MODELING THE HYDRODYNAMIC CHARACTERISTICS OF TIDAL AND MONSOONAL CURRENTS IN PONDOK DAYUNG PORT OF TANJUNG PRIOK HARBOR, JAKARTA

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Abstract. The Pondok Dayung port forms a significant segment of the Tanjung Priok harbor in the Jakarta coastal bay. Studies on the hydrodynamic characteristics of tidal and monsoonal currents appear very important to ship movement and laid/dock operations in port basins/jetties. These flow conditions have been simulated using a two-dimensional shallow water equation, while the tidal and monsoonal wind were coupled to model the ocean current. In general, the simulation results of the ocean current characteristics were dominated by tidal effects, as well as the interactions with the coastlines, jetties, and breakwaters. Also, the geometric replica has been validated satisfactorily, using time series sea elevation from the tidal station in the research area managed by the National Geospatial Agency (BIG). Strong RMSE and linear correlation values ranging from 0.0405-0.0458 m and 0.9648-0.9843 were obtained, respectively. During the flood tides, the ocean current is directed towards the basin area, while an outward flow is observed under ebb conditions. Furthermore, the maximum tidal current speed of ±0.26 m/s was recorded at the port waterways. A similar outcome was also reported during the west and east monsoon, in addition to a minimum ocean current speed of approximately 0.00 m/s. These conditions implied that the Pondok Dayung port and its breakwater system served as protective structures to the surrounding vessels and the harsh ocean current impacts.

1. Introduction

Pondok Dayung is home to a major port in the Jakarta bay area. This facility accommodates two newly-built jetties, termed Damar and Sunda. Information on current characteristics in the dock pool region and the inflow/outflow conditions are very essential to vessel safety [13]. Therefore, holistic research, including two-dimensional hydrodynamic numerical modeling, appears necessary in the data derivation [7]. This approach provides a means to ascertain the active characteristics, particularly in terms of water current. The result subsequently becomes an approximation of the actual flow properties in the port area [4].

The influence of ocean currents is very significant in shipping, particularly as a major consideration in navigating narrow waters, including harbor or river channels or during dock operations [1]. Therefore, by critically observing current movements, sailors tend to avoid collisions prone to instigate severe ship damages [9].
The purpose of this research is to model the hydrodynamic characteristics of water currents in the pool area of the Sunda Pondok Dayung port and its surroundings in 2020. This attempt assumes the model results in January and July as a representation of the west and east monsoonal wind, respectively, in addition to tidal force coupling [14],[2]. Therefore, the overall performance is expected to serve as a reference in maneuvering the research area.

Figure 1. Modeling domain as a segment of the Jakarta Bay. [A] Bathymetric data is placed on the nodes of the triangular unstructured mesh. [B] Observation station for analyzing simulation results.

2. Method

2.1. Research Locations and Data
The Pondok Dayung port, Tanjung Priok, North Jakarta served as the research location. Based on the Indonesian Nautical Chart number 85A, the model area boundary encompasses 06° 04' 08.5" - 06° 06' 59" south latitude and 106° 51' 26.5" - 106° 53' 46" east longitude (Figure 1).

This quantitative study employed datasets of bathymetry, tides and shoreline measurement records, including bathymetry and shoreline from digitizing the Nautical Chart No. 86A which has been updated and published by the Indonesian Navy's Hydrographic and Oceanographic Center in 2017 and 2018. Tidal prediction data in the open boundary model has been predicted based on harmonic constant derived from sea-level elevation records from the tidal station at the Pondok Dayung port managed by the Geospatial Information Agency (BIG). Wind dataset for the simulation is provided by the European Center for Medium-Range Weather Forecast (ECMWF) archive web database.

2.2. Flow Hydrodynamic Modeling
The hydrodynamic modeling of current was conducted, using the earlier-mentioned input datasets [15]. Subsequently, the results were validated with the recorded sea-level elevation data from the tidal station at the research area owned by the Geospatial Information Agency (BIG).

The applied grid model is a triangular unstructured mesh with 3,840 elements, where the largest component was approximately 2.52 Nm² and the sharpest angle at 26° (Figure 1A). Also, the bathymetry and sea-level
elevation as scalar units were placed at the nodes, while the current as the vector resided at the triangular edge [11], see Figure 1A.

The current dynamics were generated by the sea-level elevation gradient, due to the tidal gravity and the wind’s frictional force against the water surface. This simulation has been conducted for a month during the peak of the season to obtain a representative description of the occurring phenomena in one year. Furthermore, January and July served as the peak of the west and east monsoon conditions, respectively [7].

