Sedimentation and Longshore Current Simulation with Delft3D Software in Rejoso Shoreline

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Abstract. Rejoso estuary, located 3 kilometers from the center of Pasuruan, has an unstable river mouth that threatens the existence of residents in the surrounding area. During the rainy season, when high discharge in the river meets high tide from the ocean, flooding occurred in residential areas located around the coast. It happens due to sediment deposits formed near the sea and ocean current that worsen the backwater. East Java Provincial Water Resources Agency plans to build a jetty in that area to reduce sediment deposition caused by longshore sediment transport and to protect the estuary from ocean currents. This study aims to look at the impact of jetty construction that is affected by wave and current activity by performing numerical modeling with Delft3D software. From the simulation results, jetty reduce the amount of ocean current with the biggest reduction at monitoring point A is 0.299 m/sec (94.05%) and decrease sedimentation with the biggest at monitoring point A by 91.37% in the east side of the estuary. In conditions without a jetty, the shape of the shoreline and the elevation follows the shape of the initial shoreline, while after one year with jetty the sedimentation occurred to the end of it.

1. Introduction

Integrated Water Resource Management (IWRM) must be comprehensively arranged in coordination and collaboration with Integrated Coastal Zone Management (ICZM) for water resilience as stated on the Sustainable Development Goals (SDGs) especially SDG 13 and SDG 6 which linked between Climate change adaptation and resilience and water, sanitation and hygiene. In the same way, river management efforts as part of the river basin integrated water resources management, include efforts on river utilization, development, protection, conservation and control, in an integrated river basin with cross-jurisdiction, cross-regional and cross sectoral approach.

East Java is one of the provinces that having several coastal areas, both in the north and the south. This coastal area is rich in natural resources with economic value, used for ports, tourism, etc. It is possible for the beach to experience various damage caused by natural factors, as well as factors from coastal area users. One of the estuaries in East Java is Rejoso which is located at ± 3000 meters from the center of Pasuruan and has a river mouth known as the Rejoso River, located on the border of the villages of Rejoso and Lekok.

In the rainy season, high discharge from Rejoso River occurred but the flow disrupted by sediment transport along the coast that settling right at the mouth of the river and worsen by the high tide. It threatens existing facilities and infrastructure in the Pasuruan area near Rejoso Estuary. The longshore sedimentary material is driven by waves, entering and settling in the estuary, later causing then settles and causes the sand tongue to occur. Thus, East Java Government plan a jetty to prevent deposited sediment in the estuary.
2. Data Validation

Validation is done by matching the tidal and current data from the observation with the numerical simulation results in Delft3D software. It is intended that the simulation is carried out in accordance with the conditions in the real location.

![Figure 1. Study Location](image1)

![Figure 2. Verification of Tidal Water Level Data with Measurement](image2)

![Figure 3. Verification of Current Data with Measurement for 22 May 2018.](image3)
The results used validation are derived from the simulation results of the initial conditions. Tidal validation is done by matching the simulation results of water level with tidal data. Tidal data for 15 days is inputted in Delft3D so that a graph will be obtained that matches the observed data. From the results of tidal validation, error proves that the model is in accordance with the actual conditions. The following is a graph of the comparison between field observation data and the Delft3D simulation result. The results of tide verification obtained the MRE (Mean relative Error) percentage value of 4.1%.

It used validation from the simulation results of the initial conditions. Current validation is carried out by matching the velocity simulation results with current data in the field on the measurement date, which is one day on May 22nd, 2018 for 24 hours. The results of the current verification show that the MRE percentage value is 6.9%. The error values obtained from the verification results of the model results with field data on May 22nd, 2018 are as follows.

