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Sediment relocation trial by Ejector Pump Dredger System (EPDS) in a dam reservoir

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ABSTRACT: The Ejector Pump Dredger System (EPDS) is able to pick the sediment up from the bottom of reservoir by means of the pressure gradient generated by jet water. In this system, the maximum expected size of gravel which can be transported is approximately 150 mm. The field tests on this newly developed system was very successful as approximately 3,500 m^3 sediment was dredged by ejector pump from different depths in the reservoir, 3 to 15 m deep, and then the sediment relocated to the disposal site, 400 m upstream from the suction point, by floating transportation pipeline. The sediment transportation rate was equal to approximately 70 m^3/h.

1 INTRODUCTION

Sedimentation in reservoirs causes severe negative impacts on environment such as: reduction of reservoir storage capacity, damages for infrastructures, reduction of biodiversity for aquatic species and so on. Up to now, a number of methods have been developing for dealing with the sedimentation issues in a dam reservoirs such as free-flow flushing, pressure flushing, bypassing, dredging, and density current venting (Brandt, 2000).

The free-flow flushing (draw down flushing) is one of the suggested methods, which is commonly executed world wide to de-silt the deposited sediment from reservoirs. It has been proven that free-flow flushing is much more effective than other methods due to its large-scale effect (Morris and Fan, 1998). In free-flow flushing, in fact, the water level in the reservoir is drawn down to a relatively low level, so that the flow velocities over large areas of deposited sediment are sufficient to effectively mobilize the sediment (White, 1984). Thus, it could effectively retrieve the storage capacity of dam reservoir.

However, de-silting a huge amount of sediment from dam reservoir during free-flow flushing execution is severely threatened downstream river environment. In particular, the first free-flushing execution may be the most threatening one for the life of aquatic species in downstream river. In fact, the deposited sediment in the vicinity of bottom outlet, which is rather fine, contains the major elements such as silica and iron as well as particulate nutrients and contaminants (Teoduru and Wernli, 2005). The de-siltation of this fine sediment from reservoir, results the oxidation of particulate, organic matter and iron, which ultimately leads to deoxygenated and anoxic conditions at downstream river. Thus, in turn, has resulted in the need to relocate this low quality sediment to an area far enough from the bottom outlet, where it cannot be de-silted (Yamagami, et al. 2012).

To relocate the sediment in a reservoir, dredging of deposited sediment in the vicinity of bottom outlet may require to be conducted. However, the conventional dredgers may not be suitable to use in dam reservoirs; due to their impeller type pump. This kind of pumps doesn't let the gravel, debris and rubbish pass through the system.

In present study, a newly developed dredger system has been used to relocate the sediment instead, named Ejector Pump Dredger System (EPDS). EPDS is distinguished by its ejector pump which is working without any impellers. The detail information about this ejector pump can be found in previous publications of authors (Temmyo, et al. 2012).

This paper attempts to introduce the EPDS and its components and accessories equipment which used in the sediment relocation project. Moreover, the results of trial sediment relocation project conducted at Mimikawa River reservoir in Kyushu, Japan has been presented. Lastly, the capabilities and constraints of EPDS have been discussed.

2 SEDIMENT RELOCATION SYSTSEM

2.1 *The EPDS concept and components*

EPDS aims to hydraulically dredge the deposited sediment from reservoir bed. For this purpose, it uses water to transport the dredged sediment. The sediment is picked up by the suction of a pump, which is named ejector pump, and then transported through a pipeline. In contrary with the conventional dredger system, as abovementioned, EPDS has no rotary part (impeller wheel) inside of the ejector pump. The necessary energy to vacuum the sediment from the reservoir bed is provided by differential pressure between inside of ejector pump and outside of the system (Nakamura, et al. 2012).

The EPDS consists of three main parts: a dredging barge, a transportation pipelines and an outlet barge. These parts are floating on the surface of water and connected to each other. Each part of EPDS also consists of the few components. The lists of these components are listed in Table 1.

Table 1. The list of main components of EPDS.

Main parts	Components	N. of sets
Dredging barge	Unit float	14 set
	High pressure pump 1.95 MPa, 5 m^3/min	2 set
	Air compressor 18 m^3/min	1 set
	Screw crusher 90 kW	1 set
	Telescopic type excavator	1 set
Transportation pipeline	Steel pipe φ400 mm	400 m
	Float	
	Rubber sleeve	
Outlet barge	Unit float	6 set

Both of dredging barge and outlet barge are assembled by unit floats which are equipped with wire to provide the required thrusters for the system to move. The conceptual schematic view of an EPDS and the schematic sediment relocation strategy are respectively shown in Figures 1 and 2. Photography of sediment relocation trial project in Mimikawa River in Kyushu, Japan is shown in Figure 3.

