NUMERICAL SIMULATION OF SEDIMENT DEPOSITION OF SAND-MIXTURE IN A STEEP CHANNEL RESERVOIR

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1. Introduction

This paper deals with the bed profile variations due to the deposition of the sediment mixture in a steep channel reservoir. Authors (2001) studied the process of sediment deposition for the mixture of sediment (of sizes 0.1 mm and 2.5 mm), experimentally, where the characteristics of the delta formation towards both the downstream and the upstream were revealed. The process of the delta formation was simulated well by the one-dimensional analysis using the equations of sediment transport with the step length of the sediment particles.

The bed materials usually consist of mixtures of sand and gravel in the real river. Two distinct layers of the deposition were observed in the case of sand-gravel mixture: (a) a three-dimensional layer of finer particles (F-layer), which is formed on the initial bed and (b) a two-dimensional layer of mixed (consists more coarse) particles (M-layer) is formed on the top of the layer of finer particle farther from the dam in comparison to the former, where the percentage of the sediment particles is varied. The sediment sorting in the part of the sediment deposition is caused by the difference of the mobility of each grain size in the sand-gravel mixture. One-dimensional continuity and energy equations for water flow and equations of the transport and the continuity for sediment are used to calculate the water levels and the bed levels corresponding to the flow, respectively. The tractive force on the top of the deposited sediment layer is almost critical shear stress of the bed material; sediment discharge for each grain size, q_{Bi}, should be used.

2. Experimental Study

The deposition of sediment mixture of fine and coarse particles was studied in a laboratory flume as shown in Table 1, where the dam height (W) and the flow discharge (q) are varied. The proportion of mixture of coarse (2.5 mm) and fine (0.1 mm) sediment was made 1:1. The rate of sediment supply of the mixture from the upstream end was 1.11×10^{-5} m^3/sec/m of the width. The flume was 10m long with a rectangular section of size, 0.15m wide and 0.30m deep in a fixed slope of 0.02 with a model dam built at the downstream end. The water level along the channel was measured manually on the transparent sidewall of the flume.

Table 1

Run	Dam Ht (W) m	Water Disch (q) m^3/s/m
K	0.10	2.00×10^{-2}
L	0.10	2.66×10^{-2}
M	0.10	3.33×10^{-2}
N	0.07	2.00×10^{-2}
O	0.07	2.66×10^{-2}
P	0.07	3.33×10^{-2}

The overall process of the delta formation for sand-gravel mixture in a steep channel reservoir is almost similar to that for the uniform size sediment, where the phenomenon of a stable and an unstable hydraulic jump with surface waves repeatedly occurs. In the case of sand-gravel mixture, the fine sand can only be transported just downstream of the delta because the fine particle is on the larger mobility in the mixtures than the coarse grains. As shown in Fig.1, it was observed that the layer of fine particles Z2 (F-layer) on the initial bed consists of only fine particles. In contrast, the deposition layer of the mixed particle Z1 (M-layer) was observed inconsistent in composition of the fine and coarse particles along the bed profile in Run K, where times are in minutes. Fig. 2 shows the variations of the sediment particles along the deposition layer of the mixed particle (M-layer) for Runs K, L, and M after the observations, where the composition percentage of the fine sediment (d_1) increases towards the dam in contrast to the percentage of the coarse particles (d_2).

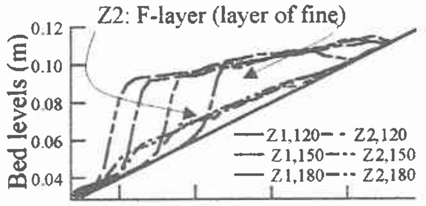

Fig.1 Observed two deposition layers (M and F-layers)

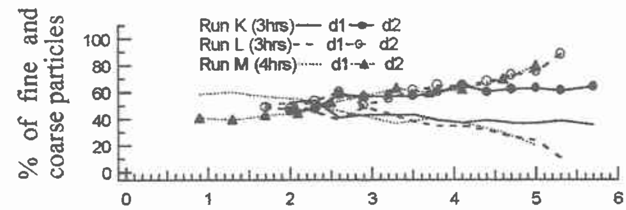

Fig. 2 Distribution of the sediment particles in Mixed Layer

3. Numerical Simulation

The one-dimensional energy equation and continuity equation for the steady flow are written as follows:

$$\partial/\partial x\left(z_S + h\cos\theta + \alpha v^2/2g\right) = -I_e, \qquad q = vh \tag{1}$$

where v is the average flow velocity of the cross section, z_s is the bed level above the reference level, q is the water discharge per unit width, h is the water depth, θ is the angle of the bed slope, α is the coefficient of energy, g is the acceleration due to gravity, and I_e is the energy gradient. The hydraulic jump occurs at the section, where the following condition of conservation of momentum equation is satisfied between two sections:

$$h_2/h_1 = \left(\sqrt{1+8G_1^2} - 1\right)/2,\ G_1^2 = F_{r1}^2/\{\cos\theta - K_j L_j \sin\theta/(h_2 - h_1)\},\ F_{r1} = v_1/\sqrt{gh_1} \tag{2}$$

