Sediments discharging using siphon system demonstration test at the Republic of Indonesia Wonogiri multipurpose dam

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ABSTRACT

The countermeasures by machines for excavation and dredging reservoir sediments have been often used in the past but in the future the total cost, including operation and maintenance costs as well as construction costs and the inhibitory effect of shoreline retreat of the coastal region have come to be required in the sediments countermeasure. In this paper, we report the results of demonstration tests of sediments countermeasure in Indonesia Wonogiri dam including sediments reduction of the reservoir sediments to downstream river by the siphon system using water level difference between reservoir and downstream river water level, not only construction costs but also aims to reduce energy consumption for operation and maintenance costs by the siphon system in Indonesia Wonogiri dam. A sufficient water level difference for the drought in the test cannot be reserved by using sediments discharge pipe with a diameter of 400mm, the system can transport sediments with a maximum particle size of about 130mm, with an average transport capacity of 30m3/h in the transport distance of 250m and with sediments discharge per unit power of about 8.1m3/kwh. Siphon system has 27 times processing capacity compared the dredging system with small pump with a capacity of 0.3m3/kwh.

1. INTRODUCTION

Siphon dredging is a natural hydro aspirator that uses the existing head of the stored water in the reservoir to hydraulically siphoning the deposited sediment over the dam through a submerged or floating pipeline (Basson & Rooseboom, 1999). This paper reports the experimental results of implemented siphon system in Wonogiri dam focusing on not only construction costs (initial costs) but also operation and maintenance costs by reducing energy consumption. Water level difference between reservoir and the downstream river water levels is used for siphon system composed of three units, namely suction, conveying and disposal tank units. Sediment is hydraulically removed and transported to the disposal unit (tank) through the sediment discharge pipe of diameter 400 mm. During the siphoning, the flow velocity and discharge in the pipe were 1.2-1.6 m/s and 0.15-0.2 m^3/s, respectively. The maximum sediment diameter was about 130 mm and the sediment transport capacity was 30 m^3/h in 250 m transport distance. The efficiency of removing sediment volume per unit power is 8.14 m^3/kWh in the siphon system which is extreme higher than 0.3m^3/kWh in conventional small pump dredging. The main features of the siphon system is capable of processing 27 times and low cost by energy-saving. Such results are confirmed and validated in the case study of the Wonogiri dam, Indonesia.

2. BACKGROUND OF DEVELOPMENT

In Japan, more than 50 years have passed since many dams have been constructed. Now in some of these dams, there are serious reservoir sedimentation problems where the amount of sedimentation has been exceeding than estimated. Since reservoir life can be extended semi-permanently if the accumulated sediments are suitably managed, the development of sediment dredging/removal techniques has become more important in recent years. At present, the main sediment removal methods are sediment flushing and bypassing which employ the energy of flowing water to remove sediments. Because removing by these methods must be implemented in a short period during the flood season when the sediment transport capacity of the downstream river is comparatively high, preservation of the downstream river environment becomes an issue. Therefore, downstream river disposal could cause undesirable effects and must be carefully evaluated at each project. While the sediment bypass tunnel is an efficient technique to reduce reservoir siltation, the cost of constructing and maintaining the bypass tunnel may increase. On the other hand, the mechanical excavation/dredging methods are feasible, but energy consumption for excavation/dredging and conveying is large, and numerous restrictions limit the quality of sediment and dredging locations where these methods can be applied.

In this project, the siphon dredging system was proposed. This system can be operated continuously, not limited to the flood season, because of various features as environmental friendly, low energy consumption and controllable the concentration of the discharged sediment. A dredging demonstration test at the Wonogiri Multipurpose Dam Reservoir in Indonesia was conducted to confirm the optimum conditions of sediment quality, dredging depth, and conveying distance, as well as differences in performance and operation with conventional pump dredging, and to collect various data for practical application.

3. WONOGIRI MULTIPURPOSE DAM RESERVOIR

The Wonogiri Multipurpose Dam is a fill-type dam located in Bengawan Solo river basin (Figure 1) that was completed in 1982 for flood control, water supply for irrigation, domestic use and power generation. It is the sole large-scale reservoir in the Bengawan Solo river basin which is the largest river on Java Island in Indonesia. The reservoir has an area of 90km^2. Inflowing and deposited sediments from the Kudowan River witch is right branch of Bengawan Solo river flowing into the reservoir causes blockage in front of the water intake for power generation obstructing the power generating function.

