at three point observation

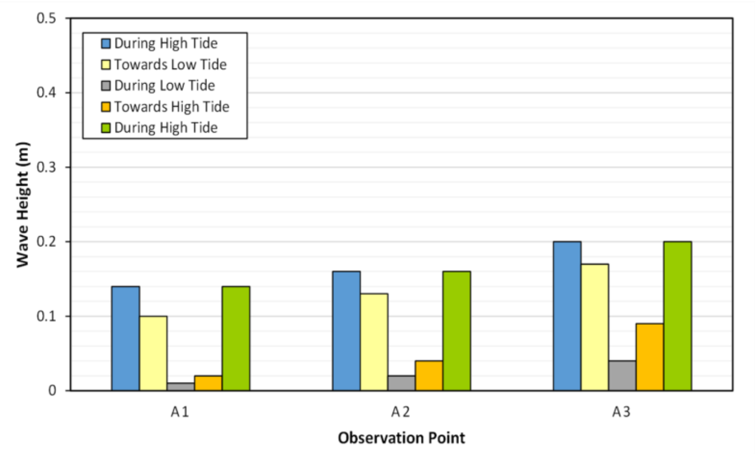

Figure 13. Wave height at three point observation

load will be received if a structure is built at a particular location. Table 4 compares wave heights at three observation points with wave return inputs of 1 year, 3 years, 5 years, and 10 years

TABLE 1.
THE CURRENT VELOCITY AT VARIOUS TIDAL CONDITIONS AT THREE OBSERVATION POINTS

Current Velocity (m/s)			
Condition	Observation Point		
	A1	A2	A3
During High Tide	0.29	0.13	0.15
Towards Low Tide	0.11	0.11	0.06
During Low Tide	0.07	0.05	0.02
Towards High Tide	0.03	0.04	0.05
During High Tide	0.27	0.12	0.15

TABLE 2.
WAVE HEIGHT AT VARIOUS TIDAL CONDITIONS AT THREE OBSERVATION POINTS

Wave Height (m)			
Condition	Observation Point		
	A1	A2	A3
During High Tide	0.14	0.16	0.2
Towards Low Tide	0.1	0.13	0.17
During Low Tide	0.01	0.02	0.04
Towards High Tide	0.02	0.04	0.09
During High Tide	0.14	0.16	0.2

TABLE 3.
WAVE HEIGHT AT VARIOUS TIDAL CONDITIONS AT THREE OBSERVATION POINTS

Wave Height (m)			
Condition	Observation Point		
	A1	A2	A3
During High Tide	0.14	0.16	0.2
Towards Low Tide	0.1	0.13	0.17
During Low Tide	0.01	0.02	0.04
Towards High Tide	0.02	0.04	0.09
During High Tide	0.14	0.16	0.2

Based on the graph, it can be seen that there is an increase in wave height based on the calculation of the wave return period. Points A1 and A2 have the lowest wave height compared to point A3 because these two points are in a place that is slightly covered by the surrounding land, while A3 is in more open waters.

IV. CONCLUSION

Hydrodynamic model predictions in Tanjung Rhu waters have been carried out with Delft3D software. The model's accuracy level (calibration) in the tidal model and current speed obtained an error of 5% and 7%, respectively. This analysis shows that the hydrodynamic model is quite good in the simulation of Tanjung Rhu waters.

Based on the model results, it was found that during high tide conditions, current velocity and wave height are always higher than during low tide. In addition, along the Tanjung Rhu shipping lane, the current speed at point A1 experiences a significant difference at high tide, namely 0.285 m/s, 0.102 m/s at low tide, 0.072 m/s at low tide, and 0.033 m/s at low tide. Because of the narrowing of the water area due to the crush of 2 landmasses. In addition, points A1 and A2 have the lowest wave height compared to point A3, namely at 1-year, 3-year, 5-year, and 10-year return periods, the wave height at point A1 is 0.028 m, 0.032 m, 0.035 m, and 0.038 m and wave height A2 are 0.044 m, 0.055 m, 0.058 m, and 0.062 m respectively. Because the two points (A1, and A2) are located far from the ship's shipping lanes and are slightly covered by the land around them, the wave flow is smaller than point A3 in more open waters.

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