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The numerical model of the sediment distribution pattern at Lampulo National fisheries port

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Abstract. The spatial distribution of sediment pattern was studied at Lampulo Fisheries Port, Krueng Aceh estuarial area, Banda Aceh. The research was conducted using the numerical model of wave-induced currents at shallow water area. The study aims to understand how waves and currents react to the pattern of sediment distribution around the beach structure in that region. The study demonstrated that the port pool area had no sedimentation and erosion occurred because the port was protected by the jetty as the breakwater to defend the incoming waves toward the pool. The protected pool created a weak current circulation to distribute the sediments. On the other hand, the sediments were heavily distributed along the beach due to the existence of longshore currents near the shoreline (outside the port pool area). Meanwhile, at the estuarial area, the incoming fresh water flow responded to the coastal shallow water currents, generating Eddy-like flow at the mouth of the river.
Keywords: Lampulo Fisheries Port, longshore current, sediment distribution, wave-induced current

1. Introduction

Lampulo National Fishery Port located at 5°35'11.11"N and 95°19'8.44"E (Figure 1) is an area where all fishery activities are conducted, providing the multiservice fishery business as well as absorbing a large workforce of both industrial and economic sectors. The function of this fishery port is to support the management as well as to utilize fishery resources and environment, ranging from pre-production, production, processing, to marketing, implemented in a fishery business system. However, such utilization of the port and the establishment of a pool protected area have created a distribution pattern of sedimentation and erosion outside the pool protected region, bringing impacts on changes in sediment distribution patterns [1], [2].

During the recent years, activities conducted in this area have been increasing in quantity as well as in variety, leading to some changes that may have unwanted side effects such as environmental damages [3]. Plans that can limit and control these adverse effects have been becoming more important than ever, including thoughts about interactions of waves propagating into coastal areas which lead to the sediment deposition and erosion that interact with the coastal structures [4], [5].

The knowledge of wave behavior near coastal areas is then becoming quite significant. Run-up waves on coastal structures, for example, determine the design of breakwater. The wave speed and energy influence the strength of the coastal structures or floating bodies [6]. A study of such wave behavior can be directly applied in engineering practices [7], [8].

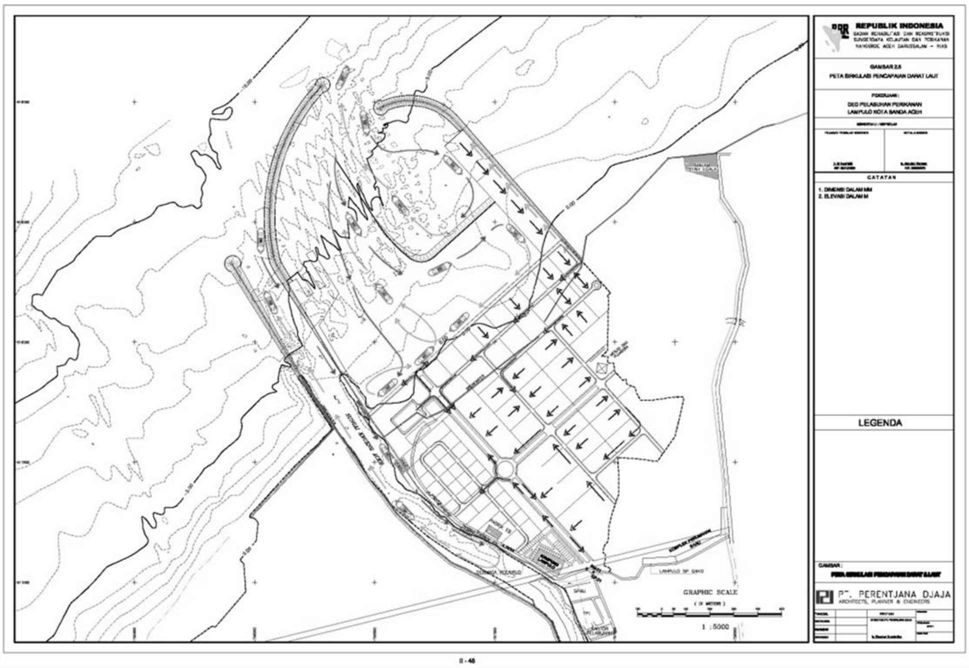

Figure 1. Map of Lampulo national fisheries port of Banda Aceh.

