"Hydro Technology" For Discharge of Sediment from Dams and Weirs

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Abstract

With long time operations of dams, reservoirs, silt basins, soils that have flown into such facilities would settle and present problems. The technology we are going to address here is a dredging technique to discharge sediment out of the facilities or to remove them from lake to downstream river. The Hydro Technology utilizes the natural water flows to discharge sediment under given conditions of water head, particle sizes of sediments, and therefore the discharging can be made with minimum energies. That is to say, because of the lower pipe friction losses the longer distance of discharging can be achieved. Moreover, risk of pipe blocking is very low because the Technology takes advantages of natural effect of slurry flows that has self-controlling function of transporting sediments at the best appropriate concentration. Furthermore, because of less chances of causing water turbidity within the reservoir, it is possible to perform the discharge without disturbing the original purpose of the reservoir for hydropower generation, etc.

In this presentation, we introduce the social significance of the Hydro Technology, explanation of its theories as well as displaying of application examples and the results of verification tests in relation to the Technology.

1. Introduction

In recent years, sediments deposited in reservoirs, lowering river bed in downstream regions, scouring cases in bases of structures such as bridges and riverbanks, and shore erosion are presenting serious problems from the viewpoint of river management. In the relation of natural environment and circumstances in which humans live, rivers and soil/sands generate very complicated problems of river management, in relation to environments as well as safety and maintenance. The flows of rivers are basically the slurry flows of water and soil that change characters under various factors including motion characteristics generated from erosion, transportation and deposition of soils, particular characteristics and properties of soil particles that may cause dispersion, coagulation and settlement. In addition, there are changes of natural conditions, passage of time, location as well as artificial works. These natural changes are not necessarily compatible to the human livings, which require consistent and constant conditions of infrastructures and social activities. Such incompatibility presents the problems of today.

In July 1998, the official report submitted by the sub-committee on general management of river titled "Toward integrated management of flowing soil" defined the movements of sands on a river along its total areas of basins from origin to offshore as "flowing sand system." It called for actual measures based on an integrated management under the concept of this system. In one of the chapters of this report is titled "Development of Integrated Management." It urged for establishment of effective measures to discharge sediment for any new projects of dam construction, and the establishment of a system to discharge the sediments from existing dams.

While the problem of sediment at dams and other reservoirs have various phases from its generation, sedimentation, dredging and transportation, erosion and finally flow-out, the hydro technology discussed here was developed in Norway as the most economical means for the dredging and transportation phase.

Features of the technology include:

1) Low-cost dredging and transportation is possible by utilizing the water head of the reservoir concerned.
2) The technology causes no turbidity of water within the reservoir, thus the dredging and the discharging of sediment can be performed from time to time without interrupting the original purpose of the dam. Water intake can be made, whether for power generation, irrigation and/or water supply.
3) Not being an operation at a fixed point, the dredging work can be performed at any point of the reservoir.
4) From the viewpoint of the principle characteristics

of this method, it should enable operators to carry out the dredging work of high concentration without risks of pipe blockage.

5) The principle characteristics of this method indicate that the dredging and transportation of the material with minimum energy requirements. In other words, the works can be performed with less pipe abrasions and with longer transportation distances.
6) Operation is simple and does not require a skilled operator

2. Principle Characteristics of Hydro Technology

The principle characteristic of Hydro Technology is quite simple. It just makes use of a natural phenomenon. (Refer Fig. 1) The hydroÅ|pipe, which has continued slots. in shape of intermittent slots in the lower portion, and laid underneath the sediment, is connected to the outlet pipes. The most upstream portion of the hydro-pipe, however, must be protruded from the surface of the sediment.

The operation of the hydro-pipe is performed in two phases as addressed below:

1) Wait until certain volume of sediment materials pile upon the pipes. One of the features of this technology is no blocking of the pipes because the slots are located on the bottom side.
2) When the outlet pipe is opened, water is suctioned into the pipe through the opening at the top of the pipe, protruding from the surface of the sediment materials. At the same time, sediment materials are also suctioned with water and discharged to the downstream. When the entire materials are suctioned to nil, the suction pipe moves toward downstream.