### Table 1. Verification of model results by field.

| No | Parameter            | Relative Error | Mean Relative Error (%) |
|----|----------------------|----------------|-------------------------|
| 1  | Water Level          | 0.04           | 4.1                     |
| 2  | Current Velocity     | 0.07           | 6.9                     |

### 3. Data Analysis

The physical data from the jetty planned in the scenario referred to East Java Provincial Water Resources Agency’s plannings are:

- Jetty mouth width: 25 meters
- Peak elevation: 3 meters
- West jetty length: 120 meters
- East jetty length: 120 meters

#### 3.1. Wind and wave data analysis

Wind data used is wind data for the last 10 years from BMKG Juanda, Sidoarjo. In wind and wave data analysis, using the following assumptions:

- The wave characteristics considered are wave height, wave period, wave refraction, shoaling and wave breaking.
- Wave analysis used is the theory of small amplitude waves
- The height and period of deep sea waves are obtained by the hindcasting method
- Waves counted are waves generated by wind

### Table 2. Maximum wind incidence at BMKG Juanda 2007-2018

| Wind Direction | 0-0.5 | 0.5-1.1 | 2.1-3.6 | 3.6-5.7 | 5.7-8.8 | Total |
|----------------|-------|---------|---------|---------|---------|-------|
| North West     | 24.6  | 2.78    | 2.51    | 0.93    | 0.23    | 6.45  |
| South          | 6.87  | 6.09    | 2.55    | 0.63    | 16.14   |
| South East     | 1.35  | 0.84    | 0.51    | 0.27    | 2.97    |
| South West     | 1.29  | 0.84    | 0.51    | 0.7     | 3.33    |
| East           | 7.46  | 4.3     | 2.61    | 1.71    | 16.08   |
| North          | 2.04  | 1.2     | 0.44    | 0.23    | 3.92    |
| West           | 0.33  | 0.32    | 0.08    | 0.08    | 2.81    |
| North East     | 4.55  | 3.51    | 0.61    | 0.11    | 8.78    |
|                | 24.6  | 23.2    | 29.5    | 21.4    | 1.3     | 100   |
From Table 2, the wind direction used in this simulation is the East and the Northeast. The choice of wind direction used in this simulation is based on the dominant wind direction that comes from the sea which can generate waves. Wind speed data has been analyzed in percentage form and then plotted in the form of wind rose. The wind data used are average wind data and maximum wind data from 2009 to 2018. The dominant wind direction becomes a reference in determining the length of the fetch, so that from the wind rose above, two dominant wind directions are obtained, namely east and northeast. Wind data is also used to obtain the Morfac (Morphological scale factor) value. To get the morphac value for 1 year with 15 days of simulation with results Morfac = 0.509 x 24 = 12,2166.

### 3.2. Tidal data analysis

In tidal calculation uses 15-day data from survey starting from May 22, 2018 to June 5, 2018 at Rejoso Estuary. The calculations are carried out in Admiralty Method so as to produce the main tidal constants as shown in Table 3. By using the Formzahl formula, F is 0.6337, so that the type of tide in the coastal waters of Rejoso is Mixed Tide Prevailing Semidiurnal with a Formzahl value of 0.6 (0.25 <F <1.5).

#### Table 3. Rejoso's Tidal Constant

| AMP | PHASE |
|-----|-------|
| M2  | 83.88 | 202.16 |
| S2  | 16.79 | 204.74 |
| N2  | 9.11  | 205.1  |
| K2  | 4.49  | 206.43 |
| K1  | 42.42 | 219.07 |
| O1  | 22.24 | 197.85 |
| P1  | 12.05 | 212.39 |
| Q1  | 3.77  | 187.12 |
| MF  | 1.4   | 17.08  |
| MM  | 0.72  | 10.93  |
| M4  | 0.32  | 14.91  |
| MS4 | 0.15  | 315.81 |
| MN4 | 0.07  | 28.72  |

The accuracy of the analysis results also depends on the accuracy and method of the survey data being carried out. It is recommended that the survey be carried out for 30 days. Furthermore, the calculation of the tide data component for the boundary during FLOW-INPUT, namely at the model boundary points in the west, north and east directions according to the coordinates.

