DEVELOPMENT OF THE SEDIMENT REMOVAL SUCTION PIPE BY LABORATORY AND FIELD EXPERIMENTS

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ABSTRACT

The authors have been working to develop a new sediment supply measure to solve a reservoir sedimentation problem and a downstream riverbed environmental problem. As a result of earlier studies, we proposed the “burrowing type sediment removal suction pipe method” using the differential water head energy between the upstream and downstream areas of a dam. We have carried out the laboratory experiments and the field tests to examine the hydraulic characteristics and the applicability of the pipe. We compared the result of the laboratory experiments (pipe diameter: 60 mm, 100 mm and 200 mm) and the result of the field test (pipe diameter 200mm) at the actual very small reservoir located in the mountainous area. As a result, we understood the hydraulic characteristics such as a relationship between velocity in the pipe and the sediment concentration, a water head energy loss of the pipe and so on. It is confirmed that the burrowing type sediment removal suction pipe could be applied to remove non-cohesive sediment material without debris in a small reservoir.

INTRODUCTION

The construction of a dam can 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. Furthermore, sedimentation causes a reduction in the reservoir storage capacity. Therefore, measures are required for 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 traditional measures such as excavating and dredging, sediment flushing with water level drawdown and sediment bypassing were developed and used in Japan. 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. Then, the authors have been working to develop a new sediment supply measure. We set following objectives of development. (1) A change of reservoir operation is not required. (2) It is able to control a sediment discharge rate according to a water discharge rate. (3) Size of facility is small and economical. As a result of earlier studies, we proposed the “burrowing type sediment removal suction pipe method” using

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the differential water head between the upstream and downstream areas of a dam (e.g., Sakurai and Hakoishi 2011,2012).

In this study, we have carried out the laboratory experiments and the field tests to examine the hydraulic characteristics and the applicability of the burrowing type sediment removal suction pipe.

BURROWING TYPE SEDIMENT REMOVAL SUCTION PIPE

Figure 1 illustrates the shape of the burrowing-type sediment removal suction pipe that the authors had proposed. 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. For further detail was described in Sakurai and Hakoishi 2011.

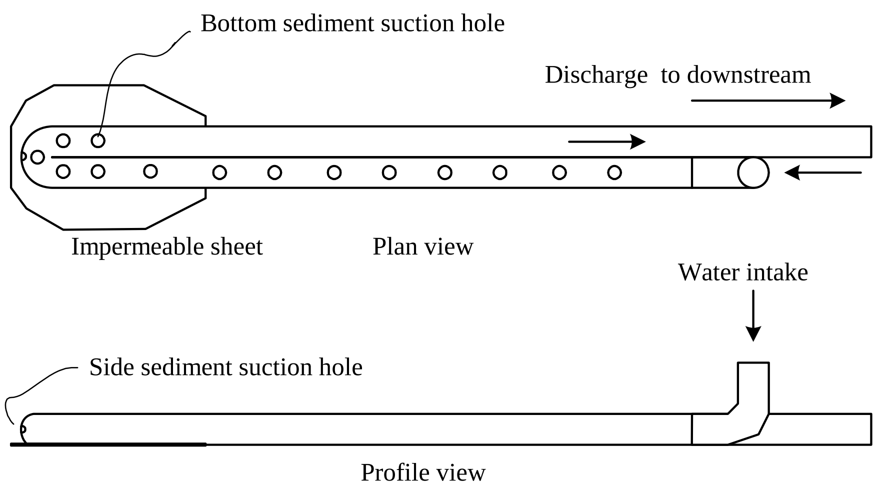


Figure 1. Outline of Burrowing Type Sediment Removal Suction Pipe.

A sediment discharge process of the burrowing-type sediment removal suction pipe is considered as follows. 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.

EXPERIMENTAL METHOD

In order to develop the suction pipe method, the authors conducted many experiments (about 100 tests) using various types of the suction pipe. Table 1 shows the specification of five representative pipes used for experiments. Figure 2 indicates the plain view of the five pipes.

