Dams and Reservoirs under Changing Challenges – Schleiss & Boes (Eds)

Burrowing-type sediment removal suction pipe for a sediment supply from reservoirs

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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, a permeable sheet and sediment suction holes at the bent 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 sediment and gradually burrow into the sediment using the differential water head energy. We carried out an experimental study on the sediment supply characteristics of the suction pipe using physical models and non-cohesive sediment materials. As a result of the model experiments, we confirmed that the suction pipe can supply sediment at almost the expected performance and we established the process of sediment supply and the influence of discharge rate and sediment particle size on the sediment supply characteristics.

1 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 (Kanazawa 2005) and sediment bypassing (Enomura 2005, Kataoka & Tada 2005) 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. 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. We have also been researching methods that use flexible suction pipes.

As a result of earlier studies (Sakurai et al. 2006, Sakurai et al. 2007), we proposed the "burrowing-type sediment removal suction pipe method".

In this study, we experimentally investigated the sediment supply characteristics of the burrowing-type sediment removal suction pipe using a small scale model (pipe diameter: 60 mm, sediment thickness: 0.6 m), a medium scale model (pipe diameter: 100 mm, sediment thickness: 2.0 m) and non-cohesive sediment materials. As a result of the model experiments, we confirmed that the suction pipe can supply sediment at almost the expected performance and we established the process of sediment supply and the influences of the discharge rate and sediment particle size on the sediment supply characteristics.

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, a permeable sheet, and sediment suction holes at the bent 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 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 shape pocket. It is difficult to discharge large amounts of sediment by 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. This measure will be useful for achieving sediment transport balance in these reservoirs that have small sedimentation. When the repose angle of the sediment in the water is assumed to be 30°, in order to discharge ten thousand cubic meters of sediment, it is necessary to dig about 15 m for the depth and 26 m for the radius of the conical shape.

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 processes are 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.

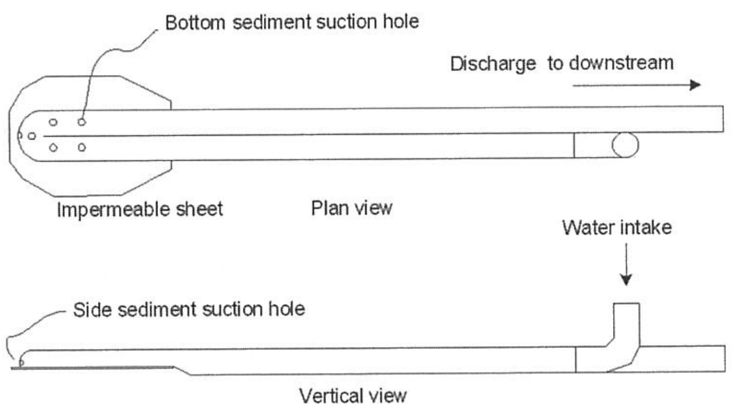


Figure 1. Shape of the burrowing-type sediment removal suction pipe.

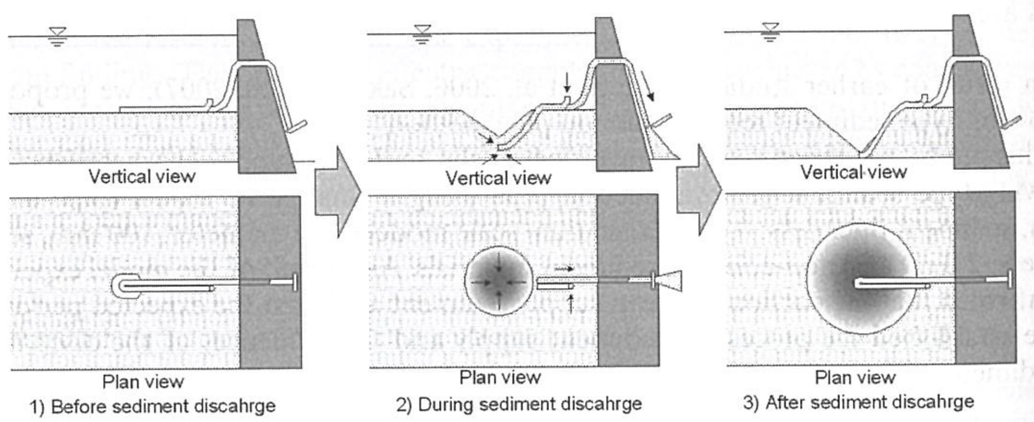


Figure 2. Sediment discharge process of the sediment removal suction pipe.

