EXPERIMENTAL STUDY ON THE RESERVOIR DEPOSITION OF SEDIMENT MIXTURE WITH THE HYDRAULIC JUMP

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The process of sediment deposition in a steep slope reservoir was studied, experimentally in a laboratory flume for the mixture of fine and coarse sediment. From the critical section of the hydraulic jump, sediment deposition starts in a steep channel due to the reduction of flow velocity and progresses towards the dam, and the hydraulic jump shifts upwards from its previous position. Two deposition layers were observed during the experiment: a layer of finer particles on the initial bed and a layer of fine and coarse sediment mixture on the layer of finer particles, and they were found three-dimensional and two-dimensional, respectively. The percentage of fine particle in the layer of the deposited mixture was found more towards the dam, whereas the percentage of the coarse particle was more to the upstream side.

Key Words**:** *Reservoir sedimentation, hydraulic jump, bed profile, delta, and sediment mixture*

1. INTRODUCTION

The bed profile of reservoir sedimentation in mountain rivers with steep slopes, like in Nepal, is characterized by the water level profile with the hydraulic jump. The sediment deposition pattern in the reservoir, as a delta form, can reflect the transport process in the reservoir and its delivery and distribution process[1)]. Authors[2)] studied the process of sediment deposition in a reservoir with the hydraulic jump in a steep channel for uniform sized sand (0.1 mm) and gravel (2.5 mm), separately and the characteristics of the delta formation towards both the downstream and the upstream were revealed experimentally, and the process of the delta formation was simulated well by the one-dimensional analysis. In the real river, however, the bed materials usually consist of mixtures of sand and gravel. In this paper, the process of sediment deposition was studied experimentally, using the mixture of coarse and fine sediment in a small and steep laboratory flume with a model dam, which causes the hydraulic jump in the reservoir.

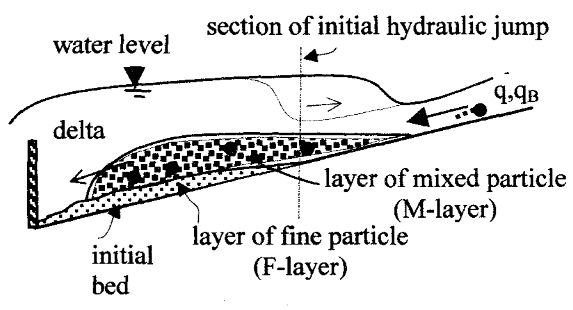


Fig.1 The schematic view of deposition layers of the sediment mixture

In the case of the mixture of sand and gravel, two distinct layers of the deposition are formed as shown in Fig. 1: (1) the layer of finer particles (F-layer), which is formed on the initial bed and (2) the 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.

The sediment transport is occurred at the flow-level only, below which there is an existence of a thin exchange layer[4]. The bed configurations of the deposition layer of mixed particles and fine particles were found two-dimensional and three-dimensional in the experiment, respectively. The percentage of fine particles in the deposition layer of mixed particle was found more towards the dam, whereas the percentage of the coarse particle was more to the upstream side. The difference of the mobility of each grain size in the sand-gravel mixture causes the sediment sorting in the part of the sediment deposition.

In this paper, the process of sediment deposition in a steep slope reservoir was studied experimentally, for the sand-gravel mixture, from the viewpoint of the change of sediment size composition in the deposited sediment as well as the process of delta formation.

2. EXPERIMENTAL STUDY

(1) Summary of the experiment

The deposition of sediment mixture in a steep slope reservoir was studied experimentally in a laboratory flume, changing the flow discharge (q) for three times with fixed slope of the channel, dam height (W), and the sediment supply from upstream (q_B) as shown in Table 1.

The experimental flume with a rectangular section was of size, 0.15m wide, 0.30m deep, and 10m long. The slope of the channel was fixed to 1/50 and the proportion of mixture (of coarse sediment of size 2.5mm and fine sediment of size 0.1mm) was made 1:1. The rate of sediment supply of the mixture from the upstream end was 0.111 cm^2/sec, which is smaller than the sediment transport capacity for the hydraulic conditions. A model dam was built at the downstream end of the flume. An electronic profile indicator with a depth-recording gauge was connected to a data recorder, which can move throughout the flume.

