DEVELOPMENT OF SEDIMENT SUPPLY MEASURES FOR RESTORATION OF RIVERBED ENVIRONMENT AT THE DOWNSTREAM OF THE DAM - SEDIMENT DISCHARGE FACILITY BY SHEET AND SUCTION PIPE, AND AIR VALVE -

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Abstract: By means of dam construction, sediment transport through the downstream river channel is reduced A reduction in the sediment supply to downstream channel causes environmental problems such as riverbed degradation, riverbed armoring and disturbance on renewal of the riverbed material. Furthermore, in-reservoir sedimentation causes the reduction of the reservoir storage capacity. Consequently, sediment supply measures from the reservoir to the river are required. Considering the condition and time variation of the downstream riverbed environment, it is desirable to be able to control the timing, volume and particle size of the supplied sediment.

In the past, reservoir drawdown and sediment bypass techniques have been developed and put to practical use for sediment flushing. However, the conditions to apply these measures are restricted and it is difficult to control the quantity and quality of the sediment discharges. Recently, we have been developing new sediment supply techniques using the water's potential energy from the reservoir and the downstream river. We have been doing research on two techniques, the first is uses a sheet and suction pipe, the second involves using an air valve facility. We carried out physical hydraulic model tests on the two techniques. From the test results, it was confirmed that these measures were able to discharge non-cohesive sediment such as sand and gravel.

Key words: Reservoir sedimentation, sediment supply measures, sheet and suction pipe, air valve, sediment discharge

1 Introduction

By means of dam construction, a significant portion of the sediment transport through the river basin is interrupted. A reduced sediment supply to downstream river causes the environmental problems such as riverbed degradation, riverbed armoring and a lack of new riverbed sediment. Furthermore, in-reservoir sedimentation causes the reduction of the impoundment’s storage capacity. Consequently, sediment supply measures from the reservoir to the river are required. Considering the condition and time variation of the downstream riverbed environment, it is desirable to be able to control the timing, volume and particle size of the supplied sediment.

In the past, the sediment flushing using reservoir drawdown (for example, Dashidaira dam[1] and Unazuki dam[1]) and the sediment bypass techniques (for example, Asahi dam[2] and Miwa dam[3]) have been developed and put to practical use. However, conditions to apply these techniques are restricted and it is difficult to control the quantity and quality of the sediment discharge. As a result, we have been trying to develop new sediment supply techniques using the water’s potential energy between upstream and downstream of the dam. We set the following objectives of development: (1) A change of reservoir operation is not required, (2) accurate control of sediment discharge rate versus water discharge rate, and (3) size of facility is small and economic.

We have been doing research about two measures, one is a technique of using a sheet and suction pipe (hereinafter called Sheet and Suction Pipe sediment discharge Facility or SSPF), second is a technique that uses an air valve facility (hereinafter called Air Valve sediment discharge Facility or AVF). The development of SSPF has been carried out in a collaborative research effort by Public Works Research Institute (PWRI) and IHI Corporation. The development of AVF has been carried out in a collaborative research effort by PWRI and YACHIYO Engineering Corporation.

We have been developing these techniques using physical hydraulic model tests. In this paper, we report on the sediment discharge properties of these two techniques from the results of the tests and the challenges of putting them to practical use.

2 Sheet and Suction Pipe Sediment Discharge Facility

2.1 Concept of the Sediment Discharge Facility

Sheet and suction pipe sediment discharge facility (SSPF) consists of suction pipe and sheet. It sucks up sediment using the differential water head energy. The pipe is cut along the bottom and it sucks sediment from the opening in the bottom. When the bed shape changes due to the progress of sediment transport, it becomes difficult to entrain sediment because the space that develops between the pipe and the sediment surface results in only water being sucked up. In order to overcome this problem, a flexible pipe is used and an impermeable sheet is attached to the pipe to force the pipe onto the sediment surface. The bottom opening on the pipe functions as an inlet and creates a low pressure zone on the sheet.

After the sediment transport (sluicing) using the SSPF, the sediment develops a conical shaped hole. As a result, it is difficult to discharge large amount of sediment from one facility. However, as shown in Fig.1, there are many dam reservoirs in Japan whose mean annual sedimentation volume is less than several tens of thousands cubic meters. The SSPF is useful for these reservoirs with small amount of sedimentation to achieve the sediment transport balance. If the sediment’s angle of repose in water is assumed to be 30 degree, a conical shaped hole about

15m deep with a 26m radius is needed to disharge ten thousand cubic meters of sediment. Operational considerations for the SSPF at present are mentioned below (Fig.2).

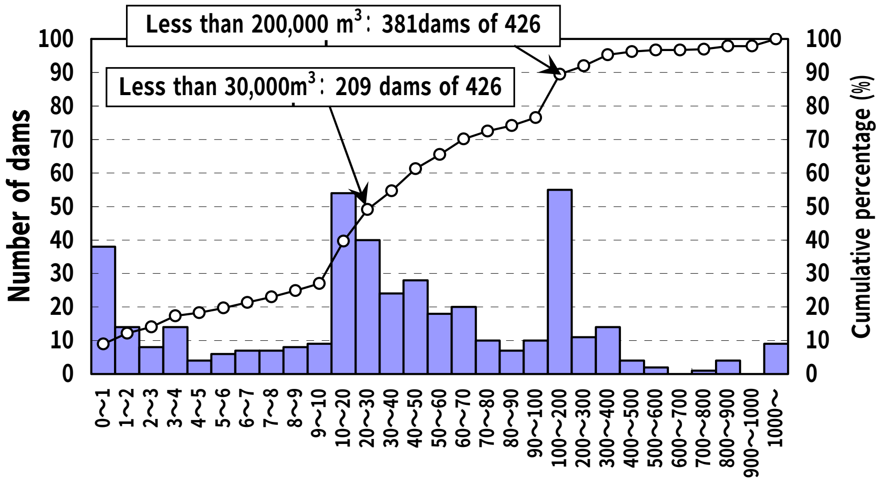


Fig.1 Mean annual sedimentation volume distribution
(This figure is based on the data of 426 dams in Japan)