The sediment consists of clay, silt, sandy clayey silt, and sandy silt. Porosity of the deposited sediment at the surface layer (0-1m) is more than 60% while less than 60% at depths greater than 1.0m. The porosity decreases with depth and a tendency to consolidation (porosity of 53%) was found at a depth of 5.5m.

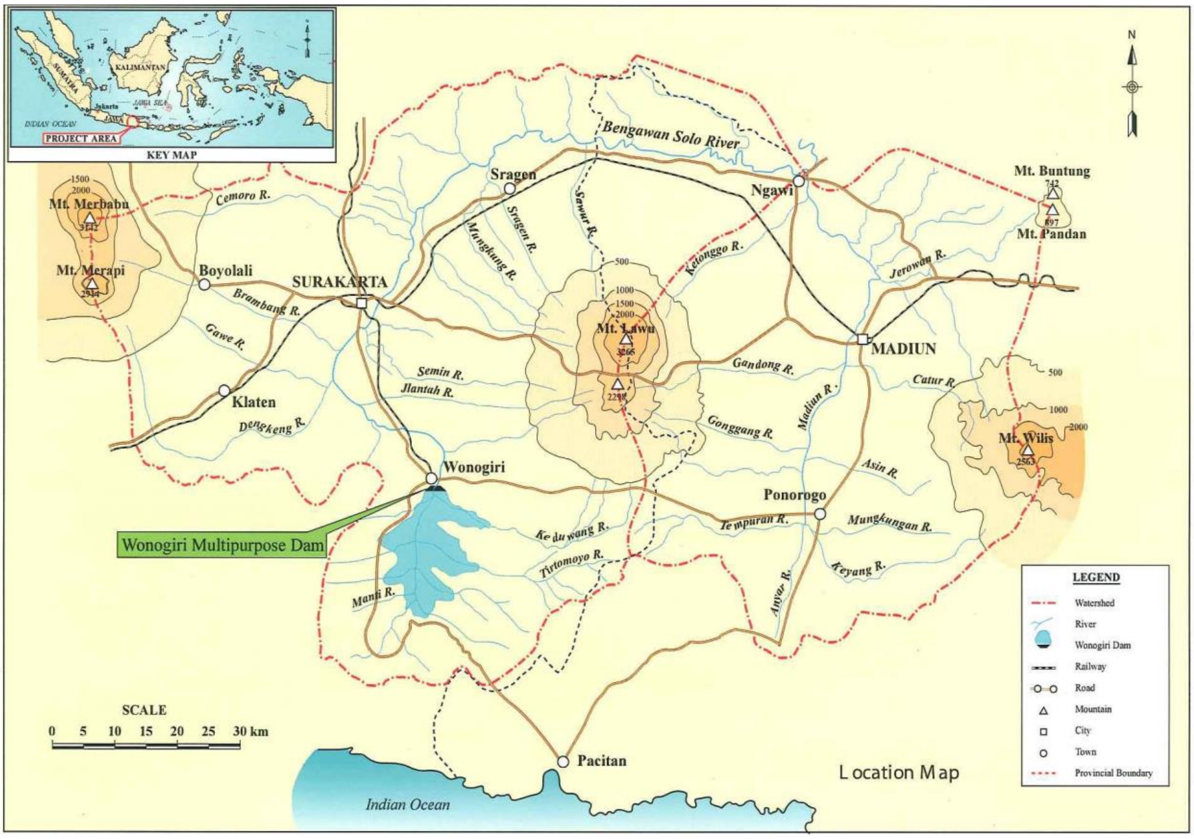


Figure 1. Location map

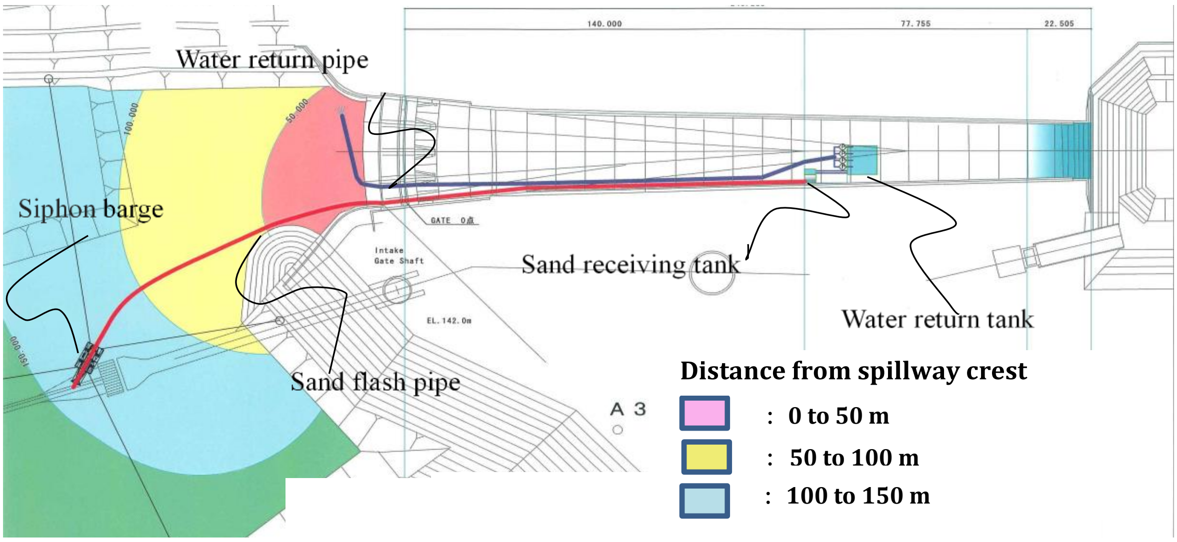


Figure 2. Arrangement of siphon system plan

4. DREDGING SYSTEM

4.1 Outline of the system

The test dredging system comprises of four main components, intake, conveying, receiving and return unit. Figure 2 shows the arrangement of the dredging system. The