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EXPERIMENTAL STUDY ON THE CONDITIONS FOR USE OF THE "VERTICAL MULTI HOLE SUCTION PIPE (VMHS)" METHOD (*)

Yuji NUMANO
Senior Chief Researcher, Second Research Department, Water Resources Environment Center

Toshikazu NAKAMURA
Techical Councilor, Water Resources Environment Center

Hiroyuki KATAYAMA
Researcher , Association of Water Resources Sedimentation Technology

JAPAN

1. INTRODUCTION

The Water Resources Environment Center has been developing the "Multi Hole Suction pipe (MHS)" method since 2001 in joint research with the Association of Water Resources Sedimentation Technology [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. Then, infiltration-induced collapse of the sediment and the piping principle result in relaxation and chain collapse of sediments, ultimately discharging the sediments outside the reservoir. And so far we have improving the MHS method to a vertical method (hereinafter referred to as the VMHS method) (Fig. 1) in which multiple suction holes were vertically aligned on the suction part, which used to horizontally buried in sediment accumulation, in order to continuously maintain the suction performance. Experiments verified the

(*) *Étude expérimentale des conditions d'utilisation de la méthode par « canalisation d'aspiration multicanal verticale (VMHS) ».*

basic suction performance in small-scale suction experiments [2]. The removal of sediment by the VMHS method initially starts with the suction of sediment near the surface after the start of the suction of sediment. Then, sediment is sucked up while the sediment forms stable gradient surfaces around the suction holes starting at the top suction hole. Meanwhile, the problem of sediment removal methods based on stationary hydraulic suction such as the MHS method is that the sediment in the upper portion of a suction part becomes solidified and resistant to collapse when the sediment accumulation is thick, or when the ratio of sediment with low permeability and high viscosity such as silt and clay increases, although the suction efficiency is high when the target sediment contains a high ratio of sandy soil.

In this report, the authors conducted indoor suction experiments with a 1:10 model scale aiming to find the upper limit of the ratio of silt or clay components in target sediment in the VMHS method and to examine countermeasures. To improve the suction performance for sediment with silt and clay components, a series of suction parts (slits) was created on suction pipes instead of multiple suction holes aligned at a regular interval. Slits were provided continuously extending from the water column above the sediment surface to inside the sediment so that the shearing force that would drive the suction force would work on the surface of the sediment in the initial stage of the suction. The suction properties were examined with this design.

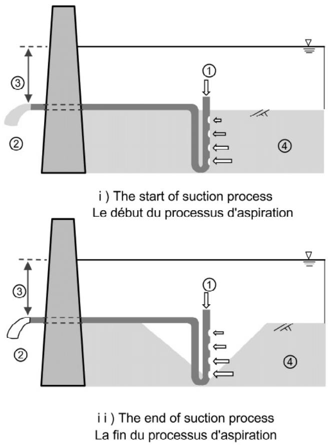


Fig. 1
Image of VMHS method
Schéma de la méthode VMHS

1	Inlet	*1*	*Prise*
2	Outlet	*2*	*Sortie*
3	Water head	*3*	*Hauteur de chute*
4	Sediment	*4*	*Sédiment*

2. INDOOR HYDRAULIC MODEL EXPERIMENTAL PLAN

2.1. SPECIFICATIONS OF THE HYDRAURIC MODEL

2.1.1. Model scale

The model was at 1:10 scale; it is assumed that the actual thickness of sediment to be sucked was six meters in the site, and the thickness of sediment to be sucked was 60 cm in the model. Transparent acrylic pipes were used as sediment removal pipes (Table 1).

Table 1
Model Scale

Conditions	Unit	Indoor	Assumed field	Ratios
Thickness of the sediment	M	0.6	6.0	1/10
The internal diameter	Mm	52	520	1/10
Sediment discharge	m^3	0.05	50	$1/10^3$
Flow velocity in the pipe	m/s	1.26	4.0	$1/10^{0.5}$
Flow rate	m^3/s	3.5×10^{-3}	1.1	$1/10^{2.5}$
Water head	M	1.5	15.0	1/10
Particle size	Mm	0.8	0.8	1/1

2.1.2. Difference in water-heads

By referring (inner diameter of 52 mm, 2 to 5% concentration) the critical velocity of 1.6 to 1.8 m/s obtained by Durand equation [3], the difference in water-heads was set at about 1.5m based on preliminary experiments conducted to find a condition which would not cause pipe clogging.