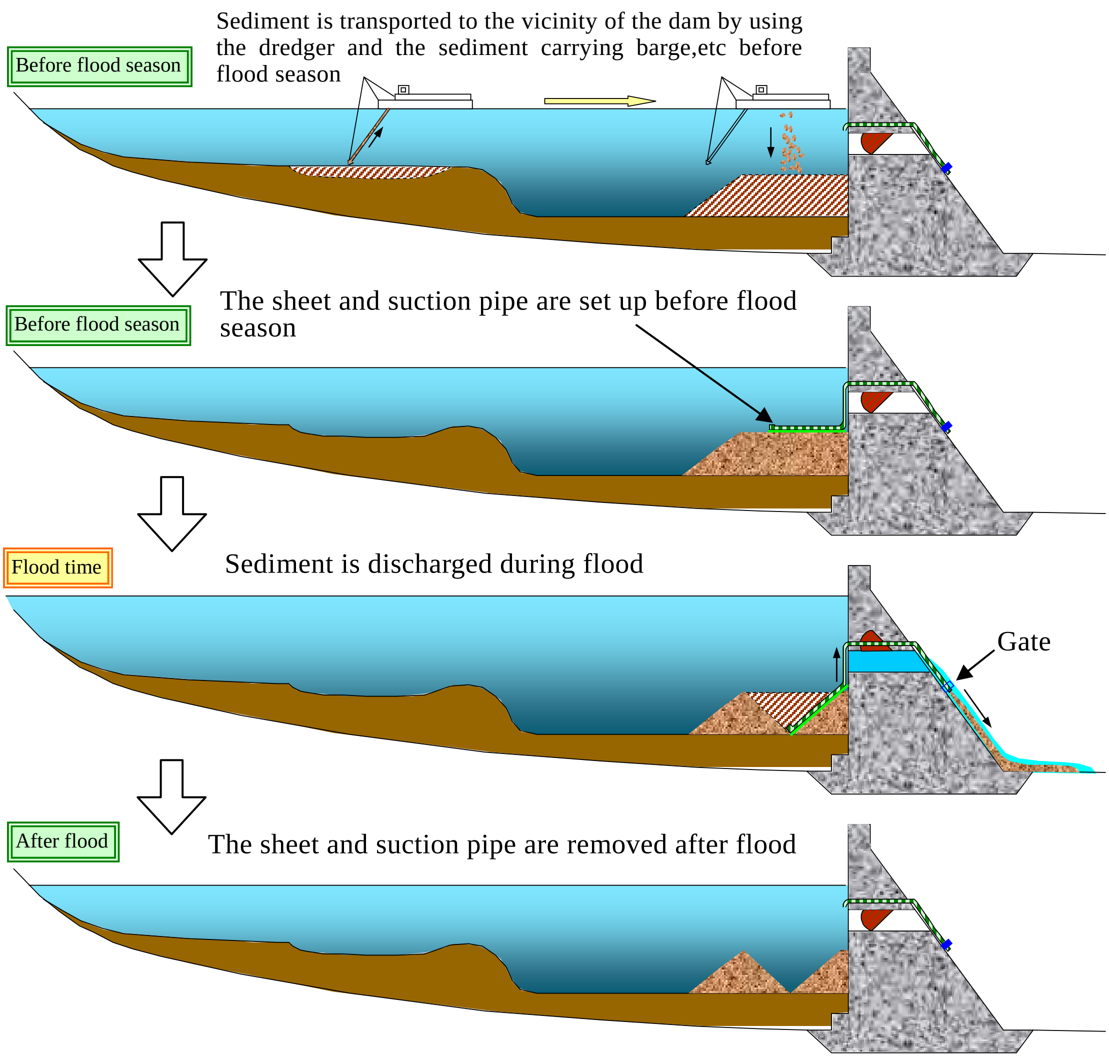


Fig.2 Operation image of sediment discharge facility by the sheet and suction pipe

1) Sediment is transported to the area near the dam before flood season.
2) Pipe and sheet are set up on the sediment to be transported before flood season.
3) Sediment discharge is carried out during flood by operation of the gate installed the end of pipe.
4) After sediment discharge is over, the pipe and sheet are removed for maintenance.
5) Processes mentioned above are repeated every year.

The reason why that sediment discharge is carried out during flood is to supply sediment at the downstream of the dam to re-create the natural sediment transport considering the downstream river environment.

2.2 Experimental Method

A hydraulic physical model was used to examine the sediment discharge characteristics of the SSPF. The outline of the experimental facility is shown in Fig.3. The water tank is 4.5m long, 2.5m wide and 1.3m high. Sand was placed 0.8m thick in the water tank, and the pipe and sheet were installed to make experiments. From the results of the examination reported before[4], using the PVC (polyvinyl-chloride) pipe inside diameter of 101.6mm, as shown in Fig.4 and Fig.5, it was confirmed that the SSPF could discharge sediment (sand) up to the cone depth became five times the pipe diameter.

In order to investigate the sediment discharge characteristics for the case when the ratio of pipe diameter to the conical depth after sediment discharge was larger than that of the past experiments and to examine the layout of pipe and sheet, experiments were performed using a pipe with a 60.5mm inside diameter.