#### Table 4. Calculation of Tidal Data from Measurement Results in the Field

| Z0   | MHWL  | MSL   |
|------|-------|-------|
|      | 0,31 meter | 1,86 meter |
| HHWL | 0,95 meter | DL = 0 meter |
| MLWL | -1,71 meter | HAT = 1,16 meter |
| LLWL | -2,35 meter | LAT = -2,56 meter |
3.3. Flow data analysis
This flow data analysis will later be used to verify the model data. The locations that become the sampling points based on the coordinates from the GPS where the current and wave locations are recorded are as in Table 5.

| No  | UTM (49S) | Elevation (msl) |
|-----|-----------|-----------------|
| BM 00 | 715418.800 | 9156707.267 | 1.727 |

The highest tide conditions have a relatively small value of current velocity or close to zero, and when conditions change from tide to low tide, the current velocity increases. This current pattern occurs because the current moves horizontally towards equilibrium. At low tide and towards the tide, the mass of water will move due to the strength of the tidal current from these conditions and when the strength of the tidal current from the tide reaches equilibrium or the highest peak, the resulting speed is close to zero and so does what happen during lowest low tide.

3.4. Bathimetry
As study of the depths under water and the three-dimensional study of the ocean floor or lake, a bathymetric map generally displays floor or terrain relief with contour lines called depth contours (isobaths), and can have additional information in the form of surface navigation information. In Indonesia, the official agency that specifically handles the manufacture of bathymetric maps is the Indonesian Navy's Hydro-Oceanographic Service.

4. Running Delft3D Model
The simulation results with these two scenarios may not be as directly as expected. Trial and error are required so that the simulation can be accepted. If the simulation results get an error result, it must be checked again from all existing data inputs until the next running result results in error = 0.

4.1. Generate meteorological data for Delft3D
Meteorological data used as input for Delft3D in this paper includes wind vectors in zonal (U) and meridional (V) wind directions at an altitude of 10 m, as well as data on air pressure above sea level or mean sea level pressure (mslp). The data used is in the form of a grid, namely data that has a spatial distribution according to coordinates. For meteorological data used re-analysis data from the European Center for Medium-Range Weather Forecasts (ECMWF), provides medium to long-term forecasting for atmospheric or weather data as well as computational facilities for scientific research and cooperates both technically and scientifically with satellite agencies and European commissions. ECMWF is also the result of dynamic and synoptic meteorological development for more than 100 years and more than 50 years of numerical weather prediction development.

4.2. Bathymetric data
Rejoso Coast bathymetry was extracted from the General Bathymetric Chart of The Ocean with a spatial resolution of 15 arc-second (~ 450m). Data on the map is presented in ASCII text file format (positive values are land, negative values are seafloor) which can be downloaded at the link below the image. It is recommended to open bathymetry files from Pusriskel KKP using the TEXTPAD application or Programmer File Editor (PFE). The bathymetry data from P3SDLP is in ASCII Text format, which contains X, Y, Z values. It can also use Global Mapper software.

To see the difference in elevation values on land and at sea, a contour was created using the Generate Contours available on the Analysis menu of the Global Mapper software. A minus (-) value is obtained for the contour in the sea area and a plus value for the contour in the land area. Apart from the above sources, bathymetry data can also be obtained at 2 kilometers resolution ETOP01 and 30 second (1 kilometer) resolution GEBCO. Both data cover regions globally.
4.3. Land boundary
Determine from Google Earth, the starting point and end point of the shoreline which will be used as the study boundary line. In this study, digitization of the coastline on Google Earth as far as 16 kilometers, namely 8 kilometers to the west at the mouth of the Welang River and about 8 kilometers to the east at Grati. The digitization results in Google Earth are saved in * kmz format and then opened in the Global Mapper software. After adding the file, then export it into vector / lidar format in Delft 3D (ldb) format.