receiving tank is installed at a level where the specified difference in water level relative to the reservoir water level can be obtained. Polyethylene pipe is supported by floats in the reservoir and laid along the spillway passing over the crest of which gate is opened during the test period. Figure 3 shows the main components of the implemented siphon system and Figure 4 shows a flowchart of the dredging operation.

As the countermeasure for environment in downstream, all discharge water is returned into the reservoir by pumping it through the returning tank and receiver tank.

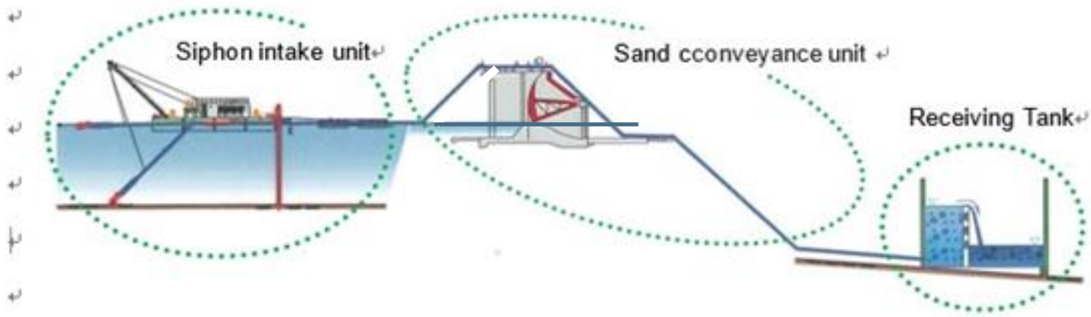
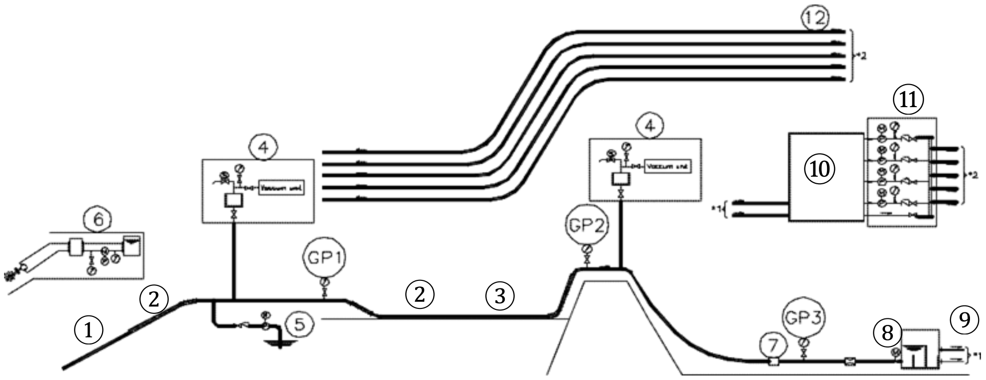


