EXPERIMENTAL STUDY ON THE VMHS METHOD USING A WATER HEAD

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ABSTRACT

The sedimentation is a major issue for dam management as it severely affects the capacity of the reservoir. To address these concerns, some recent suction systems are being developed. These natural vacuums-which utilize the clean potential energy created by the difference of the water-head in relation to the surface of the water reservoir-have a significant improvement on the removal of sediment. We demonstrated and tested the "Multi Hole Suction pipe" (MHS) method with the suction pipe positioned horizontally to absorb the sedimentation which liquefied by negative pressure. After the test, we understood that some improvement for the practical use was necessary. Then, we came up with the "Vertical Multi Hole Suction pipe" (VMHS) method which sets the suction holes on a vertically plumbed pipe. The system is superior to the conventional one in that fluid containing the sediment flows in the same direction as gravity acts. We grasped an effect to give to the flow velocity distribution, the volume of sediment discharge, water head loss and so on. And, we considered how to use this method practically in a real-life situation.

INTRODUCTION

Since 2001, the authors have been developing the "Multi Hole Suction pipe" (MHS) method (Figure. 1). The MHS method is a method of removing sediments deposited in the reservoir bottom. To be specific, the dam reservoir's water level difference is used to generate water currents inside the suction pipe. As negative pressure is generated inside the pipe, the sediments are sucked up. Sediments inside the pipe are conveyed to the outlet where they are removed from the reservoir.

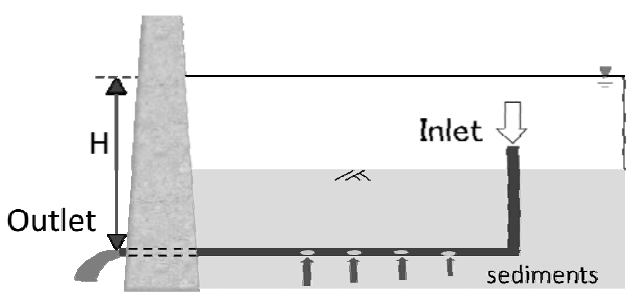

Figure 1. Image of MHS method.

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In 2009, a field full-scale experiment was conducted, but sediment suction was stopped only 20 minutes after the start of suction against a sediment thickness of 5 m.

It is speculated that the main cause of this phenomenon is the occurrence of arch action (Figure. 2), which is established in the upper part of the suction pipe after a certain volume of sediment is sucked up and causes the sediment around the suction pipe to become self-sustaining, thereby ultimately stopping sediment collapse. The same phenomenon is also seen in other case examples. As a solution, we conducted an experiment to improve the conventional procedure of suction into the “Vertical Multi Hole Suction pipe” (VMHS) method. To be specific, a suction pipe with many suction holes is installed vertically in the sediment, and the sediment is suctioned through the holes closer to the surface layer so as to promote the sediment collapse and prevent generation of arch action (Figure. 3). For the mode of sediment discharge using the VMHS method, suction begins with the sediment near the surface after the start of suction, and continues until the sediment forms a stable gradient. Thereafter, water alone is suctioned, and the suction process is completed. In our experiment, suction characteristics were examined with a 1:30 scale indoor hydraulic model by changing the size of sediment particles, the size of suction holes, and the number of holes.

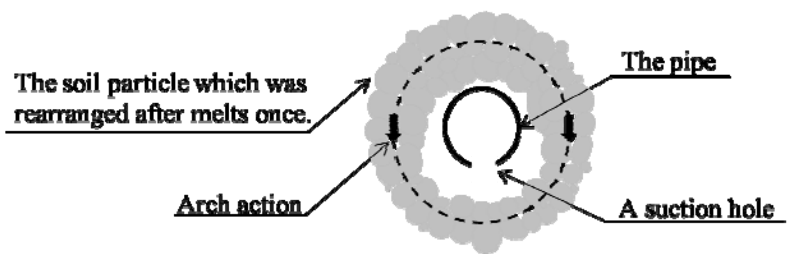

Figure 2. The Pipe cross section.