If the concentration of the slurry within the pipe would increase, frictions within the pipe would also increase and the velocity of the slurry drops, subsequently the suction would be decreased. The decrease of suction, then would help decrease of the slurry concentration. As a reverse phenomenon, the drop of the slurry concentration would help increase of the velocity of the slurry inside the pipe and consequently would increase suction and therefore slurry concentration. So, under the given condition in the most appropriate situation (minimum energy), the discharge of the sediment can be achieved in a self-adjustment process. The process should automatically prevent the blocking within the pipe.

The slurry flows theoretically make the soil particles in the saltation flow to floating situation when the velocity is slightly faster than the limit deposit velocity. However, the kinetic energy of soil particles perpendicular to the flow is not high. Therefore, the energy consumed for the particles collisions to the tube wall or among the grains would be minimum, namely the flow can be achieved with minimum friction loss and minimum flow gradient. The flow in this situation is called heterogeneous flow. Incidentally, the faster flow than this is called homogeneous flow. In this case, the concentration in the cross section of perpendicular to the flow will be the same but the friction loss of the flow would become larger. For the planning of installing the Hydro-technology facilities to discharge the sediment materials, it is not ignorable to predict the limit deposit velocity. There are several calculation methods for the limit deposit velocity. They were proposed by Durand, Wilson, Gilie, and others. For engineering purposes "Sedimentation Engineering" edited by Vito A. Vanoni of the ASCE(American society of Civil Engineers) Task Committee says the Durand method is safe enough. There are considerable differences in the calculation results by the respective methods, largely by the mean particle size of sediment and the inner diameter of the pipe. The hydraulic gradient required for discharging the slurry at the limit deposit velocity may be calculated as a value in expression of clear water with the Durand-Condolios methods or others. To perform these calculations, several characteristics of the soil properties including kinematic viscosity, drag coefficient and others are required. Still, variations of particle sizes, shapes of the sediment and the concentration of the slurry would make it difficult to establish the soil properties, although there are some formulations based on various assumptions.

All the requirements may be established through calculations but the results of these calculations are, as mentioned, based on assumptions. Therefore they should be considered as guidelines for the engineering. To obtain appropriate values, it is desirable to establish them through laboratory tests and/or small-scale experiments. We believe it is the basic principle of the engineering.

3. Types of Hydro-Technology

Types of the Hydro-Technology may be classified in two types, depending on the shape of the hydro-pipe, a straight one and a curved to the shape of "J" charac-

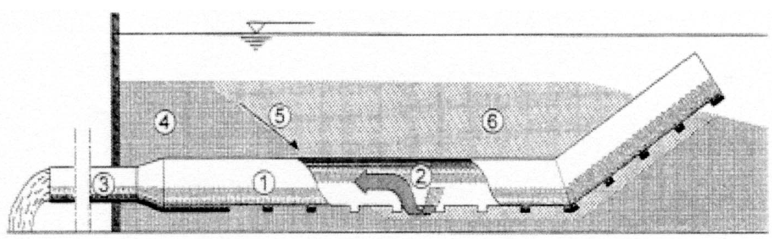


Fig.-1 Basic Composition of Hydro-Technology System
① Hydro-pipe ② Sucking point ③ Outlet Pipe ④ Sediment
⑤ Sediment collapsing toward the sucking point ⑥ Discharged portion

Table -1 Features of Hydro-Pipe and Hydro-J

Type	Conditions for application			
	Installation	Operation	Installation Method	Mobility
Hydro-Pipe	Buried in the sediment but for the portion of outlet pipe.	All operations can be done with closing and opening of valves.	Installation for new dam is easier. For installation to the existing facilities, advance dredging is necessary. Hydro-J is applicable for advance dredging.	Difficult to move once it is installed.
Hydro-J	J-pipe is hung in water. The outlet pipe portion can be positioned either in water, on the surface of in air.	It is hung and lifted by crane either from land or from a dredger. The pipe is movable with a winch. Operations can be done with closing and opening of valves.	Installation is easy.	Movable.

ter. While the principle of the suction dredging is the same, there are some differences on operation and features of the respective types. The former is called Hydro-Pipe and the latter Hydro-J. The Hydro-Pipe is used as a fixed facility for operation of longer periods with minimum operation process. On the other hand, the Hydro-J is mobile and more hands are required for operation. Table-1 below shows the basic features of both types.