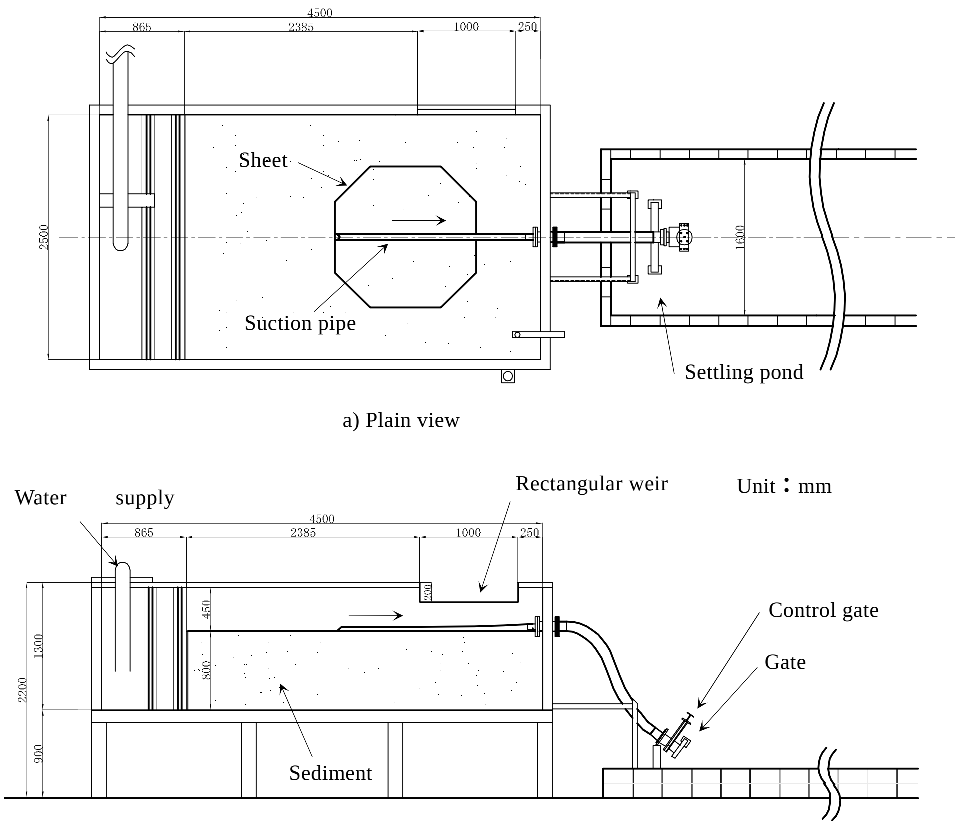


Fig.3 Outline of the experimental facility

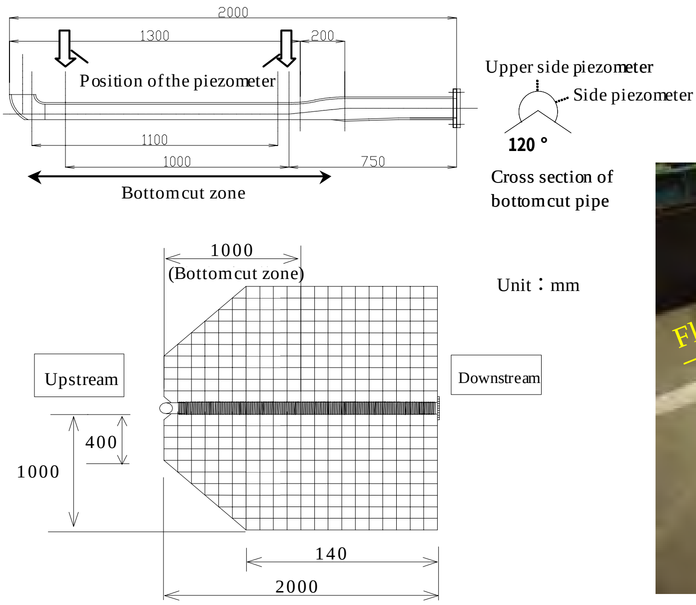


Fig.4 Outline of the hydraulic model
(Suction pipe and sheet)

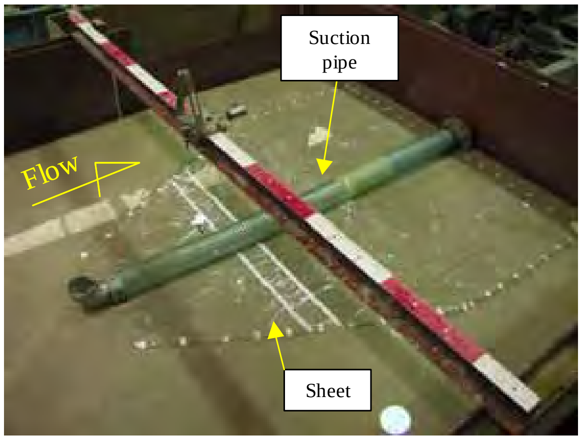


Fig.5 Installation of the suction pipe and sheet

The bottom of the upstream part of the pipe was cut as shown in Fig.4. In order to prevent the inlet at upstream of the pipe from being buried during sediment discharge, the shape of inlet of pipe was contrived. The sediment used for these experiments was silica sand with a uniform particle size distribution. The mean particle diameter was 1.3mm.

The inflow water to the tank was supplied by a constant flow rate pump. At the same time, the water level in the tank was kept almost constant by overflow from the rectangular weir. The gate was installed at the downstream end of pipe to control the flow rate from the sediment discharge facility.

2.3 Experimental Results

The results of experiments that were carried out before[4] are summarized as follow:

1) It is possible to discharge sediment till the cone depth became five times of pipe diameter for non-cohesive material (Fig.6).
2) For larger flow rates and smaller sediment particle diameters the sediment discharge increases (Table 1).
3) When the flow rate increases, the quantity of sediment sucked up from the downstream part of the bottom cut pipe increases (Fig.7).
4) As the conical shape of sediment is larger, sediment discharge rate becomes larger (Fig.8)
5) The correlation is confirmed between tractive force and sediment discharge rate (Fig.9)

Based on the result above, the layout of pipe and sheet was examined by checking the situation of sediment discharge using 60.5mm diameter pipe. The considered layouts of pipe and sheet are classified roughly as a one inlet layout, a two inlet layout, and a four inlet layout.

In the case of the one inlet layout, this case was already examined by using 101.5mm diameter pipe, an experiment using a sheet smaller than the one used before was carried out because it was thought that a smaller sheet would be easier to deploy in the reservoir. As a result, it was confirmed that SSPF is able to discharge sediment using the smaller sheet (8 times of the pipe

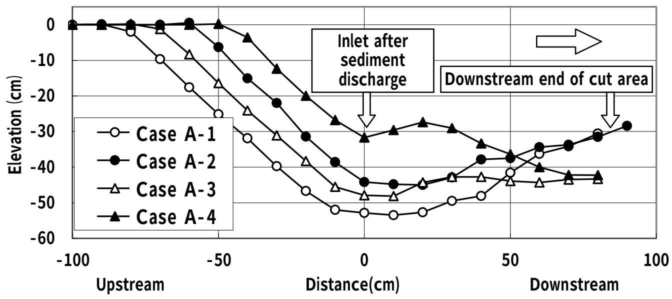
Table 1 Results of the experiments (pipe diameter: 101.6mm)

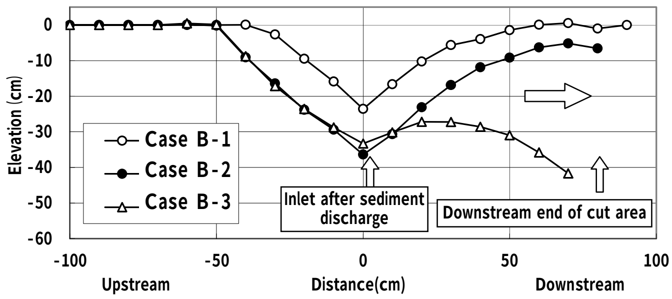
Case	Sediment material	Average flow rate (L/s)	Mean velocity (m/s) (Inside of suction pipe)	Average sediment discharge rate (Without void) (L/s)	Duration of sediment discharge (min)	Total discharged sediment volume (Without void) (m^3)
A-1	Average grain size 0.3mm	4.21	0.65	0.0266	170	0.42
A-2		5.29	0.81	0.0865	45	0.31
A-3		6.08	0.93	0.2628	30	0.44
A-4		8.37	1.28	0.8107	7	0.34
B-1	Average grain size 1.3mm	4.30	0.66	0.0035	150	0.03
B-2		5.11	0.78	0.0158	145	0.09
B-3		6.67	1.02	0.0986	30	0.23

a) Grain size 0.3 mm, discharge rate 4.21 L/s

b) Grain size 0.3 mm, discharge rate 8.37 L/s

Fig.6 Shape of sedimentation after sediment discharge





※ The position of the starting point in the direction of the upstream and downstream is based on the deepest elevation after sediment is discharged.