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 Figure 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 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, shown in Figure 4, 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, discharge rate and sediment discharge rate.

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.

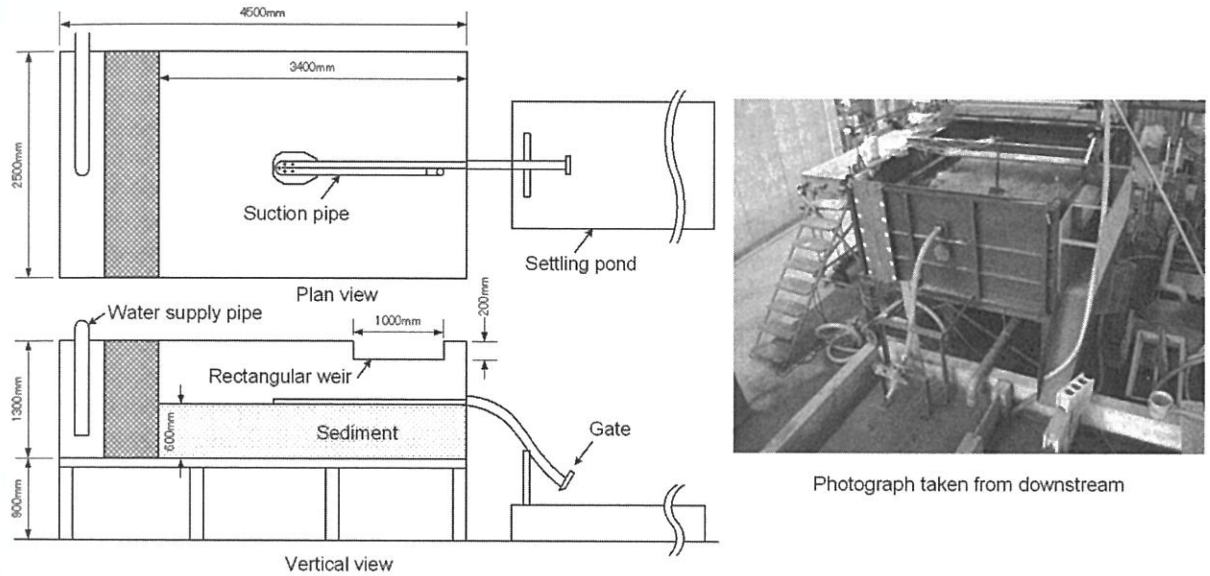
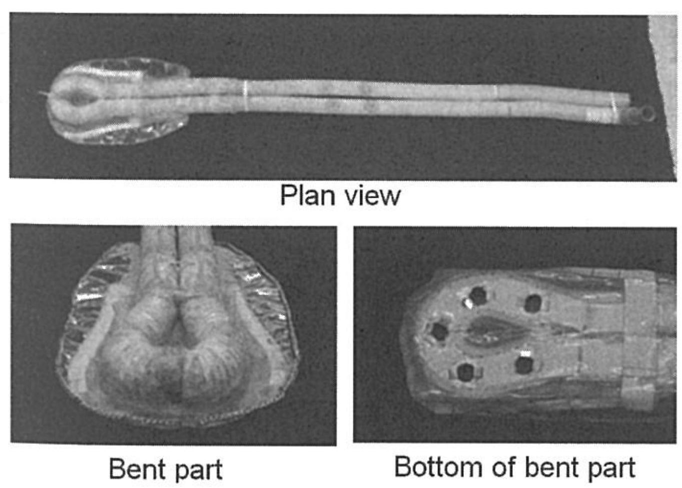


Figure 3. Outline of the experimental facility for small scale model tests.



