Hydrodynamic and Sediment Transport Simulation at The Port of The Electric Steam Power Plant Adipala and Serayu Estuary, Central Java Province, Indonesia

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Abstract. The coastal area of Cilacap Regency in Indonesia has an important role in increasing activity, economy and ecosystem. The research location is in the southern coastal area of Java and directly faces the Indian Ocean. This can lead to dynamic marine phenomena and cause various kinds of sedimentation problems. To analyze the phenomena that occur in Cilacap seawater, a numerical model is applied to obtain optimal results. MIKE21 software with Hydrodynamic and Sand Transport modules were used in this study to analyze the flow patterns and sediment transport that occurred. The model was built with Cilacap waters as the boundary and was made within 30 days. The result obtained is the model validation using the RMSE method shows a value of 16.33% so that the model is included in the good category. The average direction of the current pattern from the results of the model leads to the west and northwest. The current velocity at ebb is greater than at tide. The most significant bed level changes occurred at the mouth of the Serayu River and the east side of the breakwater.

Keywords: Modelling, Sedimentation, Hydrodynamic, Estuary

1. Introduction
The coastal area of Cilacap Regency, the state of Indonesia, is an important factor in the sustainability of activities, the economy and the Ecosystem. One of the vital locations in the coastal area of Cilacap Regency is the waters of the mouth of the Serayu River. This location is an area that functions as an industrial area such as the electric steam power plant Adipala. The electric steam power plant Adipala is located in Cilacap District, Cilacap Regency, Central Java. The electric steam power plant Adipala plays a very important role in supplying electrical energy to Java, Madura and Bali [1].

Besides, there are river estuaries which become a transitional area between river and sea [2]. Serayu estuary functions as a doorway for everyday fishermen to enter and exit. The estuary is at the most downstream location in the river basin system. Therefore, estuaries have an important role in flowing water and the materials contained in the water from the upstream to the sea [3]. Serayu River is currently having problems in the form of silting due to land use change in Wonosobo district. This causes an increase in the volume of sedimentary material carried by the Serayu river flow. The increasing amount of sedimentary material has resulted in silting rivers in several locations [4]. River silting that occurs continuously can result in increased river water level and flooding in the area around the affected river [5]. An increase in the amount of sedimentary material can also have the potential to obstruct the flow of water in the mouth of the Serayu River.
To solve the sediment problem, it is necessary to understand how the hydrodynamic processes and sediment transport processes that occur in the environment so that the characteristics of the study site can be analyzed in detail and the determination of the solution can be done correctly [6]. Several studies on the sediment transport models due to wave, currents and wave-currents interaction and also for the coastal sediment transport have been carried out by i.e. [7]-[14]. Morphological models based on numerical models have been widely used to describe field flow, sediment transport and mound changes in complex morphological situations during tides, in short and long term simulations [15] Numerical modeling is one of the most reliable ways to understand circulation, and sediment transport mechanisms that occur in waters [16].

2. Research Location Description
Geographically, the research location is located in the waters of the southern part of Java, which focuses on the mouth of the Serayu River and the pier of the The Electric steam power plant Adipala. Administratively, the location is located in Bunton Village, Cilacap District, Cilacap Regency. This research is located at the mouth of the Serayu river and directly faces the Indian Ocean which has relatively high wave characteristics compared to the northern side of Java Island.

3. Method
The numerical model is built using several environmental parameters in the research location. The environmental parameters used are bathymetry, tides, wind and waves. The numerical model is constructed by simulating a vertically homogeneous two-dimensional flow. The software used to make the model is MIKE21. The basic equations used to construct the hydrodynamic model are the mass conservation equation and the momentum conservation equation [17].

Continuity equation

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0$$  \hspace{1cm} (1)

Momentum of mass in the X-directon
\[ \frac{\partial p}{\partial t} + \frac{\partial}{\partial y} \left( \frac{p a}{h} \right) + g h \frac{\partial \zeta}{\partial x} + \frac{g p \sqrt{p^2 + q^2}}{c^2 h^2} - \frac{1}{\rho_w} \left[ \frac{\partial}{\partial x} (h \tau_{xx}) + \frac{\partial}{\partial y} (h \tau_{xy}) \right] - \Omega p - f V V_x + \frac{h}{\rho_w} \frac{\partial}{\partial x} (p_a) = 0 \] (2)

\[ \frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left( \frac{q^2}{h} \right) + g h \frac{\partial \zeta}{\partial y} + \frac{g q \sqrt{p^2 + q^2}}{c^2 h^2} - \frac{1}{\rho_w} \left[ \frac{\partial}{\partial y} (h \tau_{yy}) + \frac{\partial}{\partial x} (h \tau_{xy}) \right] - \Omega p - f V V_y + \frac{h}{\rho_w} \frac{\partial}{\partial y} (p_a) = 0 \] (3)