※ The position of the starting point in the vertical direction is based on the initial shape of sedimentation.

Fig.7 Section of sedimentation after the sediment discharge

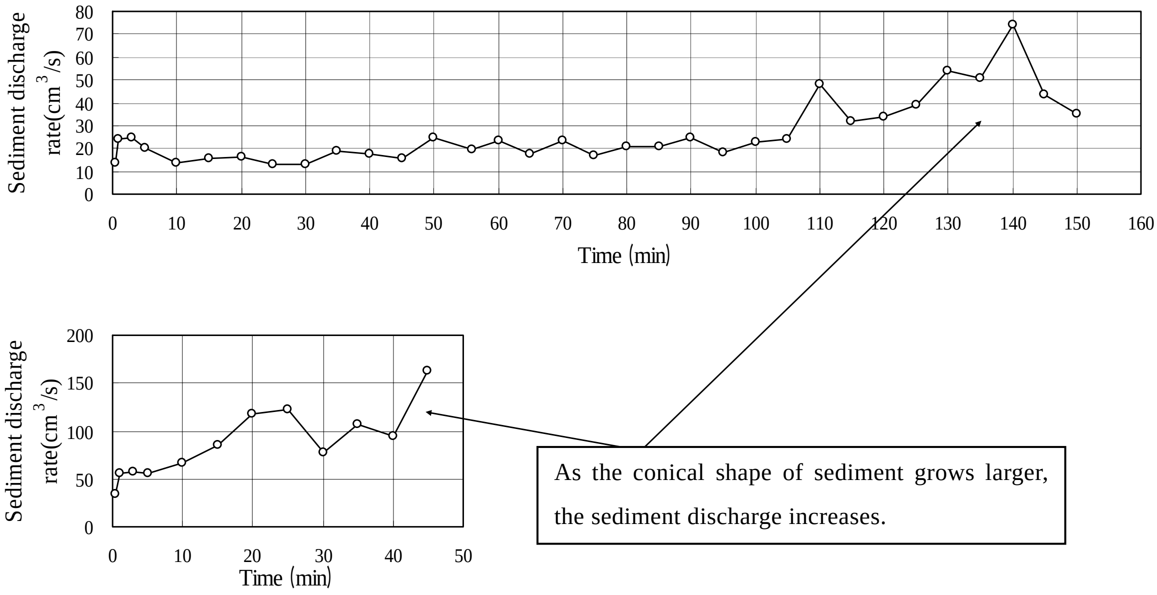
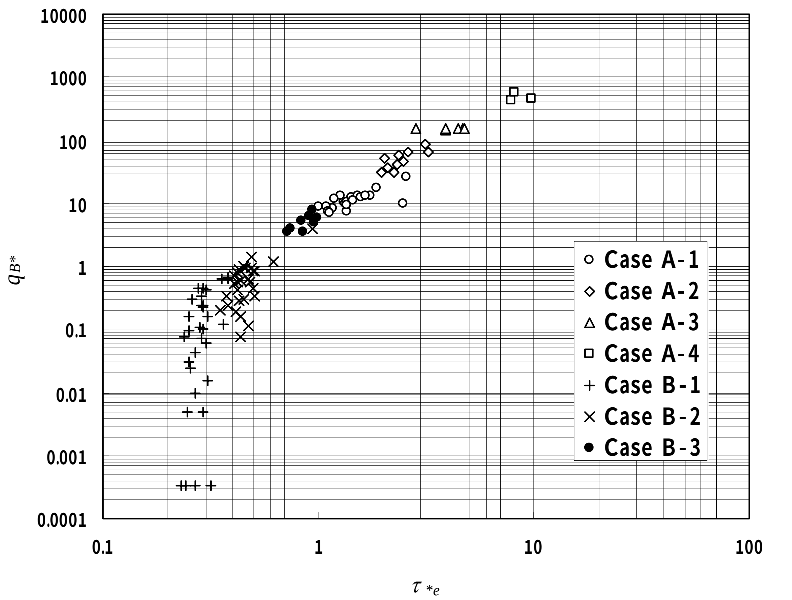


Fig.8 Time series of sediment discharge



τ_{*e} is calculated from the results of piezometric meter head in the cases of water flow only and water flow with sediment

Fig.9 Relationship between dimensionless friction resistance force of sand: τ_{*e} and dimensionless sediment discharge rate: q_{B*}

diameter) (Fig.10). However, as the sediment discharge proceeded, the conical shape of sedimentation became larger and the collapsed sediment deposited on the sheet. Finally, the pipe inlet was buried in sediment and a space in the pipe was almost filled with the sediment (Fig.11). In this situation, the system was not able to discharge sediment constantly and it was difficult to withdraw the sheet and the pipe after sediment discharge. Therefore, countermeasures against these problems will be need to be developed in the future.

In the case of a two inlet layout, we used a circle-shaped sheet and the bottom-cut pipe. We attached the pipe to the centerline of the sheet and connected another pipe at the center of the pipe (Fig.12). This layout was considered to suck up sediment from wide area by using two inlets. For the case that the bottom was cut from the entire length of pipe, the center part of the pipe sank under the sediment in advance during sediment discharge. In this situation, it is difficult to withdraw the facility after sediment discharge. Next, the bottom area near the center of the pipe was blocked. After that modification, both ends of the pipe sank in advance (Fig.13). However, as the sediment discharge proceeded, the sheet gathered toward pipe with wrinkles and the inlets were buried with sediment.