2.2 *Dredging barge*

The dredging barge (27 m length and 16 m width) includes an ejector pump, pressure pumps, air compressors and a screw crusher with telescopic type excavator. The main objective of dredging barge is to pick up the sediment from the reservoir bed and push the sediment into the transportation pipeline. The plane view of dredging barge is shown in Figure 4. The pressure pumps located at dredging barge aims to provide high water jet velocity for the system. These pressure pumps are able to discharge 5 m^3/min (1.95 MPa) of flow rate into the ejector pump through the nozzle.

To effectively pick up and then transport the mixture of water and sediment using an EPDS, it is recommended by Meshkati Shahmirzadi et al. (2012) to introduce an intermediate concentration of air into the system. Therefore the air compressors have been used to inject 18 m^3/min of air into the system, where at the beginning of transportation pipeline, just after ejector pump.

2.3 *Ejector pump*

The ejector pump plays the main role in the suction process, known as the heart of the system. Ejector pump is located at the conjunction of pressure pumps, suction pipeline and transportation pipeline. As explained earlier, pressure gradient between inside of Ejector Pump and Entrance of Suction

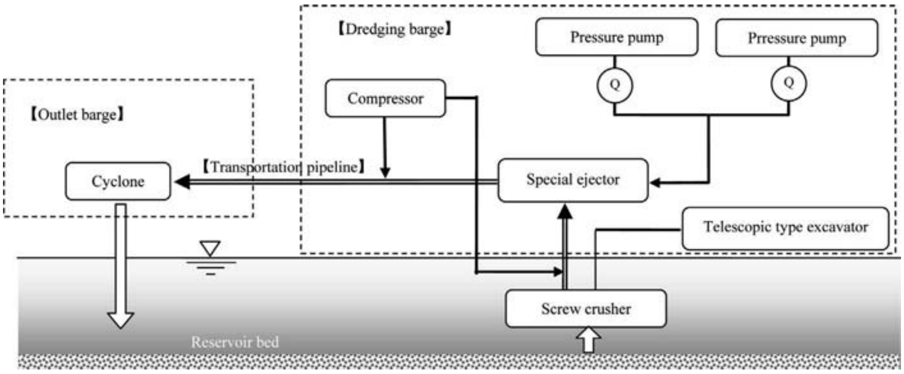

Figure 1. A conceptual schematic view of sediment relocation system.

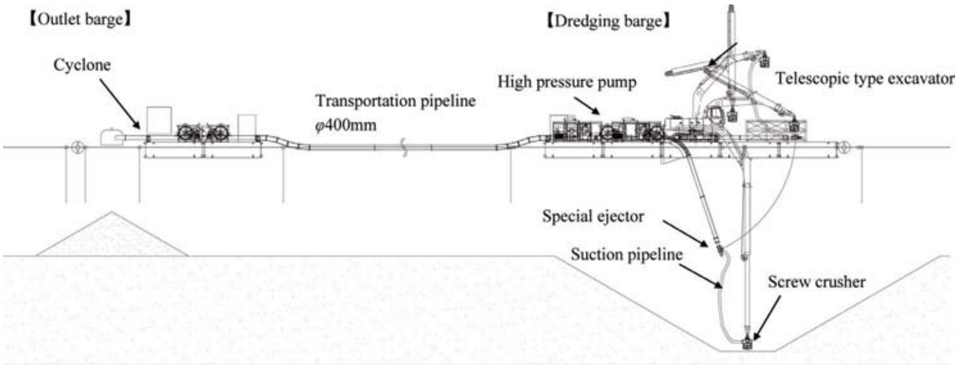

Figure 2. The schematic layout of EPDS and its components.

Figure 3. A photography of sediment relocation trial project using EPDS.

pipeline (outside of EPDS) causes the mixture of sediment and water picked up into the system. Then, the sediment would push forward into the transportation pipeline towards the disposal site.

Ejector pump is equipped by two specific accessories respectively air controller inlet and a straight inner pipeline. Both accessories are vital to preserve the ejector pump against the possible cavitations and abrasion. By varying the combination of diameter of nozzle and diameter of inner pipeline, the suction rate of EPDS can be adjusted. A schematic side view of an ejector pump with nozzle and inner pipeline and the photography of ejector pump used in this study respectively can be seen in Figures 5 and 6.