Pipe diameter	: 60.5 mm
Pipe total length	: 4.7 m
Bottom hole diameter	: 30 mm
Side hole diameter	: 20 mm
Sheet width	: 360 mm
Sheet length	: 620 mm

Figure 4. Outline of small scale model of the burrowing-type sediment removal suction pipe.

As the experimental sediment material, we used silica sand at three different particle sizes. The grain size distribution of the sand is shown in Figure 5. The model tests were carried out under the conditions of three different gate openings. The total number of experimental test cases reached nine due to the combination of sediment size and gate opening. The experimental conditions are listed in Table 1.

3.2 *Medium scale model test*

A test on medium 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. An outline of the experimental facility is shown in Figure 6. The water tank is 7.5 m long, 7.5 m wide and 3.5 m high. The sediment removal suction pipe used in the medium scale model test is 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 is also similar to that for the small scale model tests. The differences are as follows: 1) Sediment height was 2.0 m. 2) Water supply discharge rate was 47 L/s. 3) We changed the gate opening during the test depending on the sediment discharge situation. 4) The experimental sediment material was sand mixed particle size. The grain size distribution of the sand is shown in Figure 5.

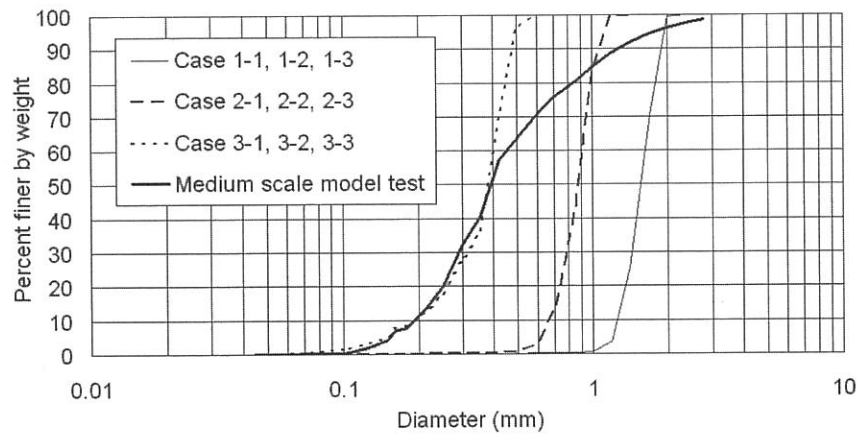


Figure 5. Grain size distribution of sediment material used for model tests.

Table 1. Experimental conditions of small scale model tests.

Case	Mean diameter of sediment Dm (mm)	Gate opening G (%)	Discharge rate Q (L/s)	Mean velocity (in pipe) V (m/s)	Test duration T (min)
1–1		24	3.32	1.17	80
1–2	1.56	18	3.05	1.08	150
1–3		12*	2.50	0.88	120
2–1		24	3.32	1.17	150
2–2	0.89	18	3.05	1.08	150
2–3		12	2.50	0.88	120
3–1		24	3.32	1.17	150
3–2	0.36	18	3.05	1.08	150
3–3		12	2.50	0.88	180

*Initially, the gate opening was set at 18%. After the pipe was buried, the gate opening was set at 12%.