4.4. Samples and depth
After finishing creating the grid, the next step is to input the FGRGRID file into QUICKIN to input the depth of each contour. Input is done by inputting the bathymetry file in XYZ or Samples format. Samples were made from bathimetric data that had been processed in the previous section. After selecting the study area using ArcGIS or Global Mapper software, it is then exported to * xyz format.

4.5. Wind and wave data analysis
Meshing is a grid that is already equipped with depth. After the process on the grid menu has been carried out, the result of the modeling is called meshing. The first step in Delft3D modeling is creating a meshing. Meshing in Delft3D is defined as a study area to be modelled. The data that is inputted in making the meshing is bathymetric data whose file has been converted into XYZ format. This file can help in making the grid because the file in XYZ format can be used as a reference in forming the study area to be modeled. Meshing is created in the grid menu, so the grid menu is selected.

4.6. Input flow
After creating the meshing, the next step is to input some parameters in Delft3D-FLOW. In this paper, the Spherical coordinate system is used because in Spherical it has calculated the distance based on the curvature of the earth (curve surface). This study uses a scenario of a jetty building at the Rejoso estuary. The Dry Points input is used to add objects that must always be above the surface of the water such as Jetty, while for Thin Dams it is used to add objects that can be surpassed by water overflow. In this Rejoso study, the boundary in the form of the coastline is in the southern part, so that the determination of the boundary in the waters is set on input boundaries in the form of 3 boundary sides: west, north and east. In setting the boundary, you must pay attention to the visualization of the area and do manual input at locations M and N, which are the start and finish parts of the boundary in question. If the section name column is red, then the M and N coordinate points in the fields are not correct so trial and error must be carried out until all columns are white and the results of the visualization of the area on the boundary form a blue boundary line. After the boundary formation process is complete, each start and finish point for each boundary must be filled with information on the edit flow condition. In the study at Rejoso Estuary, it was carried out by selecting the boundary type in the form of water level and forcing type: Astronomic.

4.7. Flow data analysis
Wave Input filling is done in order to get Mdw-file. Mdw-file is an input file in Delft3D-WAVE which contains information for running a wave simulation. Similar to Mdw-file, Mdw-file also consists of several groups of input data. In this modeling, the group data used included: description, hydrodynamics, grid, time frame, boundaries, obstacles, physical parameters, output parameters.

5. Hydrodynamics Equations
In relatively shallow areas (coastal seas) like Rejoso Shoreline, wave action becomes important because of several processes: The vertical mixing processes are enhanced due to turbulence generated near the surface by whitecapping and wave breaking, and near the bottom due to energy dissipation in the bottom layer. A net mass flux is generated which has some effect on the current profile, especially in cross-shore direction. In the surf zone long-shore currents and a cross-shore set-up is generated due to variations in the wave-induced momentum flux (radiation stress). In case of an irregular surf zone,
bathymetry strong circulations may be generated (rip currents). The bed shear stress is enhanced; this affects the stirring up of sediments and increases the bed friction.

In Delft3D-FLOW, the hydrodynamic equations are written and solved in GLM-formulation, including the wave-current interactions. The GLM velocities are written to the communication file and are used in all (sediment) transport computations. Quantities moving with the flow are transported by the total, for example the GLM, velocity and not the Eulerian velocity. The Eulerian velocities are written to the Delft3D-FLOW result files to be used in comparisons of computational results with measurements. The only difference in the computational procedure as compared to the ordinary Eulerian formulation occurs at the boundaries. At water level boundaries, just the wave-mean water level must be prescribed.

