Shoreline Changes Due to Breakwater around Navigation Channel of Belawan Port

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Abstract: Shoreline change is caused by longshore sediment transport which is the effect of nearshore wave induced current. Other causes are physical condition and coastal geomorphology such as bathymetry contour and coastal protection structure. This paper studies shoreline change in Belawan Port which is located in North Sumatra, Indonesia. In study area, breakwater is proposed to protect the navigation channel of Belawan Port from sedimentation problem. The objective of this study is to predict shoreline change around Belawan Port due to the existence of breakwater by using one-line model, GENESIS. GENESIS is used for predicting the behaviour of shorelines in response to coastal engineering and/or beach replenishment activities that may affect long shore sediment transport. The input of the model are bathymetry contour and shoreline position, waves characteristics (height, period and direction), median sediment diameter (d50), and structure position and its estimate permeability. The output of the model is the change of shoreline position after a period of time. Shoreline change around Belawan Port has been analysed under the effects of existing breakwater. The existence of breakwater can change the natural balance of sediment transport and affect the shoreline change that occurred.

1 INTRODUCTION

Shoreline change is a natural process which caused by sediment transport. Sediment can be transported by current (gravity-, wind-, wave-, tide- and density-driven currents), by the oscillatory water motion itself (wave-related transport) or by a combination of currents and short waves, while in coastal waters the sediment transport processes are strongly affected by the high-frequency waves which generally act as sediment stirring agents; the sediments are then transported by the mean current (Rijn, 1993). Shoreline change is primarily driven by the gradients in total longshore sediment transport and by the cross-shore transport owing to variability in incident wave energy (Idier, et.al, 2018). Longshore and cross-shore sediment transport leads to shoreline changes, and an accurate prediction of sediment transport is possible only if the wave and current hydrodynamics of the coastal area is well understood (Balas, et.al, 2011).

The development of coastal structures significantly affects the natural balance of sediment transport and may cause erosion and accretion in the coastal areas. The main problems in coastal structure development is determine sediment movement patterns or shoreline change patterns that have been happened or will happen to certain period of time. By knowing the pattern that happened then the optimal coastal structure development will be achieved (Pranoto, 2007).

Shoreline changes due to coastal structures existence is studied by many researchers. Vaidya et al. (2015) studied shoreline response to coastal structure, the result showed there was deposition on the up drift side and erosion on the down drift side of the groin, the effect of the increased length of the groin beyond surf zone is almost negligible, and since a longer groin traps most of the sand it results in more erosion on the down drift side. Balas et al. (2011) observed erosion between two existing coastal structure, groin and breakwater, which happen because this groin disturbs the sediment transport that feeds the beach, and based on numerical study that to prevent the erosion it is necessary to remove the previously constructed groin.

Mathematical modelling of shoreline change is very useful for understanding and predicting the long-term evolution of the sandy beaches due to the

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construction of these coastal structures. This paper study the shoreline changes due to breakwater around navigation channel of Belawan Port, so the effect of this structure in the future can be estimated.

2 STUDY AREA

Belawan Port is located in North Sumatera, Indonesia. Its mathematical coordinates are 03°47' North Latitude and 98°42' East Longitude. The location of Belawan Port is very strategic, adjacent to the Malacca Strait which is an international navigation lane. As the gateway to the economy of the North Sumatra region, Belawan Port must increase port services in the form of facilities and equipment.

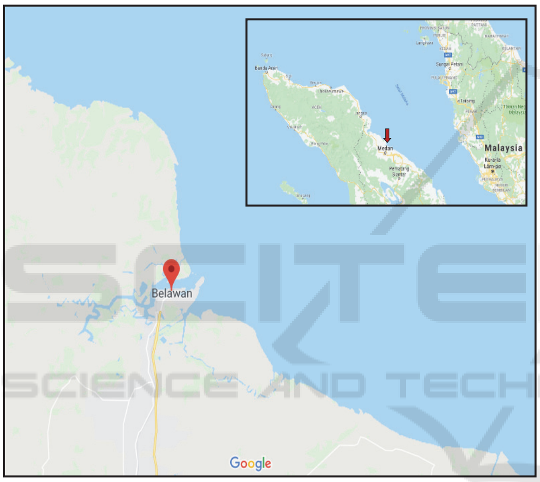

Figure 1: Belawan Port Location.