The water discharge(s), controlled by means of a computer, and the sediment (mixture of fine and coarse size) supply by means of a hopper, were carefully ensured at a constant rate from the upstream end of the flume. The bed profiles of sediment deposition (layers of fine and mixed sediment) and water levels were measured at an interval of 30 minutes in every 10cm along the channel starting from the dam. The profiles of the longitudinal deposition pattern were precisely measured with the electronic profile indicator in three locations; i.e., along the left sidewall, the right sidewall, and the center of the channel. The water level along the channel was measured manually with a mesh scale drawn on the transparent sidewall of the flume.

Table 1 Experimental conditions

Run	Dam Height (W) cm	Discharge (q) cm^2/sec	Normal depth (h_n) cm	Sediment supply (q_B) cm^2/sec
K	10	200	2.8	0.111
L	10	266	3.2	0.111
M	10	333	3.5	0.111

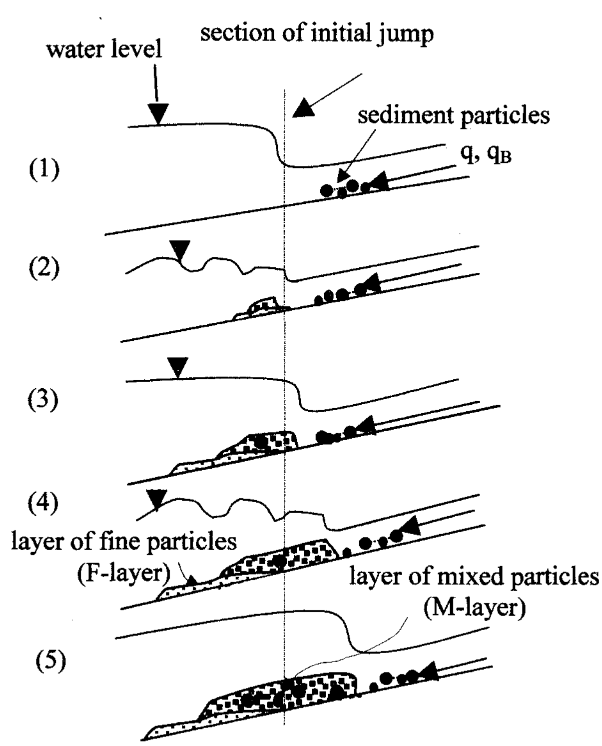


Fig.2 Schematic figure of the upward advance of the hydraulic jump with the sediment deposition layers

The depth of deposition of fine particle, i.e., beneath the deposition layer of mixed sediment, was measured, manually at an appropriate distance interval.

The sample of bed materials (sediment particles) of the M-layer (formed on the F-layer) was collected at every interval to compare the distribution of fine and coarse sediment particle in appropriate locations along the deposition layer of mixed particles. Then, the sample was dried and the percentage of fine and coarse particles by weight was calculated.

(2) Process of sediment deposition

The overall process of the delta formation for sand-gravel mixture is almost similar to that for uniform size sediment[2] (Fig. 2).

To observe the phenomenon of sedimentation in a reservoir with a steep slope, the hydraulic jump was formed in the flume, which characterizes the profiles of deposition. There was no deposition in the supercritical region upstream of the hydraulic jump, where the flow velocity is comparatively high on the supply of sediment mixture (q_B) with water discharge (q) from upstream. Because of the greater water depth in the subcritical region downstream of the jump, flow velocity is reduced and the deposition of sediment starts upwards from the initial position with the occurrence of the sediment deposition in the subcritical section, which was also reported by Matsushita[3]. The phenomenon of a stable and unstable hydraulic jump of surface waves repeatedly occurs in steep channel reservoir during the sediment deposition as shown in Fig.2.

In the case of sediment supply with sand-gravel mixture, the difference of mobility between sand and gravel becomes clear, when the bed shear stress becomes small in the downstream of the hydraulic jump. And only fine particles are transported further from the delta and from a layer of deposition with fine particles only (F-layer), on which the delta layer with sediment mixture (M-layer) are formed as shown also in Fig.2.