2.1.3. Target sediment

Target sediments were the sediment accumulated in dam sites (Yahagi Dam) containing a significant ratio of sandy soil and the sediment produced by mixing the accumulated sediment with sediment containing fine particles smaller than silt (Table 2). The average particle size of the sediment accumulated in dam sites in the experiment was d_{50}=0.82 mm, and the ratio of particles smaller than silt was 0.6 % (Sample A). The average particle size of the mixed sediment was d_{50}=0.24 mm, and the ratio of particles smaller than silt was 20 % (Sample B). This experiment was intended to verify basic performances; thus, it did not take into consideration the effects caused by obstacles such as driftwood.

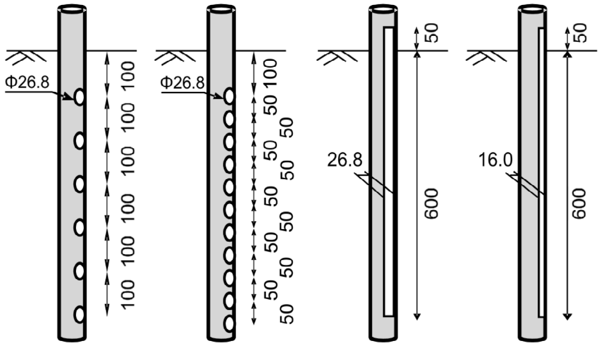
Table 2
Experimental Condition

Item	Condition
Pipe	Diameter : Φ60mm(External) Φ52mm(Internal) Extension : Close to 0.7m(Suction process) Close to 4.0m(Rundown process)
Suction shape type	Hole : Diameter : Φ26.8 mm Spacing : 100mm,50mm Number of Holes : 6,11 Slit : Width : 26.8mm,16mm Length : 650mm
Water head	1.5m
Thickness	0.6m
Target sediment	Mix Sample A and Sample B Sample A : d_{50}=0.82mm, Sample B : d_{50}=0.24mm

2.1.4. Specifications of suction pipes

The diameter of the holes on a suction pipe was 26.8 mm. The experiment used the following two types of suction: a type in which the interval among suction holes was 100 mm (number of holes: six) and 50 mm (number of holes: eleven); and a type in which slit-shaped suction parts were created with the widths of

26.8 mm (length: 650 mm) and 16 mm (length: 650 mm) (Fig. 2). The slits were arranged such that they would protrude by 50 mm from the surface of the accumulated sediment so that the pipe could suck up sediment continuously from the underwater bottom to the inside of the sediment.



Suction hole type
Type de trou d'aspiration

Suction slit type
Fente d'aspiration

Fig. 2
Shape of suction
Forme d'aspiration

2.2. Overview of the experiment

The vertical installation type was the basic style of the experiment. The experiment was conducted by changing the types of suction pipes (ones with suction holes and ones with slits) and types of sediment (ratio of fine particles).

2.2.1. Experimental model

The models of the suction holes and suction slits of the VMHS method were used in the experiment (Fig. 3).

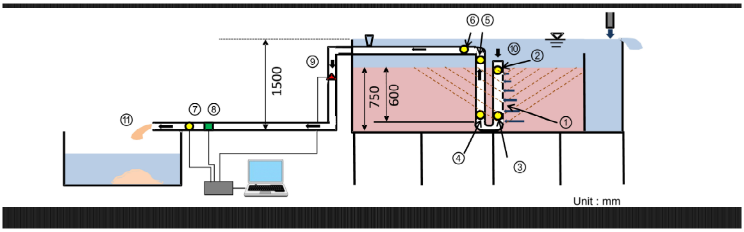


Fig. 3
VMHS method model
Modèle de la méthode VMHS

1	Hole or Slit type	*1*	*Type trou ou fente*
2~7	P1 ~ P6 : measured pressure in pipe	*2 ~ 7*	*P1 ~ P6: pression mesurée dans le tuyau*
8	Manometer and Flowmeter	*8*	*Manomètre et débitmètre*
9	Densimeter	*9*	*Densimètre*
10	Inlet velocity	*10*	*Vitesse d'entrée*
11	Outlet velocity	*11*	*Vitesse de sortie*

2.2.2. Cases of the experiment

Table 3 describes the cases of the experiment.

