Hydrodynamics in Sagulung waters, Batam City, Riau Islands Province, for the Construction of a Private Port

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Abstract. Batam is an archipelagic area in Indonesia. Batam has the advantage of being geographically close to neighboring countries, Singapore and Malaysia. The construction of a private port requires oceanographic studies of shipping lanes to the port. This study aims to provide information on the physical oceanographic conditions in the waters of Sagulung, Batam, Indonesia. The method in this study uses the MIKE 21 HD Flow Model FM. The data on high sea waves in this study for the last five years (2019–2022), collected from the Copernicus Marine Environment Monitoring Service (CMEMS). The results of this study show that the ocean current pattern around the location tends to have low speeds during both each tidal phase and the average conditions. The current speed conditions at the port-planning location during both the spring and neap periods are less than 0.2 m/s. This shows that the study location is a good place for a private port. The construction of private ports is best conducted from May to June and also from August to September because in those months the significance wave value is low.

Keywords: MIKE 21, Flow Model FM, Tidal Current, Sagulung waters, port-planning

1 Introduction

Being an archipelagic nation, Indonesia has very active sea access and transportation in the fields of fisheries, marine affairs, and industrial logistics. The geographical location of Batam City, which borders Singapore and Malaysia, makes it a highly strategic city. Shipyard operations have a significant impact on Batam Island's western waterways [1]. In Indonesia's Batam, the demand for special ports and commercial ports is critical.

The Riau Islands, Batam, will have the chance to significantly contribute to the construction of a port due to the high industrial activity and dense maritime transportation [2]. Batam needs infrastructure, particularly a private port, to facilitate international trade with Malaysia and Singapore. Studies on tides, currents, shoreline changes, water and beach pollution, and tidal flood events frequently require a hydrodynamic model [3].

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MIKE 21 is a numerical-based application that is generally used for modeling sea surface currents, waves, and sediment transport in offshore coastal areas, rivers, and harbor areas [4–6]. The MIKE 21 HD Flow Model FM is a hydrodynamic modeling module that is frequently used to identify patterns in ocean current circulation [7–9].

Besides ocean currents, another important ocean condition for a port is waves. Every time there is an increase in ocean waves, it disrupts shipping in the ocean and may also change the location of the barges anchored in the port. Ports, especially private ports, can be damaged by ocean waves [10–11].

This study intends to conduct a physical oceanographic model of the private port area in Sagulung waters, Batam, Indonesia. This study will produce ocean currents, tides, and analyze significant waves from CMEMS (Copernicus Marine Environment Monitoring Service). The study can help in the selection of shipping routes, the positioning of anchor points, loading and unloading locations, and ship maintenance facilities for the development of private ports.

2 Method

2.1 Study Location

The location of this study is from longitude 103°56'3.98"E, latitude 1° 1'0.43"N to longitude 103°56'5.70" E, latitude 1° 0'58.87" N. The study location can be seen in **Figure 1**.

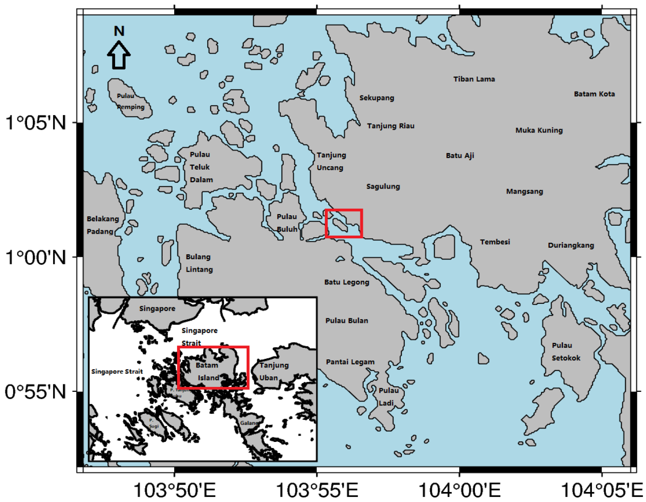

Fig. 1. The location of study, Sagulung, Batam, Indonesia Waters

2.2 Hydrodynamic model

The rules of conservation of mass (continuity) and conservation of momentum can be used to study the motion of water masses (hydrodynamics). Numerical modeling for two-dimensional (2D) hydrodynamics is used in this study.

