COUNTERMEASURES AGAINST RESERVOIR SEDIMENTATION PROBLEMS

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ABSTRACT

In the central areas of Japan, the production of sediment is higher, and some dam reservoirs cause severe problems such as lowering the reservoir storage capacity and impacting the sediment environment in the downstream river or seacoast. So, various countermeasures against reservoir sedimentation have been implemented, and the necessity to take more effective countermeasures is now increasing in order to extend the service lives of dams from the long term view, keeping functions of dam reservoirs. This paper firstly states importance of strategies against sedimentation problems, and outlines the latest situation and technical problems on countermeasures in Japan. Further, we evaluates the applicability of a sediment flushing system based on suction pipe and sediment flushing equipment (hereinafter "suction system", it is technically called Hydro-Suction Removal System), an approach not used in Japan until now, and summarizes the technical problems faced adopting an actual system of this kind and the state of efforts to resolve these problems in Japan. This system flushes sediment deposited near the inlet of a suction pipe along with water discharged from the discharge pipe when there is water in the reservoir, and includes a structure or a special pipeline to strengthen the effectiveness of suction upstream from the inlet of the discharge pipe. It is assumed that the sediment is flushed directly downstream from the dam or into a bypass tunnel, thereby contributing to conserving the downstream sediment environment.

INTRODUCTION

The production of sediment from river basins in Japan is impacted by Japan's unique topography and geology and by hydrologic conditions, and the sedimentation of dams centered in the Chubu region in particular has advanced (See Figure 1). The average sedimentation rate (sedimentation/total reservoir capacity) in dam reservoirs in Japan is 7.8% (2008), as an average, it is not such a high rate, but at dams where sedimentation has advanced, sedimentation countermeasures appropriate to guarantee flood control and water supply functions are required. Plans for dams in Japan ensure sedimentation capacity premised on sedimentation of reservoirs which will occur in 100 years. This planned sedimentation capacity has been calculated considering a variety of sediment quantity prediction equations and past sedimentation at nearby dams or sediment check dams. But, in some cases, the actual quantity of deposited sediment greatly exceeds the initially predicted quantity of sediment, and although few, some dams have already lost

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their effective storage capacity as a result of continued deposition above the planned quantity of sedimentation.

Accordingly, in response to social conditions which demand the extension of the service life of dams, sedimentation countermeasures must be taken quickly. Further, over a period of many years after the construction of a dam, a new environment is created in the downstream river course, and to mitigate this change, it is important to take early countermeasures to adapt the environment to sediment flushing. Dam sedimentation countermeasures should be taken as part of integrated sediment management of entire river systems extending from the mountains to the ocean.

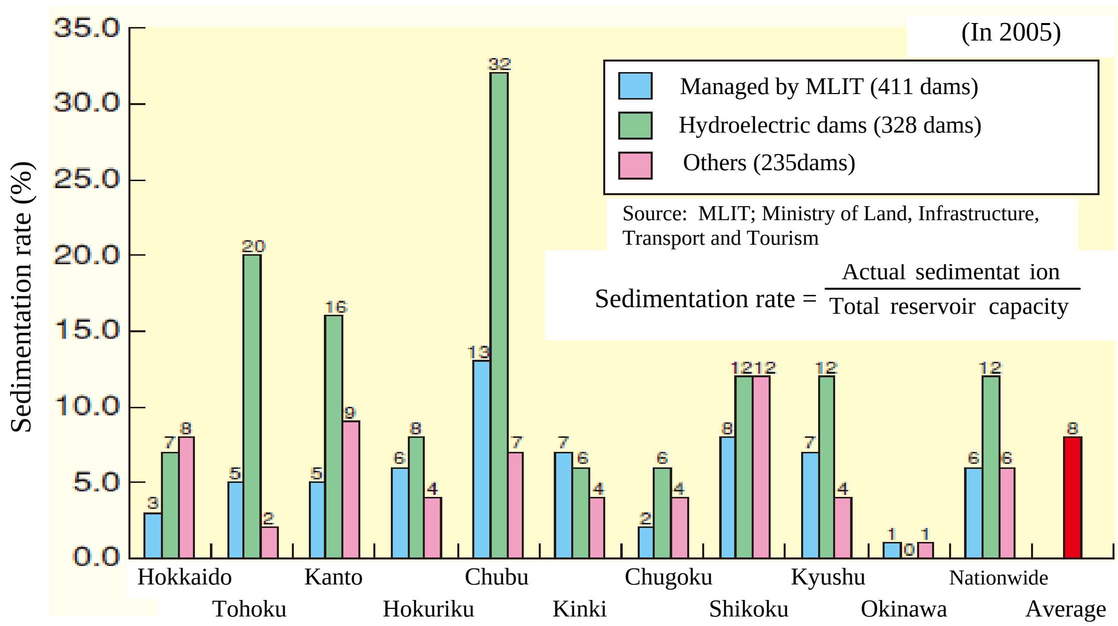


Figure 1. State of Sedimentation in Japan (Sedimentation rate by region)

