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Numerical model of oil spill at Balohan Port, Sabang

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Abstract

The research used numerical mathematics to predict the accumulative amount of oil spilled for the next 10 years. The purpose of the study is to understand how the oil will spread at the port of Balohan, Sabang in order to be able to anticipate the environmental impact from oil pollution. To understand this case, the two dimensional numerical model was used. The result informed that concentration of oil spill accumulation prediction for the next ten years diffusively concentrate at the area of the dock (parking ship). The result also notified that advection effects of the current was not significantly arose because of residual current is too small to occur.

Keywords: oil spill, numerical mathematics, oil pollution, environment

1. Introduction

Port of Balohan at Sabang island is one of the important sea transport infrastructure to support tourism from main land of Aceh to Sabang island. Located approximately 12 km south of Sabang, the port of Balohan serves to accommodate the berthing ships crossing of Banda Aceh and Sabang. Along with the establishment of Sabang as a major tourist destination in the region of western Indonesia, it will increase the flow of passengers to and from Sabang. Many investors also take advantages of the policy because they will use the sea route to reach Sabang as it is cheaper and safer. However, such developments and its activities might cost the environmental damage.

The development in Indonesia as well as in Aceh implements the sustainability development principle, therefore to support such principle, one of them is by studying the oil spill pollution because of port activities in such area. The study of oil spill in this case is by implementing the numerical model analysis to predict the amount of pollution spreading at port area. The effort is important because it can be used to monitor and evaluate marine areas (Chang et al., 2014). By doing this analysis, the efforts of precaution and prevention would be controllable.

The oil spill at the port area has relatively small in term of spatial scale (Kremer, 2007) compared to the exploration activities of oil production, the transportation/shipping of oil (tankering), and offshore pipelines (Mazurek, 2013). However, the impact caused by the oil spill at the sea port area is hazardous because the waste of oil is a harmful excess (B3 pollutant) that are explosive, corrosive, and smelled. Consequently, the costs arising from oil pollution can be several, such as: biological damage, the aesthetic damage caused by the smell waste, decreasing or obstructing phytoplankton and zooplanktons population as food source and damage the food chain system in the affected areas (Neel et al., 2007; Novelli, 2011; Chang, 2014).

The main factors that makes the oil spill spread are the wind, waves, tides, currents and solar radiation (Novelli, 2011). However, in the real situation, those data are extremely difficult to obtain, in addition to incomplete, and usually the data are uncertainty. Therefore, simplification may be made for numerical models because of the complex factors that influence them (Mazurek, 2013). The dominant effects of hydro-oceanography on oil spills around the beach is

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current caused by waves (Mazurek, 2013) compare to other factors such as tides, salinity density and temperature (Cho et al., 2012). How large the oil spill at the port is the main focus of this study in order to be able monitor and evaluate the impact occurred in the area.

2. Methodes

Oil spill analysis on this study uses numerical model of mathematics. The prediction of oil spill is based on the daily accumulation of oil spill data taken on the field in three consecutive months. The prediction analysis conducts over the next ten years based on hydro-oceanographic data and model such as: waves, tides, winds, and geomorphology.

Mathematically, the dynamic of oil spill can be done if numerical model of current and waves have been completed. To carry out the analysis, the following are the formulation implemented in this research. The current dynamic resulting from wave can be written as:

$$\frac{\partial\bar{\zeta}}{\partial t}+\frac{\partial(h+\bar{\zeta})U}{\partial x}+\frac{\partial(h+\bar{\zeta})V}{\partial y}=0 \quad (1)$$

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+F_xM_x+R_x+g\frac{\partial\bar{\zeta}}{\partial x}=0 \quad (2)$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+F_yM_y+R_y+g\frac{\partial\bar{\zeta}}{\partial y}=0 \quad (3)$$

Where:

F_x dan F_y = the friction term in x dan y direction

R_x dan R_y = the radiation stress in x dan y direction

M_x dan M_y = the forces from the radiation tension gradient

According to Horikawa (1988) the radiation tension can be calculated from the following formulation:

$$M_x=A_H\left(\frac{\partial^2\bar{u}}{\partial x^2}+\frac{\partial^2\bar{u}}{\partial y^2}\right) \quad (4)$$

$$M_y=A_H\left(\frac{\partial^2\bar{v}}{\partial x^2}+\frac{\partial^2\bar{v}}{\partial y^2}\right) \quad (5)$$

with A_H is the horizontal viscocity coeficient.