【The start of suction process】 【The end of suction process】

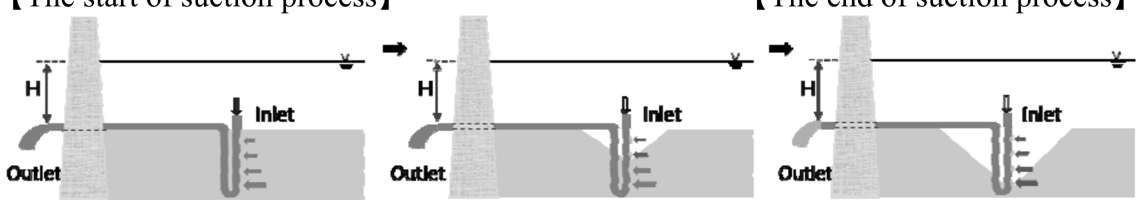

Figure 3. Image of VMHS method.

INDOOR HYDRAULIC MODEL EXPERIMENT PLAN

Model scale

The model scale is 1:30. The assumed thickness of the sediment for suction is 15 m. A based on this assumption, for the model, the thickness of sediments for suction is set to 50 cm. A transparent acrylic pipe is used as a suction pipe (Table 1).

Measurement items

Measurement items for each case include pressure in the pipe, flow velocity in the pipe, flow velocity at the inlet, sediment concentration in the pipe, flow rate, and sediment discharged. To measure the suction time, completion of suction was measured visually for inclusion in the measurement data (Figure. 5, 6).

Table 1. Model scale.

Conditions	Unit	Indoor	Assumed field	Ratios
Thickness of the sediment	m	0.5	15.0	1/30
Pipe internal diameter	mm	52	1,560	1/30
Sediment discharge	m^3/s	0.1×10^{-3}	0.56	$1/30^{2.5}$
Flow velocity in the pipe	m/s	1.4	7.5	$1/30^{0.5}$
Flow rate	m^3/s	3.5×10^{-3}	1.1	$1/30^{2.5}$
Water head	m	1.5	45.0	1/30
Particle size	mm	0.2	0.2	1/1

Water level difference

About 1.5 m was determined for the water level difference used in the experiment based on the preliminary experiment conducted under conditions that would not cause pipe clogging, while using the limit flow velocity of 1.4 m/s (experiment scale) by Durand's equation under the conditions of 52 mm in suction pipe diameter and 5% in sediment concentration.

Sediments for suction

Take Sakuma Dam for instance. The average particle size of the sediment to remove is 0.2 mm (d_{50}). Froude's law of similarity isn't applicable to the particle size. Therefore, our experiment used silica sand of 0.16 mm in d_{50} as a representative type of sandy soil. In order to identify the effects of the size of sediment particles on the suction function, silica sand of 0.67 mm in d_{50} is used in another experiment for control. Experiments were conducted under water and sediment condition without obstacles such as chip of woods.

Suction-hole conditions

Suction holes of two diameters (26.8 mm and 42.4 mm) are used. For the hole interval, three patterns are used: 100 mm (for five holes), 200 mm (for three holes), and a single hole at the bottom end. Therefore, a total of six patterns of suction-hole specifications are tested in the experiment (Figure. 4).

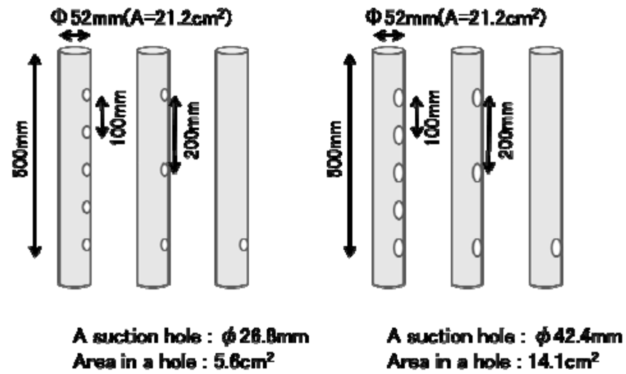

Figure 4. Number of holes and diameter.

Experiment Plan

The vertical installation (Type A) is the basic type of experiment. An experiment with the conventional horizontal installation type (Type B) is also conducted as a control experiment. Table 3 is the experimental condition.