For these two types the most desirable method of generating water flow is the utilization of the difference of water levels in and out of the dam. However, we do not necessarily stick to this method. Depending on the method to generate water flows inside the pipe and the composition of the equipment, there are several ways of dredging as described below:

3.1 Methods based on Hydro-pipe

3.1.1 Hydro-PB

This is the operation in the most basic form. Install the slotted Hydro-Pipe on the bottom of a dam or a shaft in opposite direction of the sedimentation to discharge the sediment through outlet pipes to outside the lake. The difference of water levels between outside and the inside of the reservoir, or similar difference of water levels inside the reservoir and the shaft should generate the water flow.

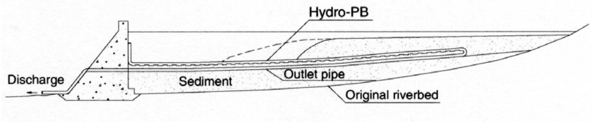


Fig.-2 Hydro PB

3.1.2 Hydro-PS

This is a method to discharge sediment materials into the shaft or hopper by differentiating the water levels of the lake and inside the shaft or hopper. The water level within the shaft or hopper is lowered by pumping or promoting natural drainage. It is possible to remove the sediment inside the shaft or hopper to outside the lake with a hydro-pipe installed on the bottom.

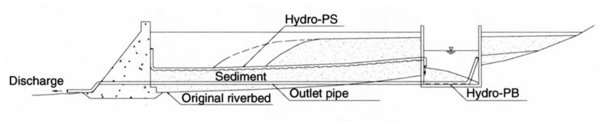


Fig.-3 Hydro PS

3.1.3 Hydro PP

Where water level differentiation is not applicable to generate water flows, connection of pumping equipment is used to generate flows for carrying out suction dredging. Because any mechanical driving system is not involved in the Hydro-pipe system itself, possibility of pipe blockages by debris or large particles is rather low. However, pumps generally have mechanical driving system like impeller, which are vulnerable to such debris and large particles. Therefore, it is recommended to select appropriate type of pumping equipment that has not mechanical driving system, such as a jet pump. Also, from the viewpoint of energy saving, it is desirable to establish the level of the sand discharge point as low as possible.

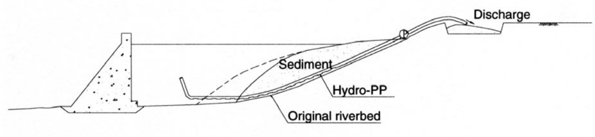


Fig.-4 Hydro-PP

3.2 Methods based on Hydro-J

3.2.1 Hydro-JB

A dredger or a working barge lifts a "J" pipe that dredges sediment materials and discharge through outlet pipes to outside the lake. Water level difference in and out of the lake generates the water flow.

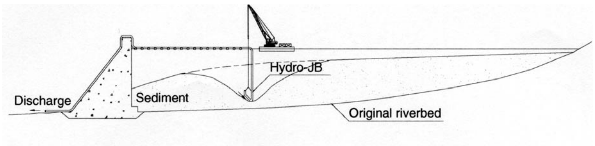


Fig.-5 Hydro-JB

3.2.2 Hydro-JS

A dredger or a working barge lifts a "J" pipe that dredges and transports sediment materials to a shaft with differentiated water level.

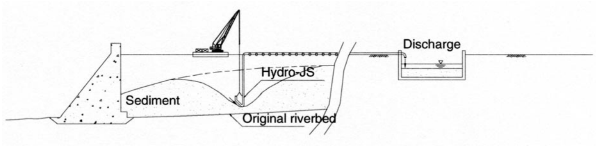


Fig.-6 Hydro-JS

3.2.3 Hydro-JT

A dredger or a working barge lifts a "J" pipe that dredges and transports the sediment materials to a tank having lower water level or into a hopper barge. Flow is generated by differentiated water levels of the dam and the tank or the shaft of which the water levels are lowered by pumping processes. The bottom-hopper type barge would be preferably used to transport the sediment.

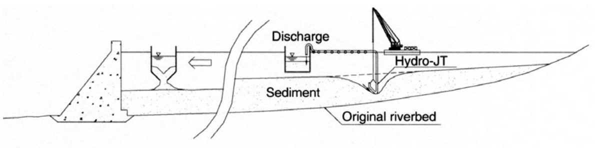


Fig.-7 Hydro-JT

3.2.4 Hydro-JP

Where the water level of the discharge point is higher than that of the lake, a pumping system is used in midway of the outlet pipe in order to transport the sediment. Similarly to the requirements for Hydro PP, selection of the pump type and making the level of the discharge point as low as possible are desirable requisites.

