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BOTTOM SHEAR STRESS AND BED LOAD SEDIMENT TRANSPORT FORMULA FOR MODELING THE MORPHOLOGICAL CHANGE IN THE CANAL WATER INTAKE

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ABSTRACT

Bed load sediment transport generally depends on shear stress and orbital wave velocity near the sea bottom. Calculation of bottom shear stress is a very important step and is required as input for the most models of sediment transport. The formula of bottom shear stress of some researchers only were tested based on experimental data and still rarely used for field data due to problems in obtaining field data quality. In this paper, the bottom shear stress and bed load sediment transport formula is proposed and be modified under irregular wave condition for modelling the morphological change based on the velocity data obtained from the results of the Hydrodynamic Modelling by Mike 21 Software. This model has been validated with field measurement data with error level of 0.5% for surface elevation. The proposed method of bottom shear stress and bed load sediment transport was examined by the sediment transport and the morphological change modeled by Sand Transport (ST) modules of Mike 21 Software. It can be concluded that the proposed method could predict well. The result from the calculation of bottom shear stress and bed load sediment transport showed reasonable results when compared with the results of modeling by Mike 21 software in the area of canal water intake.

Keywords: bottom shear stress, bed load, sedimen transport, morphological change.

INTRODUCTION

Research related to the sediment transport is very important to develop of coastal engineering knowledge. Because it is closely connected with sedimentation process, erosion, until coastal morphological changes. Bedload sediment transport generally influenced by the value of shear stress and velocity near sea bottom. Movement of sediments near seabed also depends on the level of the bed roughness of the area [1]. Therefore, the estimation formula of bottom shear stress is important to be used as an input to calculate the sediment transport rate. Moreover, the formula of bottom shear stress has been obtained by several researchers, both from experimental and numerical modeling. In a further study, the estimation formula of bottom shear stress has been proposed. The estimation of the bottom shear stress under non-linear wave was studied by using modification of stream function theory was also proposed to calculate the bed load sediment transport formula outside the surf zone [2]. The combination of parameters based on the velocity and acceleration has been used under various type of waves (i.e., linear, Stokes, cnoidal and solitary waves) using the three dimensional hydrodynamic numerical model [3]. The model show consistently accurate results for all types of wave-induced laminar boundary layer flows. However, the proposed model has not involved the variation of bed roughness under asymmetric waves. The new calculation method for calculating bottom shear stress has been investigated under saw-tooth wave based on velocity and acceleration term [4]. The effect of wave skewness is determined empirically from experimental data and the baseline (BSL) k-ω model result. The new calculation method has shown agreement with experimental data along wave cycle under saw-tooth waves and comparison with the existing calculation method. However still rare that applying the formula in field conditions. The collection of field data according to the input parameters in the calculations become one of the obstacles to the application of the formula was rarely used for. Therefore, numerical modeling is another alternative can be used to present field conditions. Many researchers have studied numerical simulations to determine the morphological change of the beach. Comparison the cross-shore distribution of longshore sediment transport was studied between predictive formula with field measurement data [5]. However, the limited amount of high-quality field data available at present makes it difficult to obtain values that would be applicable to a wide range of wave and beach conditions. Recently, the combination of numerical and physical models has been investigated for wave flumes using wave generation [6]. In the combined model, Boussinesq model mike 21 (BW) was chosen for numerical calculation. A wave flume with piston-type wavemaker and DHI AWACS control system were utilized for physical model. The measurements in the physical flume show good agreement with numerical calculation for some type of wave but the combined model is not sensitive to positioning of the point where physical model take over from numerical modeling. More recently, the numerical modeling used to investigation of sediment transport along the central Kerala coast by using Mike 21 model [7]. The sediment concentrations derived from OCM satellite data,Although, the application of the theory of bottom shear stress and sediment transport were not involved.

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In this paper, the bottom shear stress and bed load sediment transport formula was used to predict the bed level change in front of canal water intake and to examine the simulation result carried out by using the Mike 21 software. The proposed method of bottom shear stress based on incorporating both velocity and acceleration terms was used and applied to irregular wave condition in canal water intake. Furthermore, the proposed method of bottom shear stress also was applied to model the bed-load sediment transport and morphological change in the study area.