One of the keys to the development of Belawan Port is the improvement of navigation channel capacity, which can be done with several development scenarios such as increasing the width of the navigation channel and its depth, or by determining the location of a new channel. However, considering the natural condition of Belawan port is located in the mouth of two rivers and open water, so naturally it has problems with the hydraulic and environmental aspects which have the potential to cause sedimentation. Thus, the planned development scenario must be able to respond to these natural phenomena. The sedimentation phenomenon is a consequence of the existence of Belawan Port, so that sedimentation behaviour needs to be well recognized so that port development can be carried out optimally.

Figure 2 present a scenario that proposed for Belawan Port development with considering the sedimentation phenomenon. In the scenario, a new location of navigation channel is proposed with -14 m LWS depth, 140 m width, and 1: 6 slope. To prevent sedimentation, the Belawan river was diverted, and the breakwater is proposed to be built in the left and right of the navigation channel from shore area until -10 m depth. The length of the breakwater is about 9-10 km.

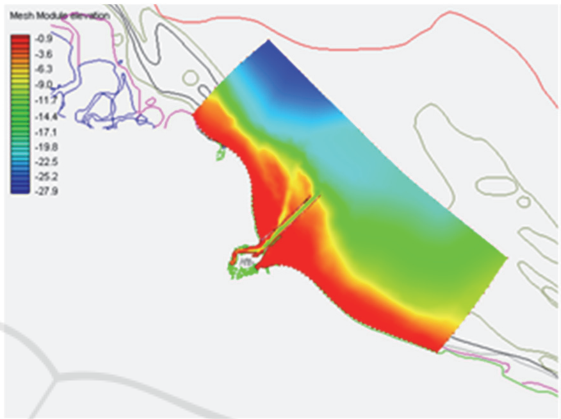

Figure 2: Belawan Port Development Scenario.

In addition to the phenomenon of sedimentation in Belawan, there have been significant shoreline changes around the Port of Belawan. This can be observed by comparing the shoreline on 1984 satellite imagery with 2018 (Figure 3). In a period of 34 years there has been considerable erosion and accretion. Erosion occurred on the coast to the right of Belawan port which reached ± 200 m, while accretion occurred on the coast to the left of Belawan Port which reached ± 100 m. The amount of erosion and accretion that occurs, shows that the shore around Belawan Port are quite dynamic. Considering the length of the proposed breakwater is quite long, 9-10 km, it certainly will have an effect on the balance of the natural sediment transport in that location, so that it needs further analysis.

Figure 3: Belawan Shoreline Position in 1984 and 2018.

3 METHODOLOGY

Generally, this study is carried out following the stage of data collection, literature study, data analysis, simulation, and evaluation. The flow chart can be seen in Figure 4.

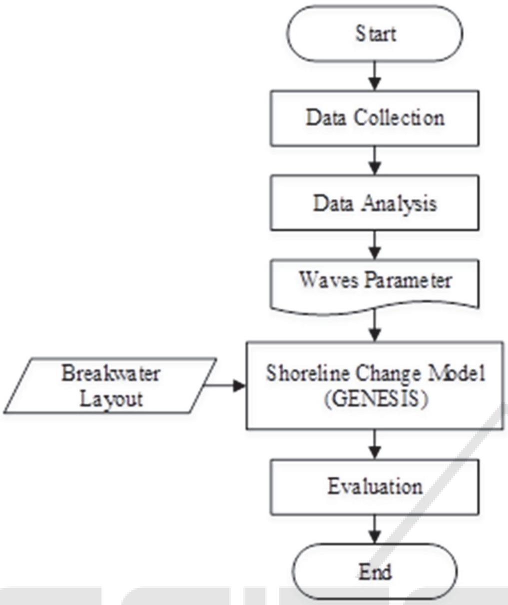

Figure 4: Flow Chart of Study.

Data collection includes the information of coastal area (shoreline position), bathymetry contour, global map, wind data (velocity and direction), sediment size, and other related data. Analysis is conducted for wind data. Wind data is analysed statistically to get the dominant wind event at study area, and to forecast wave event using hindcasting analysis. The result of hindcasting analysis is time series of wave height and wave period. Wave time series, shoreline position, median sediment diameter (d50), and structure position and its estimate permeability, will be used as the input for shoreline change simulation with GENESIS. Furthermore, shoreline change due to breakwater around navigation channel of Belawan Port can be predicted.

3.1 Shoreline Changes Model

GENESIS (generalized model for simulating shoreline) is numerical modelling system that is designed to simulate long-term shoreline change at coastal engineering projects (Hanson, 1989). This model can estimate the value of long shore transport rate and shoreline changes due to sediment transport without or with a coastal structure for a certain period. The simulating steps can be seen in Figure 5.

