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Hydraulic Characteristics of the Burrowing Type Sediment Removal Suction Pipe

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ABSTRACT:
In our work on sediment supply measures using flexible suction pipes, we developed the “burrowing-type sediment removal suction pipe method”, which employs a U-bend flexible pipe with a water intake at the upstream end, an impermeable sheet and sediment suction holes at the bent part and the upstream part of the pipe. The suction pipe is initially set on the surface of deposited sediment. After the start of discharge, the pipe is expected to suck up sediment and gradually burrow into the sediment using the differential water head energy. In this paper, we explain the hydraulic characteristics of the burrowing type sediment removal suction pipe such as the relationship between the velocity in the pipe and the sediment concentration, and the water head energy loss of the pipe examined by experiments using a small size model (pipe diameter: 60 mm, sediment thickness: 0.8 m), a large size model (pipe diameter: 100 mm, sediment thickness: 2.0 m) and non-cohesive sediment materials.

Keywords: Reservoir sedimentation, burrowing type sediment removal suction pipe, hydraulic model test, water head energy loss

1. INTRODUCTION

The construction of a dam interrupt the transport of sediment through the river. Decreased sediment supply downstream causes environmental problems related to the riverbed such as degradation, armoring, and fewer opportunities to renew the riverbed material. Moreover, sedimentation reduces the reservoir storage capacity. Therefore, measures are required to control sediment supply from the reservoir. In consideration of the conditions and time variation of the downstream riverbed environment, it is desirable to be able to control the timing of sediment supply and the quantity and quality (mainly particle size) of supplied sediment.

In the past, besides using traditional measures such as excavating and dredging, Japan also developed and used sediment flushing with water level drawdown (Kanazawa 2005) and sediment bypassing (Enomura 2005, Kataoka & Tada 2005). However, the conditions for applying these measures are restricted and it is difficult to control the exact quantity and quality of the discharging sediment by these methods. We have been working to develop new sediment supply measures using the differential water head energy between the upstream and downstream areas of the dam.

As a result of earlier studies (Sakurai et al. 2006, Sakurai et al. 2011), we proposed the “burrowing-type sediment removal suction pipe method”.

In the present study, we experimentally investigated the hydraulic characteristics of the burrowing type sediment removal suction pipe using a small scale model (pipe diameter: 60 mm, sediment thickness: 0.6 m), a large scale model (pipe diameter: 100 mm, sediment thickness: 2.0 m) and non-cohesive sediment materials. As a result of the model experiments, we clarified the hydraulic characteristics such as the relationship between the velocity in the pipe and the sediment concentration, and the water head energy loss of the pipe.