For the wave distribution, Watanabe and Maruyama (1988) formulated the wave kinematic as follow:

$$\omega_0=\sqrt{gk\tanh k(h+\eta)}+k(U\cos\theta+V\sin\theta) \quad (6)$$

Where:

ω_0 = the frequency of incoming wave angle

g = gravitation acceleration

k = the wave constant

h = water depth

η = wave elevation

U and V= current on x and y direction

From the formulas above, the value of k dan θ can be calculated, then the conservation energy can be implemented as:

$$\frac{\partial}{\partial x}\left[E(C_{gx}+U)\right]+\frac{\partial}{\partial y}\left[E(C_{gy}+V)\right]+S_{xx}\frac{\partial U}{\partial x}+S_{xy}\frac{\partial U}{\partial y}+S_{yx}\frac{\partial V}{\partial x}+S_{yy}\frac{\partial V}{\partial y}=0 \quad (7)$$

here

E = $gh H^2/8$

H = the wave hight

C_{gx}, C_{gy} = the velocity of wave group in x and y direction

S_{xx}, S_{xy}, S_{yy} = the tention of radiation

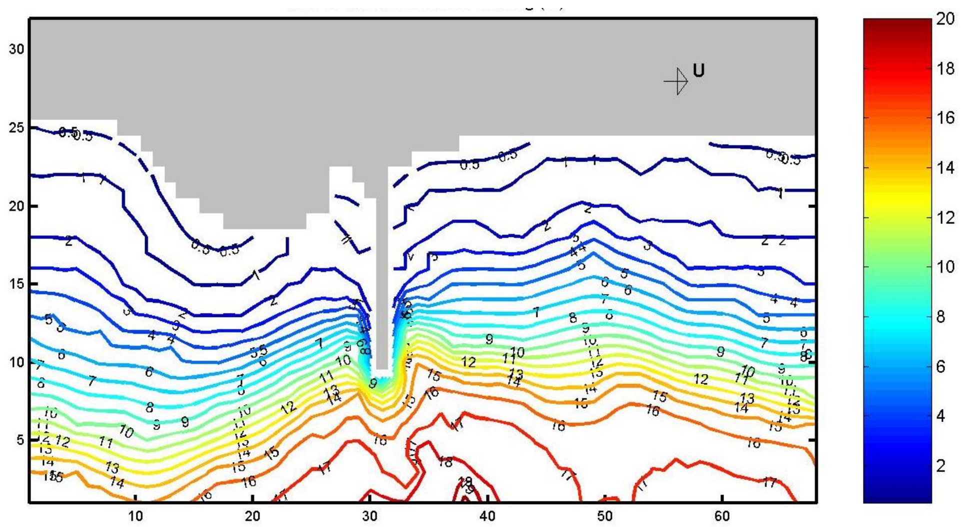
Finally, the oil spill analysis can be applied as the following formula:

$$\frac{\partial P}{\partial t} = \frac{\partial}{\partial x}\left(D_{xx}\frac{\partial P}{\partial x} + D_{xy}\frac{\partial P}{\partial y}\right) + \frac{\partial}{\partial y}\left(D_{yx}\frac{\partial P}{\partial x} + D_{yy}\frac{\partial P}{\partial y}\right) + kP \quad (8)$$

where D_{xx}, D_{xy}, D_{yx}, dan D_{yy} are diffusion coefficient and P is oil spill concentration.

