DEPTH OF CLOSURE DETERMINATION USING REPRESENTATIVE WAVE

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1. INTRODUCTION

Depth of closure (h_c) concept is commonly utilized to analyze the shoreline change quantitatively. Concept of depth of closure was introduced by Hallermeier (1981). He proposed the definition of h_c as the seaward limit of significant profile change and the seaward boundary of the litthoral zone. He derived the equation to determine h_c by considered wave height and wave period under linear wave theory by laboratory experiment. In recent years, his method was followed by many researchers. They conducted analysis to estimate location of h_c by using bathymetry and wave data.

Study area is located in Sendai Port, Miyagi Prefecture, in the north part of Sendai Coast. This area is situated with approximately 2 km breakwater that has been constructed during 1968 to 1973 as seen in Figure 1. From field measurement it is obtained bathymetry data sheet from 1967 to 1998. Bathymetry data used in this study is the latest data, 1998.

Wave condition along coastal is clearly understood by considering wave transformation; refraction, shoaling, and reflection. Wave data utilized in this research is from 1991 to 2003. In Sendai Port, the wave direction is predominant from South East (SE).

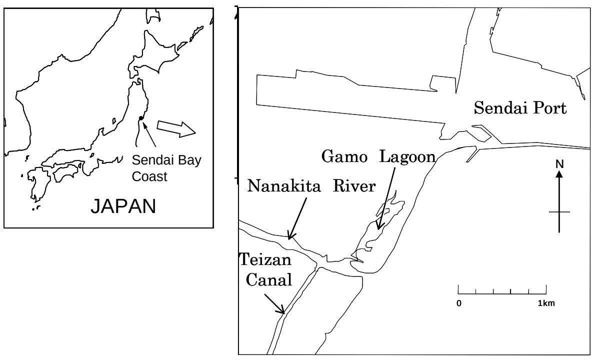

Figure 1. Study area, Sendai Port

The position and angle of breakwater becomes very important factor which influence the wave reflection. It is discussed by Rhitpring and Tanaka (2006) in their study. They concluded that wave reflection in this area is predominantly influence by length and angle of breakwater.

This study focuses on analyzing of wave reflection factor around coastal structure. Furthermore, this study will explain the relation of the dimensionless bottom shear stress of Shield parameter to the threshold initial motion that enables the integration of transport processes.

2. METHODOLOGY

2.1. Boussinesq model

In the shallow area, wave propagates by influenced phenomenon such as shoaling, refraction, diffraction, and reflection. Increasing of nonlinearity occurred due to decreasing of water depth and increasing wave amplitudes. This condition can not be explained by linear wave theory.

Boussinesq equation can be one of method which is able to explain non-linear transformation of irregular, multidimensional wave in shallow water. Velocity distribution calculated temporally and spatially using Boussinesq model derived by Peregrine (1967). He proposed equation by considering a three-dimensional wave field with water surface elevation η *(x, y, t)*, at time *t*, propagating over a variable water depth *h(x, y)*.

Governing equation in Boussinesq model are statements of conservation mass and momentum.

$$\frac{\partial u}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u} + g\nabla\eta = \frac{1}{3}h^2\nabla(\nabla\cdot\frac{\partial \mathbf{u}}{\partial t}) \quad (1)$$

$$\frac{\partial \eta}{\partial t} + \nabla[(h+\eta)\mathbf{u}]\cdot = 0 \quad (2)$$

Where u is horizontal velocity at an arbitrary depth *(u,v)*, η is surface elevation, h is local water depth, ∇ is horizontal gradient operator $(\partial/\partial x, \partial/\partial y)$, and g is gravity coeffcient.

2.2. *Bottom shear stress*

Adopting steady flow concept for wave motion, the time dependent bed shear stress can be expressed as follow:

$$\frac{\tau_{bx}(t)}{\rho} = \frac{f_w}{2}U(t)\sqrt{U(t)^2 + V^2(t)} \quad (3)$$

$$\frac{\tau_{by}(t)}{\rho} = \frac{f_w}{2}V(t)\sqrt{U(t)^2 + V^2(t)} \quad (4)$$

where $\tau_{bx}(t)$ and $\tau_{by}(t)$ represent the bed shear stress value in x and y direction, respectively. ρ is water density, f_w is friction factor, *U(t)* and *V(t)* represents the bottom velocity in x and y direction, respectively.

Friction coefficient becomes the sensitive parameter that should be considered carefully. It becomes more complex by the fact that some of equation is derived implicitly. It means that iteration should be done to obtain the f_w. Another problem is different equation should be applied in the case of smooth or rough flow yet the limit of these two boundary is still poorly defined. In rough turbulent flow case, several methods have been proposed to calculate f_w. Tanaka and Thu (1994) developed explicit expression of f_w that conveniently used in this study:

$$f_w = \exp\left[-7.53 + 8.07\left(\frac{U_b}{\sigma z_0}\right)^{-0.100}\right] \quad (5)$$

Where U_b is maximum wave velocity just outside boundary layer, σ is the angular wave frequency of wave motion ($\sigma = 2\pi/T$; T: wave period), z_0 is the roughness length ($z_0 = k_s/30$), k_s is Nikuradse's bottom roughness

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length that is assumed to be equal to mean particle diameter *(k_s = D50)*.