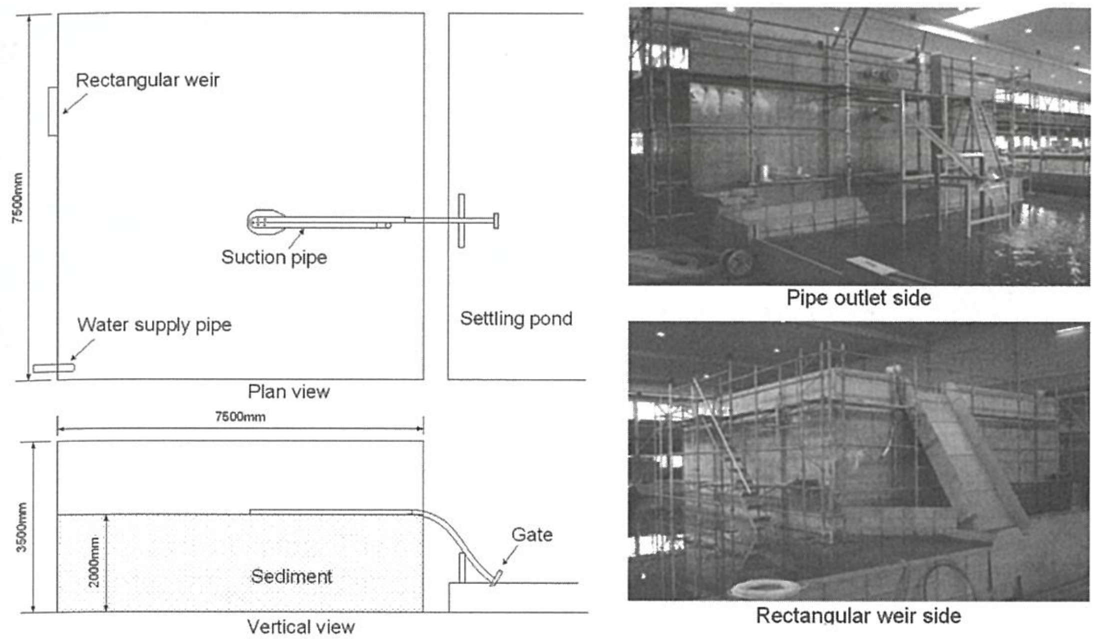


Figure 6. Outline of the experimental facility for medium scale model test.

4 EXPERIMENTAL RESULTS

4.1 *Experimental results for small scale model test*

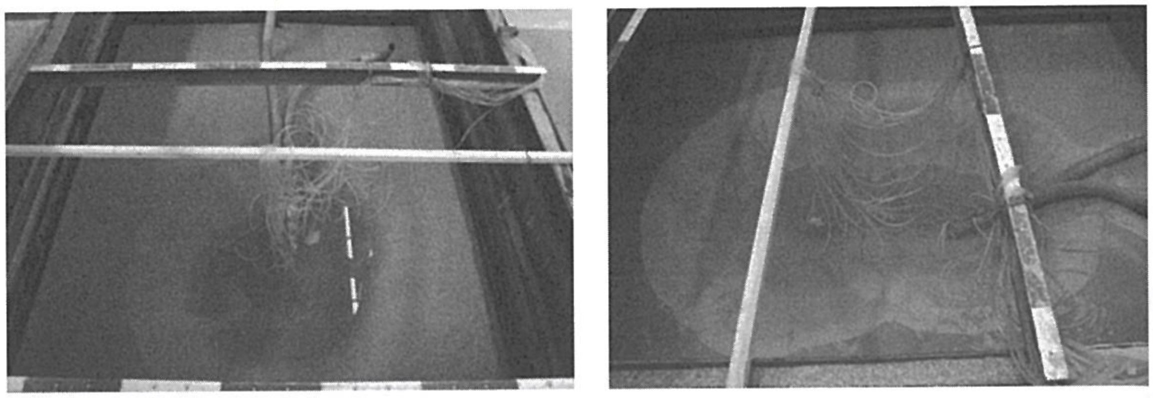
Figure 7 shows photographs of the shape of sedimentation after sediment discharge in Case 1–2 and Case 3–2. These photographs were taken after drainage of the water tank. Figure 8 illustrates the longitudinal form of sedimentation after sediment discharge in all cases of small scale model tests. It was confirmed that the conical shape void space in sedimentation was made by sediment discharge using the burrowing-type sediment removal suction pipe. Figures 7 and 8 indicate that the conical shape tends to become long in the flow direction in the case using sediment material with a small particle size.

As an example, the time series for discharge rate and sediment concentration of discharged water in Case 1–1 is shown in Figure 9. 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.