(3) Bed profiles of the sediment deposition

The bed forms of the sediment deposition in the experiment with the sediment mixture of fine and coarse sediment were observed. The layer of mixed particles (M-layer) was observed to be two-dimensional, i.e., the depth of deposition varies only along a longitudinal direction and is uniform in a transverse direction. However, the three-dimensional bed profile was observed at the downstream section of the front of the delta with sand waves in the layer of deposition of fine particles (F-layer), where the deposition configuration was also found varied along a transverse direction at that section of the channel.

The configurations of the deposition of the sediment mixture for Run K are shown in Fig. 3, where the curve z_c represents the profiles of deposition of the mixed (fine and coarse) sediment and z_2 represents the profiles of deposition of fine sediment below the mixed layer with time in minute. Here, z_2 is the value averaged over the channel width. The deposition profiles of z_c and z_2 were observed simultaneously progressed; however, the profile z_2 progresses towards the dam and the profile z_c progresses towards both the dam and upstream. Just downstream of the delta, only the finer sand can be transported because of the larger mobility of the fine sand in mixtures than the coarse grains, and the layer of only fine sand (F-layer) is formed and moves towards downstream. The delta

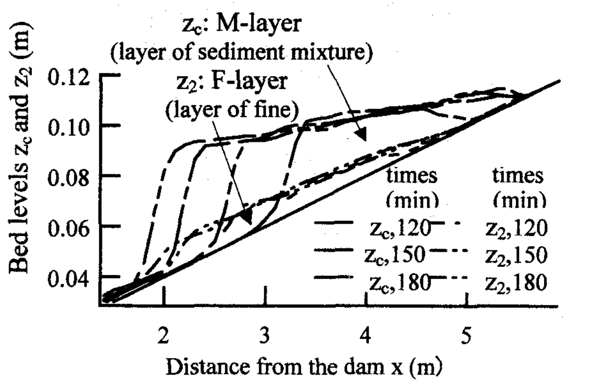


Fig.3 Observed two deposition layers of fine and mixed (coarse and fine) particles in Run K

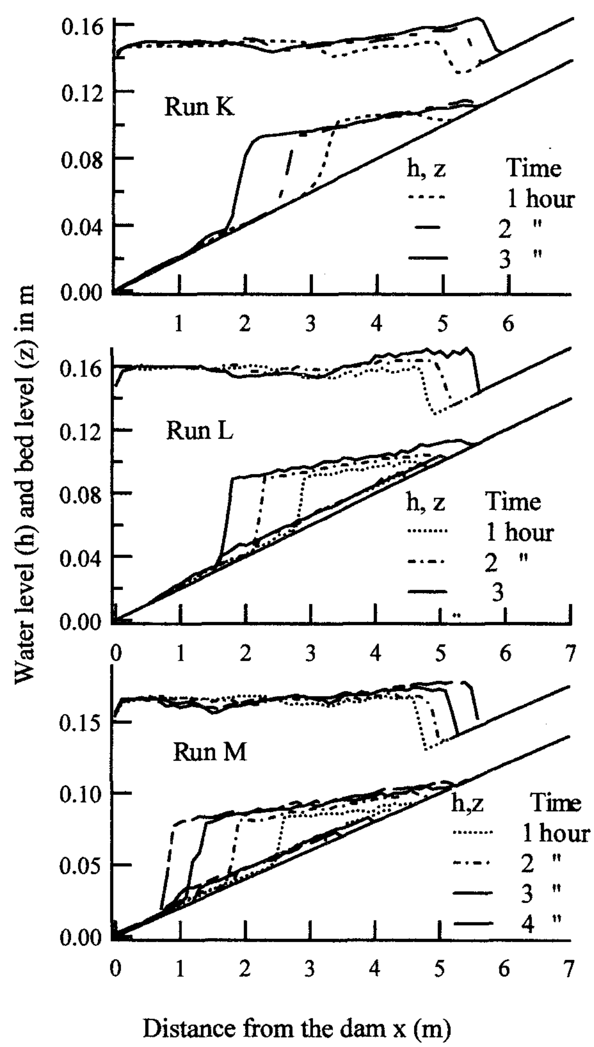
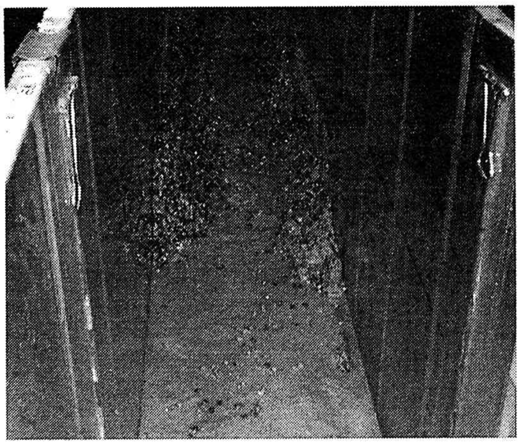
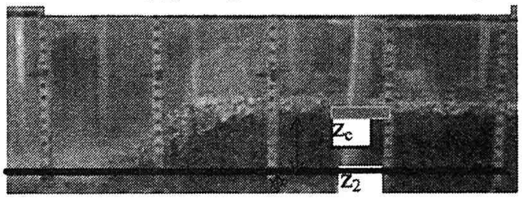