Based on the field observations, it is found that when the length of suction pipeline is relatively long, blockage in transportation pipeline often happens. Therefore, to prevent the blockage in EPDS during dredging operation in particularly from deep area, the ejector pump is placed under the surface of water to shorten the length of suction pipeline. A lifting arm is set to hold the ejector pump under the water surface of water. Thus, the depth distance between the ejector pump and entrance of suction pipeline can be adjusted easily to reduce the risk of blockage. Figure 7 depicts an ejector pump lifting arm.

2.4 *Screw crusher and suction pipeline*

The suction section includes a telescopic type excavator arm, a screw crusher and a suction pipeline. The telescopic type excavator arm is used to bring down the suction pipeline deep into the reservoir and keep its entrance close to the sediment surface. A screw crusher is attached to the excavator arm to crush the deposited gravels and ease their suction by ejector pump. The screw crusher's shaft is conical shape, which could crush the gravels placed between conical shaft and lining plates in the shell. The gravels with maximum size of 300 mm could be crushed with screw crusher's shaft. The used screw crusher is shown in Figure 8.

2.5 *Transportation pipeline*

Transportation pipeline made by steel is assembled by attaching cylindrical pipeline with diameter of 400 mm. Each steel pipeline is connected with rubber sleeve. The transportation pipeline is also floated on the water surface and it connects the dredging barge to the outlet barge. As it is apparent, the transportation pipeline aims to convey the mixture of sediment and water to the outlet barge.

2.6 *Outlet barge*

The outlet barge (11 m length and 7 m width) is the last part of the EPDS system, dedicated to keep the end of transportation pipeline floated at the surface of water, and also dissipates the energy

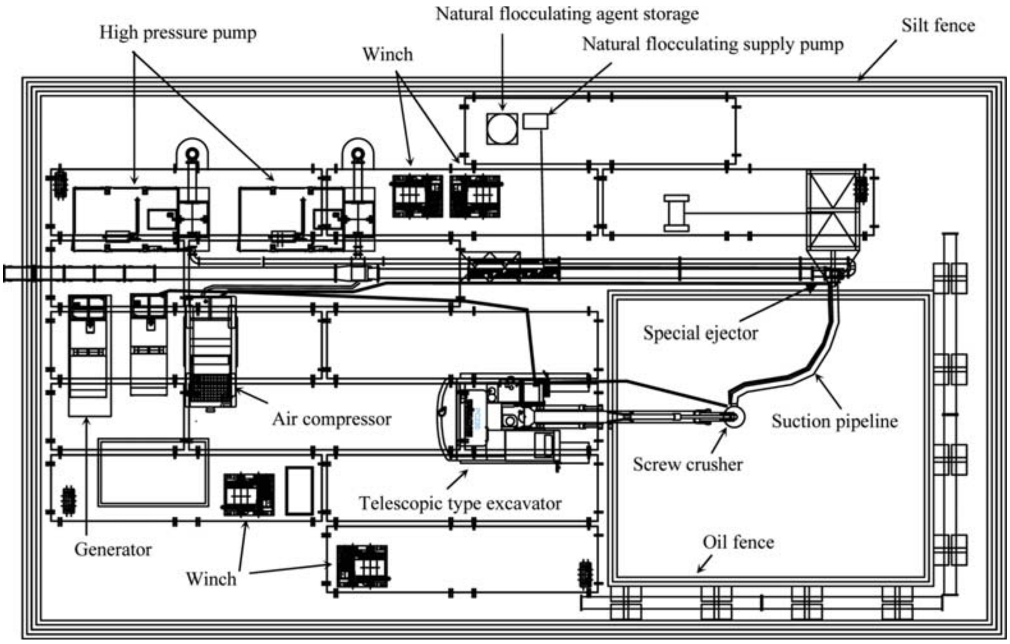

Figure 4. The layout of dredging barge.

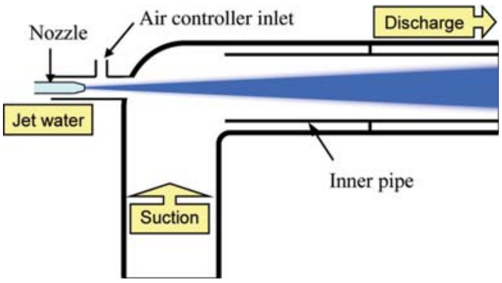

Figure 5. Schematic side view of ejector pump.