Where, h_1 is the flow depth before the jump, h_2 is the flow depth after the jump, v_1 is the flow velocity in upstream before the formation of jump, L_j is the length of the jump (=6(h_2-h_1) by Smetana), and K_j is the modified coefficient ($\approx$1.0). The tractive force on the top of the deposited sediment layer is almost critical shear stress of the bed material, where the difference of the mobility between fine and coarse grains in the mixture becomes clear, sediment discharge for each grain size, q_{Bi}, should be used. The Equation of continuity of sediment at any section can be written as follows:

$$\partial z_s/\partial t + 1/(1-\lambda)(\partial q_B/\partial x) = 0 \tag{3}$$

where t is time, λ is the porosity of the sediment, q_B is the sediment discharge per unit width of the river bed. The total bed load for mixture q_B is calculated by the summation of bed loads (q_{Bi}) of each grain size d_i for the equilibrium sediment discharge is given by Suzuki et. al (1995) as follows:

$$\partial q_{Bi}/\partial x = Ad_i\left(p_{si}(x)i_{bi}(x) - \int_0^{\infty} p_{si}(x-\xi)i_{bi}(x-\xi)f_i(\xi)\partial\xi\right),\quad f_i(\xi) = 1/L_i \exp(-\xi/L_i) \tag{4}$$

where i_b is the concentration of each sediment particles (=0.5), L_i is the step length of the particle, P_{si} is the pick up rate depends on the q_{Bi}(=$i_{bi}(sgd_i^3)^{0.5}K(\varepsilon_1\tau_{*i}\ .\varepsilon_2\tau_{*c})^m$), s is the submerged relative density of the sediment, τ_{*i} (=u_*^2/sgd_i) is the dimensionless shear stress, u_* is the shear velocity, τ_{*c} ($\approx$0.047) is the dimensionless critical shear stress, ε_1 and ε_2 are the modification factors for the shear stresses τ_{*i} and τ_{*c}, respectively, K(=8) and m(=2/3) are the constant coefficients.

The observed total bed profiles averaged over three longitudinal lines and water levels were compared with simulated ones. A typical comparison of profiles of temporal variations of water surface and bed level are shown in Fig.3 (considering the value of i_b=0.5 for each grain sizes), where H and Z represent the water level and bed level, respectively. The observed averaged bed profiles and water surface profiles seem to be coincided with the simulated ones. The observed downstream edges and upstream edges of sediment deposition and the upward shift of the hydraulic jump also seem coincided with the simulated ones.

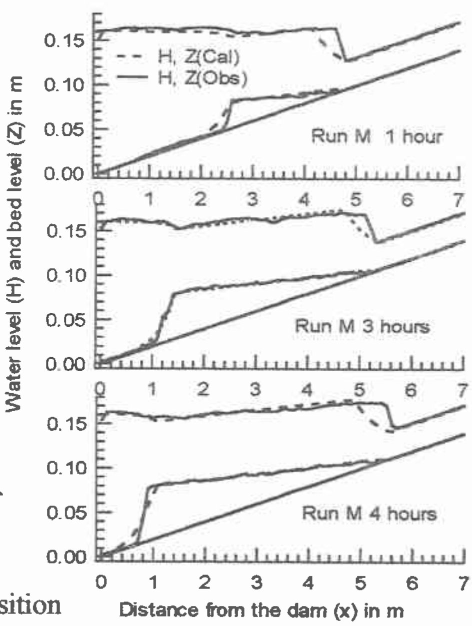

Fig.3 Observed and calculated averaged bed profiles in Run M

4. Conclusions

The progress of the deposition profile of the sand-gravel mixture is characterized with the hydraulic jump, where the two distinct layers of deposition are formed, where the upward shift of the hydraulic jump was observed with the progress of deposition. The total averaged bed profile of the sand-gravel mixture is simulated considering the average composition percentage of each grain size; however, it varies in the mixed layer (M-layer) as shown in Fig.2. The simulated bed profiles by one-dimensional continuity equations of flow and energy and the continuity of sediment with the application of the hydraulic jump were almost coincided with the observed ones.

References

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