The laboratory experiments were carried out using two experimental facilities. The field experiments were implemented at the actual very small reservoir located in the mountainous area managed by Disaster Prevention Research Institute Kyoto University. The plain view and vertical view of the experimental facilities are shown in Figure 3.

Table 1. Specification of the Pipes Used for Experiments.

Pipe	Diameter (mm)	Pipe material *)	Bent part structure	Diamiter of suction hole	Length (m)	Laboratory water discharge test	Laboratory sediment discharge test	Field sediment discharge test
Pipe-1	60.5	PVC AP: 0.04MPa	Polyvinyl chloride pipe with sheet	Upstream bottom: 3cm Bent part bottom: 3cm Bent part side: 2cm	3.0	Examined	Examined	-
Pipe-2	100.0	PVC AP: 0.03MPa	Same of the pipe with sheet	Upstream bottom: 4.5cm Bent part bottom: 4.5cm Bent part side: 3.3cm	5.0	Examined	Examined	-
Pipe-3	200.0	PVC AP: 0.01MPa	Same of the pipe with sheet	Upstream bottom: 9cm Bent part bottom: 9cm Bent part side: 6.6cm	4.0	Examined	-	-
Pipe-4	200.0	Fiber reinforcement PVC AP: 0.02MPa	Same of the pipe with sheet	Upstream bottom: 9cm Bent part bottom: 9cm Bent part side: 6.6cm	4.5	-	Examined	-
Pipe-5	200.0	PVC AP: 0.15MPa	Steel without sheet	Upstream bottom: 9cm Bent part bottom: 10cm	5.0	Examined	Examined	Examined

*) PVC: Polyvinyl chloride resin, AP: Allowable pressure

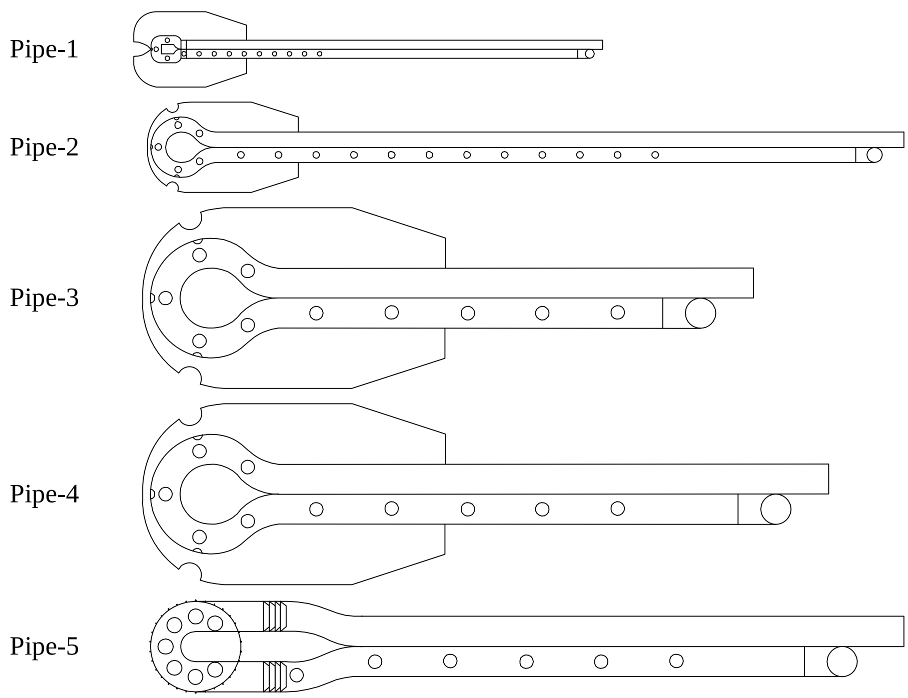


Figure 2. Plan View of the Suction Pipe Shape.

The laboratory small water tank 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 laboratory large water tank was 7.5 m long, 7.5 m wide and 3.5 m high. The small dam reservoir was 14 m long, 6.55 m wide and 4.65 m high.