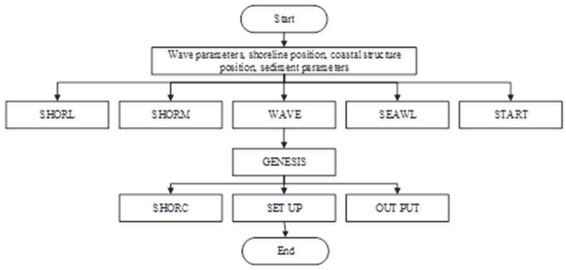

Figure 5: Simulating Step by GENESIS.

The calculation process is carried out by predicting longshore transport based on the shape of the beach face, while shoreline forecasting will be calculated by considering longshore transport aspect that occurs. The longshore transport rate (Q) has a unit of m3/year, because the movement is parallel to the coast so there are two alternative movements, the right and left relative to an observer standing on the beach facing the sea. Left movement is Qlt, and right movement is Qrt, so that obtained gross sediment transport rate (gross), Qg = Qlt + Qrt and level of net transport (net), | Qn | = Qlt – Qrt.
Qg values are used to predict siltation levels in an open water channel, Qn is used for protected groove designs and estimates of coastal erosion, and Qlt and Qrt for the design of sediment build up behind a coastal structure that withstand sediment movement. In the calculation of the Genesis model, longshore transport calculations are carried out using the result of equation modification from the equation:

$$Q(+) = \tfrac{1}{2}(Qg + Qn) \tag{1}$$

$$Q(-) = \tfrac{1}{2}(Qg - Qn) \tag{2}$$

The results of the modified equation are written in the following equation:

$$Q = \frac{\left(H^2 C_g\right)_B}{8\left(\frac{\rho_s}{\rho} - 1\right) a(1{,}416)} \left[\frac{k_1}{2}\sin 2\theta_b - \frac{k_2 \cos\theta_b}{1{,}416 \tan \beta\chi}\right]_b \tag{3}$$

Where:

H = wave height

Cg = speed of wave motion (based on wave theory linear)

a = 1 - sand porosity in the coastal area

ρs = sand density

ρ = density of water

θb = the angle of breaking waves is measured from the local coastline

k1 = approach coefficients form the relationship between transport values and long shore energy

k2 = coefficient of comparison between beach slope and breaking wave height

tan β = slope of the coastline along the surf zone area until the longshore sand transport

4 RESULT AND DISCUSSION

4.1 Wind and Wave Condition

The wind events in 1992-2001 at Belawan Port showed in Table 1.

Table 1: Percentage of Wind Events in 1992 – 2001.

Percentage of Wind Events						
Direction	Wind Velocity (knot)					
	<10	15-10	15-20	20-25	>25	Total
North	3.621	0.405	0.037	0.001	0.003	4.07
Northeast	13.099	2.106	0.082	0.017	0.004	15.31
East	3.543	0.749	0.064	0.003	0.003	4.36
Southeast	2.113	0.182	0.028	0.012	0.000	2.33
South	3.144	0.084	0.019	0.009	0.001	3.26
Southwest	5.252	0.113	0.036	0.013	0.004	5.42
West	6.054	0.14	0.015	0.006	0.003	6.22
Northwest	3.841	0.233	0.036	0.004	0.003	4.12
Percentage of wind events						45.08
Percentage of calm						54.92
Total						100

The wind event in the port of Belawan is 45.08%, with the dominant wind coming from the Northeast which is 15.31%, while the calm condition (no wind) is 54.92%.

Wave data is obtained from wind data analysis, hindcasting. The result of hindcasting is wave height and wave period. The wave events in 1992-2001 at Belawan Port showed in Table 2.

Table 2: Percentage of Wave Events 1992-2001.

Percentage of Wave Events						
Direction	Wave Height (m)					
	<0.25	0.25-0.5	0.5-0.75	0.75-1	1-1.5	Total
North	2.65	0.53	0.08	0.01	0	3.27
Northeast	7.95	3.39	1.49	0.53	0.10	13.47
East	2.26	0.78	0.29	0.11	0.07	3.51
Southeast	1.32	0.27	0.10	0.03	0.00	1.72
Northwest	3.06	0.45	0.10	0.02	0.00	3.63
Percentage of wave events						25.60
Percentage of calm						74.40
Total						100

The wave event in Belawan port is 25.6% with the dominant wave coming from the Northeast which is 13.47%, while the calm condition (no wave) is 74.4%.