Where,
- \( h(x,y,t) \) = water depth (=\( \zeta - d \), m)
- \( d(x,y,t) \) = time varying water depth (m)
- \( \zeta(x,y,t) \) = surface elevation (m)
- \( p,q(x,y,t) \) = flux densities in x- and y-directions
- \( C(x,y) \) = Chezy resistance (m\(^{1/2}\)/s)
- \( g \) = acceleration due to gravity (m/s\(^2\))
- \( f(V) \) = wind friction factor
- \( V, V_x, V_y(x,y,t) \) = wind speed and components in x- and y-direction (m/s)
- \( \Omega(x, y) \) = Coriolis parameter, latitude dependent (s\(^{-1}\))
- \( p_a(x,y,t) \) = atmospheric pressure (kg/m/s\(^2\))
- \( \rho_w \) = density of water (kg/m\(^3\))
- \( x,y \) = space coordinates (m)
- \( t \) = time (s)
- \( \tau_{xx}, \tau_{yy}, \tau_{xy} \) = component of effective shear stress

To model the sediment transport that occurs, a non-cohesive sediment transport model is used. Modelling with the Sand Transport module is made by considering the flow conditions in the hydrodynamic model and the wave conditions based on the spectral wave model, so that these two models greatly influence the sediment transport simulation [17]. The sand transport model uses several approaches with formulas to solve the sediment transport problem. Sediment modelling resulted in the change in bed level values at the study site. The formula used to set the modelling of this module is:

\[ \frac{\partial z}{\partial t} + \frac{z (1+a-e^{z})}{e^{z}(z-1)+1} \frac{U_0}{U_0} \frac{\partial U_0}{\partial t} + \frac{30K}{k} \sqrt{\frac{K^2 U_0^2 + z^2 U_0^2 + 2KzU_0V_0 \cos \gamma}{e^{z}(z-1)+1}} \] (4)

Where,
- \( K \) = Von Karman's constant
- \( t \) = time
- \( z \) = parameter of boundary layer thickness
- \( U_0 \) = orbital velocity of the nearest wave base
- \( U_0f_0 \) = current shear velocity in the wave boundary layer
- \( \gamma \) = angle between current and wave
- \( k \) = surface roughness 2.5 \( d_{50} \) for plane bed and 2.5 \( d_{50} + kR \) for ripple covered bed
- \( d_{50} \) = average grain diameter size
- \( kR \) = ripple as it relates to roughness
4. Results and Discussion

The results of this study provide some data that can be analyzed. The first data describes the validation between the measurement data and the data generated from the numerical model. The second analysis explains how the hydrodynamic phenomena that occur around the research site. The third analysis describes the sediment transport process and its consequences.

4.1. Model data validation

Model validation is used to determine how accurate the model has been. Model validation is done by comparing the tidal data from the measurement data with the model data that has been obtained. The equation used to calculate data validation with Root Mean Square Error.

\[
RMSE = \sqrt{\left(\frac{1}{n} \sum (X_{measured} - X_{model})^2\right)}
\]  

Where n is the amount of data, \(X_{measured}\) is the data from the measurement results and \(X_{model}\) data from the modelling results. Figure 2. Explains the comparison graph between water level data derived from measurements and from the model. Based on the calculation results obtained an error value of 16.33% between the two data. The large error value means that the model that has been made is good enough.

![Figure 2. Graphic water level measurement and water level models.](image)

4.2. Boundary Condition

In making the model, it is necessary to determine the boundary conditions. Boundary conditions are used to determine the input parameters used in the model to be created. The boundary condition can be seen in Figure 3. The boundary conditions used in this model include the sea denoted in green colour, land denoted in blue colour and rivers denoted in red colour. Environmental parameters that are inputted in the sea boundary include tide, wind, sediment and wave data. At the land boundary the data entered includes sediment data. Environmental parameters used at the river boundary include river discharge and sediment data. Unstructured grid is used in this model by applying triangular cells.
4.3. Hydrodynamic Model