Fig.4 Typical observed temporal variation of the bed profiles and water surface profiles in Run K, Run L, and Run M



Run K (typical plan view after 3 hours)



Run M (typical side view after 4 hours)

Photo 1 Typical plan and elevation (sectional view) showing the deposition layers in Run K and M

with sand-gravel mixtures (M-layer) is formed on the fine sand layer and moves towards downstream as well as upstream. Thickness of the layer with fine sand starting from the position of the initial hydraulic jump becomes larger to the downstream.

The temporal variations of bed profile and water surface profile were observed as shown in Fig.4, where h and z represent the water level and the bed profile, respectively with time in hour. The upward advance of the position of the hydraulic jump was observed during the deposition of sediment mixture. The front of delta and the deposition layer of fine particle moved progressively towards the dam, and the movement of the deposition layer of mixed particles was observed to move both the upstream and the downstream side.

The plan view of the delta front (in Run K after 3 hours) and the longitudinal profiles of two deposition layers (in Run M after 4 hours) are shown in Photo 1, where symbols z_c and z_2 represent the depth of the mixed (of fine and coarse particles) and fine particle, respectively. The deposition profile of fine particle follows towards dam from also the front of the delta.

(4) The particle size distribution in mixed layer of the sediment deposition

It was observed that the layer of fine particles on the initial bed consists of only fine particles. On the other hand, the deposition layer of the mixed particle was observed inconsistent in composition of the fine and coarse particles along the bed profile, which were compared by weight. Fig.5 shows the distribution curves of the composition for the fine sediment (d_1=0.1mm) and the coarse sediment (d_2=2.5mm) particles in M-layer for Run K. The percentage of the fine sediment is represented by curve d_1 and the percentage of the coarse sediment is represented by curve d_2, with time in minutes. Similarly, Fig.6 shows the variations of the sediment

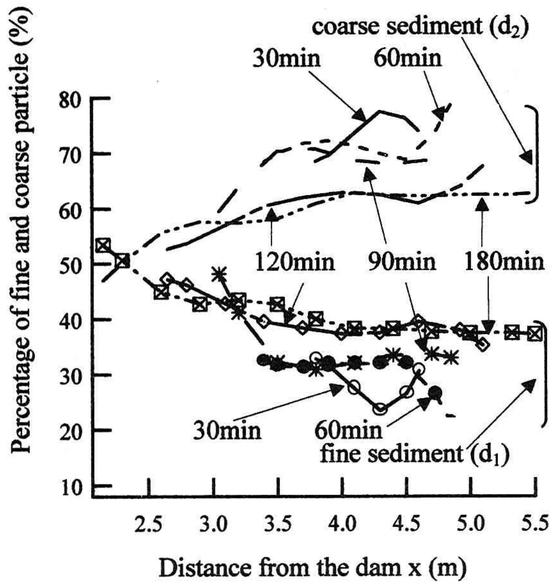


Fig.5 The temporal variations of the sediment distribution of fine and coarse particle in M-layer for Run K