In the case of a four inlet layout, we used a circle-shaped sheet and bottom-cut pipes cross-jointed. We attached the pipes to the sheet and connected another pipe at the center of the pipe (Fig.14). This layout was considered to suck up sediment from a wider area and use the pipes as frame structure for spreading the sheet. In the case that the bottom was cut from the entire length of pipe, the center part of the pipe sank under the sediment in advance as it did for the two inlet layout (Fig.15). In the case that the bottom area near the center of the pipe was blocked, cross-shaped pipes prevented the sheet to follow sediment surface. As a result, the ends of the pipe were lifted and SSPF could not suck up sediment (Fig.16).

At present, there are problems in each layout. Authors believe the one inlet layout has the most potential because of its simple shape and structure. We will continue to develop countermeasures for the problem where the inlet is buried by sediment.

3 Air Valve Sediment Discharge Facility

3.1 Concept of the Sediment Discharge Facility

In order to discharge sediment using a fixed discharge facility without lowering the reservoir water level, it is required to move the inlet to follow the sediment surface which moves during the sediment discharge process. This is because to act the suction power on the sediment surface constantly by discharging water. Then, the air valve type withdrawal equipment is adopted as an inlet movable vertical direction.

The air valve type withdrawal equipment is one of the selective withdrawal facilities. It has continuous inverted V-shaped siphon pipes which stop water by pouring air into the top of pipe and it can take water through selected siphon pipe[5]. It is also called as continuously selectable gateless withdrawal equipment.

As for sediment discharge facility, there is concern that the gate will not work because of sediment clogging the gate guides. The air valve is suitable for the inlet portion of the sediment discharge facility because it uses air to stop water and doesn’t have the gate.

Fig.10 One inlet layout

Fig.11 Situation of the sediment discharge
(One inlet layout)

Fig.12 Two inlet layout

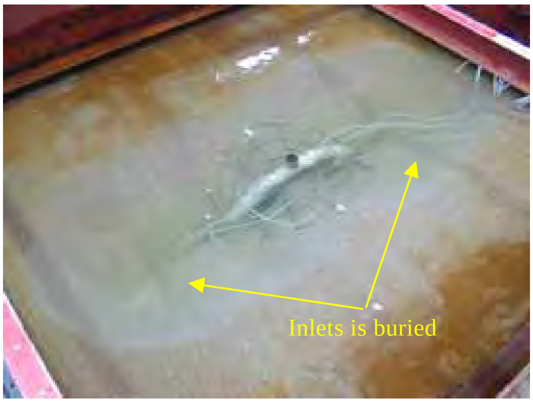


Fig.13 Situation of the sediment discharge
(Two inlet layout)

Fig.14 Four inlet layout

Fig.15 Situation of the sediment discharge
(The bottom of all length of the pipe is cut)

Fig.16 Situation of the sediment discharge
(Bottom cut parts are installed at the edge)

An image of sediment discharge by the air valve sediment discharge facility (AVF) is shown in Fig.17.It discharges sediment through the siphon pipe from upper to lower to fit the slope of the sediment surface.

After sediment discharge using the AVF, the shape of the sediment is considered to become a half conical shape pocket. It is also difficult to discharge large amount of sediment by one facility as with the SSPF. When the sediment's angle of repose in water is assumed to be 30 degree, in order to discharge sediment of ten thousands cubic meters, it is required to excavate a half conical shape that is about 19m deep with a 33m radius.

Operational considerations for the AVF at present are mentioned below (Fig.18).

1) Sediment is transported to the area near the dam before flood season.
2) Sediment discharge is carried out during flood by operation of the gate and selection of siphon pipe.
3) Processes mentioned above are repeated every year.

3.2 Experimental Method

A hydraulic physical model was used to examine the sediment discharge characteristics of the AVF. The outline of the experimental facility and the hydraulic model are shown in Fig.19. The water tank is 4m long, 3m wide and 1.4m high. We placed a 1.2m thick sand in the water tank, and set up the air valve model. The cross section shape of the siphon pipe is 0.33m wide and 0.05m high. Two siphon pipes, an intake tower, and the discharge pipe were modeled. The sediment used for these experiments was silica sand with a uniform particle size distribution. The mean particle diameter was 1.3mm.

The experimental procedure is summarized as follows:

1) The initial shape of the sediment hole is a half-conical shape with an angle of repose of sediment in water. The inlet of upper pipe is about 50 percent blocked by sediment.
2) Sediment is discharged through the upper pipe with 80% opening of downstream gate. 80% is the largest opening that maintains the air lock in the lower pipe.
3) After the sediment discharge through the upper pipe was finished the downstream gate is closed and the shape of the sediment scour hole is measured.

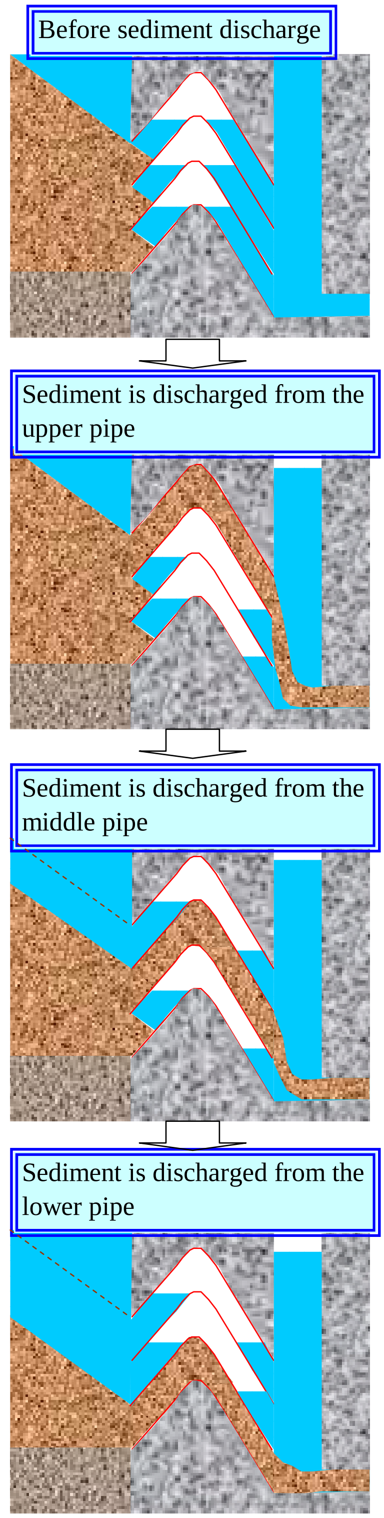


Fig.17 Sediment discharge image by the air valve facility

4) Flow is changed from the upper pipe to the lower pipe by coordinating the air valve, and sediment is discharged through the lower pipe. At that time, sediment discharge rate, water level in the tank, water level in the intake tower and pressure in the pipe are measured.