In order to understand the basic characteristics of the pressure loss of the pipes, we carried out water discharge tests using the laboratory experimental facilities. The experimental condition of the water discharge tests are summarized in Table 2.

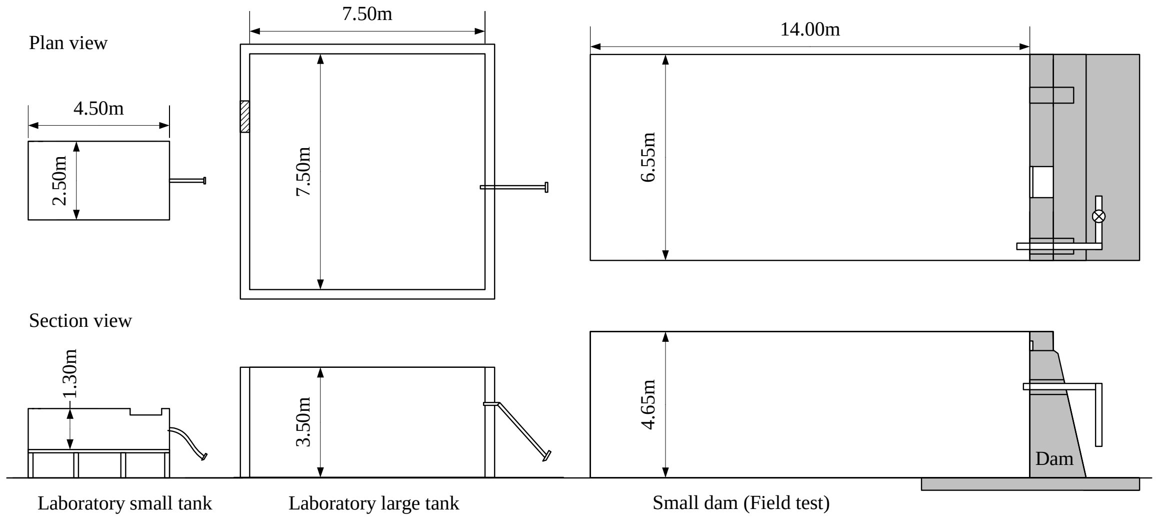


Figure 3. Experimental Facilities.

Table 2. Experimental Condition of Water Discharge Tests.

Case	Pipe	Diamiter (mm)	Experimental facility	Discharge rate (L/s)	Velocity of pipe flow (m/s)	Reynolds number
W-1	Pipe-1	60.5	Small tank	2.43 - 4.82	0.85 - 1.68	51,100 - 101,400
W-2	Pipe-2	100.0	Large tank	6.00 - 19.60	0.76 - 2.50	76,400 - 249,600
W-3	Pipe-3	200.0	Large tank	18.10 - 63.50	0.58 - 2.02	115,200 - 404,300
W-5	Pipe-5	200.0	Large tank	19.02 - 69.60	0.61 - 2.22	121,100 - 443,100

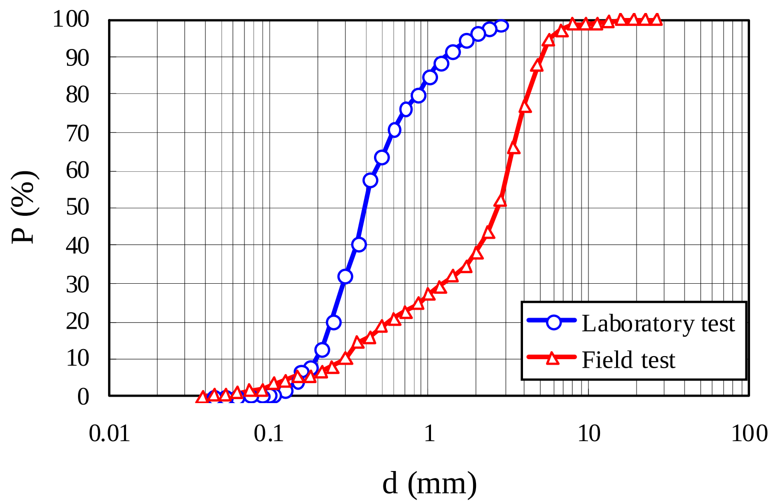
The sediment discharge tests were conducted using the all pipes at the laboratory tanks. However, the pipe-3 was broken by its lack of pipe strength during sediment discharge test. The field sediment discharge tests were carried out using the pipe-5. The experimental conditions of sediment discharge tests are shown in Table 3.