Table 3
Case of Experimental

No.	Case	Suction			Target sediment		
		Shape	Number	Diameter or Width(mm)	Mixing rate of Sample A to Sample B	Rate of fine particles (0.075mm or smaller) (%)	d_{50} (mm)
1	Case1	Hole	6	26.8	Only A	0.6	0.82
2	Case2-1	Hole	11	26.8	Only A	0.6	0.82
	Case2-2						
	Case2-3						
3	Case3	Slit	1	26.8	Only A	0.6	0.82
4	Case4-1	Hole	11	26.8	6 : 1	0.87	0.72
	Case4-2				3 : 1	1.23	0.69
5	Case5-1	Slit	1	26.8	6 : 1	1.10	0.70
	Case5-2				2 : 1	1.28	0.69
	Case5-3				3 : 1	1.51	0.70
6	Case6-1	Slit	1	16	6 : 1	1.49	0.69
	Case6-2				3 : 1	1.72	0.68

(*)Sample A : d_{50}=0.82mm, Sample B : d_{50}=0.24mm

3. INDOOR RESULT OF THE EXPERIMENT

3.1. ASPECTS TO BE MEASURED

Pressure inside pipes, velocity inside pipes, velocity at the inlet, concentration inside pipes, amount of sediment removed, and other aspects were measured in each case. The duration of sediment removal was found by visually confirming the end of suction and used as the measured data. Measured pressure(P1-P6) in pipe, inlet velocity, outlet velocity, concentration in pipe and the amount of sediment removed were shown in following figures (from Fig.4 to Fig.15). First stage in the figure shows the measured pressure at the pipe portion (P1-P6) shown in Fig 3 and in pipe the suction force by the negative pressure was generated. Second stage in the figure shows the velocity at the inlet and outlet of the suction pipe shown in Fig.3. Third stage in the figure shows the concentration calculated from densimeter data shown in Fig.3. Fourth stage in the figure shows the amount of removed sediment calculated from the flowmeter and densimeter data shown in Fig.3.

3.2. RESULTS OF THE EXPERIMENT

3.2.1. Case No.1 (Case1)

The target sediment consisted of sand, and the number of holes on a suction pipe was six. Yet, the suction pipe could not suck up all the accumulated sediment. The suction ended in the experiment when the suction shifted from the fourth to the fifth hole from the top. This is estimated that the effect of the coarse sediment remained near the suction holes and the compacted sediment near suction holes was created while only the water was sucked up until the suction had reached the fifth hole. The duration of the suction was 1,050 seconds. The amount of sediment that was sucked up was 0.43 m^3 (Fig. 4). A cone-shaped sediment with a stable gradient was formed around suction holes after the suction of the accumulated sediment.

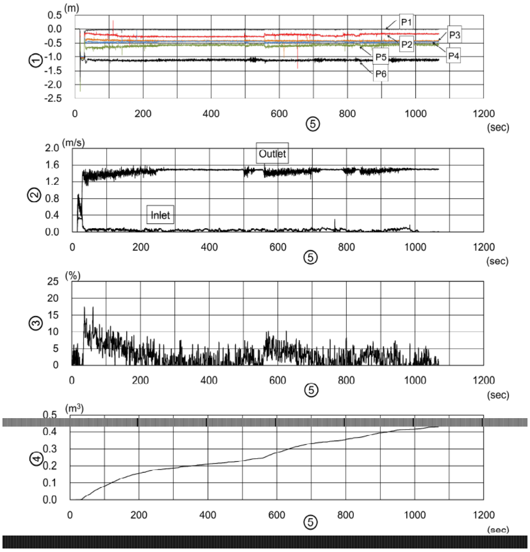


Fig. 4
Result of measured data (Case1)
Résultat des données mesurées (Cas 1)

1	In-pipe pressure	*1*	*Pression dans la tuyauterie*
2	Velocity	*2*	*Vitesse*
3	Concentration	*3*	*Concentration*
4	Amount of sediment	*4*	*Quantité de sédiments*
5	time	*5*	*Temps*

3.2.2. Case No.2 (Case2-1,Case2-2,Case2-3)

The number of holes on a pipe was changed to eleven. Case2-1 sucked up all the accumulated sediment. The increased number of holes compared to Case1 resulted in higher suction efficiency, and the suction ended in 510 seconds. The amount of sediment that was sucked up was 0.37 m^3. The suction of Case2-2 ended at the ninth hole. The duration of the suction was 920 seconds, and the amount of sediment that was sucked up was 0.28 m^3. The suction of Case2-3 ended at the tenth hole. The duration of the suction was 890 seconds, and the amount of sediment that was sucked up was 0.31 m^3. The concentrations in pipes reached the peak at 15 to 18% immediately after the start of suction in all cases, and the concentration then gradually decreased. Multiple suction holes at the upper portions of pipes simultaneously sucked up sediment at the initial phase of the suction in all cases, and the suction then gradually shifted to the lower holes.

The suctions in Case2-2 and Case2-3 stopped before the end due to the likely same phenomenon as Case1 (Fig. 5, 6, and 7).