The momentum equation in x-direction, averaged over the wave motion and expressed in Cartesian co-ordinates is given by:

$$\frac{\partial \bar{u}_j}{\partial t} + \bar{u}_i \frac{\partial \bar{u}_j}{\partial x_i} + \ldots + g \frac{\partial \bar{\zeta}}{\partial x_j} - \frac{1}{\rho} \frac{\partial \tau_{ij}}{\partial x_i} = F_j$$

where for i and j the summation rule applies, 
\(i, j = \{1, 2, 3\}\),
the wave averaged quantity is indicated by an overhead bar,
\(\bar{u}_j\) is the wave-mean velocity component,
\(\bar{\zeta}\) is the wave-mean free surface elevation,
\(\tau_{ij}\) are the components of the wave-averaged normal stress tensor, and
\(F_j\) is the wave-induced force that remains after averaging the momentum equation over the wave period.
This wave induced force can generally be written as the gradient of the radiation-stress tensor \(S\):

$$F_i = -\frac{\partial S_{ij}}{\partial x_j}$$

Using wave propagation model, we can express \(S_{ij}\) in terms of the wave parameters, such as the wave energy, the phase and group velocity, the wave length and the wave figure.

6. Simulation Results

Based on the results of Delft3D-Flow modelling, current conditions indicate a relationship between fluctuations in the direction and velocity of the current with the tidal pattern that occurs, by looking at the movement of the direction of the current which tends to back and forth. At low tide the current tends to be north-east (0 - 90) and at high tide the current direction is west-south (180-270). The current velocity at low tide is relatively greater than during high tide. The velocity in the surface water column has a higher current velocity than the middle and bottom water column. Getting to the seabed, it is relatively small current velocity. This condition indicates that the influence of wind and the roughness of the seabed plays a significant role in the movement of currents in that location. The effect of wind on current speed can also be seen from the data where the current speed tends to increase in line with the increasing wind speed.

6.1. Current Simulation

The simulation results of Delft3D software show that the currents come from the east at the highest tide and there are currents coming from the north at the lowest tide. The following is a picture of the magnitude and direction of the flow of the two model scenarios at low tide on 22 May 2018.

After simulating with two scenarios, it was found that the current magnitude changes in Rejoso Estuary as an effect of jetty structure. In the initial conditions of the simulation, you can see a gradual decrease in the amount of current after the jetty is built. Further clarify the current reduction analysis as an effect of jetty structure, three monitoring points are determined as follows and can be seen in Figure 6.

- Monitoring Point A: East of Rejoso Estuary (east of the jetty on the right)
- Monitoring Point B: West side of Rejoso Estuary (west side of jetty on the left)
- Monitoring point C: Approximately 500 meters west of Rejoso Estuary (east side of the Petung River, to observe the effect of jetty planning on other estuaries)

![Figure 4. Location of Monitoring for Scenario 1 and Scenario 2](image)

| Table 6. Percentage of Current Reduction. |
|------------------------------------------|
| %            | A   | B   | C   |
| Increasing Current | 5,95 | 13,09 | 8,33 |
| Decrease Current   | 94,05 | 86,91 | 91,67 |

![Figure 5. Current Simulation without Jetty](image)

![Figure 6. Current Simulation with Jetty](image)
As in Figure 8, the change in the current magnitude east of the estuary as an effect of jetty structure. The existence of a jetty can reduce the amount of flow in the estuary by 94.05% of the total analysis results at monitoring point A. There are fluctuations at certain times where there is an increase in the current caused by the wind direction at that time. When the wind direction is west-east or vice versa, it tends to make the current decrease because it is obstructed by the jetty, but when the wind direction at the monitoring point is north-south, the currents tend to be higher.

The amount of current reduction at Monitoring Point A due to the presence of a jetty is 0.299 m/s. It also can be seen the change in the current magnitude east of the estuary as an effect of jetty structure. The existence of a jetty can reduce the amount of flow in the estuary by 86.91% of the total analysis results at monitoring point B. At monitoring point B there are also fluctuations at certain times where an increase in current occurs due to the direction of the wind at that time. When the wind direction at
the monitoring point is in the north-south direction, the current tends to be higher and when the wind direction is west-east or vice versa tends to make the current decrease because it is blocked by the jetty.