DATA AND METHOD

Mike 21 Model

Mike 21 software was often used for simulating the hydraulics and related phenomena in rivers, lakes, estuaries, bays, beaches and sea. It was included the modules such as Spectral Wave, Boussinesq Wave, Hydrodynamics, Sediment Transport, Mud Transport, Oil Spill, River Channel Design, etc. In this paper, the Spectral Waves (SW), Hydrodynamics (HD) and Sediment Transport (ST) module (Figure-1) were used to simulate flow condition of area canal water intake. [8]

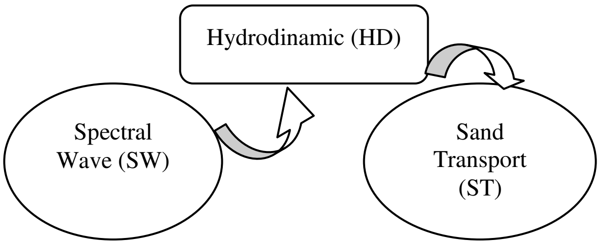

Figure-1. Flowchart of flow model by using module in Mike 21 software.

- MIKE 21 Hydrodynamic (HD) is one of module include in software package that use non-linear model and become one of the most comprehensive hydrodynamic models. This module is based on the numerical solution of the two dimensional shallow water, and Navier-Stokes equations.[9]
- MIKE 21 Spectral Wave (SW) is the 3rd generation spectral wind-wave model that simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas.[10]
- Moreover, Sand Transport (ST) module can show erosion, transport and deposition of sand under the action of currents and waves or pure current.[11]

Simulation Data

Data used as an input of numerical modelling such as bathymetry, water surface elevation, wind, wave, current, and grain size of sediment data. The data was also used to validate the model in the end of simulation for obtaining comprehensive model. The study area was shown in Figure-2.

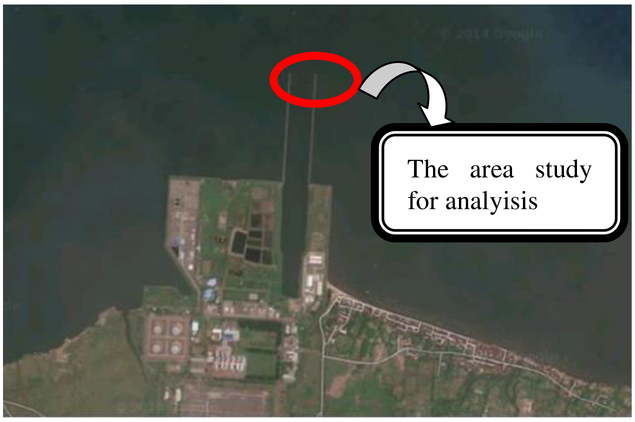

Figure-2. Map projection area in canal water intake Grati, West Java, Indonesia.

Model Simulation

The model simulation was carried out by using mike 21 flow model that have been validated by field measurement data. The performance of the simulation model was measured by using the formula RMSE with the error level of 0.5% for surface elevation. The simulation take 15 days that consist of 2161 time step and 3600 second time step interval. Moreover, the result of model can be shown in Figure-3. The characteristic of sediment transport is evaluated through simulation effect by pure current and combine wave and current.

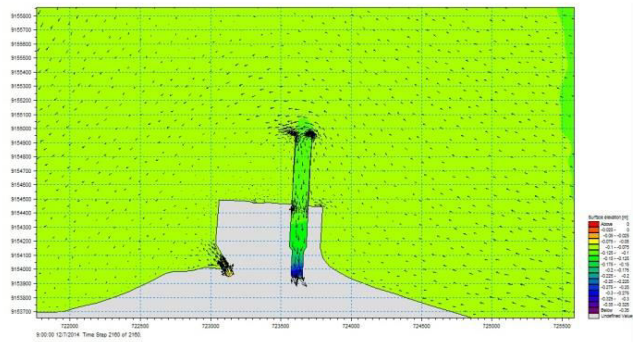

Figure-3. The orbital velocity distribution simulated by using the Mike 21 software.

The Wave Orbital Velocity

The wave orbital velocity data was obtained from the hydrodynamic model result of flow model MIKE 21 software. There are 24 points from area canal water intake will be investigated to calculate the bed load sediment transport and morphological change by applying the proposed bottom shear stress formula. The area of analysis and time series of orbital velocity data can be shown in Figure 4 and 5.

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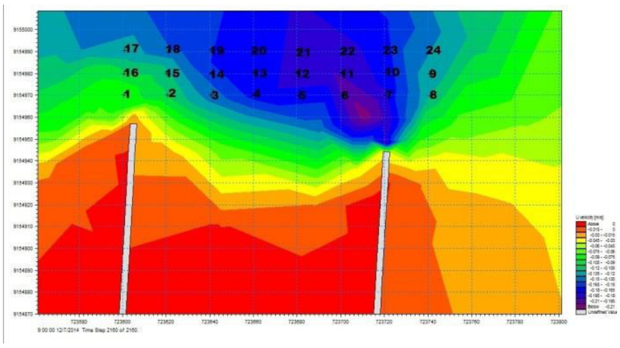

Figure-4. The study area for analysis in canal water intake.