CHARACTERISTICS OF EXISTING COUNTERMEASURES IN JAPAN

Sediment flows into reservoirs constantly, so sedimentation countermeasures must be performed continually. It is necessary to lower running costs by some methods using energies of flowing water such as suction system, hydraulic power, and directly compressed air. The following are characteristics of sedimentation countermeasures now taken at dams in Japan, and Table 1 shows specific sediment management measures.

Excavation or Dredging

Excavation or dredging of sediment deposited in reservoirs is widely adopted in Japan and the excavated materials are used effectively as aggregate. The water level inside the reservoir is lowered, and sediment in the middle and upstream parts of the reservoir is excavated by land-based excavation machinery, but sediment under the water surface is dredged by pump dredgers and grab dredgers. When a pump dredger is used, dewatering the dredged sediment is very costly. Further, the transport cost and sediment disposal costs are high.

Flushing, Sluicing or Bypassing

Flushing, sluicing or bypassing is a method of using the agency of flowing water to cause sediment to flow into downstream rivers. Flushing or sluicing are highly effective ways of discharging sediment, but both require a sharp lowering of the water level, so in Japan where many river basins face harsh water supply and demand, their applicability is extremely limited. Bypassing can also lower the sedimentation according to the bypass flow rate, but dams including the flood control purpose are required to store flood water, so the quantity of sediment which can be bypassed is limited.

Sediment Replenishment

It is also important to supply sediment to downstream for the desirable river ecosystem and the erosion mitigation. Sediment replenishment is a method recently increasing in Japan, which is performed by dredging sediment in a reservoir and placing sediment in a downstream flood basin of river. However the disposable quantity by this method is limited and it is difficult to apply it as a main resolution method at many dams.

Table 1. Examples of Sedimentation Countermeasures (S/C)

Dam name	Project body	Pur-pose	Dam type	Countermeasure Method	Dam completion year and S/C
Ohi	Kansai Electric power co.	P	G	Flushing pipe, Dredging	1924
Senzu	Chubu Electric power co.	P	G	Flushing gate	1935
Koyadaira	Kansai Electric power co.	P	G	Flushing gate	1936
Hiraoka	Chubu Electric power co.	P	G	Dredging, Spillway flushing	1951
Ikawa	Chubu Electric power co.	P	HG	Flushing pipe, Ground excavation and dredging, Spillway flushing	1957
Makio	Japan Water Agency	AWIP	R	Ground excavation and dredging, Sediment check dam	1961
Katagiri	Nagano Prefecture	FNW	G	Holes with curtain walls, Open orifice (Density current venting)	1989
Asahi	Kansai Electric power co.	P	A	Sediment bypass tunnel	1978, S/C since 1988
Unazuki	Hokuriku Regional Development Bureau. MLIT	FWP	G	Flushing	2000, Linked flushing started since 2001
Dashidaira	Kansai Electric power co.	P	G	Flushing	
Miwa	Chubu Regional Development Bureau. MLIT	FIP	G	Sediment bypass tunnel, check dam, Ground excavation and dredging	1959, S/C since 2009
Koshibu	Chubu Regional Development Bureau. MLIT	FNAP	A	S/C: Sediment bypass Tunnel, check dam, Ground excavation	1969, S/C will complete soon.
Matsukawa	Nagano Prefecture	FNW	G	S/C: Sediment bypass tunnel, check dam, Ground excavation	1974, S/C will complete soon.
Sakuma	J-Power: Electric power development co.	P	G	Dredging by ships S/C: Sediment bypass Tunnel	1956, S/C under design
Akiba	J-Power: Electric power development co.	AIP	G	Ground excavation and dredging S/C: Flushing	1958, S/C under design
Yahagi	Chubu Regional Development Bureau. MLIT	FNAWIP	A	S/C: Sediment bypass tunnel, check dam	1970, S/C under design

F: flood control, A: agricultural water, W: municipal water I: industrial water, P: hydroelectric power, N: normal function of river, G: gravity dam, A: arch dam, R: rockfill dam, HG: hollow gravity

NEW CONCEPT USING SUCTION SYSTEM

In circumstances where it is clear that existing countermeasures are limited, expectations to the suction system are rising as a new concept method, using suction pipes capable of flushing sediment by flowing water without lowering the reservoir level.