Table 3. Experimental condition.

Item	Condition
Pipe	Diameter : φ60mm (External) φ52mm (Internal) Extension : Close to 0.6m(Suction process) Close to 8.0m(Rundown process)
Suction hole	Diameter : φ26.8mm,φ42.4mm Spacing : 100mm,200mm Number of holes : 5,3,1
Water head	1.5m
Thickness	0.5m
Sediments	d_{50}=0.16mm,d_{50}=0.67mm

<u>Type A</u>. Type A is a model based on the basic type of the VMHS method (Figure 5).

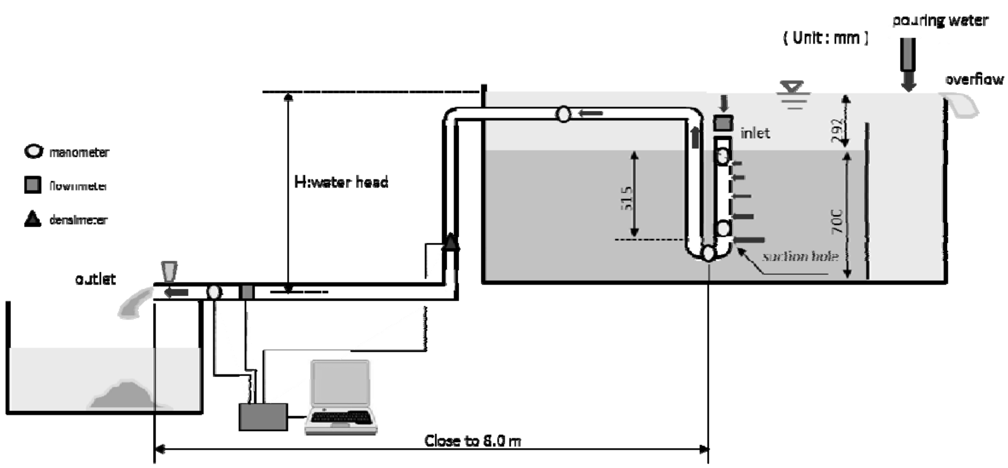

Figure 5. Type-A model.

Type B. Type B is a model of the basic type of the MHS method (Figure 6).

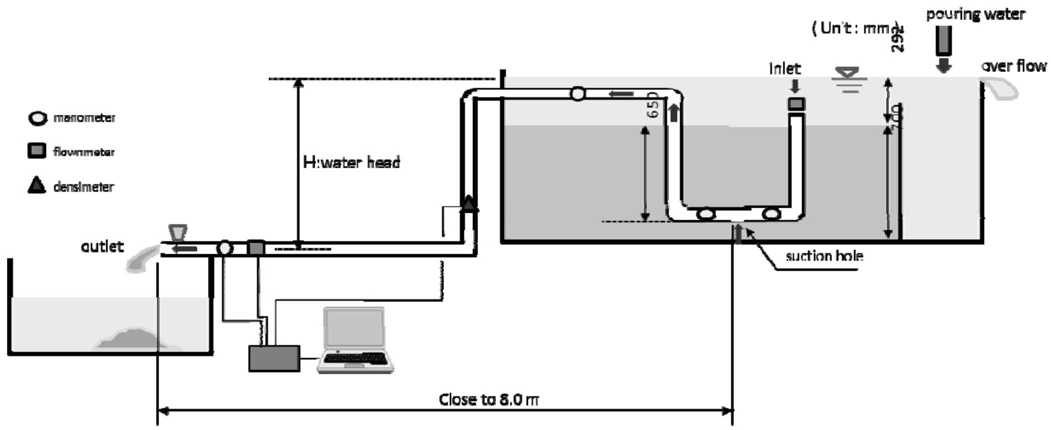

Figure 6. Type-B model.

Experiment cases. Experiment cases are shown in Table 4.

Table 4. Case of experimental.