The model produced from the Hydrodynamic module has a tendency to move the current back and forth according to the rise and fall of sea level and wind movements. From Figure 4, when the water surface conditions are experiencing the lowest receding, it can be seen that the movement of the current pattern is dominated towards the southwest away from the coastal area. Whereas Figure 5 shows when the highest tide conditions the dominance of the movement of currents towards the west approaching the coastal area. The difference is also seen when the water level moves from tide to ebb and moves from ebb to tide. Where when the water surface recedes, it can be seen in Figure 6 that the current movement pattern moves to the southwest leaving the coastline. Meanwhile, Figure 7 shows the movement of the water level moving towards the tide which results in a movement of current patterns towards the northeast approaching the coastline and the mouth of the Serayu River. Differences in current flow patterns that occur due to the influence of the phenomenon of the discharge of a number of water discharges from rivers and the influence of tides [18].
The difference in currents is not only in the direction of the current pattern, the current velocity at the study site also has differences in the presence of sea-level fluctuations. The velocity at ebb which can be seen in Figure 4 tends to be greater than during the tide condition in Figure 5. The current velocity that occurs in ebb conditions ranges from 0-0.651 m/s while the current velocity that occurs in tide conditions is around 0-0.325 m/s. This is indicated by the size of the vector at ebb which is greater than at tide. Figures 6 and 7 show the large difference in current velocity with the conditions of the water level from tide to ebb and the water level moving from ebb to tide. Where the current velocity in conditions from tide to ebb tends to be greater than when the water level is in conditions from ebb to tide. The current velocity that occurs during tide to ebb is around 0-0.911 m/s, while the current velocity that occurs during ebb to tide conditions is around 0-0.761 m/s. This is due to the influence of gravity on the mass of seawater at the research location. So that the mass of water moving from a higher elevation will have a greater current velocity due to the acceleration factor of gravity. The current speed on the west side of the breakwater tends to be small because the movement of currents originating from the east is blocked by the breakwater. The effect of the breakwater also causes the ocean currents around the mouth of the Serayu river to tend to get smaller.
4.4. Sand Transport model

The sediment transport model using the sand transport module shows the change in bed level during the 30-day simulation period. The bed level change parameter indicates sedimentation if the value is positive while the negative value indicates that the area is eroded. Figure 8 shows the bed level change at the study site that has lasted 30 days. Based on the simulation results that have been carried out, several locations have experienced sedimentation. The most significant changes in bed level occurred at the mouth of the Serayu river and the east side of the breakwater with changes in bed level of 2.25-2.50 m and 3.25-3.50 m, respectively. One of them is at the mouth of the Serayu River. Silting at the mouth of the Serayu river is due to the large amount of sedimentary material carried from the upstream of the Serayu River to the estuary. The sedimentary material carried through the Serayu river stops at the estuary due to the movement of currents and waves coming from the sea. The confluence of the current from the Serayu river and the current from the sea causes a loss of force that carries sediment towards the sea. These events occur repeatedly, so that sediment from the Serayu River will continue to accumulate and cause sedimentation in that location. Sedimentation also occurred on the east side of the Adipala breakwater power plant. The deposition that occurs on the east side of the breakwater is caused by the influence of ocean currents carrying a number of other coastal sedimentary materials. The dominant direction of the current moving from the east to the west causes sediment carried by the current to accumulate periodically on the east side of the breakwater. The dominant movement of ocean currents to the west is due to the influence of the east monsoon winds that blow from the west to the east. Sedimentation that occurs in the mouth of the Serayu River has the potential to cause the surface of the Serayu River to overflow. This can cause flooding inland areas along the Serayu river. Also, sedimentation in the Serayu estuary can potentially carry sediment towards the Adipala breakwater. This is due to the changing monsoon wind cycle which results in changes in current direction and sediment transport. Sediment deposition on the east side of the breakwater can also have a negative impact. One of them is silting the east side of the breakwater, causing the breakwater to continue to decrease. The closer the water level and the breakwater can cause overtopping and damage to the breakwater due to the greater force of the waves.
5. Conclusion
The conclusion that can be obtained from the results of the research conducted is that the model that has been built is classified as good because it has an error value of 16.33%. The direction of the dominant current occurs to the west and northwest. The current velocity that occurs in ebb conditions ranges from 0-0.651 m/s while the current velocity that occurs in tide conditions is around 0-0.325 m/s. The current velocity that occurs during tide to ebb is around 0-0.911 m/s, while the current velocity that occurs during ebb to tide condition is around 0-0.761 m/s, so that the greatest current velocity occurs during tide to tide conditions and the lowest at ebb conditions. The most significant changes in bed level occurred at the mouth of the Serayu river and the east side of the breakwater with changes in bed level of 2.25-2.50 m and 3.25-3.50 m, respectively.

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Acknowledgments
The authors would like to thank the Research and Development Center for Marine and Coastal Resources of the Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia for providing DHI model Mike 21/3 software facilities and author also thank to Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia for support.