Expectation of Suction Type

Discharge pipe type flushing equipment (called flushing pipes) is limited to the range where sediment can be sucked into the system when the water level is high. But because the suction pipe can realize high speed flow through pipes, its sediment transport capacity is high. If sediment can be continuously supplied up to the range in which sediment can be sucked in along with the flowing water, it can be counted on to achieve an extremely high sediment flushing function.

So, widespread research are now being undertaken to expand the range of suction capability by adding a variety of structures at the upstream end of the flushing pipes.
As directions to expand the suction range, either the depth direction (vertical) or longitudinal direction (horizontal) are hypothesized. If it is assumed that suction from the pipe extending to the underwater angle of repose of the deposited sediment is possible, the quantity of sucked sediment in the depth direction is proportional to the cube of the depth, and the quantity of sucked sediment in the longitudinal direction is proportional to the length, showing that expanding in the depth direction is more efficient.
Expansion in the depth direction on the other hand, increases the danger of the equipment being buried by the collapse of the sedimentation surface.

Installation Method of Suction Pipe

Specific equipment installed upstream from flushing pipes can be assumed below.
1) Intake tower with multiple inlets in the vertical direction.
2) Fixed suction pipes such steel pipes installed on the sediment surface or inside pockets formed on the sediment surface. A fixed suction pipe is a pipe with a slit or many holes.
3) Movable suction pipes which move the ends of flexible pipes to suck up the sediment. A movable suction pipe is one similar to the shape of a pump dredge, which uses the water head of the reservoir as its driving force instead of a pump.

Suction System

A sediment flushing method using the suction pipe is a method in which a differential head produces a flow and the flowing water transports the sediment by sucking it into the pipe. It does not require the lowering of the reservoir water level necessary for sluicing and flushing, and does not require the long tunnel from the end of the reservoir necessary for the bypass method, so it is considered to be a work method highly applicable to a dam reservoir where a large differential head can be obtained. A system which uses flowing water created by a water level difference in this way to suck in and transport sediment outside a reservoir is called a suction system.

FUNCTIONS AND TYPICAL FORMS OF SUCTION SYSTEM

A suction system is counted on to provide the following two functions. To apply it to an actual reservoir, it is necessary to resolve many problems related to the below functions.

The first is a function capable of efficiently sucking in and discharging sediment in a pocket presumably formed with specified capacity under the sediment surface. Soil inside the pocket is assumed to be bed load which passes through it, and sediment dredged and transported from inside the reservoir.

The second is a function which, according to the flow rate, sucks in and discharges suspended sediment and wash load which pass through the pocket after sediment in the pocket is discharged. This is the category of density flow flushing, but it is assumed that the standard surface density of suspended sediment in the center of the reservoir is higher than it is near a dam body with a flood spillway, and its efficiency is relatively good.

Considering these functions, the suction system can be categorized as a system with an intake tower, a fixed system, or a movable system, according to the shape of their upstream sides. The following are typical forms of these systems.

Suction System with an Intake Tower

A system that can sequentially switch downwards between intake openings installed at multiple locations vertically on the intake tower along with the fall of the sediment surface caused by suction is being studied. In order that the intake openings which are switched will continue suction by piping, the interval between the intake openings must be set within a depth at which piping can definitely be caused. In this case, sediment in a cone-shaped range centered on the intake tower is sucked in to form a pocket. And in a case where the intake tower is installed in the body of a concrete dam or in the natural ground, a semi-conical shaped pocket is formed. In Japan, the continuous syphon type intake facilities are developed and installed without gates by using air lock system of compressed air. By using this intake facility as a sedimentation countermeasure, it is possible to reliably suck in and discharge out from the sediment surface.

Fixed Type Suction System

Systems which creates suction with a structure fixed inside the deposited sediment, suction pipes installed at the bottom of a pocket, or pipes connecting suction pipes with flushing pipes for example, is being developed. It can be a system with little restriction on its operation, one in which flushing operation is executed by opening and closing a gate installed at the outlet of the downstream flushing pipe. A flow is reliably produced inside the suction pipe by projecting its upstream end above the sediment surface, sucking in sediment from the opening.