This paper presents mathematical modeling and analysis for wave-induced currents on coastal structures of Lampulo fisheries port that lead to sediment transport distribution. Based on this model, a numerical code has been designed using 2D fully non-linear equations of the wave. This article also presents a procedure for calculating the sediment transport distribution in this area.

2. Research Method

2.1 Hydro-dynamic Model and Sediment Transport

The wave-induced current model uses 2D depth-averaged momentum conservation and mass conservation which can be written as:

$$\frac{\partial \bar{u}}{\partial t}+\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}=-g\frac{\partial \zeta}{\partial x}-\frac{C_f\bar{u}\sqrt{\bar{u}^2+\bar{v}^2}}{(h+\zeta)}+R_x+M_x \quad (1)$$

$$\frac{\partial \bar{v}}{\partial t}+\bar{u}\frac{\partial \bar{v}}{\partial x}+\bar{v}\frac{\partial \bar{v}}{\partial y}=-g\frac{\partial \zeta}{\partial y}-\frac{C_f\bar{v}\sqrt{\bar{u}^2+\bar{v}^2}}{(h+\zeta)}+R_y+M_y \quad (2)$$

$$\frac{\partial \zeta}{\partial t}+\frac{\partial\left(\bar{u}(h+\zeta)\right)}{\partial x}+\frac{\partial\left(\bar{v}(h+\zeta)\right)}{\partial y}=0 \quad (3)$$

where t is time, (x,y) is the Cartesian coordinate in the horizontal plane, (u,v) is the component of velocity, C_f is basic friction coefficient, (R_x, R_y) is radiation stress in x- and y-direction, g is gravitational acceleration, h is water depth, and ζ is the water elevation.

The momentum changes caused by the turbulent currents that tend to spread due to the influence of the wave force exceeding the area of the breaking wave, then the lateral mixing can be written as follows [9]:

$$M_x=\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial \bar{u}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial \bar{u}}{\partial y}\right) \quad (4)$$

$$M_y = \frac{\partial}{\partial x}\left(\varepsilon \frac{\partial \bar{v}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon \frac{\partial \bar{v}}{\partial y}\right) \quad (5)$$

with:

ε $= N\,l\,\sqrt{g(h+\zeta)}$ [8]

N = the constant value less than 0.016

l = the distance toward offshore $= (h+\zeta)/\tan\beta$

$\tan\beta$ = the bathymetric slope

As for the irregular slope, the lateral mixing can be written as:

$$M_x = A_H\left(\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2}\right) \quad (6)$$

$$M_y = A_H\left(\frac{\partial^2 \bar{v}}{\partial x^2} + \frac{\partial^2 \bar{v}}{\partial y^2}\right) \quad (7)$$

where A_H is the horizontal viscosity coefficient.

The component of radiation stress is defined as the momentum flux due to the existence of wave motion and has the same dimension as the momentum flux formed by two factors, namely the velocity of water particles caused by waves and the pressure. If the waves come near the coast by forming an angle to the shoreline, then the radiation force is as follows [10]:

$$S_{xx} = \frac{\bar{E}}{2}(2n-1) + \bar{E}n\cos^2\theta \quad (8)$$

$$S_{yy} = \frac{\bar{E}}{2}(2n-1) + \bar{E}n\sin^2\theta \quad (9)$$

$$S_{xy} = \frac{\bar{E}}{2}n\sin 2\theta \quad (10)$$

with $\bar{E}$ is $\frac{1}{8}\rho g H^2$. Therefore, the force causing the occurrence of longshore currents is proportional to the radiation of stress gradient [8] which can be written as:

$$R_x = \frac{1}{\rho\left(d+\bar{\eta}\right)}\left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y}\right) \quad (11)$$

$$R_y = \frac{1}{\rho\left(d+\bar{\eta}\right)}\left(\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y}\right) \quad (12)$$

The total sediment transport, in this case, is defined as the sum of sediment transport, both bed and suspended sediments with a simple approach as follows:

$$q_t = 0{,}05U\,\frac{\tau_{cw}{}^2 C}{\rho^2 g^{5/2}\left[\frac{(\rho_s-\rho_w)}{\rho_w}\right]^2 D_{50}} \quad (13)$$

where:

ρ_w = water density

ρ_s = sediment density

D_{50} = 50% of the sediment size

$\tau_c = \rho g U^2 / C^2 + \frac{1}{2}\left(\xi \frac{\hat{u}_b}{U}\right)^2$ = the friction between waves and currents

$\hat{u}_b = (\pi H / T)(\sinh kh)^{-1}$ = bottom wave velocity amplitude

$\xi = \frac{c}{\sqrt{(2g)}}\sqrt{(f_w)}$ = bottom roughness

(f_w) = wave friction coefficient

Hence, the mathematical relationship for the sedimentary equilibrium of the sediment movement is written as:

$$\frac{\partial \zeta_b}{\partial t} + \frac{\partial q_{tx}}{\partial x} + \frac{\partial q_{ty}}{\partial y} = 0 \quad (14)$$

with q_t represents the total sediment transport [12].

3. Results and Discussion

The wave-induced current model was applied based on the bathymetry shown in **Figure 2**, covering 1,600 m along the coastal line and 1,350 m toward the offshore. The simulated model employed bottom stress $C_f = 0.01$, horizontal viscosity coefficient $A_H = 10$ m^2/s, $\Delta x = 10$ m, $\Delta y = 10$ m, and the interval time dt = 0.45 second. The applications of sediment transport model and bottom morphological changes were similarly designed to the current model with a sediment diameter D_{50} = 0.1 mm. The input of the sediment transport rate was based on the results of the wave-generated current model, completed simultaneously after the simulating the current model. Likewise, the bottom morphological changes were calculated from the sediment transport rate results.

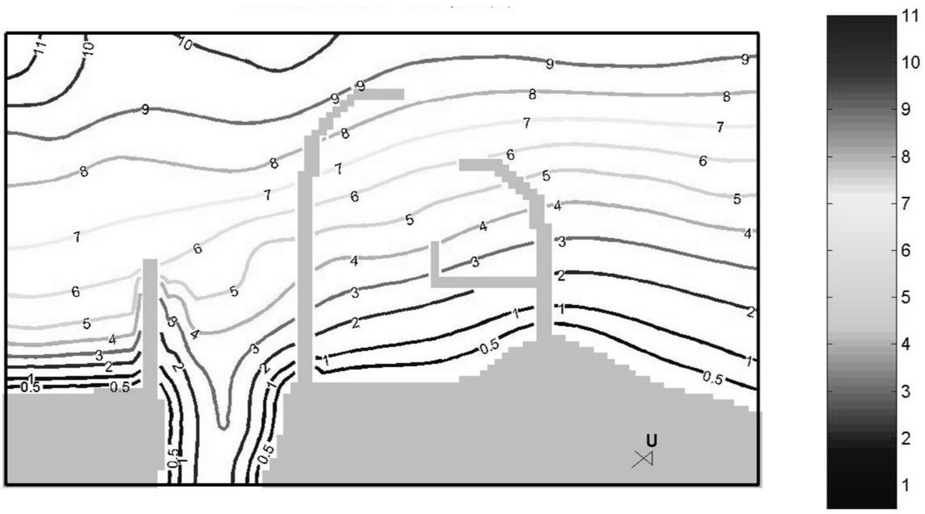

Figure 2. The bathymetry of Lampulo national fisheries port, Banda Aceh.

The results of the model showed that the pattern of current distribution was affected by the diffraction and reflection brought about by the coastal structures. Figure 3 depicts that the western area of coastal structures or around the mouth of the river (estuarial area) generated current vortexes with the largest magnitude of 6.9 cm/s. This Eddy-like circulation pattern is due to the elevation difference between the inner and outer sides of the coastal structures with the smaller flow velocity compared with the protected area [6], [13]. This whirl is also influenced by the river flow from the upstream of the estuarial area toward offshore, triggering the water particles to move faster and provide a boost to the slow-moving water particles [7]. On the other hand, the current pattern showed that currents moved eastward at the left and right of the coastal structures, while currents in the pool protected area merely had a small movement, implying that almost no flow occurred in this zone.