As shown in Figure 9, 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. It is considered that the sediment concentration increases from the time when the bent part is buried to the time when the bent part reaches the bottom, because both the bottom suction holes and side suction hole suck the sediment. After the bent part reaches the bottom, it is difficult for the bottom suction holes to suck the sediment, so the sediment concentration decreases. After the bent part reached the bottom, the sediment concentration maintained a certain value for a certain time. The discharge rate became smaller when the sediment concentration became larger, and it became larger when the sediment concentration became smaller. It is considered that the energy loss in the pipe increases as the sediment concentration increases.

The sediment discharge process in Case 1–1 described above is basically similar to the other cases. The experimental results for all cases are summarized in Table 2. The larger the flow rate and the smaller the sediment particle diameter, the larger the maximum sediment concentration becomes. It was difficult to determine the explicit influence of the discharge rate and sediment particle size on the sediment concentration during stable conditions.

Before conducting the model tests, we estimated the total removed sediment volume with the void part at about 0.52 m^3 (depth of conical shape: 0.55 m, repose angle of sediment in



a) Case 1-2 (D_m=1.56 mm, V=1.08 m/s)

b) Case 3-2 (D_m=0.36 mm, V=1.08 m/s)

Figure 7. Shape of sedimentation after sediment discharge in small scale model tests.

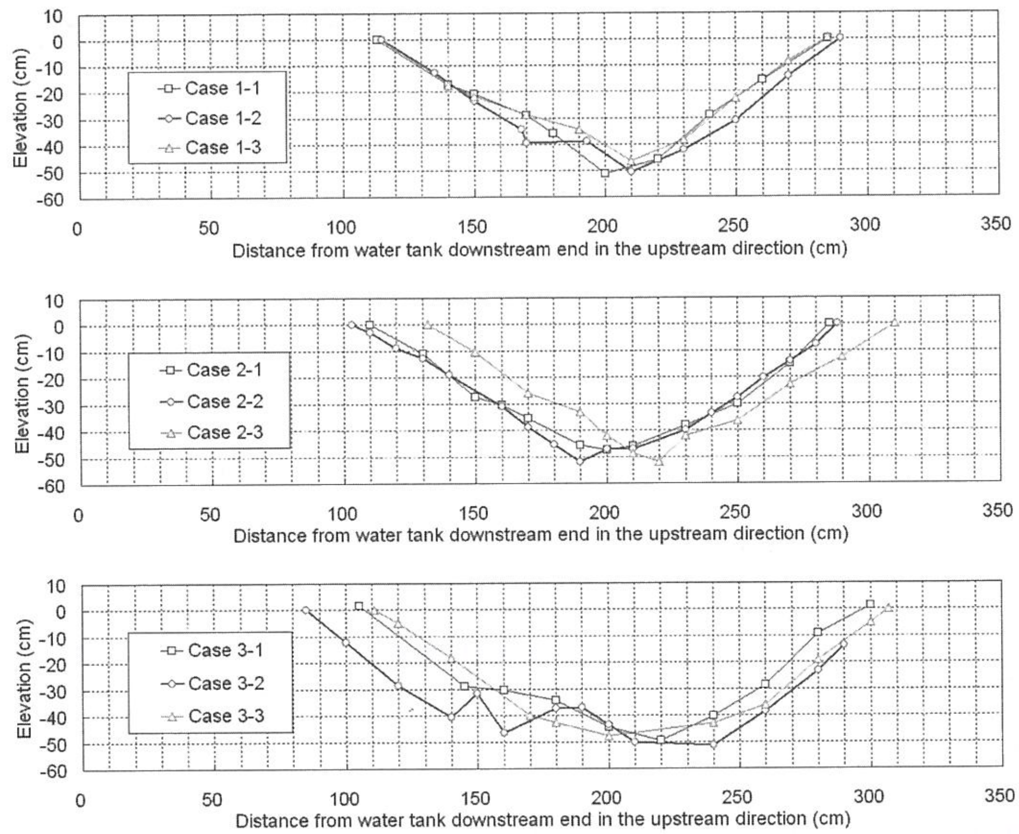


Figure 8. Longitudinal form of sedimentation after sediment discharge in small scale model tests.