Installing slits or other openings in the suction pipe almost continuously in the suction pipe axis direction permits the suction location to be moved downstream or deeper along with the suction. This expands the pocket. Because the equipment is fixed, the suction range is limited to the range of an inverted cone with the suction location as its apex point and the underwater angle of repose of the sediment as its apex angle.

Thus, it is difficult to handle consolidated sediment. The suction pipe is installed inside the sediment, so installing or repairing the suction pipe etc. imposes a heavy load.
If it is buried at a shallow location, it is possible to suck in sediment inside the inverted cone by controlling the influent volume from the upstream end of the suction pipe to reduce the pressure inside the pipe, thereby producing piping in the deposited sediment above the suction hole. A system was developed with multiple holes in the suction pipe so that in this case, the sediment flushing range is expanded by varying the suction hole by operating the gates installed at each hole.

Movable Type Suction System

A system which sucks in deposited sediment from a suction hole installed at the tip of a flexible suction pipe is being developed. By raising the suction hole mainly in the vertical direction by controlling a wire rope of a crane or a ladder installed on a barge, it is possible to form a pocket shaped like an inverted cone. The basic motion of the suction hole is vertical, but it is possible to vary the suction location according to the state of the sediment by moving the barge. The vertical location of the suction hole is controlled by the wire rope etc., but it should be possible for it to be appropriately cut into the sediment surface by its self-weight in order to simplify operation. And because the tip would be buried by the collapse of the wall surface of the pocket, it must be equipped with a mechanism to prevent its suction function from being obstructed even if it were buried to some degree. If its suction function can be maintained, the pocket can be reformed. And because the flexible suction pipe is installed underwater, it is exposed to the flood flows. So considering its unrestricted motion, the force acting under the flow and the force by contact with drifting wood, it is necessary to ensure safety and precise control of the movable system. There is, in this way, a degree of freedom in suction location with the movable system, but the challenge is to develop a system which can reliably control the tip of the suction pipe during runoff.

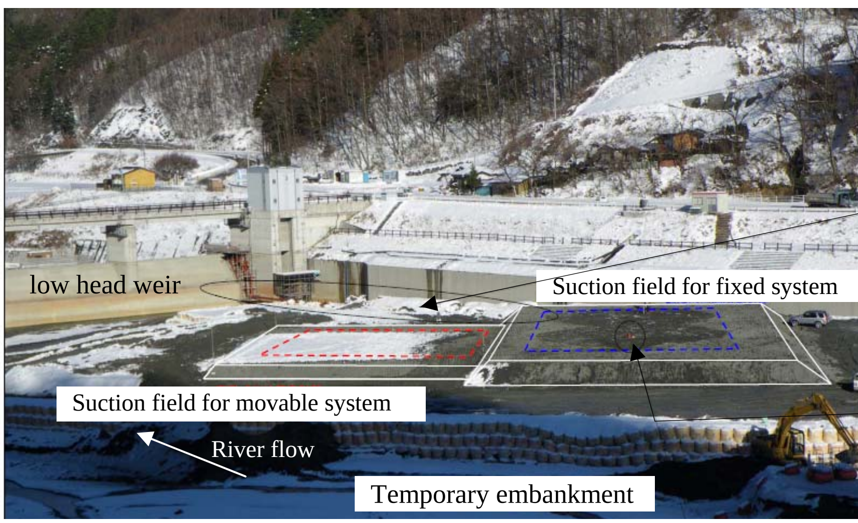
Mixed Type Suction System

A system which stands between a movable system and a fixed system is being developed. This system places a suction hole on a flexible pipe installed on the sediment surface to suck in the sediment deposited on this surface. The suction opening follows the fall of the sediment surface caused by suction to flush sediment along the track of the falling suction opening, forming a pocket. It is assumed that after the pocket is formed, the pipe is lifted in order to prevent the suction pipe from being buried.
It is possible to reduce the load of installing and repairing the suction pipe of a fixed system, and there is a degree of freedom in the range sediment can be flushed, but a challenge remains; burying measures to deal with collapse of the pipe material or pocket wall surface.

INTRODUCING A FIELD TEST BY SUCTION SYSTEM

There are many remaining challenges to be overcome in order to apply the suction system on site as a full-scale countermeasure, including ensuring a stable suction function and finding a method of moving the suction pipe and a method of accumulating sediment around the suction pipe. And corroborative testing to complete it as a practical working system is continuing. Figure 2 shows a field test by a suction system in Tenryu River, and the field test was performed at a sedimentation site upstream of a reservoir.