Table 3. Experimental Condition of Sediment Discharge Tests.

Case	Pipe	Diamiter (mm)	Experimental facility	Discharge rate (L/s)	Velocity of pipe flow (m/s)	Reynolds number
S-1	Pipe-1	60.5	Small tank	0.79 - 4.79	0.27 - 1.67	16,600 - 100,800
S-2	Pipe-2	100.0	Large tank	1.86 - 15.44	0.24 - 1.97	23,700 - 196,600
S-4	Pipe-4	200.0	Large tank	20.90 - 40.90	0.67 - 1.30	133,100 - 260,400
S-5-1	Pipe-5	200.0	Large tank	52.40	1.67	333,589
S-5-2	Pipe-5	200.0	Small dam	113.40	3.61	721,954
S-5-3	Pipe-5	200.0	Small dam	116.60	3.71	742,299

As the experimental sediment material, we used sand of mixed particle size. The grain size distributions of the sediment materials for the laboratory test and the field test are shown in Figure 4. The grain size distribution of the field test was larger than that of the laboratory test. The authors think that the suction pipe is effective to discharge non-viscous sediment such as sand and gravel. But it is difficult to apply the suction pipe to viscous sediment, because viscous sediment does not collapse easily in the water.

The experimental procedure of laboratory sediment discharge test was as follows: 1) Sediment was placed at a height of 0.6 m in the small tank or a height of 2 m in the large 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. 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. And the experimental procedure of field sediment discharge test was almost same as the laboratory test. But inflow water was supplied by the upstream small mountain stream. Because of small inflow discharge rate of the stream (about 10 L/s), we conducted the test by repeating sediment discharge and keeping water operation. In the cases of S-1 and S-2, we changed the gate opening during the test to examine the different discharge rate conditions.



d: Diameter (mm), P: Percent finer by weight (%).
Figure 4. Grain Size Distribution of Sediment Material.

EXPERIMENTAL RESULTS

Results of Water Discharge Test

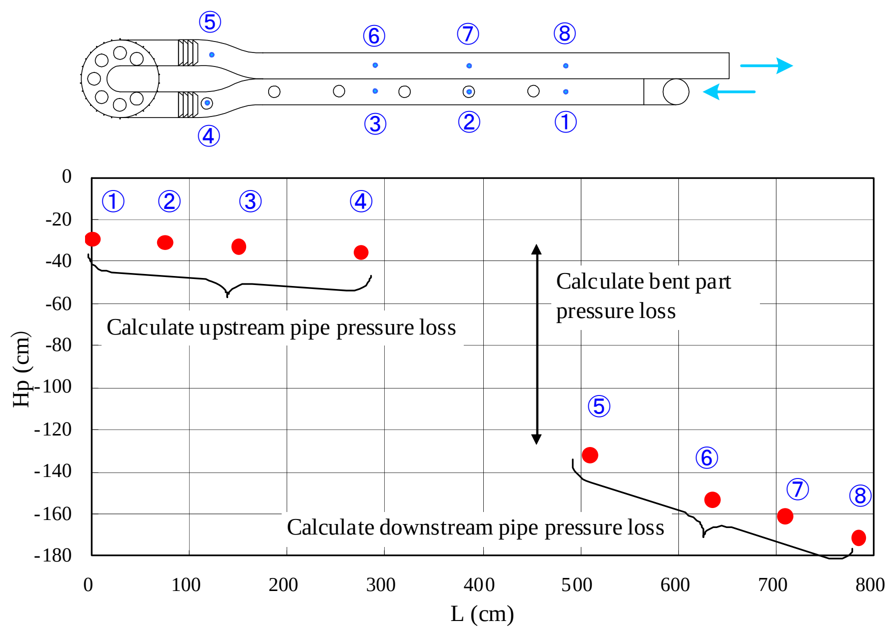
In order to explain how to calculate a pressure loss coefficient from piezometric head data, one example of the piezometric head profile is shown in Figure 5. The piezometric head decreased with increasing distance along the pipe. The pressure loss coefficient (similar equation as friction loss coefficient) of the pipe flow was calculated using Equation 1.