Open boundary conditions and closed boundary conditions are the two categories in the model. The boundary conditions directly near the land are assumed to be closed border conditions, and the current speed there is always taken to be zero. The model's open border (or the open boundary condition) is the outermost point area. The model simulation was conducted for two periods, which were chosen to match the length of the input tidal data. The simulation of this model has been adapted to the period of field data collection.

The numerical model system for simulating water surfaces and currents is the hydrodynamic model in MIKE 21. Two-dimensional flows in a fluid layer that is presumed to be vertically uniform are modeled by MIKE 21 HD. The hydrodynamic modeling inputs employed in this study are divided into five categories: domain and temporal parameters, calibration factors, initial conditions, boundary conditions, and driving force. The current conditions from the numerical model simulation are shown in transition 1, which is the transition from rain to dry, and transition 2, which is the transition from dry to rainy.

3 Results and Discussion

In this study, the modeling area is made as large and as far away from the area of interest as possible. This is to achieve good model stability in the area of interest while obtaining the right tidal open boundary flow [12-13]. The results of the domain and model discretization in triangular elements from this study can be seen in **Figure 2**.

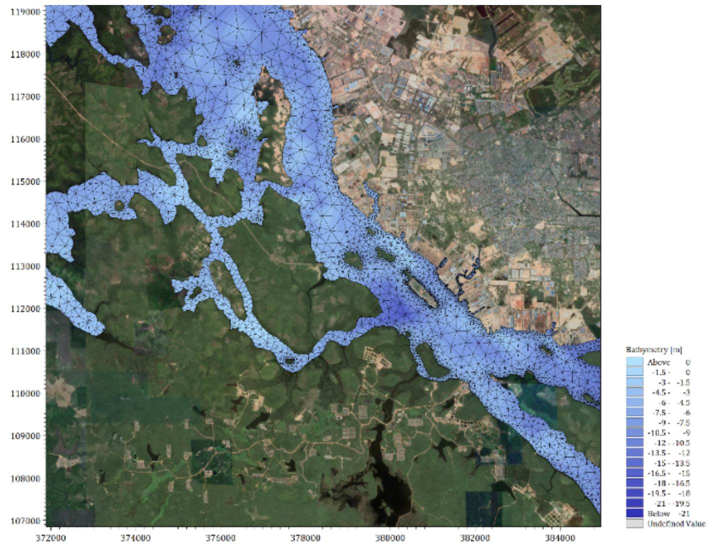

Fig. 2. Domain and model discretization of triangular elements in Sagulung, Batam, Indonesia Waters

3.1 Water depth

The depth characteristics around the study location are shown by the water depth in depth contour lines in meters. Overall, the average slope of the bottom of the waters around the study area was calculated to reach 12%. The depth of the waters at the activity location has an average value of 5 to 7 meters on the south side, precisely in front of the harbor, which is the ship channel, and is increasingly shallow towards the island of Buluh, Batam, Indonesia.

Figure 3 shows the depth values around the study location to be very shallow, with a depth range from 1.5 to 4.5 meters. This will provide information that areas in the study area where a private port will be created must conduct dredging activities, especially in the port planning area [14].

