Study of groin structures effectiveness for against abrasion in Padang Beach

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Abstract. This study was conducted to evaluating the performance of existing coastal protection structure to restrain the rate of erosion as a result of the influence of hydrodynamics process. Condition that reviewed was in form of distance shoreline as simulation results to initial reference line before. STWAVE module used to determine wave height at near shore as transformation of deep water wave height that determined before from SMB method. One Line Model was conducted to get shoreline change in each time step calculation. Model consists of two conditions, with the absence of coastal structures and with structure respectively. The simulation result show that potential erosion occurs at Batang Arau river mouth with no protection structure. Large erosion predicted around 59.04 meters from the shoreline position early. With coastal protection, model result obtained sedimentation of 7.33 meters coastline from its initial position. This occurs at a distance of 475 meters from the boundary domain. Modeling results also showed erosion is 18.39 meters at a distance of 250 m from the boundary domain. This is likely due to the limited modelling conditions that without reviewing of littoral transport direction that occurred in perpendicular to the coast. Result study show that the presence of a groins in Padang coasts looks already quite effective to maintain the shoreline of the littoral transport direction, however the installation of groins seemingly did not give significant meaning in the addition of the coastline.

1. Introduction

Padang was located on the west coast of Sumatra with the coastline that was direct toward with the Indian Ocean, so potentially have threat of ocean waves that are large relatively and then influencing on shoreline changes. Padang coastline, which is located on the northern part of the Batang Arau River since 1938 - 1969, has suffered a decline of about 67 m. The occurrence of major storms on the west coast in 1963 and 1964 has exacerbated damage to Padang coast. In 1964 after the disaster, emergency seawall / revetment construction was built as a buffer against the rate of shoreline change, however it was still unable to cope with abrasion. This condition is exacerbated by the damage to construction that has been built due to erosion of building foundations that occurred in 1968. In 1969 construction was replaced with a crib (groin) which functioned properly capturing sediment especially those close to Batang Arau river mouth. Successively due to major storm disasters such as those that occurred in 1971, 1972 and 1973 caused the coast to the north more and more experienced abrasion, especially in locations that do not have crib construction (groin). Until now, many efforts was done, including the making of the crib to the north of the Batang Kuranji River estuary (the total length of coastal handling
that had been carried out reached 6.50 km). The results of the work of the crib - crib there are functioning well but some are also crib that does not function properly.

**Figure 1.** Shoreline Setback Process (1938 - 1969) caused by abrasion, Location at Gedung Pancasila, (DPMA Director General of Water Resources, Dept. PU) and shoreline condition before 1938 (Tropen Museum, Netherland) [1,2]

This study will evaluating effectiveness level of existing of coastal protective structures using one line model numerical approach to determine coastline profile changes that occurred due to the abrasion process with compare in conditions without protective structure and the presence one in the other side. The limitation of modelling uses the assumption that transport is the main mechanism that creates the erosion process. The process of transport perpendicular to the beach (cross shore transport) which is a phenomenon of seasonal events can be ignored. Validation for simulation results was done to secondary shoreline data in certain years to obtain the calibration coefficient of the modelling scenario.

The beach on coastline was classified to experience erosion, accretion /sedimentation or remain stable depending on the material supply balance as a result of the process of sediment transport entering and leaving the observed beach segment. Most coastal problems are excessive erosion. Coastal erosion was occur if the sediment material carried away from the site is much larger than the sediment material deposited at that location. As a result of the sediment transport process along the coast will lead to changes in coastline. Based on the mechanism of the transport process that occur, shoreline changes are mainly generated by long shore drift. This is caused by the long cycle time that needed of beach to returning to its stable position due to the inability of the hydrodynamic conditions around the coast to provide the supply of sediment material into the initial location of the material undergoing transport [3]. This condition is generally very common in coastal areas where there is a significant incoming wave angle at the perpendicular position of the coastline, as well as a deficit supply of sediment towards the coast due to the reduced amount of sediment transport material from rivers that flow into the coast. Several previous studies have conducted research to see the condition of shoreline changes in various hydrodynamic conditions and local climatology. Sediment transport along the coast consists of two main components, namely sediment transport in the form of a saw blade on the shoreline and sediment transport along the coast in the region of a breaking wave (surf zone) [4]. Zenkovitch [4] measures sediment transport along the coast. The measurement results obtained two peaks of suspended sediment concentration caused by the breaking waves around the
location of the breaking waves and on the coastline. High concentrations near the coastline are caused by the mass movement of the flow in the form of a saw blade as described previously.

