II－28 BOTTOM SHEAR STRESS AND SEDIMENT TRANSPORT CALCULATION UNDER CNOIDAL WAVES

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1. INTRODUCTION

Ocean waves entering shallow water will undergo shoaling, refraction, diffraction, bottom friction and breaking. Due to shoaling and breaking cause them become asymmetric in the crest and trough resulting in large onshore-directed velocities under the waves crest and small offshore-directed velocities under the wave trough, in addition the rapid acceleration flow also occurs in the near surf zone transporting the near shore sediment. Moreover, the wave asymmetric and the wave skew-ness play an important role for the occurrence of the net onshore-directed transport rate causing accretion of beaches and that of the net offshore-directed transport rate causing erosion of beaches.

Bottom shear stress estimation is the crucial step, which is required as an input to most of sediment transport model. Therefore, the accuracy of bottom shear stress estimation used to evaluate the amount of sediment transport obtained from the sinusoidal or symmetric wave was necessary to be clarified with the sediment transport estimation incorporating the acceleration effect term in its calculations. Tanaka (1998) estimated the bottom shear stress under non-linear wave by modified stream function theory and proposed formula to predict bed load transport except near the surf zone in which the acceleration effect plays an important role. Schäffer and Svendsen (1986) had presented the sawtooth wave as a method expressing the wave motion under broken waves. Suntoyo and Tanaka (2004) have proposed a new method for calculating the bottom shear stress under sawtooth waves incorporating the acceleration effect, moreover the formulation of bed load sediment transport rate under skew waves also has been proposed based on the existing sheet flow sediment transport data from Kouchi et al. (2002), and a good agreement between calculation and experimental results has been obtained.

In this present paper, we will apply both a new calculation method of bottom shear stress under sawtooth waves and the sediment transport formula, which have been obtained in our previous study to the calculation of sediment transport rate under cnoidal waves. Moreover, the calculation results is examined and compared with the calculation method that does not consider the acceleration effect.

2. BOTTOM SHEAR STRESS AND SEDIMENT TRANSPORT CALCULATION METHOD

In this present paper will be examined the influence of acceleration term on the bottom shear stress and sediment transport calculation through two methods of bottom shear stress calculation. Method 1 is proportional to the square of the time variation of free stream velocity, $U(t)$, as proposed by Tanaka et al. (2002) as shown in Eq. (1).

$$\tau_0\left(t-\frac{\varphi}{\omega}\right)=\frac{1}{2}\rho f_w U(t)|U(t)| \qquad (1)$$

Here, $\tau_0(t)$: the instantaneous bottom shear stress, t: time, ρ: fluid density and f_w is the friction velocity factor. $U(t)$ is the time variation of free stream velocity, in which the flow velocity wave profile used in this study is cnoidal wave velocity profile calculated by using the first order cnoidal wave theory as shown in **Fig. 1**. While, φ is the phase difference between the free stream velocity and bottom shear stress as proposed by Suntoyo et al. (2004).

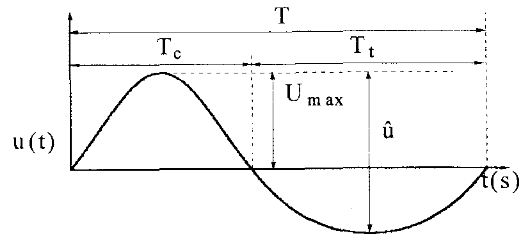

Fig. 1: Definition sketch for cnoidal wave

Where, U_{max}: the maximum flow velocity with the non-linearity index ($U_{max}/\hat{u}$) = 0.6, $\hat{u}$: the total velocity amplitude, T_c: the period of crest velocity and T_t: the period of trough velocity.

A new calculation method of bottom shear stress under sawtooth waves (Method 2) based on incorporating velocity and acceleration terms all at once is given through the instantaneous friction velocity, $U_*(t)$ as proposed by Suntoyo et al. (2004) in Eq. (2). The instantaneous bottom shear stress can be calculated proportional to the square of the proposed instantaneous friction velocity, as shown in Eq. (3),

$$U_*(t)=\sqrt{f_w/2}\left\{U\left(t+\frac{\varphi}{\omega}\right)+\frac{a_c}{\omega}\frac{\partial U(t)}{\partial t}\right\} \qquad (2)$$

$$\tau_0(t)=\rho U_*(t)|U_*(t)| \qquad (3)$$

The value of acceleration coefficient, a_c was assumed to be a constant value of 0.18 that has given a sufficient value for calculating bottom shear stress under sawtooth waves as shown by Suntoyo and Tanaka (2004).

The net sediment transport rate, which is averaged over one-period is expressed in Eq. (4), as follow

$$\Phi=AF=\frac{q}{\sqrt{(s-1)gd^3}} \qquad (4)$$

$$F=\frac{1}{T}\int_0^T sign\{\tau^*(t)\}|\tau^*(t)|^{0.5}\{|\tau^*(t)|-\tau^*_{cr}\}\,dt \qquad (5)$$

Here, Φ: the dimensionless net sediment transport rate, F: the function of Shields parameter, q: the net sediment transport rate in volume per unit time and width, s: the relative density of sediment defined by (ρ_s/ρ) in which ρ_s: the sediment density, g: the acceleration of gravity. While, $\tau^*(t)$: the Shields parameter defined by $(\tau(t)/((s-1)gd))$ in which $\tau(t)$: the instantaneous of bottom shear stress calculated from both Method 1 and Method 2, τ^*_{cr}: the critical Shields parameter, A: coefficient (A=300) and *sign*: the mark of the function in the parenthesis.