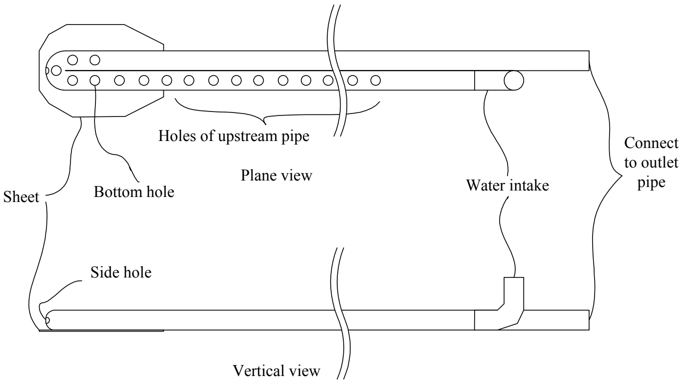

Figure 1. Outline of burrowing type sediment removal suction pipe

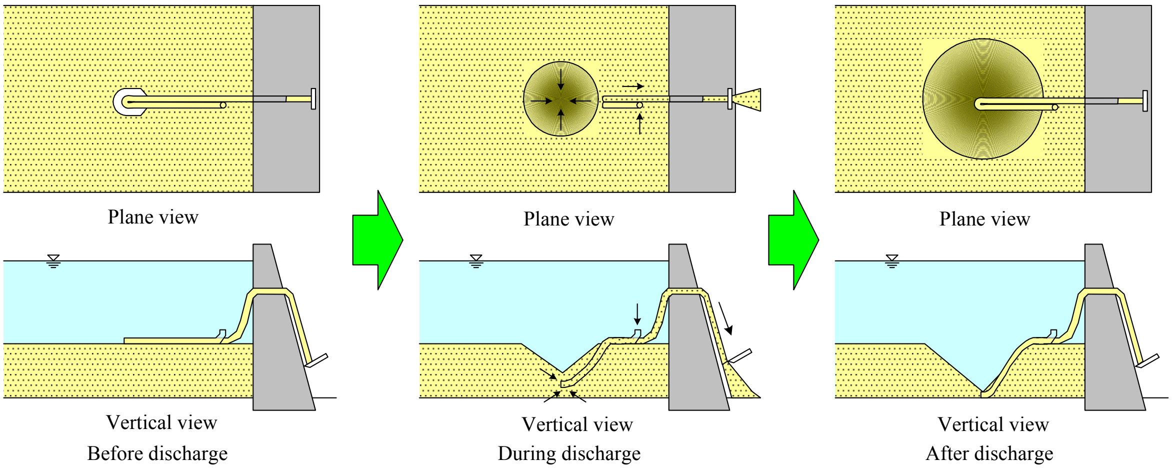

Figure 2. Sediment discharge process using the burrowing type sediment removal suction pipe

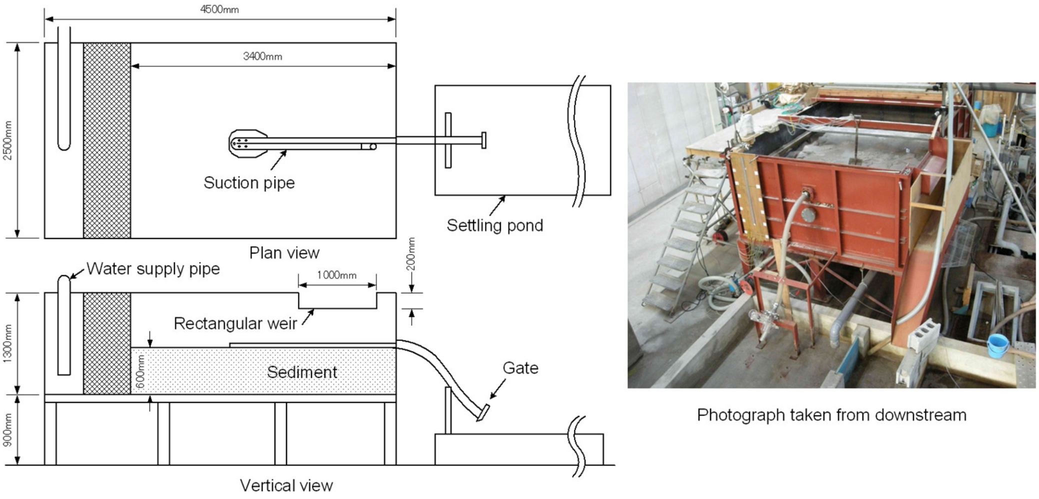

Figure 3. Outline of the experimental facility for small scale model test

2. BURROWING TYPE SEDIMENT REMOVAL SUCTION PIPE

Figure 1 illustrates the shape of the burrowing-type sediment removal suction pipe. It is a U-bend flexible pipe that has a water intake at the upstream end, an impermeable sheet, and sediment suction holes at the bent part and the upstream part of the pipe.

Figure 2 shows the sediment discharge process of the burrowing-type sediment removal suction pipe. The pipe is initially set on the surface of deposited sediment. After the start of discharge, the pipe is expected to suck up sediment through the sediment suction holes at the bent part and gradually burrow into the sediment using the differential water head energy.

After sediment discharge using the pipe, sedimentation should form a conical shaped pocket. It is difficult to discharge large amounts of sediment using only one facility. However, there are many dam reservoirs in Japan that have a mean annual sedimentation volume of less than several tens of thousands of cubic meters.