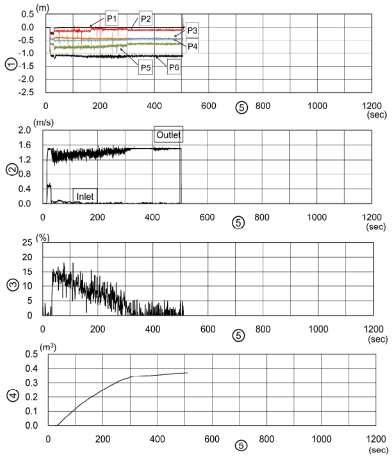


Fig. 5

Result of measured data (Case2-1)

Résultat des données mesurées (Cas 2-1)

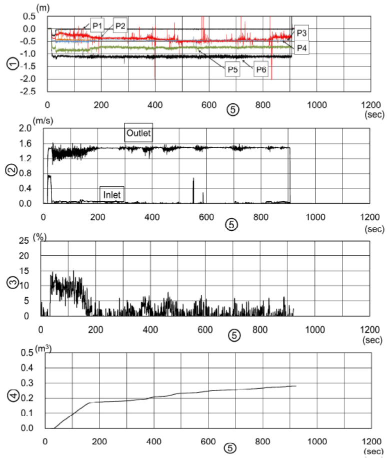
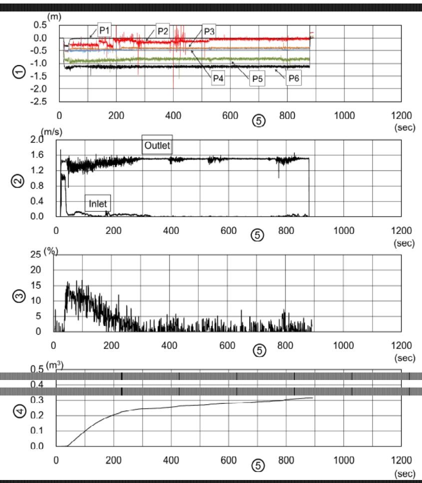


Fig. 6

Result of measured data (Case2-2)

Résultat des données mesurées (Cas 2-2)



1 In-pipe pressure
2 Velocity
3 Concentration
4 Amount of sediment
5 Time

1 Pression dans la tuyauterie
2 Vitesse
3 Concentration
4 Quantité de sédiments
5 Temps

Fig. 7

Result of measured data (Case2-3)

Résultat des données mesurées (Cas 2-3)

3.2.3. Case No.3 (Case3)

The slit-shaped suction part with the width of 26.8 mm enabled the suction of all accumulated sediments for the target sediment of sand. The slit-shaped suction hole continuously sucked up sediment starting at the sediment surface facing the water column. The duration of the suction was 560 seconds. The amount of the sediment that was sucked up was 0.43 m^3. The concentration in the pipe reached the peak at about 25% immediately after the start of the suction. The concentration then remained around 15% and then decreased. A cone-shaped sediment with a stable gradient was formed around the bottom end of the slit after the suction of the accumulated sediment (Fig. 8).

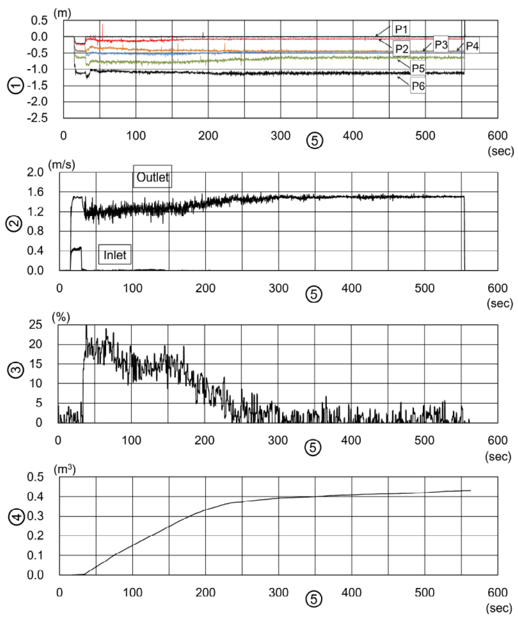
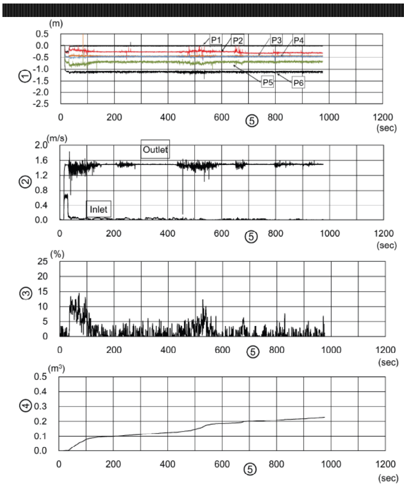