3. Result and Discussions

Port of Balohan is located at the bay of Balohan east of Sabang Island. Based on bathymetry analysis, the Balohan port is consider as a shallow water coast with the 0.04 ratio of depth to the area and gentle slope of 2.29^0 (Fig. 1). The port is located at the bay and surrounded by mountainous topography both North and South of the port. This topography becomes wind barrier that get into the port with mainly flowing from North to South. As a result, the wave high in this area can be considered small and calm. Based on wave measurement, the average of wave high is 55.16 cm with wave period 5.44 second during the high tide and 36.84 cm with wave period 4.26 second during neap tide. The result of wave distribution analysis is shown on Fig. 2. From the wave distribution, the prediction of surface wind by using Beaford scale is 12.038 km per hour with fetch is 8 km. The characteristic of wind on this case is reflected a weak wind.



Figurte 1. Bathymetry contour of Balohan port of Sabang.

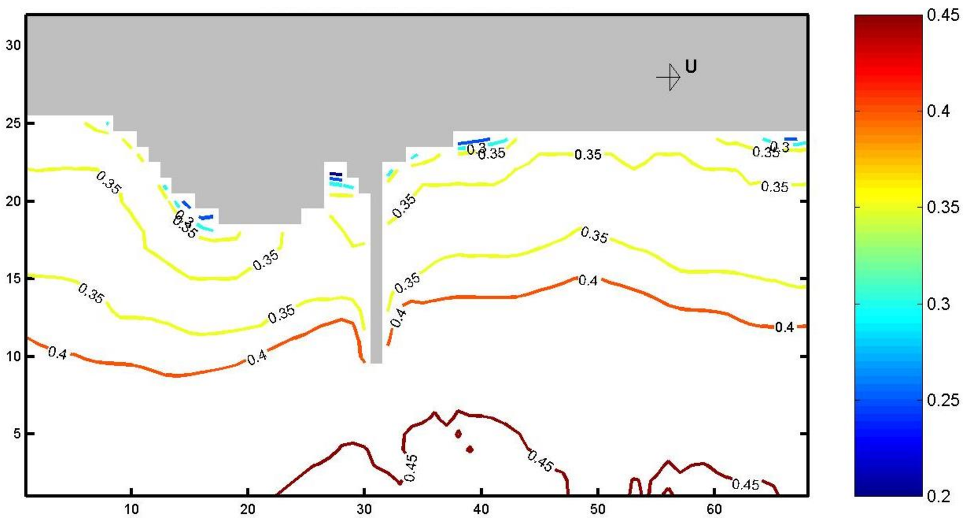


Figure 2. Wave distribution profile at port location

The result of tide measurement in the port area is a semidiurnal tide with F = 0.198. The component of tide amplitude and phase calculation can be seen on Table 1. This result differs from the prediction from Dishidros TNI AL where the location of the station is about 10 Km away from the Balohan measurement location (Table 2). Based on the data, the analysis of water elevation around the Balohan port can be seen in Table 3.

Tabel 1. The tide component of amplitude and phase at Balohan port of Sabang station based on field measurement.

Coponent	M2	S2	N2	K1	O1
Amplitude	49,85	20,7	9,84	10,03	3,99
Phase	83,67	27	72,1	42,23	82,36

Tabel 2. The tide component of amplitude and phase at Teluk Sabang port station based on Dishidros TNI AL calculation.

Component	M2	S2	N2	K1	O1
Amplitude	44	26	7	8	5
Phase	85	38	72	45	78

Table 3. Water elevation condition at the port area

No	Condition	Water High (cm)
1	During a spring tide	465,56
2	On a neap tide	384,96
3	Mean sea level	375,60
4	On neap low tides	285,56
5	On spring low tide	355,97