4.2 Shoreline Change Prediction

Shoreline change prediction has been analysed by GENESIS, in two conditions, without and with breakwater, based on the development scenario that proposed. The length of shoreline which analysed is nearly 9900 m, with grid interval is 100 m. The initial shoreline that simulated is based on shoreline in 2008. The result of simulation without breakwater will be compared to shoreline in 2018 to obtain the best calibration coefficient (K1 and K2). The median sediment diameter (d50) is 0.086 mm, which is obtained from survey result. The wave parameters that used in this simulation are the result of hindcasting analysis from 10 years of wind data, 1992-2001. The beach slope is 0.005, and the permeability of breakwater is assumed 0.8.

Figure 6: Belawan Shoreline Position in 2008.

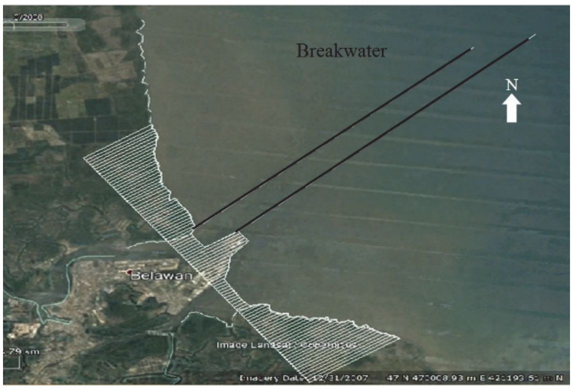

Figure 7: Simulation Grid.

Figure 8 show the prediction of shoreline position in 2018, and Figure 9 show the erosion and accretion which occurred and caused shoreline change.

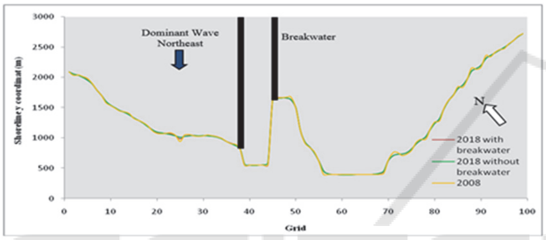

Figure 8: The Prediction of Shoreline Position in 2018.

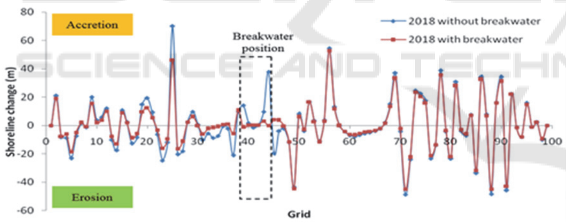

Figure 9: The Prediction of Shoreline Change in 2018.

The first simulation (without breakwater) is proposed to obtain the calibration coefficients with comparing accretion and erosion from simulation result with accretion and erosion that observed from satellite images (Google Earth). The best calibration coefficient K1 and K2 are 0.08 and 0.4. From the simulation result, there is erosion and accretion in some place which cause shoreline change. The average erosion is -6.8 m and the average accretion is 7 m.

From Figure 9, it showed the effect of breakwater existence (breakwater position are in grid 39 and 45). Inside navigation channel, the existence of breakwater can decrease accretion. The breakwater existence doesn't change the pattern of accretion and erosion that occurred, but it decreases the amount of accretion and erosion. In the left side of breakwater position, the decreasing of accretion and erosion is bigger than the right side. Considering the incoming wave direction and the layout of breakwater, breakwater might protect the shore from the East wave that effect in decreasing accretion and erosion. The East wave is not the dominant event, but it has medium amplitude.

5 CONCLUSION

Shoreline position can change due to sediment transport, longshore and cross-shore. In this study, shoreline change due to longshore sediment transport has been simulated by GENESIS. The existence of breakwater can change the natural balance of sediment transport and effect the shoreline change that occurred. In this study, the breakwater has 9-10 km length, as a long structure, it also protects the shore from incoming wave which effect decreasing the amount of accretion and erosion.

In this study, the analysis of longshore sediment transport is caused by longshore current which is wave-driven current, and not consider the effect of another current (gravity-, wind-, tide- and density-driven currents). For further study it is suggested to analyse the longshore sediment transport which is caused by mean-current, and also consider sediment input from the river in order to have more accurate result.

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