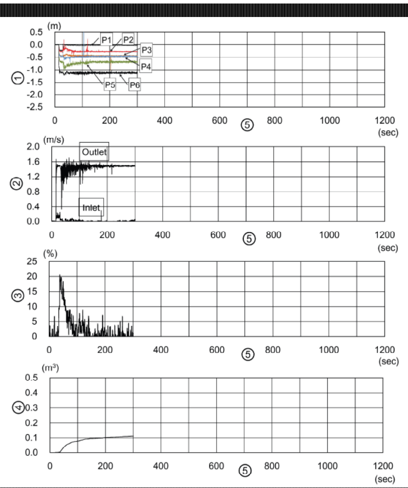
Fig. 8
Result of measured data (Case3)
Résultat des données mesurées (Cas 3)

1	In-pipe pressure	*1*	*Pression dans la tuyauterie*
2	Velocity	*2*	*Vitesse*
3	Concentration	*3*	*Concentration*
4	Amount of sediment	*4*	*Quantité de sédiments*
5	time	*5*	*Temps*

3.2.4. Case No.4 (Case4-1,Case4-2)

The target sediment consisted of fine particles, and the number of holes was eleven. The sediment containing fine particles caused the pipe to become incapable of sucking up the sediment and starting to suck up only the water, although the pipe sucked up the sediment at the beginning of the experiment. The ratio of fine particles (0.075 mm or smaller) was 0.87% in Case4-1. Up to the seventh hole from the top of a pipe sucked up the sediment, and the duration of the suction was 980 seconds. The amount of sediment that was sucked up was 0.23 m^3, and the maximum concentration in a pipe was 10 to 15%. The ratio of fine particles was 1.23% in Case4-2, and up to the sixth hole the sediment was sucked up. The duration of the suction was 300 seconds. The amount of sediment that was sucked up was 0.11 m^3. The maximum concentration in a pipe was about 20% (Fig. 9 and 10).





1 In-pipe pressure
2 Velocity
3 Concentration
4 Amount of sediment
5 time

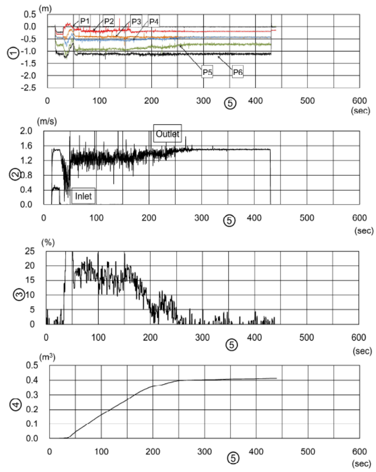
1 Pression dans la tuyauterie
2 Vitesse
3 Concentration
4 Quantité de sédiments
5 Temps

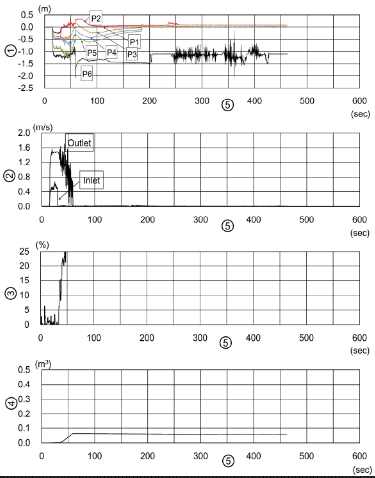
Fig. 9
Result of measured data (Case4-1)
Résultat des données mesurées (Cas 4-1)

Fig. 10
Result of measured data (Case4-2)
Résultat des données mesurées (Cas 4-2)

3.2.5. Case No.5 (Case5-1, Case5-2,Case5-3)

The width of the slit at the suction part was changed to 26.8 mm, due to the sediment containing fine particles. All sediment was sucked up in Case5-1, although the ratio of fine particles was 1.1%. The duration of the suction was 440 seconds, and the amount of sediment that was sucked up was 0.41 m^3 (Fig. 11).While the slit provided a good suction at the initial phase of the experiment in Case5-2, the amount of the suction was large, and the clogging in the transportation part (horizontal section) of the pipe occurred which ended the experiment, probably due to the slightly higher ratio of fine particles (1.28%) than Case5-1. The duration of the suction was 450 seconds. The amount of sediment that was sucked up was 0.06 m^3(Fig. 12).