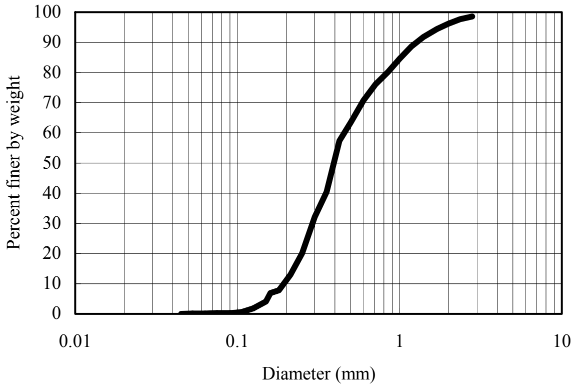

Figure 4. Grain size distribution of sediment material

This measure will be useful for achieving sediment transport balance in these reservoirs that have small sedimentation. For a repose angle of the sediment in the water of 30°, in order to discharge ten thousand cubic meters of sediment, it is necessary to dig a conical shape of about 15 m in depth and 26 m in radius.

Before sediment discharge After sediment discharge

Figure 5. Shape of sedimentation before and after sediment discharge

The operation method presently considered for the sediment removal suction pipe is as follows: 1) The sediment is transported to an area near the dam, not during the flood season. 2) The pipe is set up on the transported sediment before the flood season. 3) Discharge of the sediment is carried out during a flood by operating a gate installed at the end of the pipe. 4) After sediment discharge, the pipe is removed for maintenance. 5) The above process is repeated every year. Here, sediment discharge is carried out during a flood in order to supply sediment downstream, similar to natural conditions, considering the downstream river environment.

3. EXPERIMENTAL METHOD

3.1. Small Scale Model Test

Tests were conducted on a small scale hydraulic model to examine the sediment discharge characteristics of the sediment removal suction pipe. An outline of the experimental facility is shown in Fig. 3. The water tank used in the tests was 4.5 m long, 2.5 m wide and 1.3 m high. The tank has a rectangular weir to maintain the water level. An outlet pipe is installed at the downstream wall with a discharge control gate at the end of the pipe.

The dimensions of the pipe are as follows: 60.5 mm pipe diameter, 4.7 m pipe total length, 30 mm bottom hole diameter, 20 mm side hole diameter, 360 mm sheet width and 1620 mm sheet length.

The experimental procedure was as follows: 1) Sediment was placed at a height of 0.6 m in the water tank. 2) The sediment removal suction pipe was set up on the sediment. 3) Water was pumped into the tank at a constant discharge rate (45 L/s). The water level in the tank was kept almost constant by overflowing from the weir. 4) Sediment discharge was started by opening the gate at the end of the pipe. 5) We observed the sediment discharge situation and measured the water level in the tank, pressure head in the pipe using piezometers, discharge rate and sediment discharge rate. The sediment concentration was obtained by analysis of sampled water. The sediment concentration is a volume concentration and is estimated by “sediment volume / (water volume + sediment volume)”. In addition, sediment volume is without void volume.

The diameter of the sediment removal suction pipe used in the small scale model tests was 60.5 mm. If it is assumed that the pipe diameter in practical use ranges from 0.5 to 1.0 m, the model scale would be 1/16.5 to 1/8.3.

As the experimental sediment material, we used sand of mixed particle size. The grain size distribution of the sand is shown in Fig. 4. We changed the gate opening during the experimental test to examine different discharge rate conditions.

3.2. Large Scale Model Test

A test on a large scale hydraulic model was carried out to examine the sediment discharge characteristics of the sediment removal suction pipe under conditions closer to those of the actual facilities. The water tank was 7.5 m long, 7.5 m wide and 3.5 m high. The sediment removal suction pipe used in the large scale model test was basically the same shape as the small scale model pipe (100 mm pipe diameter, 9.4 m pipe total length, 50 mm bottom hole diameter, 33 mm side hole diameter, 600 mm sheet width and 1000 mm sheet length).

The experimental procedure was also similar to that for the small scale model tests. The differences were a sediment height of 2.0 m and water supply discharge rate of 47 L/s.

4. EXPERIMENTAL RESULTS

The sedimentation shapes of the large scale model before and after the experiment are shown in Fig. 5. These pictures were taken before water filling the tank with water and after draining the water from the tank. It was confirmed that a conical shaped pocket was formed after sediment discharge by the suction pipe.