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

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 pipe flow velocity (m/s). The pressure head loss and the pipe length of the upstream pipe were obtained from measurement data of piezometers installed the upstream pipe. Those of the downstream pipe were obtained from piezometers installed the downstream pipe as shown in Figure 5.

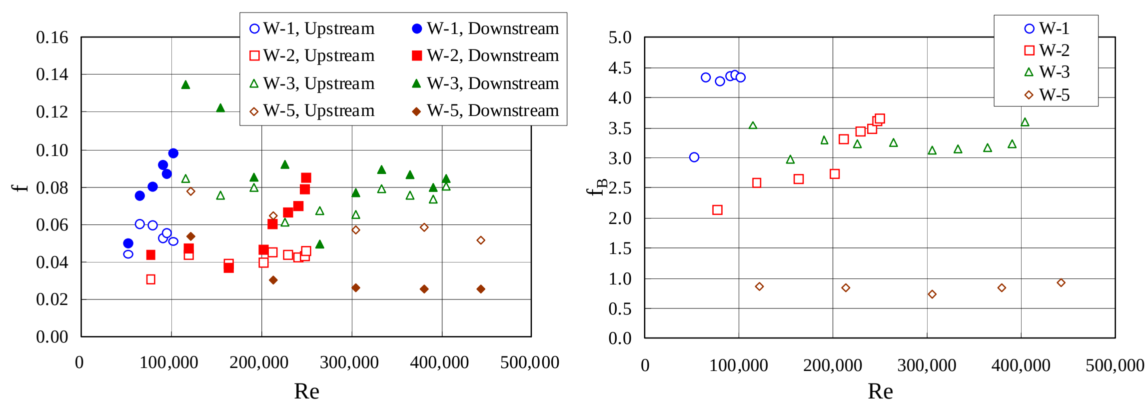
The pressure loss coefficient of the bent part was calculated using Equation 2.

$$f_B = h_{LB} \frac{2g}{V^2} \qquad (2)$$



L: Distance from the first piezo position (cm), Hp: Piezometric head (cm).

Figure 5. Example of Piezometric Head Profile.



Re: Reynolds number, f: Pressure loss coefficient (Pipe), f_B: Pressure loss coefficient (Bent part).

Figure 6. Relationship between Reynolds Number and Pressure Loss Coefficient of Water Discharge Tests.

f_B: pressure loss coefficient of the bent part, h_{LB}: pressure head loss of the bent part (m). The pressure head loss of the bent part was obtained from the difference between just upstream and downstream of the bent part piezometric heads as shown in Figure 5. In the cases using Pipe-5, the velocity was calculated using rectangular cross section shape of the bent part (200mm height and 200mm width).