Several assumptions included the neglecting effects of ship traffic on sea-level elevation as well as the Coriolis force. Eddy viscosity adopted the Smagorinsky formulation with a constant value of 0.01. The wave height was also constant at 0.2 m for initial conditions since the focus of the research domain occurred in the harbour pool. Therefore, a very minimal wave influence was assumed. Overall, the hydrodynamics of tidal elevation and current velocity were simulated by averaging over the depth [12].

2.3. Model validation
The model validation was performed using the Pearson product moment (PPM) correlation and the root mean square error (RMSE). Pearson correlation was used to measure the strength and direction of the linear relationship between two variables, in this case, the tidal data. In addition, the coefficient is typically denoted by ‘r’, where the number ‘1’ represents a strong linear correlation between the simulation results and the observation data, while ‘0’ indicates zero effect, although a non-linear correlation appears possible [6]. Meanwhile, the positive (+) and negative (-) signs provide significant information on the direction of the relationship between the two variables. Furthermore, both constraints demonstrated a unidirectional relationship for positive values and vice versa [10].

The RMSE was used to estimate the error magnitude between the modeling results and the in-situ measurement data. However, the accuracy was indicated by a lesser RMSE value (< 0.3). This means that the simulation results were close to the real hydrodynamic phenomena occurring in nature [10].

3. Results and Discussion
3.1. Analysis of the Model Validation at Sea Level Elevation
The model validation was conducted on 5 observation stations spread over the inlet of the Sunda pier pond, the mouth of the inlet, and the surrounding area, followed by determining the average value (Figure 1B). Also, the RMSE between the simulation results and the observation data ranged from 0.0432 – 0.0458 m, indicating a match between the model and the real conditions at Pondok Dayung port, as the RMSE was below 0.05 m. Those RMSE showing a good model validation [5]. This match was confirmed by the PPM value between 0.9814 - 0.9843, showing a strong positive linear correlation (Table 1). Furthermore, the sea level elevation from the model simulation results (formzahl index 3.6 – 3.74) and observation data (formzahl index 3.75 – 4.7) reported a similar tidal type, termed diurnal. This category is in accordance with the calculation results of [2], where the tidal data for 21 years from BIG’s station in Pondok Dayung (tide gauge with a sampling rate of 60 seconds) was analyzed but does not significantly vary from [8] which using a more sensitive tide gauge instrument (6Hz sampling rate = 1/6 second) for a month.

| NO | MONTH PERIOD | COMPARISON METHOD (RMSE) | CORRELATION METHOD (PPM) |
|----|--------------|--------------------------|--------------------------|
| 1  | January      | 0.0458 m                 | 0.9843                   |
| 2  | July         | 0.0432 m                 | 0.9814                   |

3.2. Dynamics of Sea Level Elevation
The first model simulation results showed an overview of the spring tide conditions for January 11, 2020, with the maximum and minimum sea-level elevation at 03.00 am and 04.00 pm, respectively. Meanwhile, the neap tide conditions were reported on January 17, 2020, with the maximum and minimum sea-level elevation at 04.00 am and 12.00 pm, correspondingly.

The second model simulation results represented an overview of the spring tide conditions for July 20, 2020, with the maximum and minimum sea-level elevation at 02.00 pm and 03.00 am, respectively. Meanwhile, the
neap tide conditions were reported on July 26, 2020, with the maximum and minimum sea-level elevation at 05.00 pm and 11.00 pm, correspondingly.

Figure 2. Mareogram comparison of sea surface elevation between model simulation results and observation data.

3.3. Dynamics of Ocean Currents in West Monsoon
January appears to be the peak of the east monsoon, where in general, the wind at Pondok Dayung port originates from the north and northwest. Subsequently, the maximum and minimum wind speeds in January 2020 attained 5.6 and 0.11 m/s, respectively, with an average of approximately 2.3 m/s.

In addition, the current observations at 5 stations (Figure 1B) showed that the lowest maximum current speed (0.0545 m/s) occurred at Station 2 in the southern region of Sunda Pier, while the highest (0.2609 m/s) was reportedly at Station 5 at the inlet area.
This range (0.0545 – 0.2609 m/s) was significantly higher, compared to the simulation by [3] at 0.035 – 0.17 m/s, under spring tide conditions. Meanwhile, [3] simulation is using only tidal as hydrodynamics generating force for the model, without any wind involvement.

The analysis of ocean current simulation results on sea level elevation was conducted by obtaining snapshots of the spring and neap tide conditions. Each constraint was further analyzed on ebb to flood, flood, flood to ebb, and ebb categories [12].

In the January 2020 model simulation during the spring tide, the current pattern formed at the port expanded into the Sunda Pier pool area (Figure 3). Conversely, at the receding period, a directional change was observed by an outward flow from the region. Meanwhile, Figure 4 shows a similar occurrence under the neap tide conditions.