Figure 3. Conceptual drawing of siphon dredging



①Suction pipe	④Vacuum unit	⑦Densitometer	⑩Return tank
②Flexible tube	⑤Water pump unit	⑧Flowmeter	⑪Return pump unit
③Discharge pipe	⑥Excavator	⑨Receiving tank	⑫Return pipes

Figure 4. Flowchart

4.1.1 Intake unit:

An intake pipe with an inner diameter of 400mm is installed on a steel barge as shown in Figure 5. A side rotary-type excavator is mounted at the front of the intake pipe. The excavator has rotor blades on its two sides (Figure 6) to cut and break up trash and consolidated soil which are then sucked into holes on the two sides.

Figure 5. Barge

Figure 6. Rotary-type excavator

4.1.2 Conveying unit:

The flush pipe has an inner diameter of 400mm. A high density polyethylene pipe is used in the reservoir section. Steel pipes are used in the siphon at the spillway gate and in part of the line which discharges into the receiving tank. The line reaches the area downstream of the dam by passing over the top of the opened spillway gate.

4.1.3 Disposal and receiving unit:

A receiving tank (L=4m x W=5m x H=4m) is installed at the end of the pipe route to stabilize the difference in water levels.

4.2 Method and conditions

Tests were performed by varying the flow rate through adjusting the opening of the start/stop valve at the end of the pipeline varying both the dredging depth at the range of 1 to 4 m and the conveying distance by changing the length of the reservoir geometry, independently. Dredging was performed by artificially adjusting the distance between the intake pipe and the reservoir bottom so that sediment would not accumulate in the conveying pipe. In the dredging tests, effective dredging was possible after various dredging tests carried out to eliminate the influence of silting in the pipeline.

Various parameters were monitored during the test such as flow rate and density as shown in the flowchart in Figure 4. They were measured by an electromagnetic flowmeter and γ-ray densitometer installed in the line near the receiving tank, respectively. Pressure in the pipe was measured at three locations by gauge pressure (GP1, GP2, GP3) which are at the barge, in the siphon at the crest of the spillway gate and before the disposal tank. Power consumption limited to the excavator installed on the intake pipe and total power consumption by the winch, vacuum devices and pipeline filling pump were measured with two watt-hour meters, respectively. The amount of dredged sediment was calculated by bathymetric survey before/after siphoning dredging.

5. RESULTS AND DISCUSSION

5.1 Confirmation of Operation

Work efficiency and operability did not differ greatly from that of pump dredging. Since the siphon system is not power-driven, the working environment was good because of no mechanical vibration or noise.

- The time required for initialization until a siphon formed was approximately 20 minutes. Starting and stopping were performed by opening and closing the start/stop valve, and could be performed easily with no vibration of the piping or other parts.

- Although depending on the condition at the suction holes, operating performance was stable. In particular, there were no problems at the siphon section passing over the spillway crest, even When Instantaneous blockage occurred.

- The practical advantage of using lightweight and high density polyethylene pipe in the pipeline was confirmed. Silting in the line can be easily checked by visual observation of floating/sinking of the pipe which is sensitive to changing conditions.

5.2 Pressure Loss in Pipeline

The pressure loss in the piping system was obtained from the measured values of GP1, GP2, and GP3 shown in Figure 4 by varying the flow rate with adjusting the valve opening during dredging. The pressure loss coefficient was obtained from the pressure loss during water conveying using the Darcy-Weisbach equation (Eq. 1, where, H : Head loss due to friction in pipeline (m), λ : Coefficient of pressure loss with clear water, v : Flow velocity (m/s), L : Length of pipeline (m), D : Diameter of pipeline (m)).

$$H = \lambda \cdot V^2 / 2g \cdot L / D \qquad \cdots\cdots\cdots\cdots\cdots (1)$$

Pressure loss in the pipe is shown in Figure 7. The average value of the pressure loss coefficient was 0.0258. Although the pressure loss coefficient of the high density polyethylene pipe was expected to be 0.018, the actual value was larger than the planned value. Therefore, the flange connections in the high density polyethylene pipes were concave, and joints between pipes are not smooth. As this test system included 6 flange connections and 11 bonded joints, it would appear that these parts affected the pressure loss coefficient.