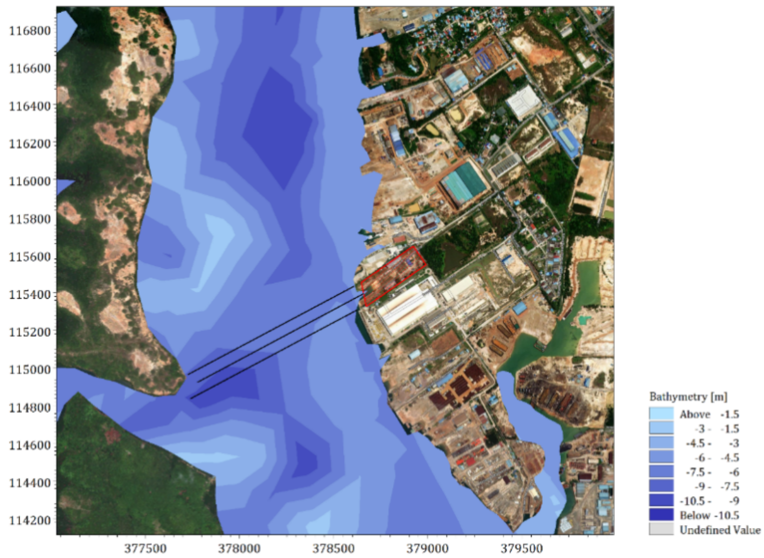

Fig. 3. Bathymetry around the study location.

3.2 Tides

The process of moving the sea level up and down on a regular basis due to the gravitational pull of celestial bodies, particularly the sun and moon, on saltwater masses on earth is known as tidal activity. Tides are a crucial consideration for studying the environmental effects of activities in coastal seas and for being used for the technical planning of coastal structures and navigation. Its tidal data was obtained from a tidal observation station for the waters surrounding the study location (**Figure 4**). The tide is dominated by only one high tide and one low tide in nearly one day.

The value of the tidal harmonic components must be calculated using the admiralty method in order to establish the type of tide that is present in the waters surrounding the private port. To get the Fomzahl value, values from tidal components such as Z_0, M_2, S_2, N_2, K_2, K_1, O_1, P_1, M_4, MS_4, K_2, and P_1 will be employed. Table 1 shows the following tidal component results from calculations made using the admiralty approach. The calculated tides are mixed semi-diurnal tides based on measurement data and predicted data from the model (**Figure 5**).

Fig. 4. Location of tidal data measurement

Table 1. Tidal components.

Tidal components	Z_0	M_2	S_2	N_2	K_1	O_1	M_4	MS_4	K_2	P_1
Amplitude (cm)	118.8	65.0	26.4	8.8	6.1	24.7	22.0	8.1	3.4	3.7
Different Phases (Deg)		30.7	349.2	244.7	349.2	88.8	152.8	88.8	105.1	17.2

F	0.51
LLWL	30.1
MSL	118.8
HHWL	306.0

F 0.51 = Mixed tide with prevailing semi-diurnal

Source: Tidal Station recording data from site, January 2023

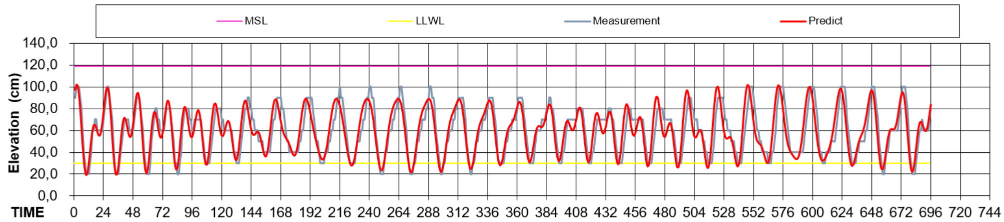

Fig. 5. Tidal fluctuation graph from model results and measurement data verification

3.3 Ocean waves

The Copernicus Marine Environment Monitoring Service (CMEMS) provides the high seas wave data for the last five years (2019–2022), which may be obtained from the website Marine Copernicus. The study area is on the north side of Batam Island, so the dominant waves that affect this location are those coming from the north and northeast.

The height and period of the waves that occurred in the study area over the last 5 years appear to be quite varied. The highest significant waves generally start to occur at the beginning and end of the year (December–February) when the west season (west monsoon winds) occurs, then decrease when entering March–May at the transition season.