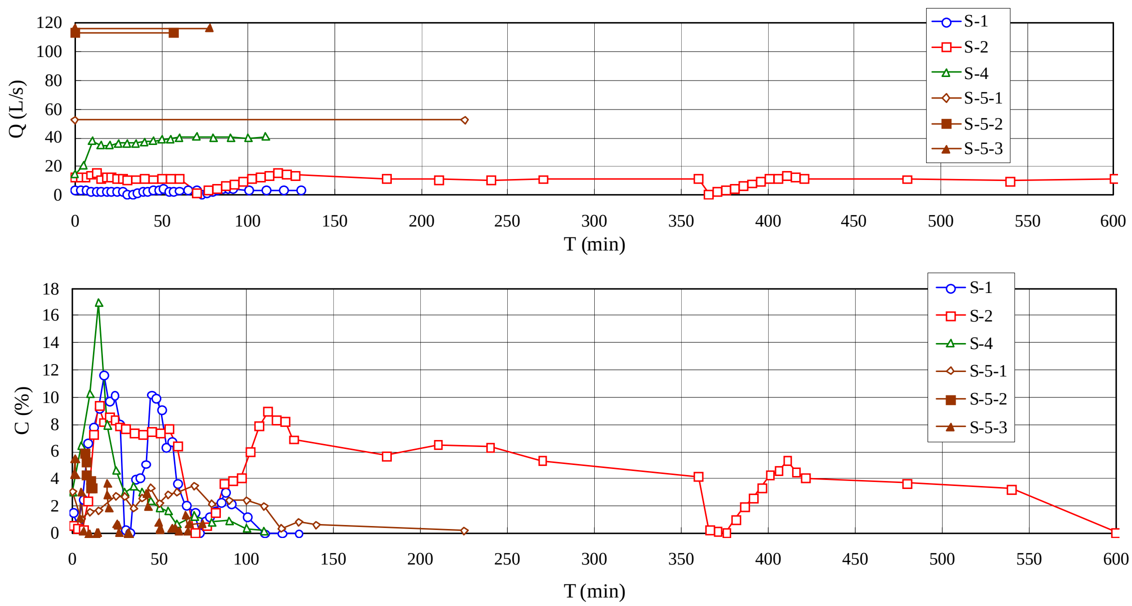
Figure 6 shows the relationship between Reynolds number and pressure loss coefficient of the results of the water discharge tests. There is a low correlation between Reynolds number and pressure loss coefficient as a whole. The reason for a great deal of scatter of the data, especially Case W-1, W-2 and W-3 is considered that there is roughness at the inner surface of the pipe due to the weakness of the pipe. As for pipe flow, pressure loss coefficients of upstream pipe are larger than those of downstream pipe except Case W-5. Pressure loss coefficients of bent part of Case W-5 are smaller than other cases.

Results of Sediment Discharge Test

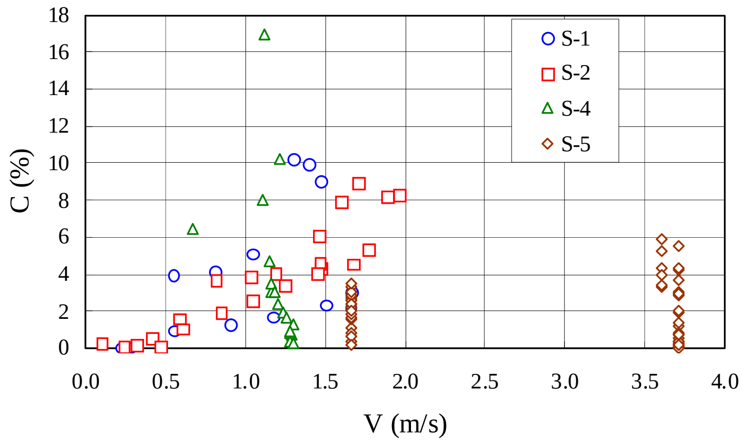
The time series of discharge rate and sediment concentration of the sediment discharge tests are shown in Figure 7. Figure 8 shows the relationship between velocity and sediment concentration.

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.

In the Case S-1 and S-2, as the discharge rate was increased, the sediment concentration became larger. However, the rate of increase in sediment concentration in the second discharge rate increase was smaller than that in the first change. The sediment concentration of the Case S-5-1, S-5-2 and S-5-3 are smaller than the other cases.



T: Time (min), Q: Discharge rate (L/s), C: Sediment concentration (%).
Figure 7. Time Series of Discharge Rate and Sediment Concentration.