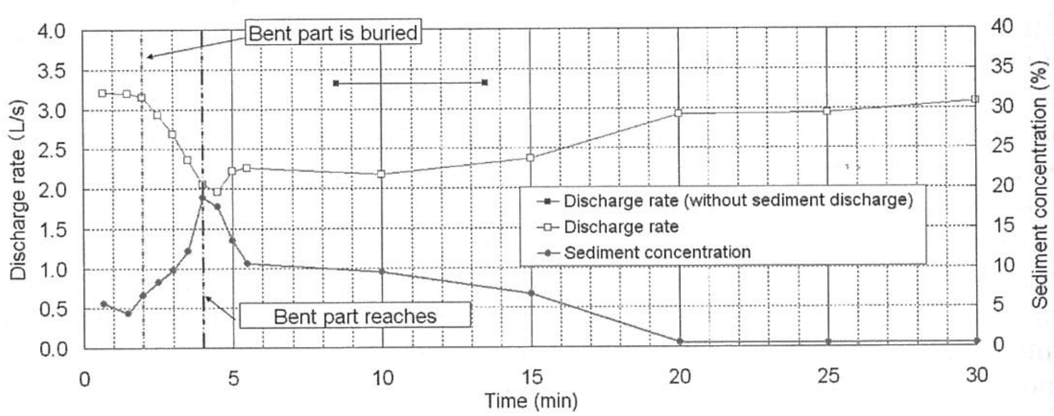


Figure 9. Time series of discharge rate and sediment concentration in Case 1–1.

water: 30°, radius of conical shape: 0.95 m). As shown in Table 2, the experimental results for the total removed sediment volume are close in value to the estimation. It was confirmed that the sediment removal suction pipe can supply sediment at almost the expected performance in the small scale model tests.

4.2 *Experimental results for medium scale model test*

The shape and section form of sedimentation after sediment discharge in the medium scale model test are shown in Figure 10. As in the small scale model tests, a conical shape was made in the medium scale model test. The total removed sediment volume with the void part was about 7.1 m^3. We expected the depth of the conical shape to be 1.9 m, but the actual depth was about 1.3 m. Even though there was still a layer of sediment about 0.6 m thick on the bent part of pipe, the sediment removal suction pipe could not suck the sediment.

The time series for discharge rate and sediment concentration is illustrated in Figure 11. The maximum sediment concentration was 9.3% and occurred at 43 min after the start of the test at the 25% gate opening. The bent part of the pipe reached the bottom of the water tank at 105 min, after which the sediment concentration became smaller.

Before 330 min, trouble with air accumulation in the pipe occurred several times. Precautions will have to be taken in the actual facility. The sediment concentration became very small at 330 min. We considered that the reason for this was suction hole blockage by debris or space around the hole by arch action of sediment. However, we could not confirm the

Table 2. Experimental results for small scale model tests.

Case	Bent part was buried Time (min)	Bent part reached bottom Time (min)	Total removed sediment (with void part) (m^3)	Maximum sediment concentration (%)	Sediment concentration during stable situation (%)
1–1	2.0	4.0	0.49	18.9	8.9
1–2	3.0	6.5	0.52	11.4	5.4
1–3	–	6.0*	0.47	9.7	3.0
2–1	1.5	2.5	0.50	23.3	4.5
2–2	1.5	3.5	0.57	22.2	3.7
2–3	4.5	10.0	0.43	13.5	5.1
3–1	4.5	6.0	0.53	32.4	5.3
3–2	3.5	5.0	0.73	26.2	5.5
3–3	11.0	15.0	0.48	13.2	4.6

*The time was measured from when the bent part was buried.