During June-August, the significant wave height increases again, but overall it does not exceed the wave height at the beginning or end of the year; this change occurs in the east season (east monsoon winds). In the following month (September–November), the significant wave height decreases again. This change occurs in transition season 2, with fluctuations in wave height followed by fluctuations in wave period. As the wave height increases, the period increases, and likewise, when there is a decrease in height, the wave period also decreases. The wave height can be seen in **Figure 6** (transition 1, which is the transition from rain to dry, and transition 2, which is the transition from dry to rainy).

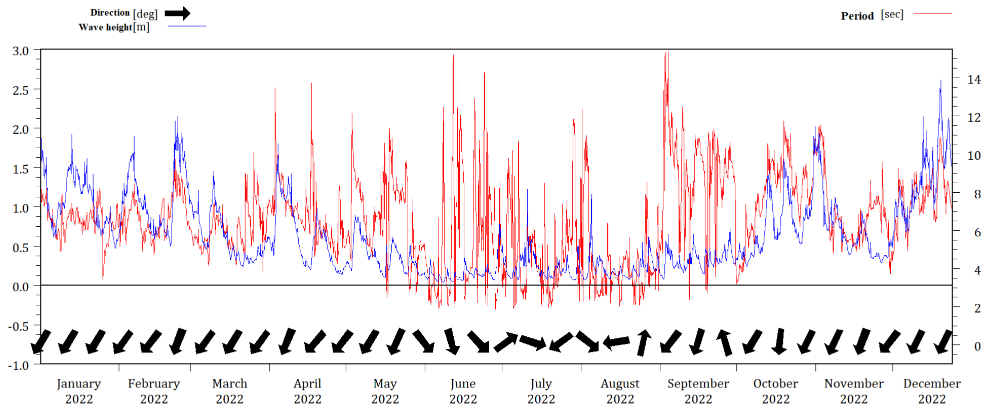

Fig. 6. Direction and significant wave period for 2022

3.4 Flow pattern

Hydrodynamic modeling was used to simulate details on the area's current characteristics. The goal of this simulation is to provide a complete understanding of the properties of the currents in the study area, both geographically and temporally. The spring tide and the neap tide were the two tidal periods used to evaluate ocean current patterns in the study area. The time series (temporal) pattern indicates that currents are consistently greater during the spring tidal period than currents during the neap period (**Figures 7-10**).

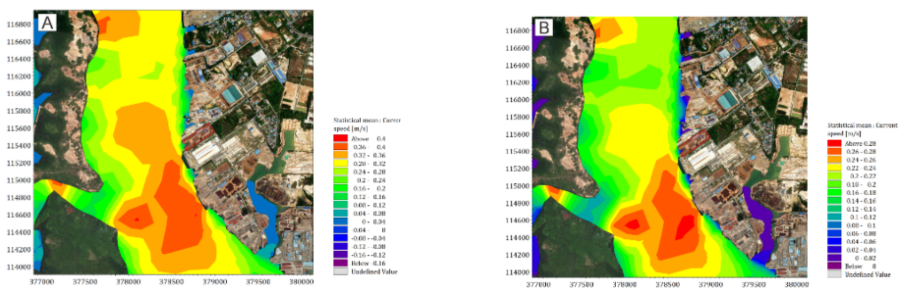

Fig. 7. Average current pattern during spring tide (A) and neap tide (B)

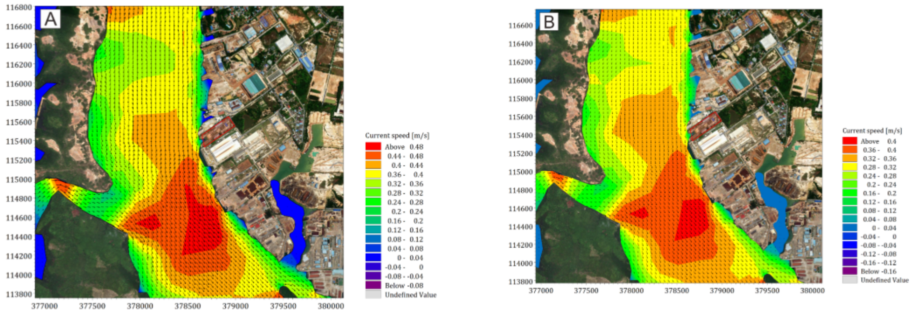

Fig. 8. Current patterns during the highest tide during the spring tide (A) and neap tide (B).