3. RESULTS AND DISCUSSION

To model the wave condition spatially, it is used regular wave with H=3.4 m and T=11.1 second as representative incident wave. Numerical modeling proposed with dx and dy equal 5 m, respectively, and dt equal 0.1 second. Significant wave height distribution furthermore can be modeled as shown in Figure 2. It can be seen that in shallow area and area near the coastal structure wave height become higher. In the shallow area, increasing wave height is caused by wave transformation, such as shoaling and refraction. However, influence of wave reflection can not be explained clearly only using this result.

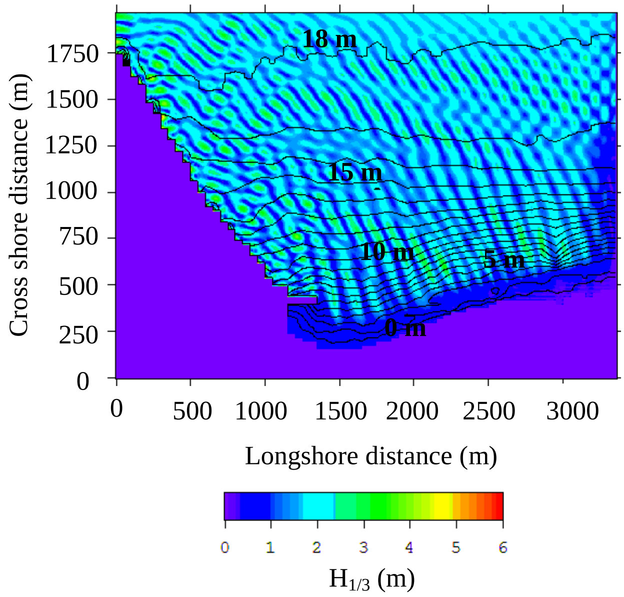

Figure 2. Significant wave height, Sendai Port

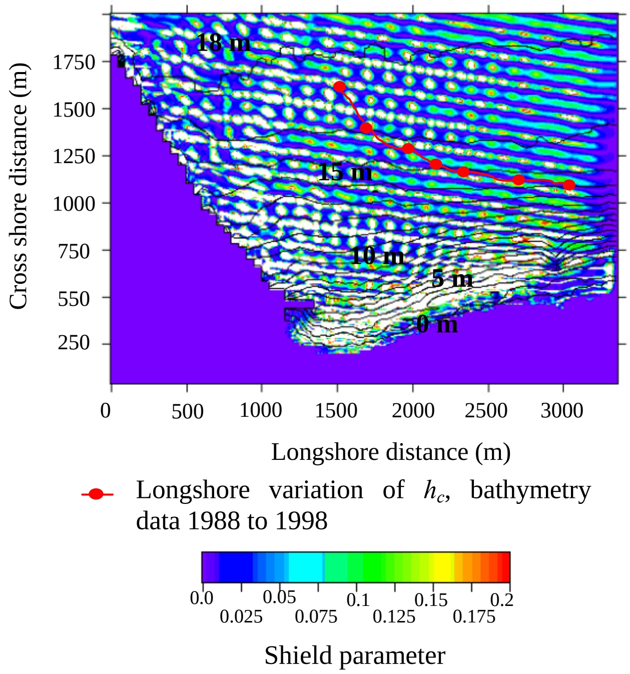

Figure 3. Shield parameter obtained from bottom shear stress calculation (time step 3500 s)

Furthermore, bottom shear stress can be calculated using velocity distribution from Boussinesq model. Total bottom shear stress is one of parameter that can be used to observe initial motion of sediment as represent in Shield parameter as shown in Figure 3. Plotting of longshore variation of h_c determined from bathymetry data also can be seen in Figure 3.

From Figure 3 it can be observed that increasing value of Shield parameter implies bottom shear stress increases in shallow area. Increasing bottom shear stress also can be seen in the area near the coastal structure. By considering the relation of bottom shear stress and velocity, it can be easily conclude that in that region velocity becomes higher than deeper area.

Decreasing value of Shield parameter in deep area expresses decreasing bottom shear stress. It means that sediment move insignificantly in that region. In relation with h_c, location of h_c can also be determined using this condition. By using bathymetry analysis, longshore variation of h_c in Sendai Port implies the good agreement that in the area near structure the h_c is deeper that other area. Furthermore, h_c is gradually decreasing as the distance to the structure increase.

4. CONCLUSION

This study models the hydrodynamic condition in Sendai Port using bathymetry and wave data. Regular wave as incident wave is used as first approach to model the wave condition spatially. Velocity distribution is calculated using Boussinesq model that can be used to analyze wave reflection phenomenon. Furthermore, the bottom shear stress is calculated and Shield parameter is obtained. Bigger value of Shield parameter in shallow area implies increasing of bottom shear stress. In relation with wave height and velocity, it can be implied that wave reflection become predominant in this area.

Position of h_c can also be predicted using dimensionless Shield parameter. Position of h_c predicted using Shield parameter shows good agreement with longshore variation of h_c obtained from bathymetry analysis.

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