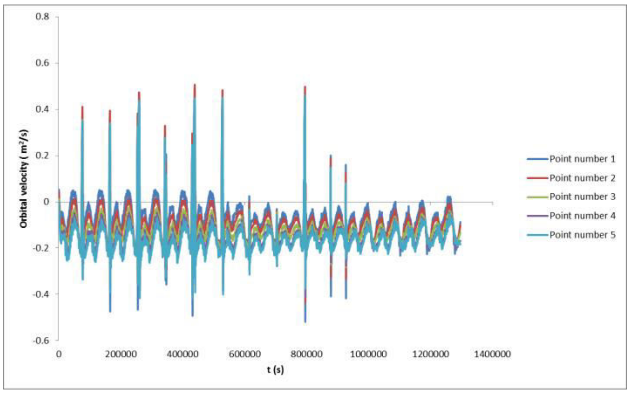

Figure-5. The time series data of orbital velocity in point 1, 2, 3, 4 and 5 by Mike 21 Hidrodinamic (HD).

Bottom Shear Stress Calculation Method

There are two formulation method of the bottom shear stress used to evaluate the bed load sediment transport. The existing calculation methods for bottom shear stress are presented with basic harmonic wave cycle modified by the phase difference [12] (Method 1) as follows:

$$\tau_o\left(t-\frac{\varphi}{\sigma}\right)=\frac{1}{2}\rho f_w U(t)|U(t)| \quad (1)$$

where $\tau_o(t)$ is the instantaneous bottom shear stress, t is time, σ is the angular frequency, $U(t)$ is the time history of free stream velocity, φ is the phase difference between bottom shear stress and free stream velocity, and f_w is the wave friction factor as proposed by [13]:

$$f_w=\exp\left\{-7.53+8.07\left(\frac{a_m}{z_o}\right)^{-0.100}\right\} \quad (2)$$

Recently, estimated of bottom shear stress is evolved which add the effect of velocity and acceleration. The proposed method based on Equation. 1 with add phase different and acceleration effect by irregular wave. Method 2 is based on bottom shear stress formula proposed by [14] under irregular wave. The value of wave friction factor (f_w) is calculated by combining method by [15] with [16]. The bottom shear stress formula (Method 2) can be shown in Equation. 3 and 4 as follows:

$$\tau_o(t)=0{,}039\,\rho\left(\frac{a_m}{k_s}\right)^{0{,}184}(\omega\upsilon)^{0{,}16}U_a(t)|U_a(t)|^{0{,}68} \quad (3)$$

$$U_a(t)=\left\{U\left(t+\frac{\varphi}{\sigma}\right)+\frac{a_c}{\sigma}\frac{\partial U(t)}{\partial t}\right\} \quad (4)$$

Where, U (t) is time series of orbital velocity, σ is the angular frequency, φ is the phase different, a_c is the acceleration coefficient based on irregular wave (a_c = 0.485 is suitable in irregular wave condition), $U^*(t)$ is the instantaneous of friction velocity.a_m/k_s is roughness parameter, k_s is bed roughness ($k_s=2.5D_{50}$), ω is angular frequency,$U_a(t)$ is the instantaneous of friction velocity as proposed by [1, 4].

Bed Load Sediment Transport

Bed load sediment transport is a part of total sediment transport which directly contact with the bed. Therefore, bottom shear stress formula can be applied to calculate bed load sediment transport. The instantaneous bed-load sediment transport rate, q(t) may be expressed as function of the shields number $\tau^*(t)$ as given in the following equation:

$$\Phi(t)=\frac{q(t)}{\sqrt{(\rho_{s-}\rho)gd_{50}^3}}=11\,sign\{\tau^*(t)\}\,|\tau^*(t)|^{0.5}\{|\tau^*(t)|-\tau^*_{cr}\} \quad (5)$$