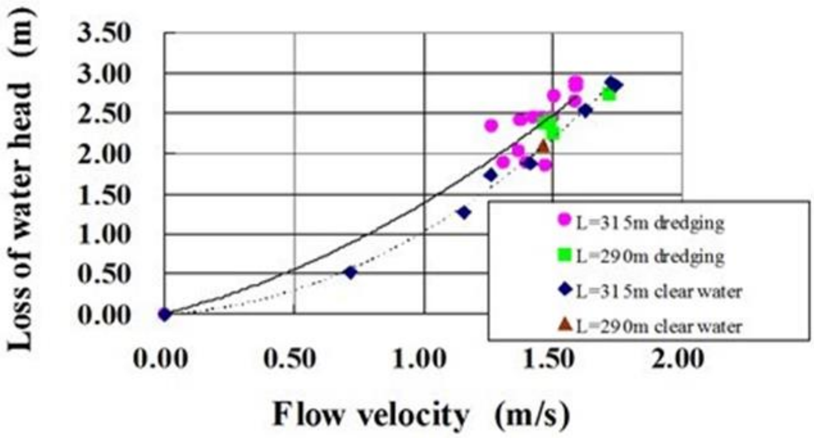


Figure 7. Pipeline head loss

The pressure loss coefficient during dredging was calculated based on a simplified equation proposed by Hasegawa et al. (Port and Airport Research Institute, 1958). As regards the frictional resistance of the pipe when conveying mud, the frictional resistance of the pipe when conveying water is proportional to the mud content of sediment bearing water, and the increment of resistance is thought to differ depending on the soil,(Eq. 2,3, where,. α :Coefficient of increment of pipe friction during dredging, β :Soil coefficient (shown in Table) , γ :Density of muddy water (measured value))

$$H = \alpha \cdot \lambda \cdot v^2 / 2g \times L / D \qquad \cdots\cdots\cdots\cdots\cdots (2)$$

$$\alpha = 1 + \beta (\gamma - 1) \qquad \cdots\cdots\cdots\cdots\cdots (3)$$

Table 1. Soil coefficient

Soil property	β
Clay ・ Silt	2
Fine sand ・ Normal sand	3
Coarse sand ・ Gravel mixed sand	4
Gravel	5

The coefficients of the increment of pipe friction during dredging and soil coefficients (shown in Table 1) were obtained from the average pressure loss coefficient during water conveying and pressure loss during dredging. The results are shown in Table 2.

Table 2. Soil coefficient (Average)

Dredging depth		0~1	1~2	2~3
Soil	Clay	1.5	-	-
	Sandy silt	-	2.5	4.0

Large differences can be seen in the soil coefficient depending not only on the type of soil but also on the dredging depth (0-2m, 2-3m).

At a dredging depth of 0-1m, the soil is clay and the average soil coefficient was 1.5; however, at 1-2m, the soil is sandy silt, and the average coefficient was 2.5. The test value in the case of clay is small in comparison with the value indicated by Hasegawa et al. Because the sandy silt at Wonogiri Dam consists of approximately 50% fine sand, its coefficient is assumed to be an intermediate value between "clay・silt" and "fine sand・normal sand". Based on this, the test value 2.5 for sandy silt is considered to agree with the value proposed by Hasegawa et al. Accordingly, the measured values of the soil coefficient in the dredging depth range of 1-2m are considered to be in rough agreement with the soil coefficient proposed by Hasegawa et al.

On the other hand, although the soil at dredging depths of 2-3m is sandy soil, the average soil coefficient was 4.0. The sandy silt at Wonogiri Dam is considered to have a coefficient on the order of 2.5. Thus, a large difference could be seen in the soil coefficient which is influenced by the following factors.

Factor 1: Intake pipe vertical head : $(\gamma - 1) \times h$,

γ: specific weight during dredging (kg/m^3), h: dredging depth (m).

Factor 2: Increment of pressure loss due to change of angle around intake pipe.

From this, it appears to be necessary to consider not only the soil type, but also the dredging depth in the increment of pressure loss during dredging. Further study is needed including collection of data on the relationship between the soil coefficient and the dredging depth.

5.3 Relationship between Pipe Flow Velocity and Density

The test data on the flow rate and density during dredging are shown in Figure 8. A decreasing tendency in the flow rate can be noticed under the operating conditions indicated symbols of ①, ②, ③ and ④. These phenomena are caused by the flow reduction with sediment flocculation. To prevent the increased sediment accumulation, the clear water flow was discharged through the pipeline. For such condition, the dredging water density was 1.03-1.05. This suggests that sediment accumulation may start if dredging is performed under these operating conditions. In other words, these are unstable condition which indicate the approximately critical velocity in the pipe.