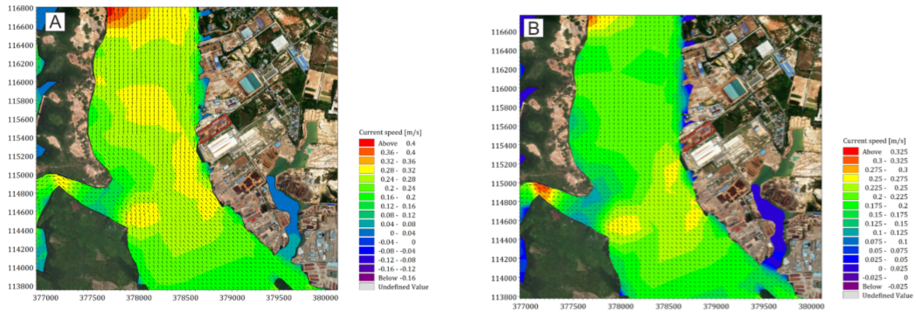

Fig. 9. Current pattern during high tide towards low tide during spring tide (A) and neap tide (B).

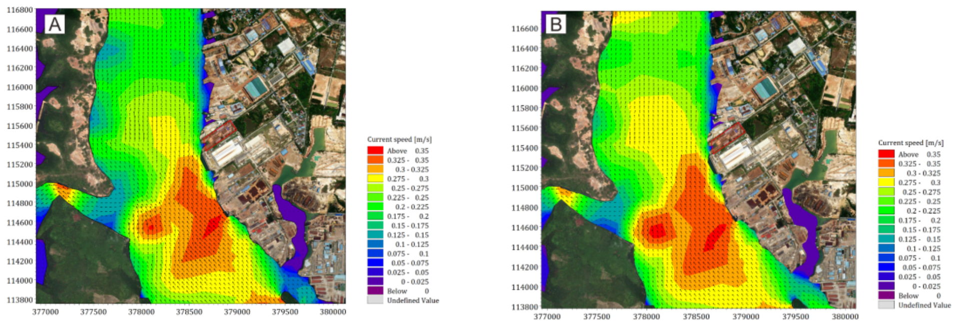

Fig. 10. Current pattern at lowest low tide during spring tide (A) and neap tide (B)

The results of the current simulation are presented but are only presented under certain conditions, namely conditions of highest tide, low tide to high tide, and lowest low tide. The average current pattern from the model simulation results for each tidal period, with the spring and neap tides, is shown in **Figures 7–10**. In general, the average current pattern between the spring and neap tides shows a pattern that tends to be calm at the port-planning location for both the neap and spring periods, with the same current speed of 0.10–0.14 m/s around the study area.

During the highest tide conditions, currents move from north to south (**Figure 8)**, with the speed of currents during the spring and neap periods being relatively the same at 0.14-0.24 m/s. During tidal conditions toward low tide (**Figure 9**), the current pattern tends to be calm both during the spring and neap periods, with speeds around the study area reaching 0.04-0.08 m/s.

During the lowest low tide conditions (**Figure 10**), the current pattern moves from south to north with a maximum speed around the study area reaching 0.075 m/s during the neap period and 0.1 m/s during the spring period.

4 Conclusion

Based on the results of the mathematical model predicting the impact of the construction of the private port, it can be concluded that the current speed conditions at the port-planning location during both the spring and neap periods are less than 0.2 m/s. From January to February, significant waves reached 2.1 meters, and this also happened from October to November. At the end of December, the highest significant wave value was 2.5 meters. Private port construction was very well conducted from May to June and also from August to September.

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