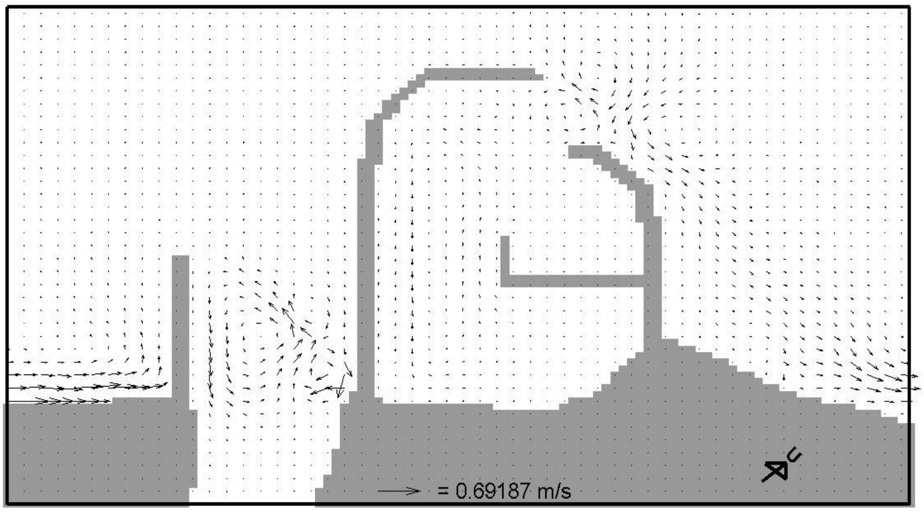

Figure 3. The average current distribution in Lampulo National Fisheries Port.

The application results of the sediment transport model in this area can be seen in Figure 4 below. This sediment transport model, as well as the current model (Figure 3), was carried out for a month. The results showed that on the left side of coastal structures near the river mouth, the erosion was more dominant than the sedimentation. The largest sedimentation occurred in the western part where the jetty that protects the estuary has a large contribution to settling the sediments and deposits in this area [14]. Figure 4 illustrates that the erosion predominantly took place on the eastern coast, while neither sedimentation nor erosion occurred in the pool protected port since the weak current pattern formed in this area could not transport the bottom sediments upward to create a sedimentation and erosion.

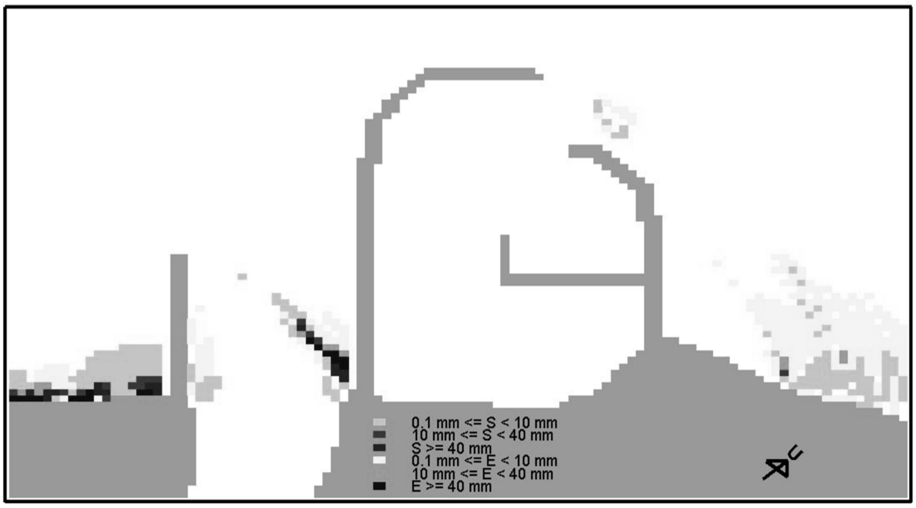

Figure 4. The profile and distribution pattern of erosion and sedimentation in Lampulo National Fisheries Port

4. Conclusion

The model employed in this study has been able to simulate the wave-induced currents representatively, depicting the longshore current pattern. Qualitatively, the erosion and sedimentation model in this coastal area has shown a correspondence with the field measurements that both phenomena predominantly occurred outside the protected port area by the coastal structures, while neither sedimentation nor erosion took place in the pool area because of the weak current pattern. On the other hand, the sediment distribution was displayed along the beach due to the existence of longshore currents near the shoreline. Meanwhile, in the estuarial area, the outcoming river flow toward the offshore responded to the coastal shallow water currents that generated Eddy-like flow at the mouth of the river.

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