Type	No.	Case	Particle size (mm)	Suction hole Diameter (mm)	Suction hole Number of holes
A	1	Case-A1-1	d_F=1.14	φ42.4	1
	2	Case-A1-2			3
	3	Case-A1-3			5
	4	Case-A2-1	d_F=1.57	φ42.4	3
	5	Case-A2-2			1
	6	Case-A3-1	d_F=1.57	φ25.5	1
	7	Case-A3-2			3
	8	Case-A3-3			5
	9	Case-A4-1	d_F=1.14	φ25.5	3
	10	Case-A4-2			3
B	11	Case-B1-1	d_F=1.14	φ42.4	1
	12	Case-B1-2		φ25.5	1

EXPERIMENT RESULTS

Experiment results

In measurement items for each case, velocity, concentration and volume (as cumulative sediment discharged) are as follows with a chart of the result:

Case A1-1. The time it takes to reach a steady suction state differs between the suction inlet and the outlet, but the inflow velocity through the inlet almost agreed with the theoretical value, which is (1.5; flow velocity at the outlet) × (19.6; area of the inlet) / (19.6; sum of the area of inlet and 14.1; the area of suction holes) and takes a value of 0.9 m/s for this case. Once the conditions reached a steady state, the concentration of sediments reached the maximum, or about 13% (Figure. 7).

Case A1-2. The pipe used had a greater number of holes than in the previous case. A steady suction state was reached immediately. Consequently, the inflow velocity was smaller than the theoretical value (which is 0.5 m/s for this case), and there was a large inflow from the suction holes. The sediment discharge time was earlier than in Case A1-1 for just about 2 minutes, and the maximum concentration of sediments was about 14% (Figure. 8).

Case A1-3. The pipe used had even more holes than in the previous case. Like Case A1-2, a steady suction state was soon reached, and the inflow velocity was smaller than the theoretical value (which is 0.4 m/s for this case). Inflow was observed through almost all suction holes, and the inflow velocity was greater than in Case A1-2. The maximum concentration of sediments was about 15% (Figure. 9).

Case A2-1. The size of sand particles used was greater than in the previous case. Then, the suction pipe occluded. Put a rise flow, as much as the size improves, the gravitational action is superior to the water pressure to depend on a projection area. Therefore, the system was not capable of transporting the greater particles within the pipe. It is indicated as in Figure. 10 that the pipe is more likely to be clogged with a greater particle size even though the number of suction holes and the size of holes remain the same.

Case A2-2. The pipe used had fewer holes than in the previous case. The pipe occluded 15 minutes later. For reference, after I shook the pipe, suction continued. In early 15 minutes, the maximum concentration of sediments reached was about 9% (Figure. 11).

Case A3-1. The pipe used had a smaller-hole size than in the previous case. The inflow velocity was almost the same as the theoretical value (which is 1.2 m/s for this case), and the sediment concentration remained almost constant. The maximum reached was about 5% (Figure. 12).

Case A3-2. The pipe used had a greater number of holes than in the previous case. Although the total area of three smaller suction holes was greater than that of the larger one hole, no pipe clogging occurred, unlike in Case A2-2. The inflow velocity was smaller than the theoretical value (which is 0.8 m/s for this case), and a large inflow through the suction holes was observed. This case saw a larger suction (sediment discharge) velocity than the case with one suction hole. The maximum concentration of sediments reached was about 7% (Figure. 13).

Case A3-3. The number of suction holes further increased from the previous case. The sediment concentration was high in the initial stage of the experiment but began to decline gradually. The inflow velocity was smaller than the theoretical value (which is 0.7 m/s for this case), and there was a large inflow through the suction holes. The suction velocity was larger than the case with three holes, and the maximum concentration of sediments was about 9% (Figure. 14).

Case A4-1. The sediments used had a smaller particle size than in the previous case. A steady suction state was reached immediately, and the inflow velocity was smaller than the theoretical value (which is 0.7 m/s for this case). During the steady suction state, the sediment concentration reached the maximum, and the cumulative volume of sediment discharge came out smaller than in the case with a larger particle size (Figure. 15).

<u>Case A4-2</u>. The pipe used had fewer holes than in the previous case. The same trend as that of Case A4-1 was observed (Figure. 16).

<u>Case B1-1</u>. The type of method used in Case A1-1 was replaced with the conventional type in this case. About 35 minutes after the start of the experiment, the volume of sediments suctioned increased, the inlet velocity reduced, and the sediment concentration enhanced. It is speculated that the increase in the cumulative volume of sediment discharge is because sediments were suctioned at a relatively greater depth (Figure. 17).