Figure 7. The photography of ejector pump and lifting arm.

Figure 6. The photography of ejector pump.

Figure 8. The photography of screw crusher.

of outflow. Dissipating the energy of outflow is not only for reducing water turbidity around the outlet barge but also for the stability of the outlet barge. To dissipate the energy of outflow from an EPDS, a dissipation unit named cyclone is set at the outlet barge just at the end of transportation pipeline. The layout of outlet barge is shown in Figure 9.

3 SEDIMENT RELOCATION TRIAL PROJECT

3.1 *Properties of sediment*

Figure 10 demonstrates the sample of dredged sediment by EPDS. The sediment excavation was conducted at different points range from 3 m to 15 m depth in the reservoir. The dredged sediment from these depths, neglecting the stones and debris, comprises fine sediment (sand) with maximum size of 2 mm. Investigation on the dredged sediment shows that 88% of dredged sediment range from 0.425 mm to 0.85 mm diameter, and mean grain diameter ratio (D50) is 0.39 mm. However, in addition of fine sediment, there are lots of stone, gravel, branches and debris in the dredged sediment. The photography of dredged stones and debris are shown in Figure 11.

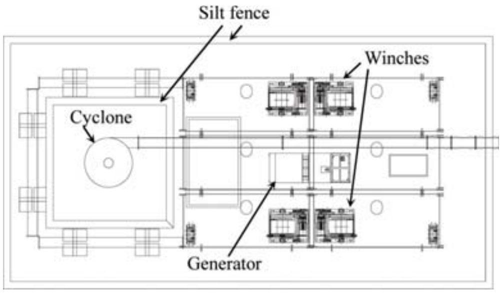

Figure 9. The layout of outlet barge.

Figure 10. A sample of dredged sediment by EPDS.

3.2 *Effect of the location of ejector pump on suction flow rate*

As above mentioned, the vertical distance of ejector pump from the reservoir bed can be adjusted in EPDS using a lifting arm. In this section, the variation of water depth of ejector with variation of water flow rate is investigated. Figure 12 illustrated the relationship between the water depth of ejector and flow rate when the pressure pumps set to 1.86 MPa and the length of suction pipeline is 15 m. The square and triangular points in this figure respectively represent the situation in which the water depths of suction points are 7 m and 11 m. As it can be seen, when placed ejector is the same elevation, by increasing the depth of suction point, the flow rate decrease. And then each cases of water depth of suction points are 7 m and 11 m, by increasing the water depth of ejector, flow rate linearly increase. It could be concluded that when

Figure 11. Stones and blanches in the dredged sediment.

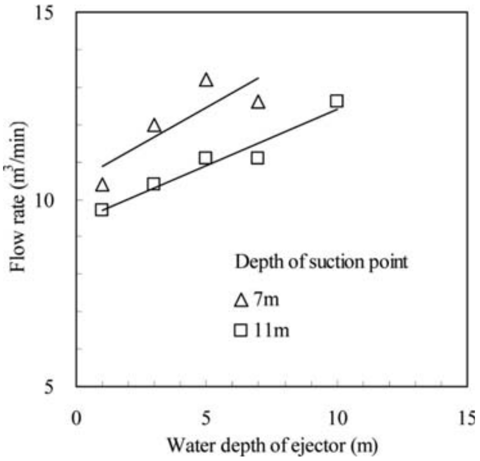

Figure 12. Water depth of ejector and flow rate.

the ejector pump system dredge sediment from the bottom of reservoir, locating the ejector pump deep under water, EPDS is more advantageous and effective to transport the sediment.

3.3 *Sediment transportation rate*

Measuring the sediment transportation rate in EPDS is difficult in a sediment relocation project, simply due to the re-deposition of dredged sediment into reservoir, which is not detectable directly. Herein, three different indirect methods have been proposed to calculate the sediment transportation rate:

1. Setting a valve on the transportation pipeline and take samples through this valve over time. Then, sediment transportation rate is estimated by calculating Equation 1:

   $$Qs1 = Qr \times \frac{Vs}{V} \times 60 \tag{1}$$

   where, *Qs*1 is the sediment transportation rate obtained by samples of the sediment (m^3/h), *Qr* is the flow rate in the transportation pipeline measuring by magnetic flow meter (m^3/min), *Vs*: is the volume of sampled sediment (m^3) and *V* is the volume of sampled water and sediment (m^3)
2. Setting a γ-ray density meter along the transportation pipeline. Sediment transportation rate then can be expressed by calculating Equation 2:

   $$Qs2 = Qr \times \left(\frac{\alpha \times \rho - \rho w}{\rho t - \rho w} \right) \times 60 \tag{2}$$

   where *Qs*2 is the sediment transportation rate obtained by γ-ray density meter (m^3/h), *Q*r is the flow rate measured by magnetic flow meter on the transportation pipeline (m^3/min), α is the density correction factor (in this study equal to 1.02), ρ is the density of mixed flow in the transportation pipeline measured by magnetic flow meter (m^3), ρw (= 1 t/m^3) and ρt (= 1.833 t/m^3) are respectively the density of water and wet density of sediment in the transportation pipeline.
3. Lastly, the sediment relocation rate can be calculated by considering the total operation time and the result of bathymetric survey before and after dredging operation. The calculated sediment relocation rate using bathymetric results and total operation time is equal to 73.8 m^3/h as the bathymetric result was equal to 3,572 m^3 and the total operation time was 48.8 h.

In Figure 13, the sediment relocation rate estimated using Equation 1 is plotted versus the sediment relocation rate obtained by Equation 2.

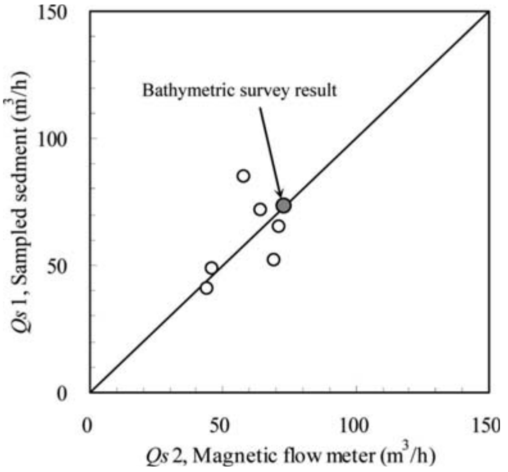

Figure 13. The result of estimated sediment transportation rate between *Qs*1 and *Qs*2.

The figure demonstrates a plausible correlation between method 1 and 2. Moreover, these results are not far from the result by bathymetric survey. Therefore, the sediment relocation rate is obtainable through either sampling the sediment or measuring the density meter.

In conclusion, setting density meter and magnetic flow meter enable the EPDS operators to monitor sediment transportation rate in real time. This monitoring system is very effective to manage the sediment transportation rate.

4 CONCLUSION

The special ejector pump system is able to suck the sediment up from the bottom of reservoir by means of the pressure gradient generated by jet water. The field tests on this newly developed system was very successful as approximately 3,500 m^3 sediment was dredged by special ejector pump from different depths in the reservoir, 3 to 15 m deep, and then the sediment relocated to the disposal site, 400 m upstream from the suction point, by floating transportation pipeline. The sediment transportation rate was equal to approximately 70 m^3/h. However, the possible maximum capacity of the system is depends on the condition such as particle size of the sediment, water depth, transportation length and so on.

Field research of sediment relocation system also shows some of other useful results. When the ejector pump system dredge sediment from the bottom of reservoir, locating the ejector deep under water is more advantageous and able to increase the sediment transportation rate.

The sediment transportation rate is able to be calculated by sampling sediment or by bathymetry survey. However, setting density meter and magnetic flow meter enable to monitor transportation rate in real time. This monitoring system is effective in case of trouble happen during dredging as well.

Reservoir sedimentation poses the greatest challenge toward the sustainable management in reservoir. In this regard, one of the major problems is deposition of coarse sediment at the upstream end of reservoir, in areas far away from the bottom outlet. Thus, it is difficult to transport coarse sediment by free flow even in flood events. This problem, transport of deposited coarse sediment, can be solved using the ejector pump dredger system discussed in this paper.

Using the ejector pump dredger system to pick up the deposited coarse sediment, transport them by horizontal pipeline, and finally release them in the areas in the vicinity of bottom outlet. Relocation of coarse sediment from upstream end of reservoir to the areas near the bottom outlet, would increase the chance of sediment removal by flood events.

Above mentioned sediment relocation system can be effectively used at dam sites without any interruption in their daily operations. The authors hope that this system contributes to the sediment management for reservoirs, and is considered as a positive jump for environmental remediation of rivers.

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