On the other hand, operating conditions ⑤ and ⑥ show a peak density. In these timings, it is considered that dredging is performed without sediment accumulation because the flow rate is comparatively stable before and after this peak, and furthermore, the density is relatively low in comparison with that under other operating conditions with the same flow rate.

Figure 9 shows a comparison of the above measured data and an experimental equation for the critical flow velocity proposed by Yagi et al. (Port and Airport Research Institute, 1979). The representative particle size of the mixed sediments adopted here is d60=0.093mm. In the range where the flow velocity is comparatively slow, the pipeline is basically horizontal excluding an inclination of about 15° in the siphon section.

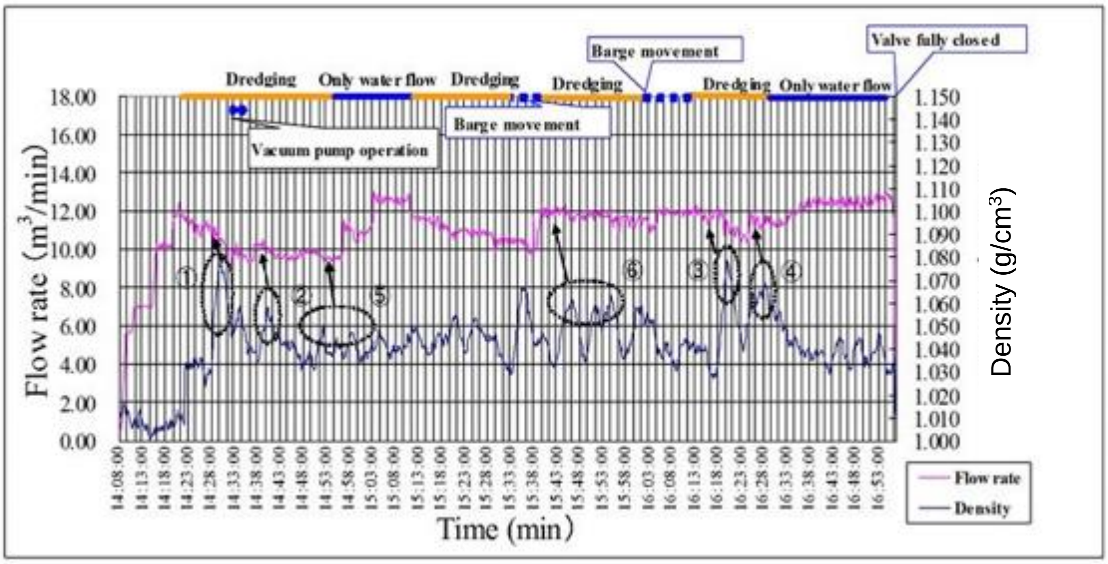


Figure 8. Relationship between flow rate and density

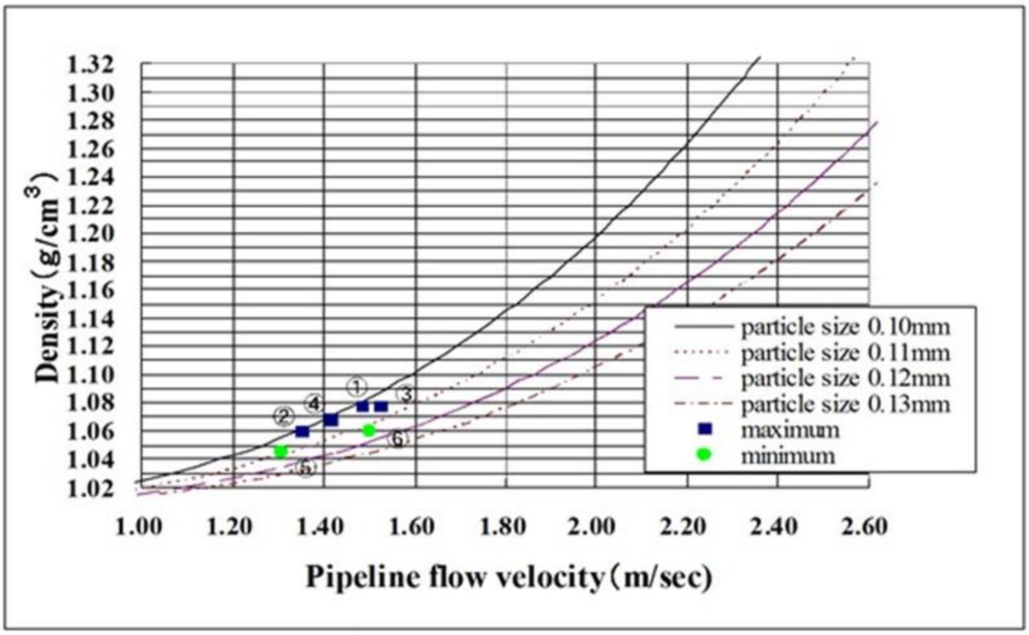


Figure 9. Pipeline flow velocity and density

5.4 Energy Consumption in Dredging

With the presented results of the experimental test system, dredging was performed at the maximum flow velocity of 1.7 m/sec, while adjusting the intake pipe operation to approximately 50% of the rated speed of the rotary excavator at the intake head. The maximum dredging depth was 4.0 m.

Table 3 shows key data obtained by the dredging test with the rotary excavator such as flow rate, volumetric sediment concentration, dredging volume, operation time and electricity consumption, and calculated dredging volume per hour and dredging rate per unit power consumption. As reference, the table shows the specifications of a small-scale pump dredging barge (E200PS) with almost the same capacity as this test system.

The dredging rate per unit power consumption is 8.14 m^3/kWh or more than 12 times higher than that in pump dredging (0.625 m^3/kWh; pump dredging power = pump drive power x 0.8). The siphon dredging system is clearly an extremely effective energy saving system in comparison with the pump dredging barge and other power dredging methods. In this test, the volumetric concentration was limited to about 6 %, but this can be increased by increasing the flow velocity.

Table 3. Test data for side rotary method

Type of sedimental excavator	Flow rate	Volumetric concentration (Average)	Dredging volume	Operation time	Dredging volume per hour	Electricity consumption	Dredging rate per unit
	(m^3/min)	(%)	(m^3)	(h)	(m^3/h)	(kwh)	(m^3/kwh)
Side rotary method	9～12	6	122.1	4.06	30.1	15	8.14
Hydraulic dredge	15.4m^3/min. x31m x147kw	10	92.0	1	92.0	147	0.63

5.5 Trash Passing Performance