In this field test for sedimentation countermeasures, three kinds of corroborative studies related to suction systems are being conducted. The first test confirms the applicability of two kinds of fixed systems and two kinds of movable systems using a low head weir as shown in Figure 2, and suction function and application range of each system are now being evaluated. The test is done by installing a temporary embankment with 5m height in a test field, and the diameter of the flushing pipe is 0.3m, and the sediment is flushed into a pool downstream from the weir.



Flushing pipe
for fixed system

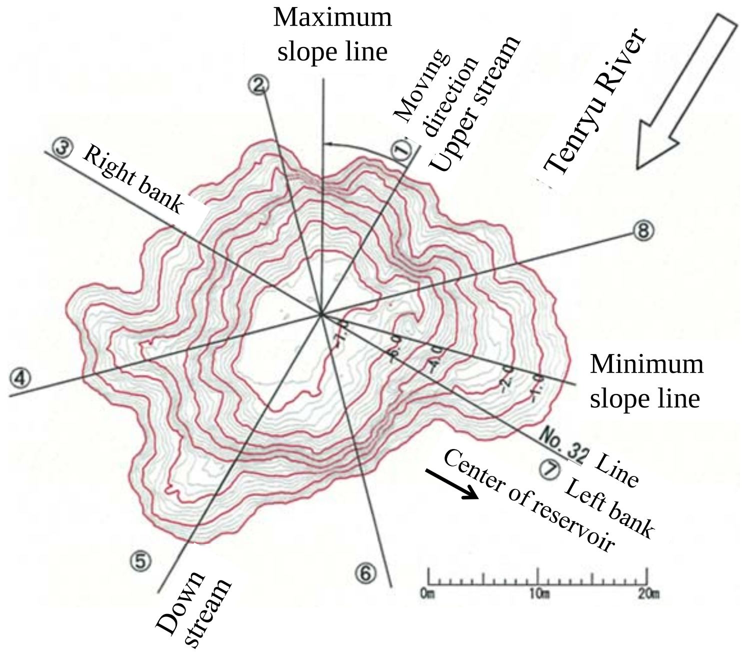
Field situation with two suction test yards before

Water jet test for
fixed system

Suction pipe for movable system;

Operating situation of suction pipe for
movable system after impounding

Figure 2. Field Test Situation by a Suction System in Tenryu River



After suction dredging for 14 days, a big corn hole was formed, of which diameter was about 50 m.

Figure 3. Ground Plan of Corroborative Test by a Suction System in Tenryu River

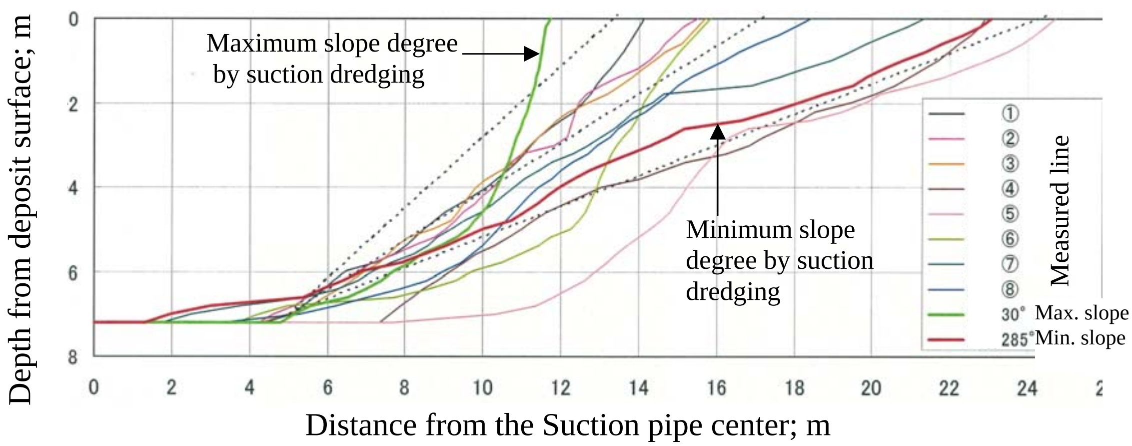


Figure 4. Sucked depth from deposit surface by distance from the suction pipe

The second test, which is a hydraulic model experiment intended to clarify the basic functions of a suction system and establish a design method which reflects the findings in execution design, is now being conducted.