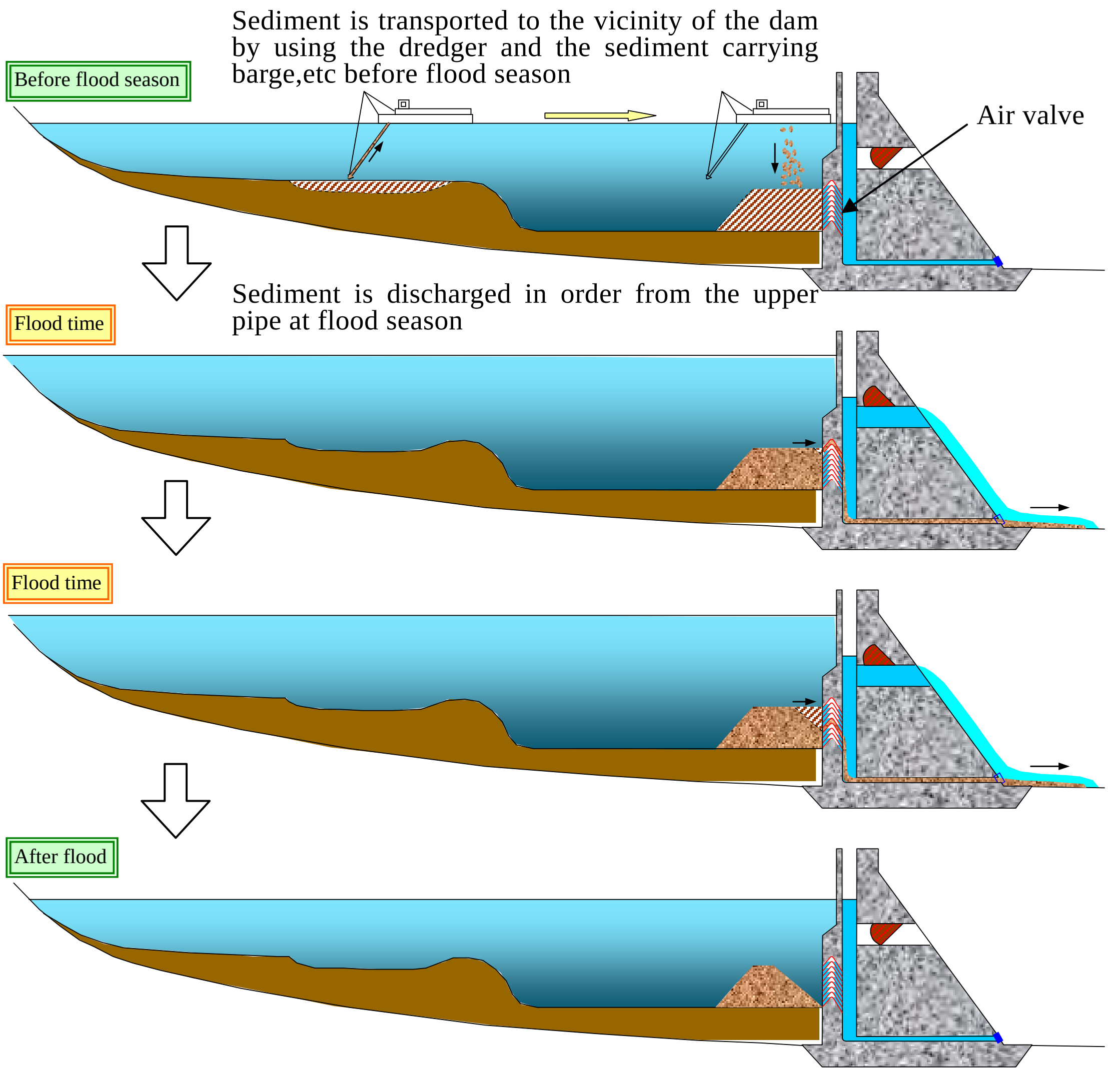
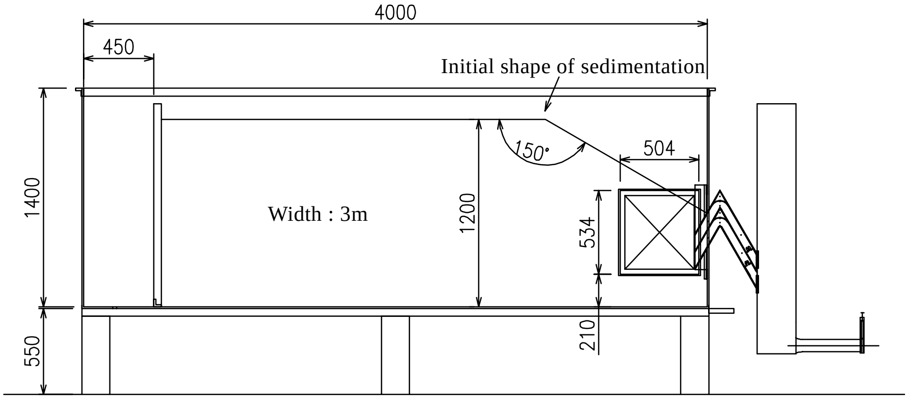
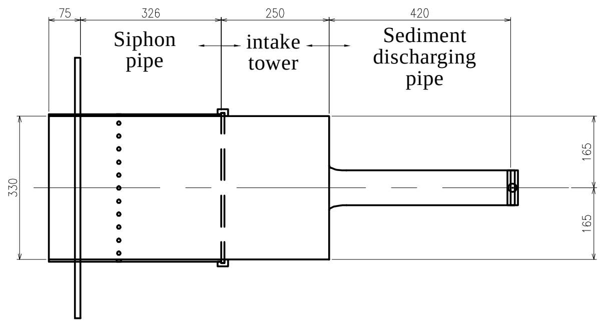