2. Study location and methodology
Location under review was coastal segment between the Batang Arau river mouth and the Banjir Kanal river mouth with a coastline of ± 3.7 km. The existing beach structures at this study site are seawall, revetment and groins. Situation map of the study location and the position of the existing coastal protective structures between the Batang Arau estuary and the Banjir Kanal estuary as shown in Figure 8. This study will look at the extent of the existence of existing coastal protective structures able to withstand the rate of erosion as a result of the influence of coastal hydrodynamics that using STWAVE modules. The governing equation of wave transformation in STWAVE using wave dispersion relationship that was given in the moving reference frame as [5,6]

\[ \omega^2 = gk \tanh kd \]  

where \( \omega \) is angular frequency, \( g \) is gravitational acceleration, \( k \) is wave number and \( d \) is water depth.

The wave orthogonal direction for steady-state conditions is given by [5,7]

\[ C_{ga} \frac{Da}{DR} = \frac{C_{k}kDd}{\sinh 2kd} \frac{k_{l}Du_{l}}{k_{l}Du_{l}} \]  

where \( D \) is a derivative, \( R \) is a coordinate in the direction of the wave ray, and \( n \) is a coordinate normal to the wave orthogonal.

The governing equation for steady-state conservation of spectral wave action along a wave ray is given by [5]:

\[ \left(C_{ga}\right) \frac{\partial}{\partial x_{i}} \frac{C_{w}C_{ga} \cos(\theta - a)E}{w_{r}} = \sum_{w_{r}} S \]  

where \( E \) is wave energy density spectrum (which is a function absolute angular frequency \( w_{a} \) and direction \( \theta \)) and \( S \) is energy source and sink terms.

The model scenario was divided into simulation without and with the presence of a coastal structure. Calibration factor was used into the scenario by validating the data obtained on the field. Some variables which are field data are taken as input in model, such as sediment grain size data. Simulation results obtained are compared between without and with groins. From these results an analysis of the extent to which the existence of existing coastal structures is able to withstand the rate of erosion that occurs that have an impact on coastline changes. In this study, One-Line Model is used to predict the shoreline changes [8]. Simulation is based on sediment continuity equations. To solve this equation a process of discretization was needed, where the beach is divided into a number of cells. Each cell was examined for incoming and outgoing sediment transport. In accordance with the law of conservation of mass, the sum of the net mass flow rates in cells is equal to the rate of change in mass in each unit of time. Figure 5 showing division of the coast into a number of cells with uniform lengths, ie \( \Delta x \). Figure 3b shows sediment transport in and out of cells and changes in sediment volume that occur therein. The net sediment mass flow rate in cell and rate of mass change in cells per unit time was [9]:

\[ M_{n} = \rho_{s}(Q_{m} - Q_{k}) = -\rho_{s}(Q_{k} - Q_{s}) = -\rho_{s}\Delta Q \]  

Rate of change of mass in cells per unit time is:

\[ M_{t} = \frac{\rho_{s}V}{\Delta t} \]  

Where \( \rho_{s} \) is sediment mass density, \( Q_{m} \) and \( Q_{k} \) are sediment discharges in and out of cells respectively.
The solution of equation (6) is done numerically using the finite difference method. The settlement is done by dividing the coast into several pias (discretization) of space and each time step. This discretization aims to change the form of partial differential equations into discrete forms at a number of points count. The discrete equation form is then solved numerically to get the position of the coastline.

Figure 2. Study area and aerial photograph

Figure 3. Situation map of the area between the Batang arau estuary and the Banjir Kanal river estuary (2006) and division of shoreline into a number of cells

3. Result and discussion
SMB method was applied to determine height wave in deep water condition (Ho) (CERC, 1984). The effective fetch was calculated from eight main cardinal directions. The effective fetch calculation process can be seen in Figure 9 and Table 1 below. From Table 1 it can be seen the direction of wave propagation on the coast of Padang which is the longest originating from the south.

Figure 4. Fetch length to Padang coast (West direction)
Table 1. Effective Fetch Length and Deep water wave height for Area Study

| Direction    | Fetch Length (m) | Effective Fetch Length (km) | Deep water wave Height, Ho (m) |
|--------------|------------------|-----------------------------|-------------------------------|
| Southeast    | 52,171.05        | 52.17                       | 1.13                          |
| South        | 366,803.40       | 366.80                      | 1.71                          |
| Southwest    | 3,888,813.68     | 3,888.81                    | 3.18                          |
| West         | 3,982,640.98     | 3,982.64                    | 5.2                           |
| Northwest    | 1,029,694.42     | 1,029.69                    | 2.9                           |

Wave hind casting is a calculation of wave height (H) and wave period (T) due to wind with a certain magnitude, direction and duration. Wind data were obtained from the BMG wind measurement station at Tabing airport for 5 years from 1998 to 2002 with the assumption of representing wind events on the Padang coast. The distribution of wind events is the result of grouping hourly wind data and can be seen in the form of a wind rose diagram in Figure 10. Based on the results of the processing of wind data from BMG Tabing Airport in 1998-2002, it can be seen that the dominant wind occurs from the west direction of the city of Padang with a total incidence of 12.45% at speeds of 5 to 15 knots. Wave distribution of hind casting results based on wind data in BMG Padang Tabing in 1998-2002, can be seen in the rose wave diagram (Wave rose) in Figure 11. The results of the analysis show that the dominant wave is seen coming from the West with the percentage of events of 12.45%.