<u>Case B1-2</u>. The pipe used had a smaller hole-size than in the previous case. There was a large inflow from the inlet, but the volume of suction was small, and the sediment suction concentration was high. It is speculated that a smaller volume of suction promoted suction suspension by arch action (Figure. 18).

The explanatory notes in the charts are as follows:

①:Velocity (m/s),:Velocity (m/s), ②:Concentration (%), ③:Volume (m^3)

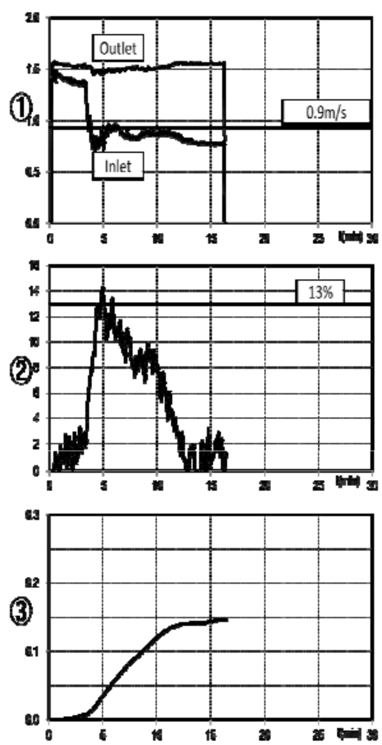

Figure 7. Case-A1-1.

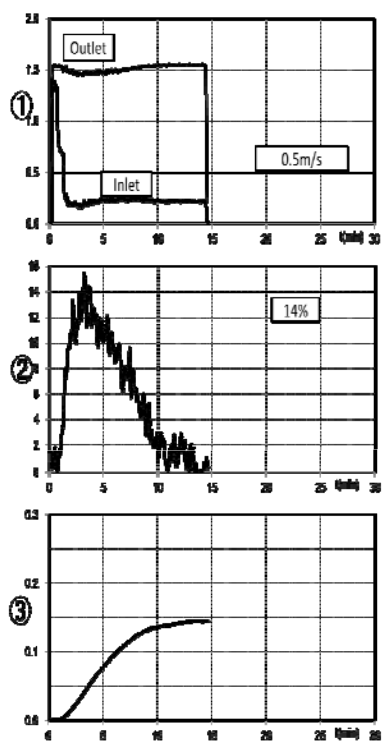

Figure 8. Case-A1-2.

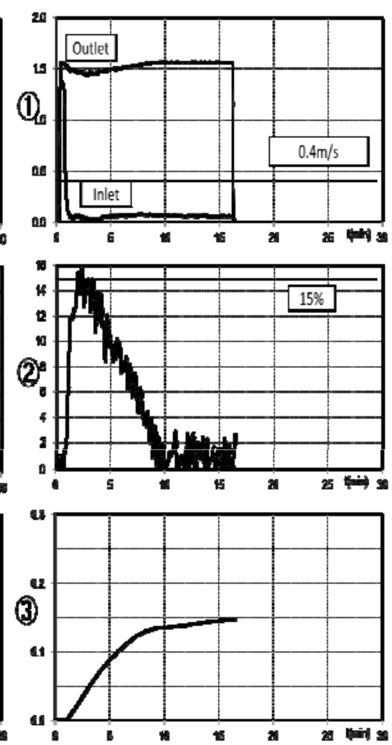

Figure 9. Case-A1-3.

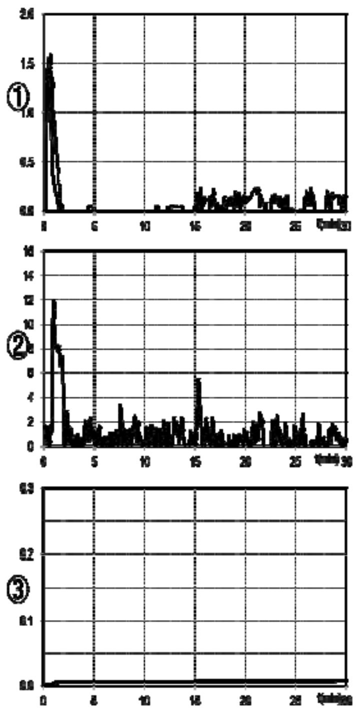

Figure 10.Case-A2-1.