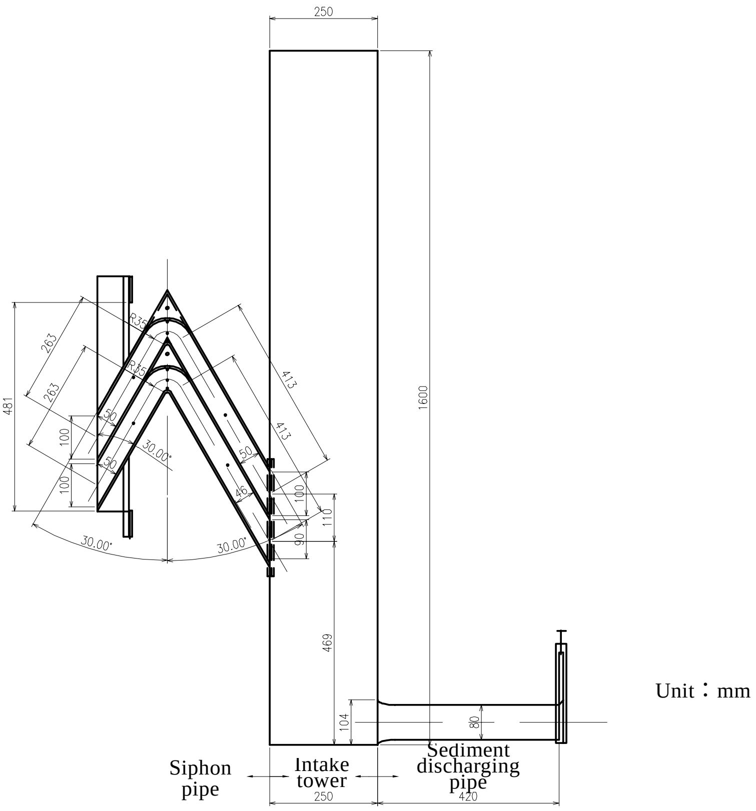
Fig.18 Operation image of the air valve sediment discharge facility



a) Side view of the experiment water tank



b) Plain view of the air valve facility



c) Side view of the air valve facility

Fig.19 Outline of the hydraulic model of the air valve facility

3.3 Experimental Results

The rate of sediment discharge is shown in Fig.20. Immediately after the start of flow, large sediment discharge occurred and the peak sediment transport occurred about one minute after the start. After that, the sediment discharge rate decreased rapidly. Five minutes into the test sediment discharge practically finished.

The resulting shape of the sediment hole is shown in Fig.21 and Fig.22. After sediment discharge through lower pipe was finished, the shape of sedimentation became one size lager than before discharge and stable. In the front of inlets the sediment surface at the centerline was elevated and was scoured near the edges in both cases – upper pipe discharge and lower pipe discharge. The reason of this pattern was considered that there was scouring at the corners affected by local flow.

The experimental situation of the sediment discharge is shown in Fig.23. From observations of the experiment, the following points were confirmed. After the sediment discharge through upper pipe was completed, the inlet of lower pipe was almost buried (as shown in Fig.22). But it was possible to discharge sediment through lower pipe by diverting water through the lower pipe. Just after the start of discharge, very high condensed sediment flowed through pipe into the intake tower. At that time, the water level in the intake tower declined significantly. In the preliminary experiments, when the lower gate was suddenly opened, the air lock in the upper pipe was broken. It is important to consider this point for operation of the AVF. In this experiment, during initial

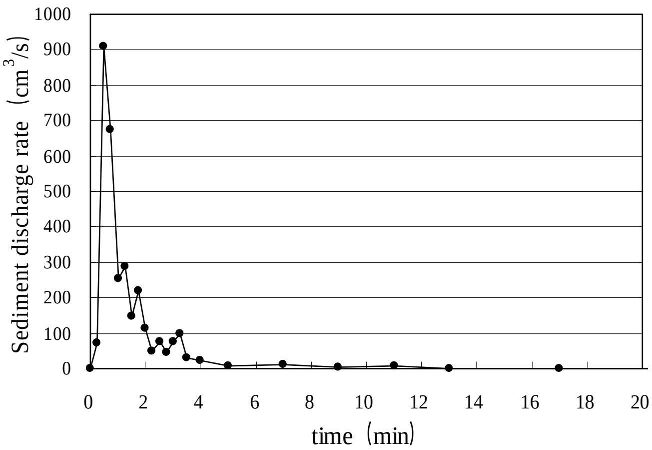


Fig.20 Time series of sediment discharge through the lower pipe

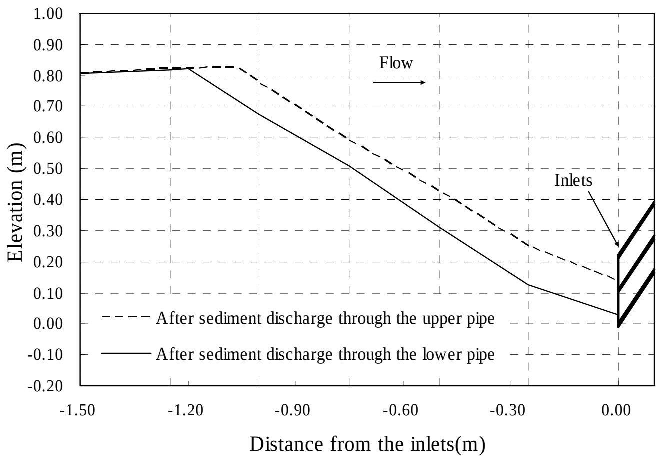


Fig.21 Shape of sedimentation after sediment discharge (longitudinal direction at center of the inlets)

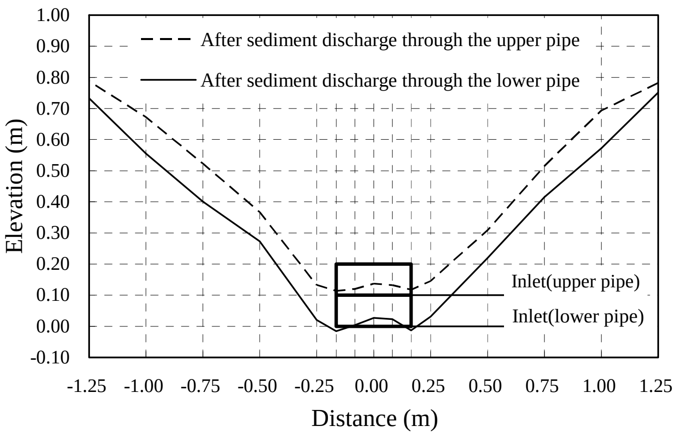


Fig.22 Shape of sedimentation after sediment discharge (transverse direction at just upstream of the inlets)

stage of discharge (high codensed sediment), sediment flowed into the space above the pipe for air supply route through air supply opening holes made at upper aspect of bending of pipe. This point should be considered during the facility design. As for the situation downstream of pipe, during high codensed sediment discharge period, sediment flow in the intake tower was rather turbulent and there was sediment deposition at the bottom. However, sediment flow from the siphon pipe into the lower gate was relatively smooth.