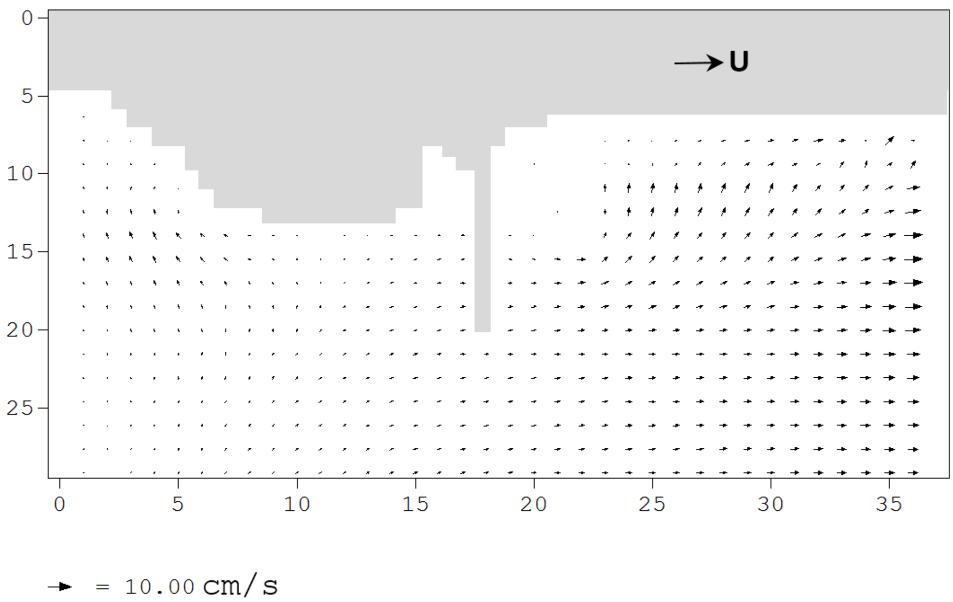


Figure 3. Current profile at the port area during the spring tide

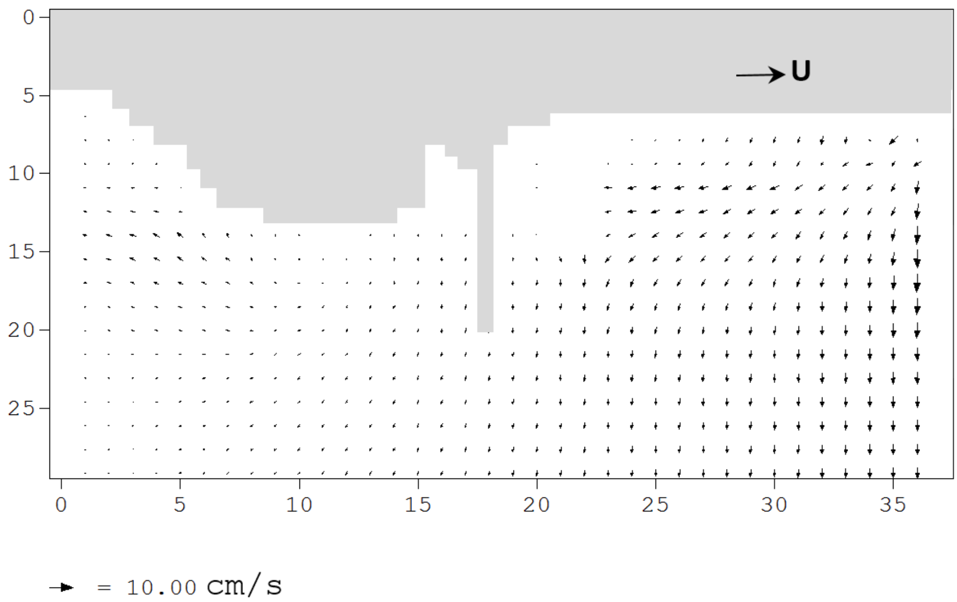


Figure 4. Current profile at the port area during the neap tide

Wave induce current in this area can be seen of Fig. 3 and 4 during high tide and low tide respectively. Flow analysis caused by waves on two tidal condition shows that the dominant current flow from South to North during the spring tide and from North to South during the neap tide. This condition is parallel to the surface wind that occur on the same direction as water flow. Near by the jetty, the current flow toward the beach during spring tide, however, during the neap tide the current flow away from the coast. It means that on this area (North side of jetty) the mixing occurred that potential to any pollutant to be concentrated in this area.