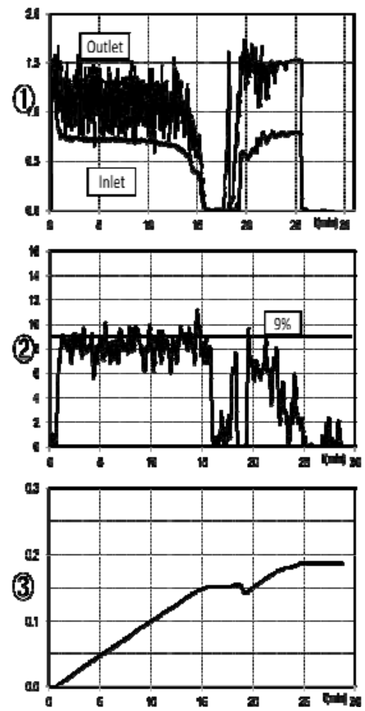

Figure 11.Case-A2-2.

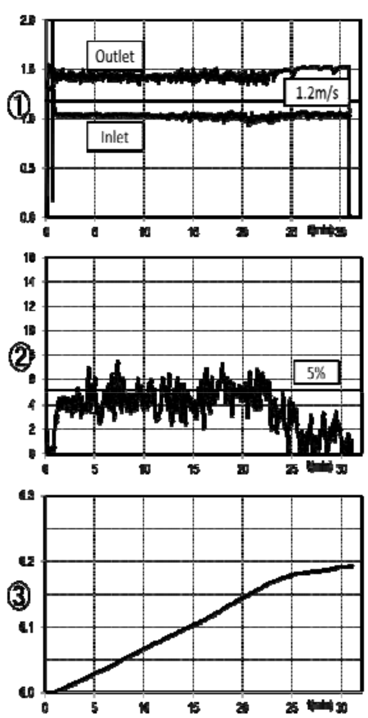

Figure 12.Case-A3-1.

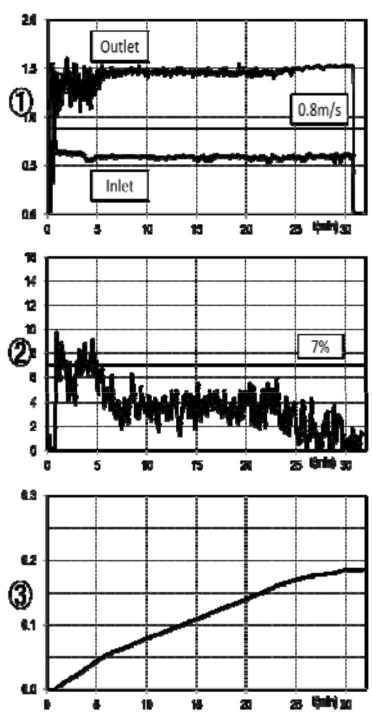

Figure 13.Case-A3-2.

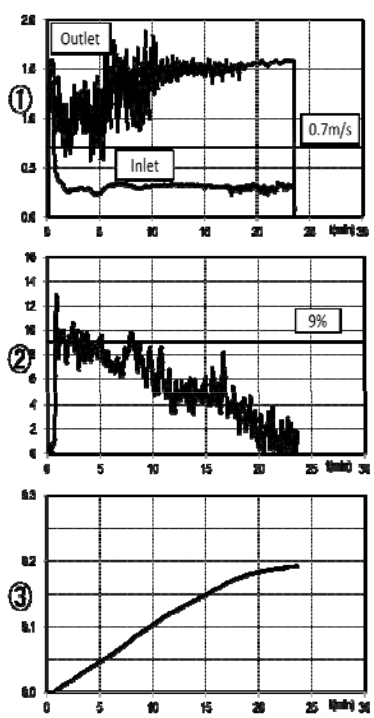

Figure 14.Case-A3-2.