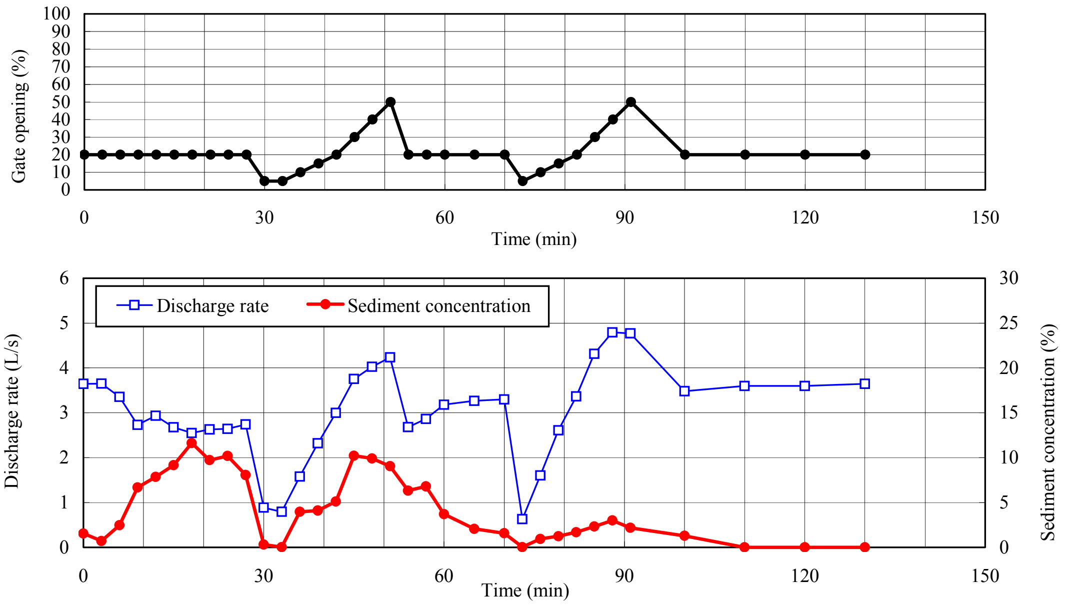

Figure 6. Time series of gate opening, discharge rate and sediment concentration (small scale model)

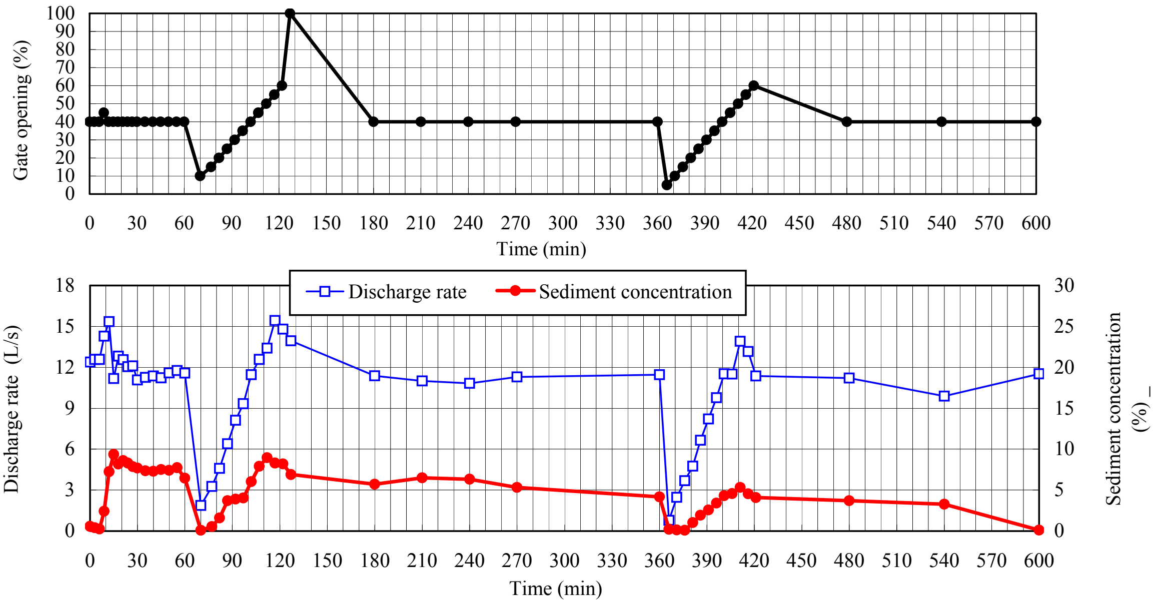

Figure 7. Time series of gate opening, discharge rate and sediment concentration (large scale model)

The time series for gate opening, discharge rate and sediment concentration of discharged water in the small scale model test are shown in Fig. 6 and those in the large scale model test are shown in Fig. 7.