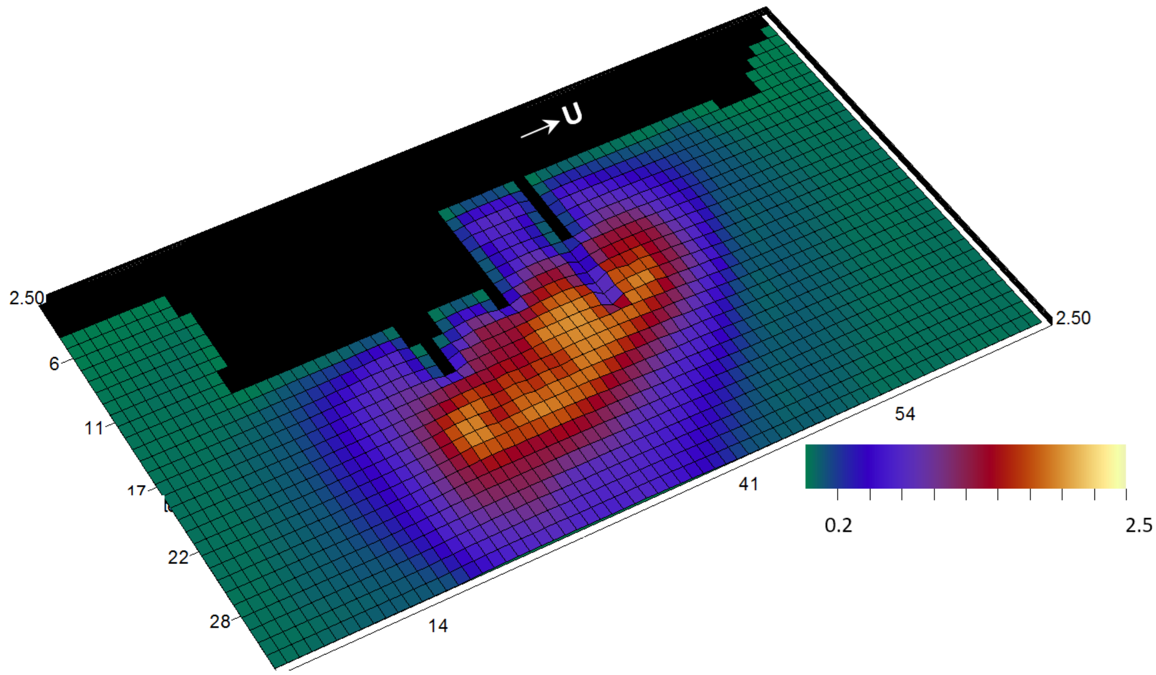


Figure 5. Oil spill contour from the result of 10 years' prediction of oil spill accumulation model in L/m^2 at Balohan port of Sabang.

In prediction of oil spill in this area, the wave distribution, tidal condition and current are applied based on numerical formulation (8). The result of the oil spill is shown on the Fig. 5. The result displays that most of oil is concentrated around the embarking ship where the source of oil spill occurs. The concentration, then, spreads toward offshore where the current transports the concentration outward of the beach. This prediction model agrees with the current model as alongshore current hit the jetty form North will turn the direction offshore and the oil concentration that flow South-North also follow the current outward. Based on the display of oil spill contour, it illustrates that the dynamic of current diffusion strongly occur to the oil concentration distribution compare to advection distribution. This happen is be caused of the residual flow at the port too weak to transport the oil.

4. Conclusions

The study shows that oil spill spreading at Balohan port of Sabang parallel to the condition of current model. However, the accumulation of 10-year oil spill result displays that as time increase the oil spill starts to concentrate offshore. The result agrees to the profile of current either during spring tide or during neap tide. Based on the research done in this area, the further study about the oil spill in this area should be continued in order to be able to understand more about this phenomenon.

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