![Figure 3. The current pattern on Spring Tide Sea level elevation in January 2020.](image)

Under the spring conditions in January 2020, the outside current speed appeared significantly higher, in comparison to the inside of the port. Comprehensively, the maximum current speed occurred towards the high tide (ebb to flood) with the inflow direction into the port, while the minimum value was reported in low tides (ebb), with the outflow path (Figure 3).

As the wind direction from the northwest and north head towards the tide end route to the port, the current speed becomes higher (Figure 3).
Under the neap conditions in January 2020, the outside current speed appeared higher, compared to the inside of the port at the time of flood to ebb and ebb. Comprehensively, the maximum current speed occurred in the low tide (flood to ebb), while the lowest value was at the high tide (ebb to flood), with both conditions experiencing outflow direction from the port (Figure 4).

As the wind direction from the south and southeast heads towards the outward ebb from the port, the current speed becomes higher (Figure 4).

Those simulation results showing a different situation from [3] simulation, where the directional condition of the current movement tends to vary, as no breakwater limiting the port was observed. Based on the results of the modeling simulation by [3], the current path practically migrates into every path without any barrier.

3.4. Dynamics of Ocean Currents in East Monsoon

July appears to be the peak of the east monsoon, as the wind emanates from the east, southeast, south, and southwest. The average wind speed in July 2020 was 2.2 m/s, with the maximum and minimum values attaining 6.4 and 0.07 m/s, respectively.

The results of the current observations at 5 stations in July 2020 showed that the lowest maximum current velocity (0.0343 m/s) occurred at Station 2 in the southern region of Sunda Pier, while the highest maximum estimate (0.2585 m/s) was reportedly at Station 5 in the inlet segment (Figure 1B).
Furthermore, the maximum current speed (0.0343 – 0.2585 m/s) was higher, compared to the current speed simulation by [3] with a range of 0.019 – 0.125 m/s, under neap tide conditions. The outcome was due to the use of only current-generation power in the form of tides, without any wind involvement.

The current pattern from the simulation model in July does not significantly vary from January performance. In spring tide conditions, the pattern is formed in the port as the flow extends towards high tide into the Sunda pier pool (Figure 5). Conversely, at receding intervals, the current pattern migrates out of the port. Figure 6 shows a similar occurrence under neap tide conditions.

Under the Spring conditions in July 2020, the current speed outside the port was greater, compared to the inside. Conversely, the maximum current speed occurred towards the ebb (flood to ebb), while the lowest value was related to flooding conditions, both with an outflow direction from the port (Figure 5). As the wind direction from the south and southeast aligns with the current direction towards the flood to ebb (ebb), both moving out of the port, the current speed tends to improve (Figure 5).
Figure 6. The current pattern on the sea-level elevation at neap tide in July 2020.

Under neap conditions in July 2020, the current speed outside the port was higher, compared to the inside at the time of flood to ebb and ebb. Comprehensively, the maximum current speed occurred towards the low tide (flood to ebb), while the minimum value was reportedly at high tide (ebb to flood), both with an outflow direction from the port (Figure 6), although not as large as the spring conditions in the similar period.

As the wind direction from the south and southeast occurs in the current path towards the ebb, both moving out of the port, the current velocity becomes higher (Figure 6), although not as extensive, compared to the spring events.

3.5. Comparison of the Effect of Tides and Wind on Current Speed

Based on Figure 7, the simulation results showed a more significant tidal effect (black line) on the current speed, compared to the wind impact (red line). In addition, the red line represents the variation between the total and the pure currents generated by the tidal forces. However, the total current was obtained by the coupling force between the tides and the wind’s drag force on sea-level elevation.

Current conditions due to the tidal forces simulated in this research (black line) showed the maximum speed at 0.2064 m/s, with an average value of 0.0898 m/s. This outcome was slightly higher, compared to the maximum tidal current speed simulated by [3] at approximately 0.17 m/s and an average speed closely occurring at about 0.085 m/s.
Figure 7. Comparison between the current speed of the Tidal-Monsoon coupling and the pure current due to tides, along with the difference as a representation of the current due to wind.

4. Conclusions and Suggestions
This hydrodynamic simulation shows a high tendency to reconstruct the dynamic conditions of sea-level elevation and currents at Pondok Dayung port (RMSE 0.0432 - 0.0458 m and PPM 0.9814 - 0.9843). The underlying characteristics are possibly influenced by tides rather than the wind effects, in both the west and east monsoon. However, under certain conditions where current movement occurred due to tides in the direction of the wind gust, an increase in the driving force tends to also accelerate the current speed. This circumstance indicates a very effective breakwater construction as a sea wave protector towards ensuring the ships’ stability and safety during maneuvering and dock operations. These results serve as a possible reference for captains in the navigation planning process ship’s maneuvering the Port basin area, particularly by considering the direction and current speed in the jetty inlet.

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