In the previous experiments, if the gate opening was not changed, after the bent part was buried, the sediment concentration increased. Then, after the bent part reached the bottom of the water tank, the sediment concentration decreased. In this study, we changed the gate opening two times after the bent part reached the bottom.

As the gate opening was increased, the discharge rate and the sediment concentration became larger. However, the rate of increase in sediment concentration in the second gate opening change was smaller than that in the first change.

It is considered that the amount of the sediment at the time of suction pipe energy loss increases as the sediment concentration increases.

The relationship between the velocity (cross sectional average flow velocity in the suction pipe) and sediment concentration is indicated in Fig. 8 (D: pipe diameter). As the velocity increases, the sediment concentration increases. It is considered that we can control the sediment concentration to some extent by adjusting the velocity. Under these model test conditions, when the velocity is set to more than 1.0 m/s, the sediment concentration exceeds 2 %.

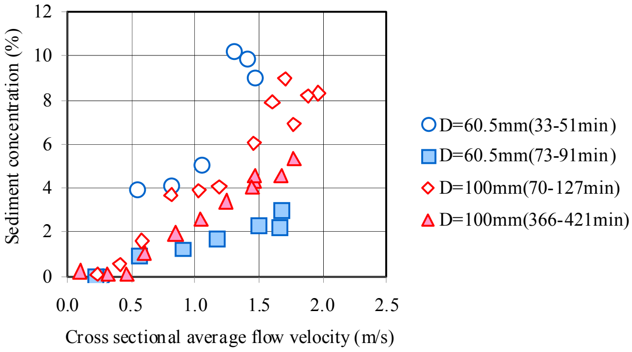

Figure 8. Relationship between velocity and sediment concentration

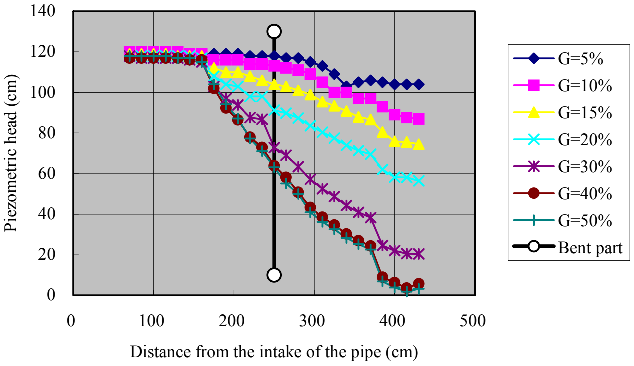

Figure 9. Piezometric head profiles of small scale model (33-51 min)

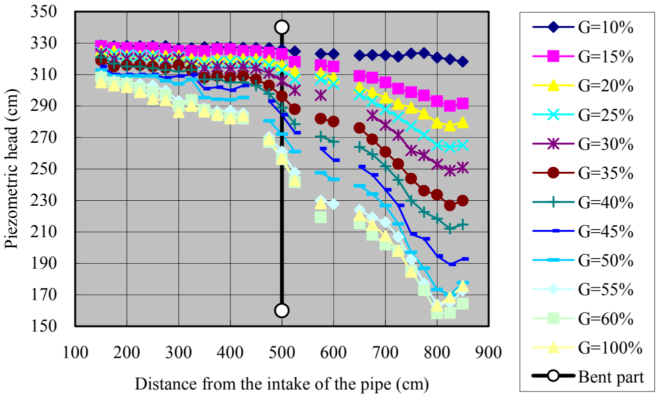

Figure 10. Piezometric head profiles of large scale model (73-91 min)

Figure 9 shows the piezometric head profiles in the small scale suction pipe model during the first gate opening change (33-51 min). The x-axis indicates the distance from the intake of the pipe. The bent part was located at 250 cm from the intake. Piezometers were set at 15 cm intervals. The y-axis indicates the piezometric head elevation measured from the bottom of the tank. 'G' is the gate opening.