Where, $\Phi(t)$ is the instantaneous dimensionless sediment transport rate, q_{net} is the net sediment transport rate, ρ_s is the sedimen density, g is gravitational acceleration, d_{50} is the grain size diameter, sign is the sign of the function in the parenthesis, τ^*_{cr} is the critical Shields number calculated using the expression proposed by[17], $\tau^*(t)$ is shield parameter as follows :

$$\tau^*(t)=\frac{\tau_0(t)}{((\rho_s/\rho)-1)gd_{50}} \quad (6)$$

The net sediment transport rate, averaged over one period is expressed as follows:

$$\Phi=AF=11F=11\frac{1}{T}\int_0^T sign\{\tau^*(t)\}\left|\tau^*(t)\right|^{0.5}\left\{\left|\tau^*(t)\right|-\tau^*_{cr}\right\}dt, \quad (7)$$

where, F is the function of Shields parameter and A is a coefficient. The integration of Equation. (7) was assumed to be done only in the phase $|\tau^*(t)|>\tau^*_{cr}$, and

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during the phase $|\tau^{*}(t)|<\tau^{*}_{cr}$ the value of the function of integration is assumed to be 0 [4].

Morphological Change Model

The morphological change can be investigated by applying sediment conservation equation; it can be shown in Equation. 8 as follows:

$$\frac{\partial d(x,t)}{\partial t} = (1+p)\frac{\partial \tilde{q}_t(x,t)}{\partial x} \tag{8}$$

Where $\widetilde{q_t}(x,t)$ is the total sediment flux and ρ is bed porosity.The contribution of total sedimen flux is composed by flux bed load $\widetilde{q_b}(x)$ and suspended sediment $\widetilde{q_S}(x)$ which related with bottom shear stress and sediment concentration.

RESULT AND DISCUSSIONS

1. Comparison of Bottom Shear Stress Method

Comparisons of bottom shear stress Method 1 and 2 can be shown in Figure-6 for point area number 1. From the calculation of bottom shear stress, Method 1 give a smaller value of bottom shear stress compare with Method 2.

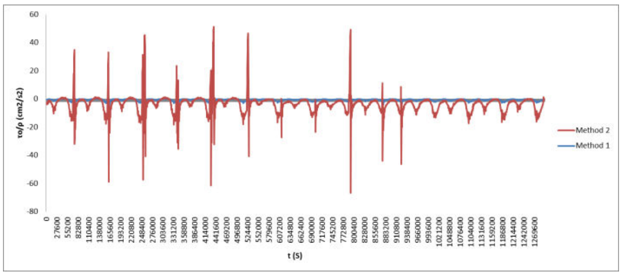

Figure-6. Result of bottom shear stress method 1 and 2 in point number 1.

2. Application of Bottom Shear Stress Method in Bed Load Sediment Transport and Morphological Change

The result of bottom shear stress in both method was used for calculating bed load sediment transport by applying Equation. 7 to show the best method can be selected. The simulation model by Sand Transport (ST) modules mike 21 has been used for validating both method. Comparison of bed load sediment transport can be shown in Figure-7. The bed load sediment transport calculated by Method 2 show good agreement with the modeling result obtained by mike 21 software. Method 1 show the overestimates results compare with model, so it can be conclude that method 1 cannot be applied in irregular wave condition.

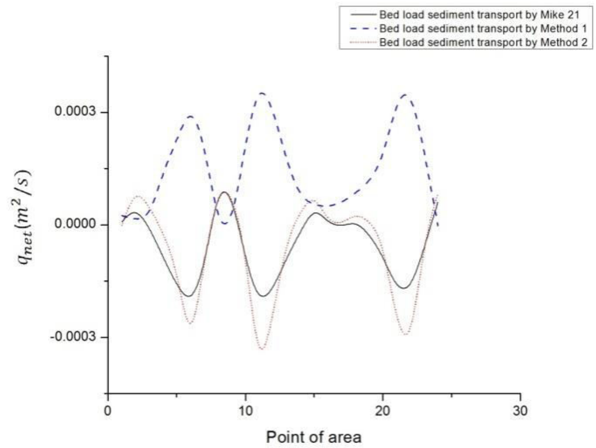

Figure-7. Comparison of bed load sediment transport from 24 viewed points.

In this paper, the modeling result from Sand Transport (ST) module by mike 21 software has been used for investigating the proportion of bed load sediment transport. From the result in figure 8 can be shown that bed load sediment transport take the dominant contribution from total sediment transport in each area of analysis.