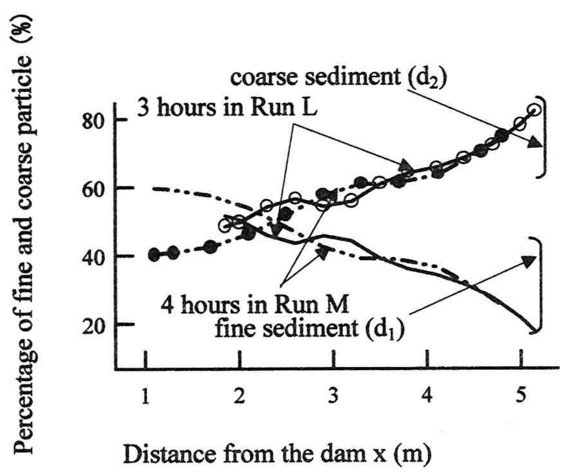


Fig.6 The distribution of the sediment particles in M-layer for Run L (after 4 hours) and Run M (after 3 hours)

particles along the deposition layer of the mixed particle (M-layer) for Runs L and M after 3 hours and 4 hours, respectively.

The composition percentage of fine sediment increases towards the dam, because the transport of the fine particles were observed for a longer time along the channel. The particles of coarse sediment decrease towards the dam, because the deposition of more particles was observed more at a short time compared with fine sediment.

3. DISCUSSIONS AND CONCLUSSIONS

As shown in Fig. 3, the bed profiles of deposition for the mixture of the fine and the coarse sediment were observed in two layers in the experiment: (1) the layer of finer particles (F-layer), which is formed on the initial bed and (2) the layer of mixed (consists both fine and coarse) particle (M-layer), is formed on the top of the layer of fine particle (F-layer) and farther from the dam in comparison to the former. The two-dimensional bed profile was observed in the deposition layer of mixed particles, i.e., the depth of deposition varies only along a longitudinal direction and is uniform in a transverse direction. However, the three-dimensional bed profile was observed at the downstream section of the front of the delta with sand waves in the layer of deposition of fine particles, where the deposition configuration was also found varied along a transverse direction.

The deposition of sediment starts just below the downstream section of the hydraulic jump, where the flow velocity is tended to decrease, as shown in Fig. 3 and Fig. 4. The progress of the deposition profile of the mixed layer was observed as a delta form towards both the upstream and the downstream side, where the movement of profile of fine layer progresses vigorously towards the dam as a tapering form. The upward shift of the hydraulic jump was observed with the progress of deposition.

In the mixed layer (M-layer), the percentage of the fine sediment increases towards the dam and decreases to the upstream side, as shown in Fig. 5 and Fig. 6. On the other hand, it (the distribution percentage) was found decreasing for the particle of coarse sediment towards the dam.

The temporal profiles of sediment deposition for uniform size grains were well simulated by one-dimensional analyses with the hydraulic jump[2]. The phenomenon of the deposition in the sand-gravel mixture was found similar to the uniform size, i.e., developments of delta and upward advancement of the hydraulic jump, the profile of deposition would be calculated by the continuity equation of the sediment mixture and the water flow with the application of the hydraulic jump. In addition, the continuity equation of each grain size as well as the continuity equation of the total sediment should be used considering the composition and pick up rate of each grains in the mixture of bed surface, where the sediment discharge can be calculated by the modified Mayer-Peter and Müller's equation for the sediment mixture[5].

In the deposition of sand-gravel mixture, 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 should be used. Further, the concept of exchange layer with the thickness of order of the largest grain size on the bed surface would be used to calculate the variation of the composition of grains along the mixed layer, where transported grains can be replaced by the grains on the surface.

REFERENCES

1) Morris, G. L. and Fan, J.: Sediment Deposits in Reservoir-Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use, McGraw Hill Publication, pp.10.1-10.9, 1997.

2) Suzuki, K., Parajuli, B. B., and Kadota, A.: Study on characteristics of reservoir sedimentation with hydraulic jump, Annual Journal of hydraulic engineering, JSCE, No.44, pp.1071-1076, 2000, (in Japanese).

3) Matsushita, F.: Back Sand Phenomenon in Steep Slope River –Case of Rectangular Section, Straight River, Trans. JSDRE, No. 66, pp.48-54, 1976, (in Japanese).

4) Hirano, M.: River bed degradation with armoring, Proc. JSCE, No.195, pp.55-65, 1971, (in Japanese).

5) Suzuki, K., Kadota, A., and Yamamoto, H.: Estimation for the bed load of the each grain size of sand-gravel mixtures by modifying both tractive and critical tractive force, Proc. JSCE, No.621/II-47, pp.91-99, 1995, (in Japanese).

(Received October 2, 2000)