1 In-pipe pressure
2 Velocity
3 Concentration
4 Amount of sediment
5 time

1 Pression dans la tuyauterie
2 Vitesse
3 Concentration
4 Quantité de sédiments
5 Temps

Fig. 11
Result of measured data (Case5-1)
Résultat des données mesurées (Cas 5-1)

Fig. 12
Result of measured data (Case5-2)
Résultat des données mesurées (Cas 5-2)

Since the ratio of fine particles was also high in Case5-3, the slit sucked up a large amount of sediment, as in Case5-2, which resulted in clogging at the transportation part (horizontal section) of the pipe and ended the experiment. The duration of the suction was 180 seconds. The amount of sediment that was sucked up was 0.05 m^3. Although there were only slight differences in ratios, these experiments found that higher ratios of fine particles increased the amount of sediment that was sucked up through slits, and that there was a possibility that the velocity in the pipe could not remove the sediment and caused the sediment to accumulate in the pipe and clog it (Fig. 13).

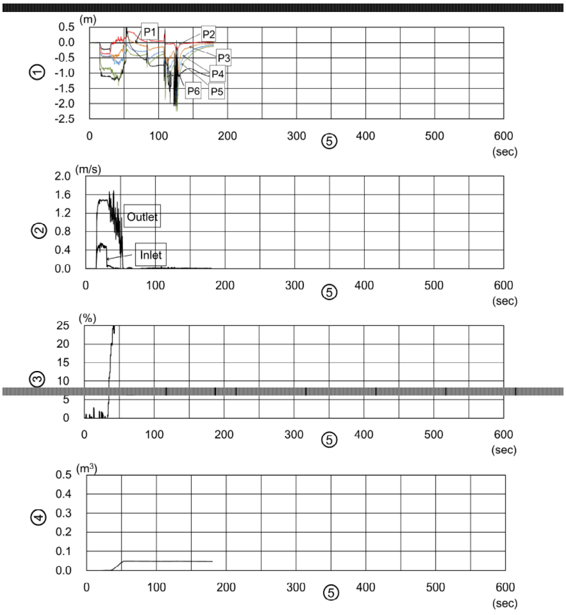


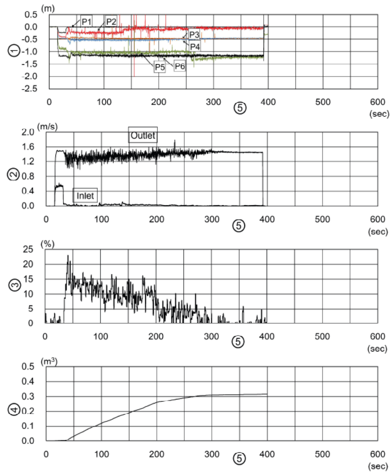
Fig. 13
Result of measured data (Case5-3)
Résultat des données mesurées (Cas 5-3)

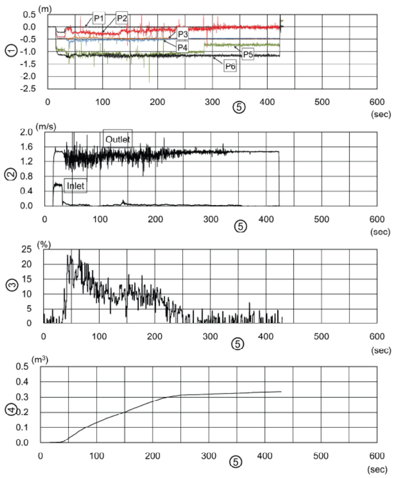
1 In-pipe pressure
2 Velocity
3 Concentration
4 Amount of sediment
5 time

1 Pression dans la tuyauterie
2 Vitesse
3 Concentration
4 Quantité de sédiments
5 Temps

3.2.6. Case No.6 (Case6-1,Case6-2)

To enable suction for the sediments containing fine particles, the width of the slit in *Case No.5* was changed from 26.8 mm to 16 mm to decrease the amount of sediment to be sucked up and prevent clogging at the horizontal section of the pipe. Case6-1 sucked up all sediment, although the ratio of fine particle was 1.49%. The duration of the suction was 400 seconds. The amount of sediment that was sucked up was 0.31 m³. Case6-2 also sucked up all sediment, although the ratio of fine particles was 1.72%. The duration of the suction was 430 seconds. The amount of sediment that was sucked up was 0.33 m³ (Fig. 14 and 15).