The third test is pump dredging performed at a dam site to clarify the process of formation of pockets by sediment suction and to identify problems which could occur in a suction system. The Figure 3 and 4 show the shape of the pocket which was formed. The dredged depth which was the target during the test period (approximately 2 weeks), was 10m, but in fact about 7m was achieved. This was a result of the removal work taking a long time, because the dredging pump’s function was obstructed by the unpredicted large quantity of foreign matter such as wood chips mixed with the deposited sediment. There are diverse pocket wall surface section shapes. This is assumed to be a result of the fact that while the deposited sediment consists mainly of fine sand, it also contains a large quantity of silt and cohesive soil, and sediment with differing properties is distributed in layers around the pocket. But it is judged that if the sediment is in this condition, a suction system is highly applicable.

Wood chips and other foreign matter were a major cause of obstruction of the dredging pump, but their size would not cause any problems for a suction system, which has few causes of obstructions of the section of the flowing water. By the eleventh day after the test start, the surface near section 5 was steep, but later, it collapsed abruptly, causing the results shown in the figure. The dredging pump was not buried, but it is presumed that the deeper the pocket, the more likely such phenomenon will occur, so it is necessary to consider burying for the design and operation. The results of these experimental efforts will soon be summarized as a research report.

SUBJECTS OF THE SUCTION SYSTEM IN PRACTICAL USES

There are some subjects below to be solved in practical uses of the suction system.

(1) Installation location: It can be assumed that sediment will be effectively removed by installing the sediment flushing pipe at an appropriate location inside the reservoir considering the shape and deposition location of the sediment to be flushed. Lengthening the pressure tunnel imposes a heavy maintenance burden, so the outlet of the discharge pipe must be installed on the bypass tunnel installed parallel to the reservoir (used both as a specialized suction system and a sediment bypass) or on the adjoining river. In both cases, because the suction system supplies sediment to the downstream river, it can contribute to the conservation of the sediment environment on the downstream river.

(2) Timing of the sediment flushing operation: Flushing sediment to the downstream river causes turbidity problems and temporary sedimentation, so basically, the flushing operation is done during floods. So, it is necessary to discharge sediment within the limited duration of the flood, and this is one condition limiting the application of this system. And the advance deposition of sediment near the suction pipe by transporting it inside the reservoir can increase the degree of freedom of choosing the location of the suction pipe at the same time as it relaxes the above limiting conditions. If the sediment is discharged inside the reservoir, an effective way is to use pump dredging. In order to use a suction system effectively in this way, combining methods is also an important point.

(3) Pocket formation process: Suction of sediment forms a pocket, but in order to reliably form a pocket, it is important for there to be a mechanism which moves the suction location consecutively from the surface to the depths of the deposited sediment. But in a case where the required suction depth is shallow, it is possible to also apply a system which uses the piping phenomena etc. to start suction from inside the deposited sediment. In the case of cohesive material such as consolidated sediment, the formation of the pocket is not accompanied by the collapse of the wall surface and the supply of sediment

to the suction range is insufficient. So it is assumed that the suction system will not function, and the selection of the suction location is extremely important.

(4) Clogging by foreign matter: There is danger of foreign matter such as drift wood or wood chips mixed in the deposited sediment obstructing the operation of the suction system. But, a suction system is not obstructed except at the downstream end gate or in curves on the pipe, so compared with pump dredging etc., this problem is not nearly as severe and can be prevented. When large drift wood etc. accumulates near the suction pipe, it is necessary to consider removal using a bucket boat, etc..

CONCLUSION

So far, studies of the suction system and the related research and development have been progressed, and many facts have been clarified by these efforts. As a result, researches to develop diverse suction systems are approaching the stage of practical application. It may obtain new sedimentation control technologies which have more advanced capacity and are more economical than existing technologies. Although a suction system is restricted in ways not seen in other sedimentation countermeasures, it is possible to mitigate these restrictions by combining it with in-reservoir transport for example. And we can count on the expansion of the choice including sediment bypasses, flushing, and sluicing.

Further, a sediment bypass or flushing uses the natural flow for the sediment transport upstream or inside the reservoir. On the other hand, the suction system has an operational feasibility of the following two benefits by manual operations to remove deposited sediment. Firstly, stable suction can be counted on at relatively high densities, permitting flushing operation which has little impact on the dam operation. Discharging a high density sediment flow seriously impacts the downstream river, but it is possible to adjust it by diluting it with water discharged from a dam. Secondly, the properties of the sediment supplied downstream can be controlled to a certain degree by clarifying the properties such as size, grading, etc. of the deposited sediment inside the reservoir.

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