From the modeling results, it can be seen that it turns out that the construction of a jetty at Rejoso Estuary also has an influence on other nearby river estuaries, one of which is the Petung River estuary which is west of Rejoso Estuary. The jetty structure in Rejoso was also able to reduce the flow rate by 91.67%. Thus the current reduction on the coast may also be able to reduce longshore sediment on the coast and reduce flow resistance from rivers to the sea. From the modeling results for 15 days, the amount of current reduction at Monitoring Point C as an effect of jetty structure is 0.033 m/s.

6.2. Sediment Simulation

The following is an image of the simulation results of Delft3D software for sediment transport from two model scenarios during high tide to low tide on May 22, 2018. After the simulation is carried out, it can be seen the changes in the amount of sediment transport. In scenario 1, where large sedimentation without a jetty at the mouth of the estuary, the presence of a jetty makes the river mouth more protected with less sediment around the jetty so that the river flow is relatively smooth and is not obstructed by sediment.

![Figure 8 Sediment Simulation without Jetty.](image1)

![Figure 9. Sediment Simulation with Jetty.](image2)

| %                     | A         | B         | C         |
|-----------------------|-----------|-----------|-----------|
| Increasing Sedimentation | 8,630952381 | 17,26190476 | 14,28571429 |
| Decrease Sedimentation  | 91,36904762 | 82,73809524 | 85,71428571 |

Figure 9. Sediment Simulation with Jetty.
From the simulation results, it can also be seen that the direction of the dominant current is from east to west. Therefore, apart from considering the current direction angle, it is also necessary to consider the possibility of adding the length dimension of the jetty with a westward turning angle. The morphological change that can be monitored at the end of this simulation is the possibility of sediment deposition in the western part of the jetty for a long time which will change the shape of the beach morphology at that point. For this reason, a simulation over a longer period of time is needed to see significant morphological changes. Meanwhile, when compared to the conditions at that time when a jetty has been built (Figure 12), it can be seen that the current pattern tends to be more stable and the flow from the river can flow smoothly towards the sea.

The presence of a jetty shows that the current direction and direction of sediment movement are always in the same direction, but without a jetty at certain times, especially when the tide changes towards low tide and low tide towards the tide, there is a reverse pattern between the direction of sediment movement and the direction of the flow. One example can be seen at high tide, which starts at 02.00 in conditions without jetty there is a reverse direction pattern where surface currents from the direction of the sea enter the river and collide with the current from the downstream of the river, while the direction of sediment transport shows the opposite.
7. Conclusion

Without a jetty, the shape of the beach and its elevation follow the shape of the initial coastline, while in conditions after the jetty is built for one year there is a silting along 120 meters to the end of the jetty, so that the base elevation in the western part of the jetty becomes higher and changes the shape of the beach morphology at Rejoso. It is occurred by the current moving from the West to the Northeast which carries the sediment grains being held up by the jetty construction. Retained sediment grains result in relatively large sedimentation in the area. In currents moving from the northeast to the west there is no significant increase in sedimentation. This is because the sediment grains that are carried from the Northeast to the West are blocked by the construction of the right side.

Without jetty, currents that occur from the west side carry sediment grains to the Northeast without any obstacles. This causes the sedimentation occurred is relatively large, causing deposits of the mouth of the estuary. There was no significant morphological change at the Rejoso estuary as the effects of the jetty construction for one year at rivermouth. The contributing factors include the presence of a fairly balanced flow pattern and direction so that sediment movement back and forth at the Rejoso estuary is still balanced.

Another factor that needs to be considered is the lack of dominance of the influence of river flow on sediment flushing from the river because it is still blocked by tides and currents from the sea, so that the sediment will only settle downstream of the river without being able to move towards the sea. This can be considered in the planning of a jetty which only functions to extend the river channel without having a significant influence in flushing sediment towards the open sea. Another consideration is the need to consider the jetty's slope angle to the shoreline and the direction of the dominant current, so that the direction of the river flow does not collide with the direction of the current in the sea.
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