Deep water height wave (Ho) that resulted then used as height wave to calculating wave height transformation on near shore. From the result of STWAVE modules the wave formation is influenced by various factors such as geographical condition between study area and wave formation area, changes in depth or Shoaling, and refraction - diffraction phenomena. On Figure 5 (b) is the wave height transformation with wind formation from the West. The stages of shoreline model that will be carried out are changes in shoreline for 5 years, starting January 1, 2006 until January 1, 2011, from the results will be seen erosion and sedimentation patterns caused by the presence of coastal structures. The coastline included in the simulation is the 2006 coastline, the measurement result of the West Sumatra Coast Flood and Safety Control Project. The position of the initial shoreline (initial condition) based on the length and distance of the grid to the reference line (base line) is shown in Figure 12 below. Groin is a structure that was erected to prevent litoral sediment transport. This condition in the model results in a balance of sediment discharge at that point, Q (i) = 0.

Figure 5. Windrose and waveroses based on BMG Tabing station data 1998-2002 (a) and wave transformation with wind formation from the west (b)
The shoreline model is intended to simulate the condition of the shoreline in the simulation interval of change for 5 years (January 1, 2006 - January 1, 2011), so that erosion and sediment patterns can be seen at the location and direction of movement of sediment along the coast. Results show the magnitude of changes in the coastline at each distance in the 5th year of the simulation since 2006 under conditions with and without the presence of a coastal protective structure, as can be seen in Figure 13. Based on the simulation results, the part of the beach that experienced extreme erosion is the area around the estuary of Batang Arau with the distance from the starting point of model is 475 meters with large erosion that occurs close to the magnitude of 60 meters from the initial condition coastline. This is expected to occur due to the presence of sediment transport which is influenced by the direction of wave motion diffracted in the presence of the headline next to it. By providing coastal protection in the form of groin no. 1 and groin no 2 seen to reduce erosion by 66.37 meters. This is quite effective in maintaining the stability of the coastline from erosion. Another part that experienced significant erosion was the area in the area of around 3,800 meters from the beginning of the model, where the area was eroded quite large at around 49 meters. The calculation results get the average total number of shoreline retreats to the initial shoreline position simulation without shore protection obtained by 10.49 m, while using the groin structure the average total coastline progress is 0.435 meters. From the results of this simulation it can be seen that the presence of the groin structure have been effective enough to withstand shoreline changes caused by the rate of erosion and is clearly seen in the coastal segments around the Batang Arau estuary.
4. Conclusion and suggestion

Using hourly wind data for 5 years (1998 to 2002) generated dominant waves from the west of 12.45% and southwest of 6.25%. The wave height transformation based on model using ST WAVE module result is range from 0.15 to 2.5 m with refraction coefficient, Cr = 0.13 - 0.51. From the results of the transport simulation for 5 years, it can be seen that erosion is indicated around the Batang Arau estuary if no protection is carried out with the predicted magnitude as far as 59.04 meters from the initial coastline position. By providing coastal protection, there was even a reduction in the coastline of 7.33 meters from the initial position which occurred 475 meters from the edge of the domain. This might be due to the limitations of the model that does not review shore perpendicular transport. In field conditions this does not happen because it has been protected by a revetment building in anticipation of a perpendicular wave attack of the coast. In terms of the coastline against the direction of littoral transport, the presence of Padang beach groins seem to be quite effective. This is mainly at locations near the Batang Arau estuary. However, when viewed on the side of the addition of the coastline, the installation of groins structures on the Padang coast does not seem to have a significant meaning. Model results that is currently being carried out is based on littoral transport without observing the onshore-offshore transport sediment transport. Although for the coastal erosion process the littoral direction is a very dominant direction, but model should also be carried forward to include the perpendicular transport component of the coast. This can be done to describing changes in the shape of the beach profile that occurs due to storm conditions (surge). By looking at erosion and abrasion patterns that occurred in coastal areas, it is time for the government to make legislation that explicitly regulates coastal border areas. This is needed to free up the dynamics of the shoreline dynamic.

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