Figure 10 shows the piezometric head profiles in the large scale suction pipe model during the first gate opening change (73-91 min). The bent part was located at 500 cm from the intake. Piezometers were set at 25 cm intervals.

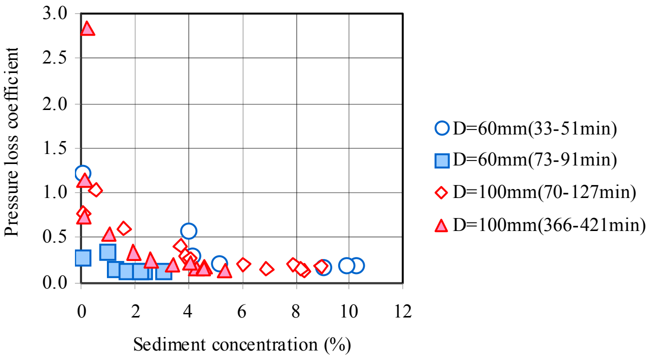

Figure 11. Relationship between sediment concentration and pressure loss coefficient

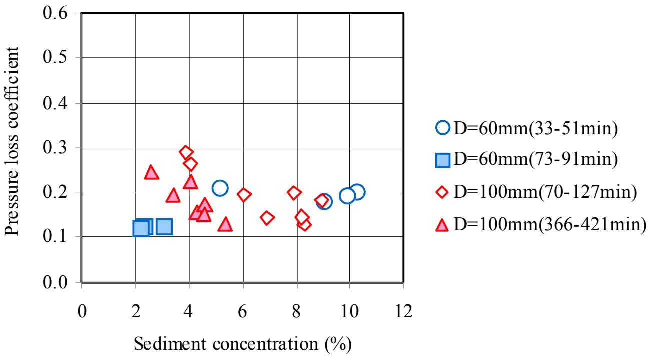

Figure 12. Relationship between sediment concentration and pressure loss coefficient (data that the sediment concentration was over 2 % and the velocity was over 1 m/s)

The piezometric head decreased with increasing distance from the intake. Also, as the gate opening became larger, the decrease in head became greater.

Figure 11 shows the relationship between the sediment concentration and pressure loss coefficient. The pressure loss coefficient was calculated using Eq. 1.

$$f = \frac{h_L D}{L}\frac{2g}{V^2} \qquad (1)$$

f: pressure loss coefficient, h_L: pressure head loss (m), *D*: pipe diameter (m), *g*: gravity acceleration (m/s^2), *L*: pipe length (m), and *V*: cross sectional average flow velocity (m/s). The pressure head loss and the pipe length were obtained from measurement data for the pipe from the bent part to the downstream end piezometer.

In Figure 11, the data for the large sediment concentrations lies in the area of small pressure loss coefficients. However, the data for the small sediment concentrations lies in the area of very large pressure loss coefficients. The small sediment concentration flow was attributed to the accumulation of sediment at the bottom of the pipe under small velocity conditions. Thus the actual *D* in the small sediment concentration flow should be set smaller in Eq. 1.

In order to use the suction pipe efficiently, we should set the sediment concentration to 2 – 5 %. The data when the sediment concentration was over 2 % and the velocity was over 1 m/s are shown in Fig. 12. The data are distributed in the area of pressure loss coefficient of less than 0.3. It is considered that we can use a pressure loss coefficient of 0.2 - 0.3 to estimate the pressure loss of the suction pipe approximately. To achieve a more precise and reliable design, larger scale experiments or field tests in a real reservoir need to be conducted.

5. CONCLUSIONS

(1) We proposed the "burrowing type sediment removal suction pipe method" for sediment supply from reservoirs and carried out small and large scale experimental model tests on the pipe (pipe diameter: 60 mm and 100 mm, sediment thickness: 0.6 m and 2.0 m). As a result, we obtained the relationship between the velocity in the suction pipe and the sediment concentration and the approximate pressure loss coefficient of the suction pipe during sediment discharge.

(2) In order to achieve practical use of the "burrowing type sediment removal suction pipe method. We must conduct larger scale experiments or field tests. It is also necessary to solve problems such as blocking by debris or driftwood and discharging cohesive sediment.

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