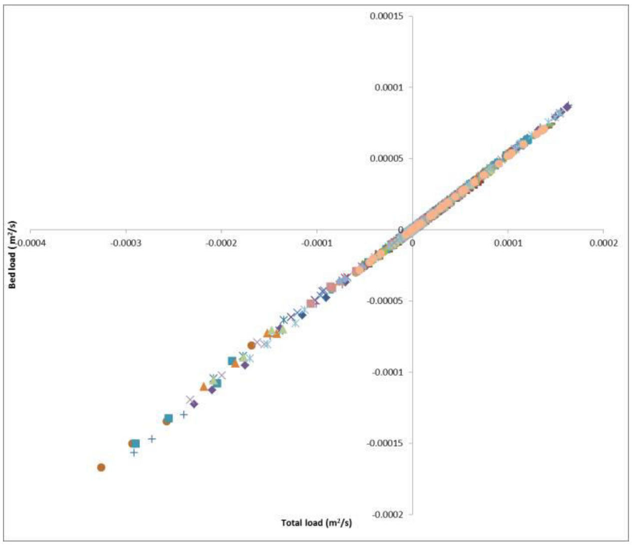

Figure-8. Contribution of bed load sediment transport from total sediment transport each point area of analysis.

Furthermore, bed load sediment transport calculated by Method 2 can be used for calculating morphological change by applying Equation. 8 and it was assumed the bed load has dominant contribution from total sediment transport under combine wave and current or pure current condition.

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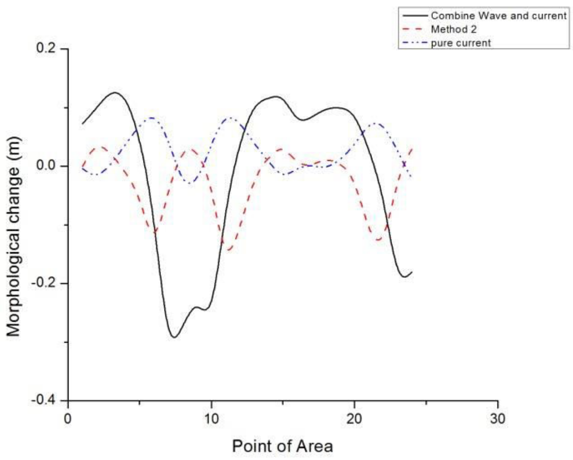

Figure-9. Comparison of morphological change from 24 viewed points.

From Figure-9 can be shown that the proposed method (Method 2) give a good aggrement with the modeling result from Sand Transport (ST) modules of Mike 21 software under combination of wave and current or pure current condition. The morphological change by method 2 show average result between both condition and give a little different result in bed level in morphological surface as shown in Figure 10 and 11.

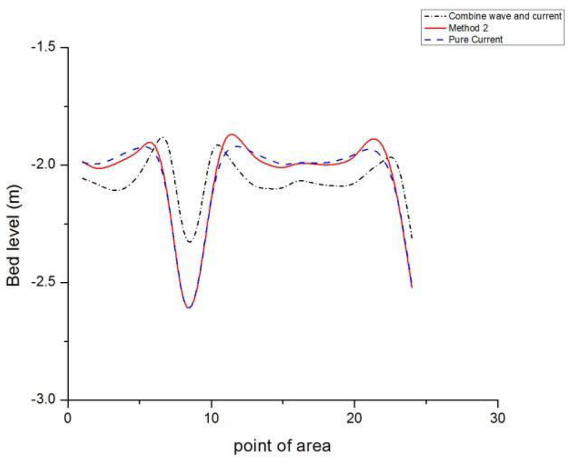

Figure-10. Comparison of the final bed level from 24 viewed points.

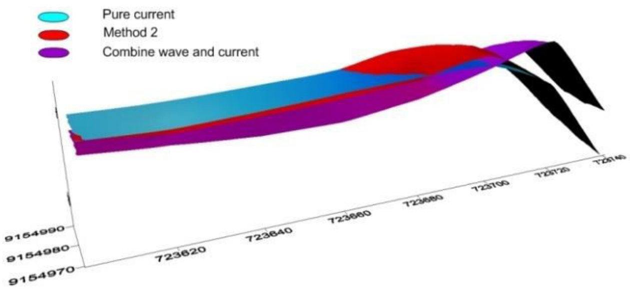

Figure-11. 3D morphology surface by method 2 and model by mike 21 sand transport (ST) modules.

CONCLUSIONS

The bottom shear stress and bed load sediment transport formula has been investigated for modeling morphological change in canal water intake within uses model by mike 21 software. The new bottom shear stress method has been proposed with add phase different and acceleration effect by irregular wave. The proposed method of bottom shear stress show a good agreement and reasonable result compare with the modeling result from simulation Sand Transport (ST) modules by mike 21 under pure current or combine wave and current condition. It can be concluded that the proposed method may be used to calculate morphological change in real situation.

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