1 In-pipe pressure
2 Velocity
3 Concentration
4 Amount of sediment
5 time

1 Pression dans la tuyauterie
2 Vitesse
3 Concentration
4 Quantité de sédiments
5 Temps

Fig. 14
Result of measured data (Case6-1)
Résultat des données mesurées (Cas 6-1)

Fig. 15
Result of measured data (Case6-2)
Résultat des données mesurées (Cas 6-2)

4. OBSERVATION

The obtained experimental results are observed as follows.

The suction was accelerated in the suction hole method when the number of holes was increased from six to eleven if the target sediment consisted of sand. The some cases of suctions stopped, however, before completion while sediment remained at the outside of suction holes in some cases (*Cases No.1 and 2*).

The suction efficiency decreased when the ratio of fine particles increased, and the suction stopped without reaching the lowest suction hole, while sediment remained outside of suction holes even though the number of holes was increased from six to eleven in the suction hole method when the target sand consisted of sediment with low permeability and high viscosity such as silt and clay *(Case No.4)*. This is thought to be affected by a condition in which the cohesion force of the sediment increased in the lower layer due to the effect of the sediment in the upper layer as the ratio of fine particles increased. The permeability of the sediment also decreased under such conditions, and the water flow through the sediment layer that caused the collapse of sediment near suction holes also decreased.

Meanwhile, the slit method in which the suction part extended from the water column above the sediment surface to inside sediment successfully completed suctions of sandy sediment and the sediment containing up to about 2% of particles which were finer than silt when the width of the slit was properly set *(Cases No.3, 5, and 6)*. This is because the main suction force of the slit method was the shearing force generated by the suction flow that worked on the surface layer of the sediment. The shearing force generated with the suction force allowed the gradual suction of the sediment from the surface of the sediment to the lower layers. Thus, the suction efficiency did not decrease like the suction hole method, even when the permeability of the accumulated sediment in the lower layer was low (Fig. 16).

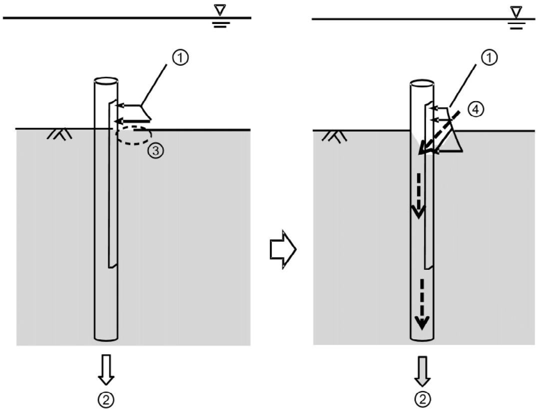


Fig. 16
Image of suction from the slit
Image de l'aspiration de la fente

1 Flow of inlet
2 Outlet
3 Erosion by the shearing force
4 Suction of the sediment

1 Débit en entrée
2 Sortie
3 Erosion par la force de cisaillement
4 Aspiration des sédiments

5. CONCLUSION

The VMHS method, which is an improved version of the conventional MHS method, has limits when dealing with sediments containing fine particles with low permeability and high viscosity. This study therefore proposed the use of slits for the suction part as a way to improve the suction performance and certificated the applicability by indoor suction experiments. Future studies need to examine limits of the use of slits in dealing with sediments containing fine particles. In order to apply this method in the dam site, it is necessary to carry out the design of the switchgear of the suction part construction and planning of how to install the equipment and the obstacles measures such as driftwood that comes flowing into the suction part. In addition, it is necessary to also consider treatment method of sediment to be discharged. We believe this method will become a valid way for the dam with the deposition problem if solve these problems.

ACKNOWLEDGEMENTS

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SUMMARY

Accumulation of the sediment in a dam reservoir reduces the flood control and water use functions of the dam and shortens the service life of the reservoir. The development of technologies to effectively and efficiently remove the sediment in reservoirs is thus called for. We have been researching and developing methods for sucking up sediments accumulated in dams by using water pressure (the MHS method) since 2001 to deal with this problem. Stationary hydraulic suction method including the MHS method provides high suction efficiency if the sediment to be sucked up mainly consists of sandy soil. The problem is that this suction becomes difficult when the ratio of sediment with low permeability and high viscosity such as silt and clay increases, because the sediment accumulated on the upper portion of the suction part becomes solidified and resistant to collapse. The authors therefore proposed the “vertical multi hole suction pipe (VMHS) method,” in which sediment removal pipes were vertically installed to suck up sediment through suction holes on the side of the pipe while the pipe was horizontally installed in the conventional MHS method aiming to eliminate the phenomenon, in which the solidification of sediment in deep suction depths prevents the sediment from being sucked up, and to increase the reliability of suctions. The authors then assessed the basic suction performances of the method in model-based experiments by using silica.