Moreover, the integration of Eq. (5) was assumed to be done only in the phase $|\tau^*(t)| > \tau^*_{cr}$ and during the phase $|\tau^*(t)| < \tau^*_{cr}$ the function of integration is assumed to be 0.

3. RESULTS AND DISCUSSIONS

A comparison between the calculation of bottom shear stress result by Method 1 and Method 2 is shown in the lower row of **Fig. 2**. The time-variation of free stream velocity is shown in the upper row, while the middle row shows both velocity (first) and acceleration (second) term from Method 2. It is confirmed that Method 2 gave a more asymmetric shape of bottom shear stress under crest and trough than Method 1 caused by incorporating the acceleration term in Method 2, which further has a role to produce the higher net sediment transport rate.

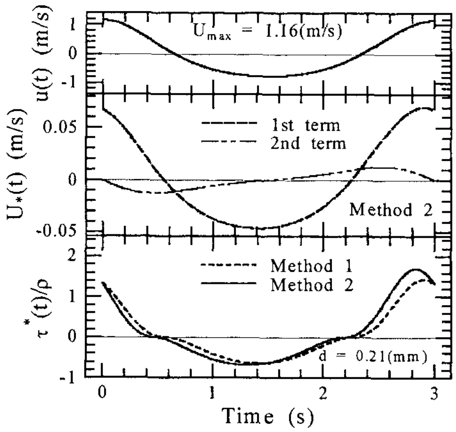

Fig. 2: Comparison of bottom shear stress between Method 1 and Method 2

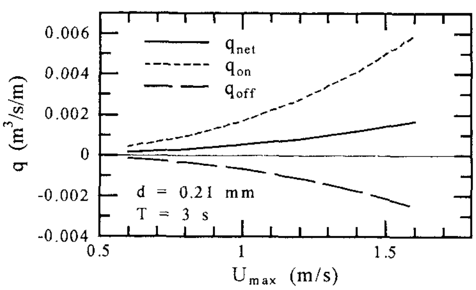

Fig. 3: Change in amount of sediment transport rate according to an increase in flow velocity

The calculation result of the amount of sediment transport based on Method 2 was separated into onshore and offshore sediment transport rate shown with subscript on and off, respectively, and in addition the net sediment transport (subscript net) is according to the difference of both. However, it was fixed to the value of calculation condition (T, d) and only U_{max} that has been changed as shown in **Fig. 3**. The difference between the onshore and offshore sediment transport occurs remarkable according to the increasing U_{max}. It can be seen that the net sediment transport increases with increasing the value of U_{max}.

Moreover, the acceleration effect of the net sediment transport rate is examined through the correlation of the net sediment transport rate between Method 1 and Method 2 as shown in **Fig. 4**. The solid line showed that the value of the net sediment transport rate was in the same value, while the correlation result between Method 1 and Method 2 is shown by Δ, □ and O marks, for d=0.21 mm, d=0.49mm and d=0.74 mm, respectively. The gap between the solid line and this correlation result is caused by the acceleration effect was not included in calculation of bottom shear stress on Method 1. It can be concluded that incorporating the acceleration effect in calculation of bottom shear stress has given a significant effect on the net sediment transport calculation. Therefore, the new calculation method of bottom shear stress under sawtooth waves could be used to calculate the net sediment transport rate under rapid acceleration in surf zone in practical application. Nevertheless, the accuracy of the net sediment transport calculation incorporating the acceleration effect in this present paper is still necessary to be verified by the net sediment transport experimental results under cnoidal waves expressing the cross-shore sediment transport under rapid acceleration.

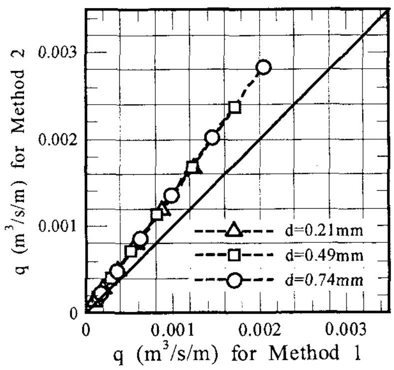

Fig. 4: Correlation of the net sediment transport rate between Method 1 and Method2

REFERENCES

Kouchi, J., Sato, S. and Watanabe, A.: Sheet flow transport rate due to atlit waves and currents, *Annual Journal of Coastal Eng.*, JSCE, Vol. 49, pp. 426-430, (2002) (in Japanese).

Schäffer, A. H. and Svendsen, I. A.: Boundary layer flow under skew waves, *Inst. Hydrody. and Hydraulic Engineering, Tech. Univ. Denmark, Prog. Rep.*, No. 64, pp. 13 – 33, (1986).

Suntoyo and Tanaka, H.: Calculation method of bottom shear stress under sawtooth waves and its application to sediment movement, *Annual Journal of Coastal Eng.*, JSCE, Vol. 51, pp.396-400, (2004) (in Japanese)

Suntoyo, Tanaka, H. and Yamaji, H: New method for calculating bottom shear stress under skew waves, *Journal of Applied Mechanics*, Vol. 7, pp. 1089-1097, (2004).

Tanaka, H.: Bed load transport due to non-linear wave motion, *Proc. of 21st ICCE*, ASCE, pp. 1803-1817, (1998).

Tanaka, H., Suzuki, T., Suntoyo and Yamaji, H.: Time-variation of bottom shear stress under irreguler waves over rough bed, *J. Hydro. and Hydrc. Engineering*, Vol. 20, No. 2, pp. 217-225, (2002).