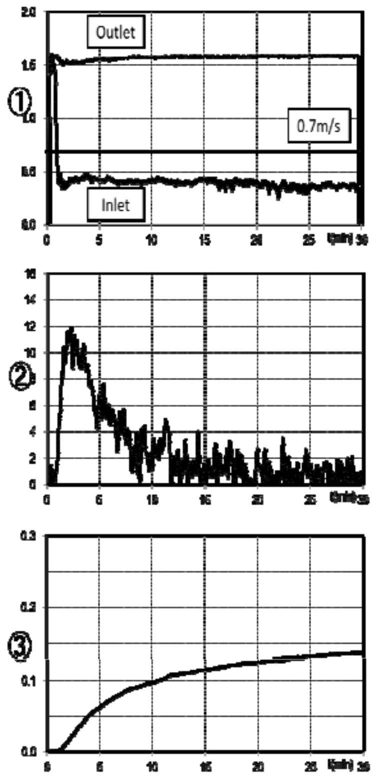

Figure 15.Case-A4-1.

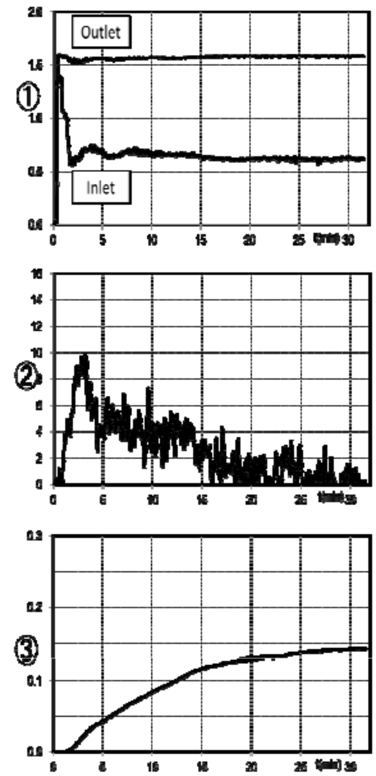

Figure 16.Case-A4-2.

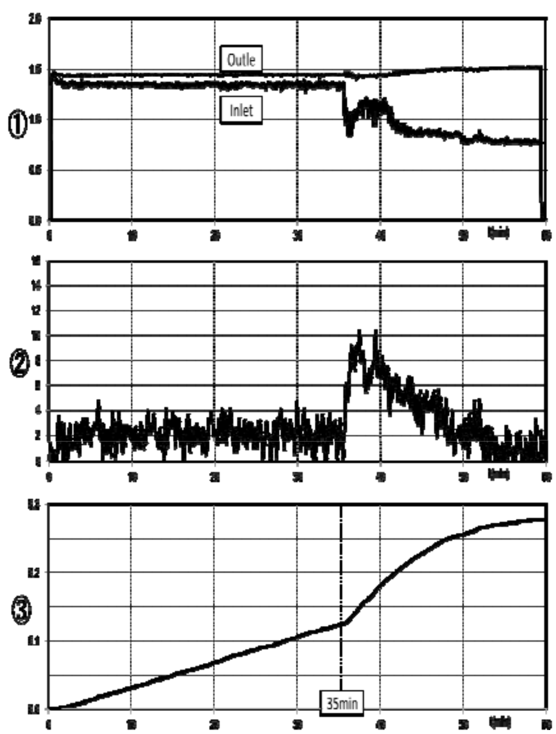

Figure 17.Case-B1-1.