This report aims to verify the limits of the use of the VMHS method when the sediment sucked up contains silt or clay components and to examine its countermeasures. The authors conducted indoor suction experiments using about a 1:10 scale model of the actual system. The experiment first examined conditions with which the method works using different sediment properties. The sediment deposited in dam sites contained a significantly high ratio of sandy soil. Sediment containing finer particles than silt was mixed with that sediment, and suction experiments were conducted using the ratios of the mixed fine particles as parameters. We used the average particle size of the 0.82 mm sediment and the ratio of 0.6% finer silt mixture than silt for dam sites, and the average particle size of the 0.24mm fine particles to be mixed with a 20% mixture ratio of particles that were finer than silt for mud conditioning. As a measure to improve the performance to suck up sediment containing silt and clay, the conventional suction holes were improved to a series of slit-type suction parts that extend from the surface of the sediment to the water column above the sediment. The experiment also verified the usability of this method. As a result, the suction was completed using a slit-type suction system with proper width to prevent high concentration of the sucked water if the mixture ratio of particles which were finer than silt was about 2%, even when the suction was interrupted with the conventional suction hole method.

RÉSUMÉ

L'accumulation des sédiments dans une retenue réduit les fonctions de régulation du débit et d'utilisation de l'eau et diminue la durée de vie du réservoir. Le développement de technologies permettant d'éliminer de manière efficace les sédiments dans les réservoirs est donc nécessaire. Face à ce problème, nous avons, depuis 2001, entrepris des recherches et développé des méthodes d'aspiration des sédiments accumulés dans les retenues à l'aide d'eau sous pression (méthode dite MHS). La méthode d'aspiration hydraulique stationnaire qui inclut la méthode MHS assure un haut rendement d'aspiration quand les sédiments à éliminer sont principalement constitués de sols sablonneux. Un problème de difficulté d'aspiration se pose quand le taux de sédiments à faible perméabilité et forte viscosité comme le limon et l'argile augmente, parce que les sédiments accumulés à la partie supérieure de l'aspiration se solidifient et deviennent résistant à l'écrasement. Par conséquent, les auteurs préconisent la "méthode à canalisation d'aspiration multicanal verticale (VMHS)" dans laquelle les canalisations d'enlèvement de sédiments sont installées en position verticale pour aspirer les sédiments par des canaux d'aspiration disposés sur le côté des canalisations et non en position horizontale comme c'est le cas avec la méthode MHS où la solidification des sédiments empêche leur aspiration et diminue l'efficacité de l'aspiration. Les auteurs ont ensuite établi les performances d'aspiration de base de la méthode au cours d'expériences à base de modèles et à l'aide de silice.

Ce rapport a pour but de déterminer les limites d'utilisation de la méthode VMHS quand les sédiments aspirés contiennent des composants de limon ou d'argile et d'examiner les contremesures possibles. Les expériences d'aspiration ont été menées sur un modèle à l'échelle 1/10 du système réel. Les expériences ont d'abord porté sur les conditions dans lesquelles la méthode était valable selon les diverses propriétés des sédiments. Les dépôts de sédiments dans les retenues contiennent un taux assez élevé de sols sablonneux. Des sédiments contenant des particules plus fines que le limon ont ensuite été mélangés au sédiment sablonneux et les expériences ont été conduites en prenant pour paramètre les taux de mélange des particules fines. Nous avons utilisé des sédiments à particules de taille moyenne égale à 0,82 mm mélangés à 0,6 % à du limon plus fin que celui trouvé dans les retenues, et des sédiments à particules de taille moyenne 0,24 mm mélangés à raison de 20 % avec des particules plus fines que celle du limon afin d'obtenir une boue. Dans une tentative d'amélioration de la performance d'aspiration de sédiments contenant du limon et de l'argile, les canaux d'aspiration traditionnels ont été transformés en points d'aspiration en forme de fente couvrant toute la partie entre la surface des sédiments et la colonne d'eau au-dessus de ces sédiments. Les expériences ont également permis de vérifier la fonctionnalité de cette méthode. En résultat, l'aspiration a été exécutée à l'aide d'un système type à fente de largeur appropriée pour éviter une trop forte concentration de l'eau aspirée quand le taux de mélange des particules plus fines que le limon était d'environ 2% même si l'aspiration était interrompue avec la méthode à canal d'aspiration traditionnelle.