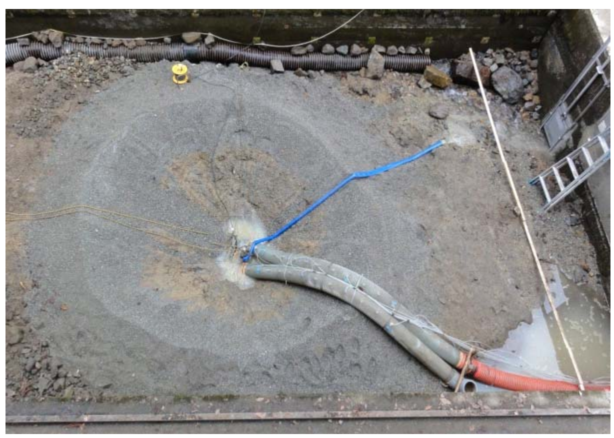


V: Velocity (m/s), C: Sediment concentration (%).
Figure 8. Relationship between Velocity and Sediment Concentration.

In Figure 8, as the velocity increases, the sediment concentration increases for Case S-1 and S-4. It is considered that we can control the sediment concentration to some extent by adjusting the velocity.

Table 4. Experimental Results of Sediment Discharge Tests.

Case	Pipe	Diamiter (m)	Discharge rate (L/s)	Velocity (m/s)	Discharge time (min)	Total discharge water volume (m^3)	Removed sediment volume without void (m^3)	Removed sediment volume with void (m^3)	Average sediment concentration without void (%)
S-1	Pipe-1	0.0605	0.79 - 4.79	0.27 - 1.67	130	24.4	0.72	1.20	2.95
S-2	Pipe-2	0.1000	1.86 - 15.44	0.24 - 1.97	600	387.6	18.70	31.16	4.82
S-4	Pipe-4	0.2000	20.90 - 40.90	0.67 - 1.30	110	246.8	18.75	31.25	7.60
S-5-1	Pipe-5	0.2000	52.40	1.67	225	707.4	11.58	19.30	1.64
S-5-2	Pipe-5	0.2000	113.40	3.61	57	387.8	2.07	3.45	0.53
S-5-3	Pipe-5	0.2000	116.60	3.71	78	543.0	10.44	17.40	1.92

Before sediment discharge | After sediment discharge

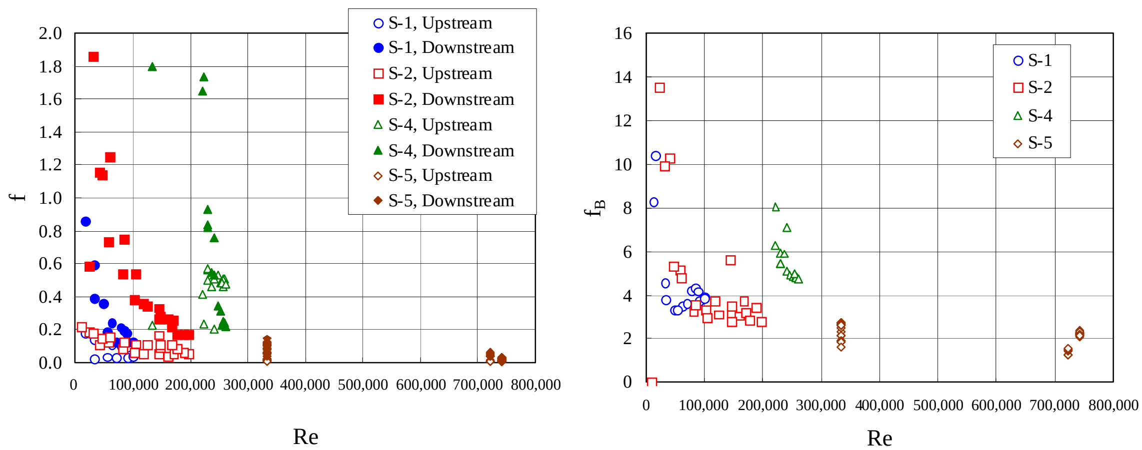
Figure 9. Sedimentation Situation of Field Sediment Discharge Test (Case S-5-3).