Future test plan include experiments of various discharge rates and sediment diameters, and the

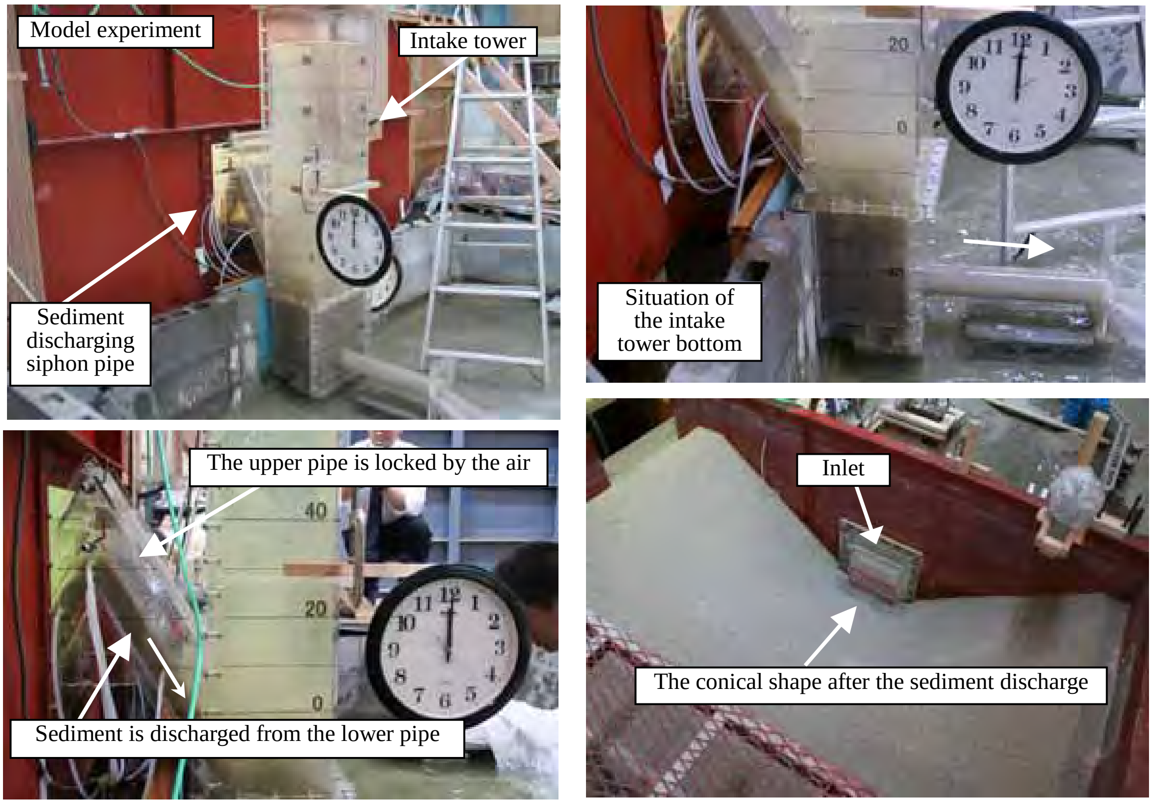


Fig.23 Experimental situation of the sediment discharge using the air valve facility

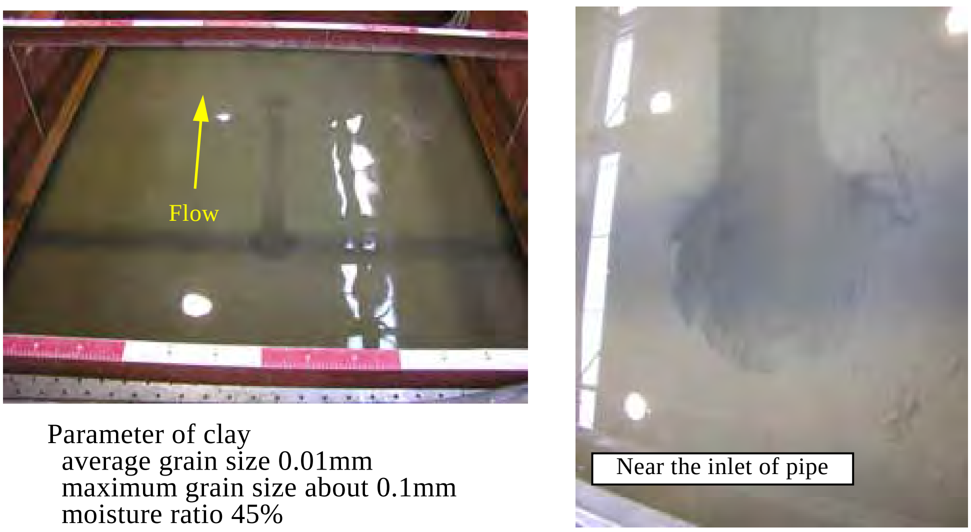


Fig.24 Shape of sedimentation(clay) after sediment discharge using the sheet and suction pipe

accumulation of more experimental data. We will also try to further develop sediment discharge ability, design methods and operational methods.

4 Summary

The results of experiments to develop the sediment discharge techniques using the differential water head energy without lowering reservoir water level are reported. Using physical hydraulic model tests, it was confirmed that it was possible to discharge non-cohesive sediment by sheet and suction pipe sediment discharge facility and air valve sediment discharge facility.

However, there are problems mentioned in section 2 and 3 that need to be addressed in order to put these two techniques into practical use. Other areas of research include cohesive sediment discharge and sediment transport in reservoir. Both of two reported techniques utilize fixed facilities. Sediment around the inlet is required to collapse and collect at the point of the inlet. Therefore, it seems difficult to apply these techniques to cohesive sediments that can sustain a vertical face in the water. In fact, experiments in the sheet and suction pipe facility using cohesive sediment, showed it could only suck up sediment near the pipe (Fig.24). In order to cope with this problem, we have to develop an auxiliary measure to disturb cohesive sediment in addition to this or we have to limit to non-cohesive sediment. Considering the actual operation, sediment transport through the reservoir is needed for these techniques to be effective. If the techniques, at present, are adopted, the sediment will need to be transported by dredgers or sediment carrying barge to the facility. Since dredge and haul operations are relatively expensive, it will be necessary to develop economical methods to transport sediment through the reservoir to the sediment transport facility.

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