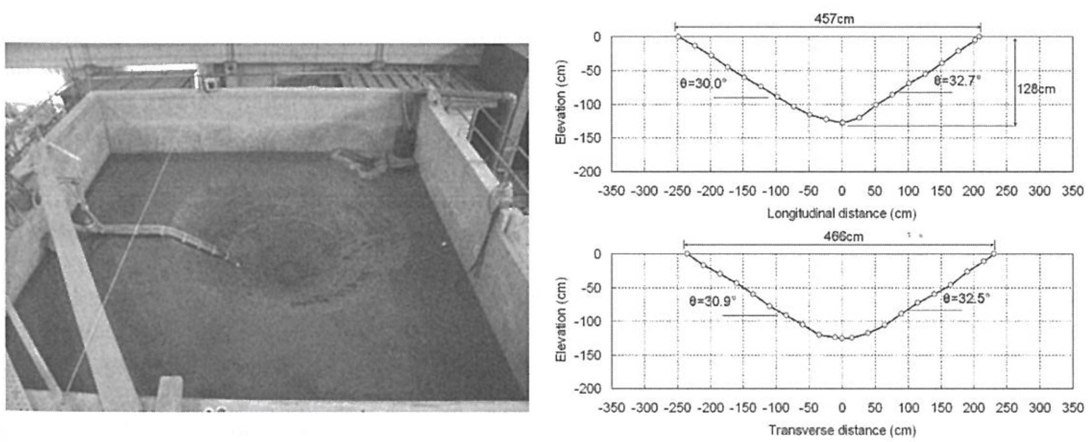


Figure 10. Shape and section form of sedimentation after sediment discharge in medium scale model test.

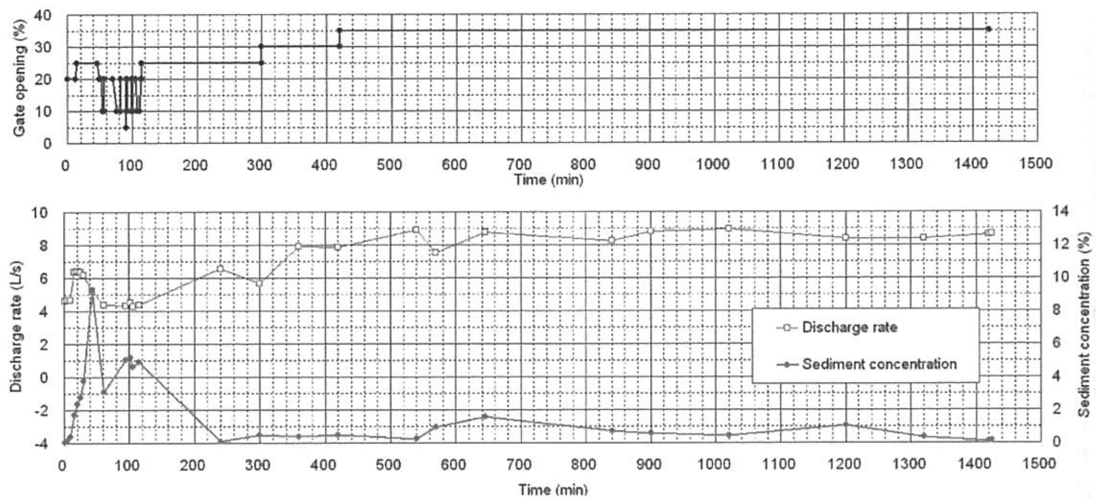


Figure 11. Time series of discharge rate and sediment concentration in medium scale model test.

reason. We tried applying vibration to the pipe after which the sediment discharge restarted and continued for a while. We repeated this process, but finally the sediment discharge could not be restarted by vibration at 1425 min. We identified new challenge from the results of the medium scale model test.

5 CONCLUSIONS

1. We proposed the "burrowing-type sediment removal suction pipe method" for sediment supply from reservoirs and carried out small scale experimental model tests on the pipe (pipe diameter: 60 mm, sediment thickness: 0.6 m). As a result, we confirmed that the suction pipe can supply sediment at almost the expected performance and we established the process of sediment supply and the influence of discharge rate and sediment particle size on sediment supply characteristics in the small scale model tests.
2. We carried out a medium scale experimental model test (pipe diameter: 100 mm, sediment thickness: 2.0 m) to examine the sediment discharge characteristics of the sediment removal suction pipe under conditions closer to those of actual facilities. As a result, the suction pipe could supply sediment until the bent part of the pipe reached the bottom, but after that it was difficult to continue stable sediment supply. We identified a new challenge from the results of the medium scale model test.

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