Experimental Results of sediment discharge tests were summarized in Table 4. A removed sediment volume with void was obtained by a surveying sedimentation surface shape before and after sediment discharge. For example, sedimentation situation of Case S-5-3 is shown in Figure 9.

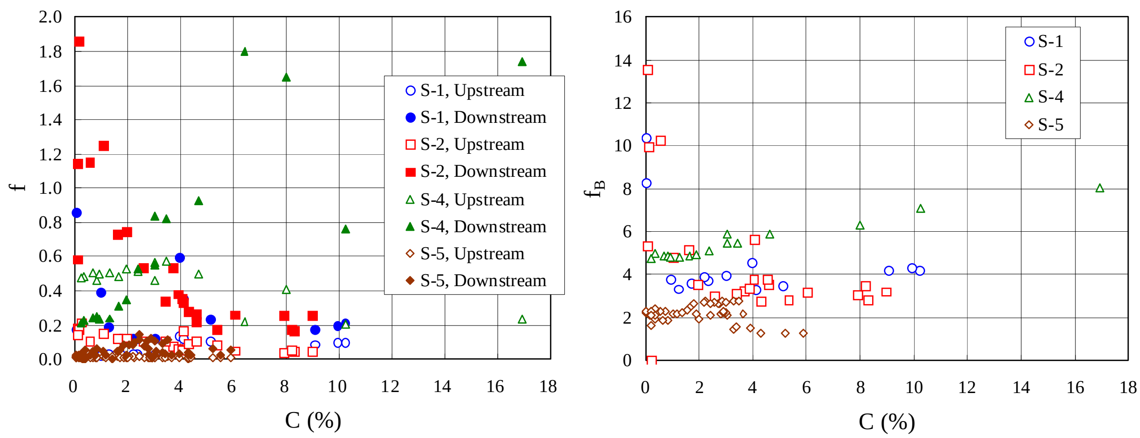
At present, we set the target sediment concentration to from 2 to 5 % considering actual situation of Japanese reservoir. The average sediment concentrations without void in Table 4 are larger than or equal to about 2 % except Case S-5-2.

Because of the simple setting method that the pipe is placed on the sediment surface, the actual setting and removing the pipe in the field tests were easy.

Figure 10 shows the relationship between Reynolds number and pressure loss coefficient of the results of the sediment discharge tests. Figure 11 shows the relationship between sediment concentration and pressure loss coefficient. Pressure loss coefficient data in Figure 10 and 11 were calculated by the same method as the water discharge tests.



Re: Reynolds number, f: Pressure loss coefficient (Pipe), f_B: Pressure loss coefficient (Bent part).
Figure 10. Relationship between Reynolds Number and Pressure Loss Coefficient of Sediment Discharge Tests.



C: Sediment concentration (%), f, f_B: Same as Figure 10.
Figure 11. Relationship between Sediment Concentration and Pressure Loss Coefficient.

As a whole, the pressure loss coefficients of the sediment discharge tests are larger than those of the water discharge tests. Both of the pipe flow and bent part pressure loss coefficients of Case S-5 are smaller than those of the other sediment discharge test cases. These quantitative data of pressure loss coefficient would be useful for design of the actual suction pipe facility.

CONCLUSION

(1) We proposed the "burrowing type sediment removal suction pipe method" for sediment supply from reservoirs and carried out laboratory and field tests. As a result, it was confirmed that three diameter suction pipes (60.5mm, 100mm, 200mm) can discharge sediment at almost the expected performance for sand material.

(2) As a result of experiments, we obtained quantitative data of the pressure loss for various pipe diameters and bent part shapes. Those are useful to design of the actual suction pipe facility.

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

ACKNOWLEDGEMENTS

The authors are deeply grateful to Professor Masaharu Fujita, Dr. Daizo Tsutsumi, Dr. Shusuke Miyata of Disaster Prevention Research Institute Kyoto University, and Mr. Shuuich Maeda of Electric Power Development Co., Ltd for their cooperation with our field experiment research.

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