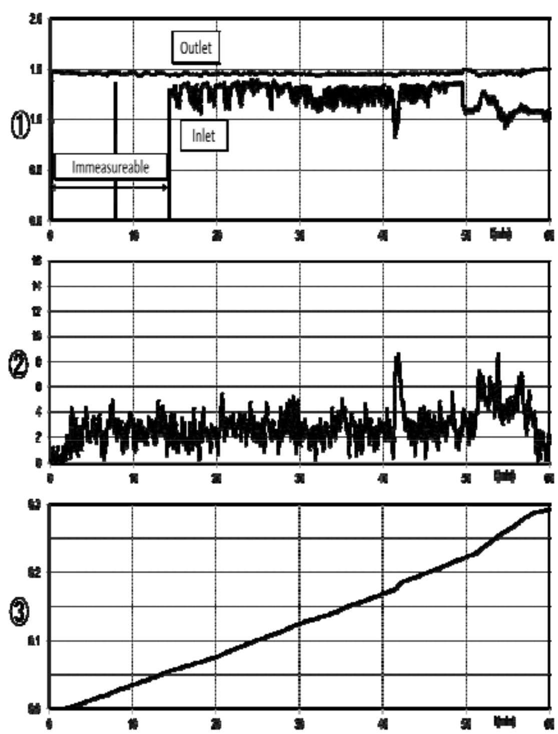

Figure 18.Case-B1-2.

DISCUSSION

The experiment results are examined as follows:

Suction velocity

In Cases A1-1,A1-2, and A1-3, the number of holes was changed to 1, 3, and 5, respectively, keeping the same suction hole size (42.4 mm) and sediment particle size (0.16 mm in d_{50}). With the increased number of holes, the velocity through the inlet decreased while the velocity at the outlet remained almost constant, confirming that the inflow through the suction holes increases as the number of holes increases. When the number of holes increases, the concentration of removed sediments also increases. Since the cumulative volume of sediment discharge is constant (or about 1.5 m^3), increasing the number of holes can shorten the time until sediment discharge is complete. Since suction with one hole sucks up sediments at a great depth, it takes a lot of time to reach a steady suction state. On the other hand, it does not take much time to reach a steady condition in cases with two or three holes.

Pipe clogging

After all, the size of sediment particles influenced performance. Cases A2-1 and A2-2 are larger sediment particle size versions of Cases A1-1 and A-3, respectively. The results also show that as the particle size increases, the pipe becomes more likely to clog even if other conditions stay the same. On the other hand, Cases A3-2 and A3-3 see no pipe clogging even though the total area of suction holes is greater than that of Case A2-2. Since pipe clogging does not necessarily depend on the total area of suction holes, results analysis shows that making appropriate arrangements about the layout of suction holes or the number of holes can control pipe clogging.

Total volume of sediment discharge

The total sediment discharge volume is proportional to the cube of the depth of the suction-hole installation. But since the stable gradient also changes, the difference in type of sediment will also change the total sediment discharge. For cases with smaller particle sizes, the cumulative sediment discharge was 1.5 m^3. But for cases with larger particles, the cumulative sediment discharge reached 1.9 m^3. As the sediment particle size decreases, impermeability becomes dominant due to the trickle current contained in the flow, thereby increasing the stable gradient. It is therefore necessary to pay attention to the fact that the cumulative sediment discharge will change as a result of change in particle size.

Arch action of the conventional MHS method

Case B1-1 uses the conventional MHS method, but since the flow velocity between the outlet and the inlet remains low for a long time, analysis results show that inflow through the suction holes will remain small for a long time. It takes over 30 minutes to realize effective sediment suction, and the suction volume remains low until effective suction is established, indicating that this case has a low sediment suction capacity. Therefore, arch action is likely to occur. For Case B1-2, which has a smaller suction hole to enlarge the suction velocity, it was also shown to take a long time to reach effective suction conditions. The VMHS method, as is seen so far, is designed to install suction holes in the shallow layer of the sediments, thereby making it possible to control without causing arch action.

CONCLUSION

We proposed the VMHS method and conducted a laboratory hydraulic model experiment in order to eliminate the problems caused by arch action affecting smooth sediment discharge, which had been a major drawback of the conventional MHS method, and to improve the reliability of the method's sediment discharge capability. As expected, the sediment was suctioned through the holes closer to the surface layer.

In our experiment, we conducted a control experiment with different numbers of suction holes, diameters of suction holes, and sediment particle sizes, and successfully confirmed the important points about basic sediment discharge capability and design of VMHS method. The next assignments are to check applicability of VMHS quantitatively by experimenting on the big scale using the mixed sediment particle size.

REFERENCES

Association of Water Resources Sedimentation Technology: Multi-Hole Suction (MHS) Sediment Discharge Method Technical Manual, 2006