Figure 10 shows examples of the trash found in the receiving tank and return tank in this test. Types and their maximum dimensions of trashes are shown in Table 4. Stalks and wood debris with lengths exceeding the pipe diameter passed through the line. Because there are no obstacles to the passage of trash through the line in the siphon system, virtually no blockage occurs in the system if trash enters the intake hole. Thus, the system has excellent trash passing performance.

Table 4. Type of trash

Type	Dimensions
Gravels	Maximum diameter: 130mm
Bamboo, stalks	Maximum length: 600mm x width : 50mm
Others	Scraps : approx. 150mm x 150mm

Figure 10. Discharged trash gravels and bamboo

6. CONCLUSION

This study presented an experimental test and evaluation of the siphon dredging system at the Wonogiri Multipurpose Dam Reservoir which excavates/dredges and conveys sediments using the difference in the water level of a dam reservoir and the downstream river. This system can be operated continuously without limitation to the flood season. It is also considered to be a comparatively environment-friendly system because energy consumption is low and it is possible to control the concentration of discharged sediments. The main features of the implemented siphon dredging system are:

1) Workability and operability are similar to those in conventional pump dredging whereas the siphon system is not power-driven, mechanical noise and vibration are minimal. Thus, the proposed system can be characterized as energy saving and environment-friendly.

2) It is possible to control the concentration of discharged sediments by adjusting the opening of the start-stop valve.

3) The increment of pressure loss in the pipeline during dredging shows comparatively good agreement with a simplified equation proposed by Hasegawa et al. However, in order to improve accuracy, it is necessary to consider the dredging depth (soil consolidation).

4) In the range where the flow velocity in the pipeline is comparatively slow (1.0m-1.7m/sec) and the range where the total conveying distance is short (315m), the relationship between the sediment particle size, critical flow velocity and volumetric concentration show good agreement with an experimental equation proposed by Yagi et al.

In the future, while continuing to accumulate actual results, the authors will plan to clarify the conditions for maximizing the effectiveness of the siphon system by further tests of the sediment particle size, dredging depth, and conveying distance.

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