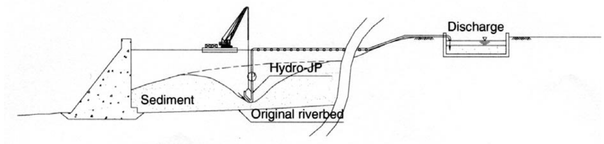


Fig.-8 Hydro-JP

3.3 Combination

A typical example of combined use of the above technologies is illustrated in Fig. 9 below.

In the upstream area of the dam or reservoir, dredging is performed with Hydro-PP to move the sediment to the downstream area. In midstream area the dredging work is carried out by Hydro-JT and transport the dredged material with bottom hopper type floating tanks to the downstream area. The sediment materials so collected in the downstream area are finally discharged by Hydro-PB method. Sizes of the downstream basin mentioned here vary from a few meters to several kilometers by the particle sizes, thickness of the sediments and applicable water head differentials. The range is limited in a range where the Hydro-PB is applicable. The midstream area must be deep enough to allow accesses of dredging or working barges. The area of course may be expanded toward upstream area with the progress of the dredging works. There are some difficulties in the upstream area to secure water level differentials.

4. Suitability Tests of Hydro-J Method

Following is the results of suitability tests on Hydro-JT technology performed at Sakuma Dam Reservoir belonging to Dengen Kaihatsu (Electric Power Development Co. Ltd. known as J-Power)

Testing Facilities:

1) A working barge of 30 x 10.5 meters loaded with a 35-ton crawler crane to suspend Hydro-J pipe.
2) A 2,5meter dia. floating tank fixed to the working barge
3) A 250mm dia. Hydro-J pipe and a 60-meter long outlet pipe with 200mm diameter.
4) A γ-ray densitometer and an electromagnetic discharge meter
5) A sand pump of 200mm, portable power generator, etc.

Testing method:

1) The Hydro-J pipe is lifted down to the bottom of the reservoir of about 20 meters deep.
2) Operate the sand pump inside the floating tank, for lowering the water level in the tank (3-5 meters).
3) With the lowering of the water level in the tank, dredged sediment materials began to flow into the tank from the Hydro-J pipe.

Mud and sands subjected to the test mainly composed of silty fine sands with the grain size below 2mm. (some gravel stone of minimum size of 140mm

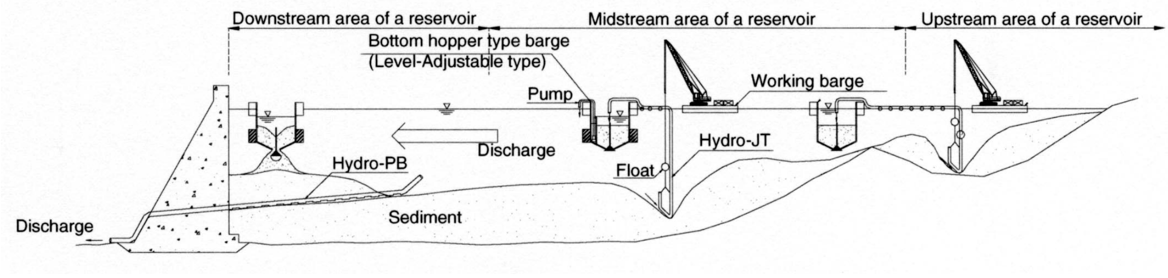


Fig.-9 Combination of Hydro Technologies as well as sunken tree branches of 20mm dia., 60mm long were also included.)

Findings from the results of the tests included:

1) The absence of mechanical elements within the Hydro-J pipe and outlet pipe showed ability to dredge out considerably large objects mentioned above, namely, gravel stones and sunken wood branches. In comparing the fact that there were considerable residues in the floating tank of gravels and other foreign objects which sand pump system could not take, the Hydro-J system was quite effective to dredge out miscellaneous objects.
2) Supposing the increasing ratio of gradient of slurry flow to that of clear water flow on various losses of intake, valve, bending, and discharge are equal to the increasing ratio on pipe friction loss, we tried to express the results in the formula to obtain utilizable dimensionless excess head loss (ϕ) and calculated following value:

   $\phi = (i_m - i)/(i*C_v) = 6.78$

   where:

   i_m = hydraulic gradient of slurry as expression of clear water gradient

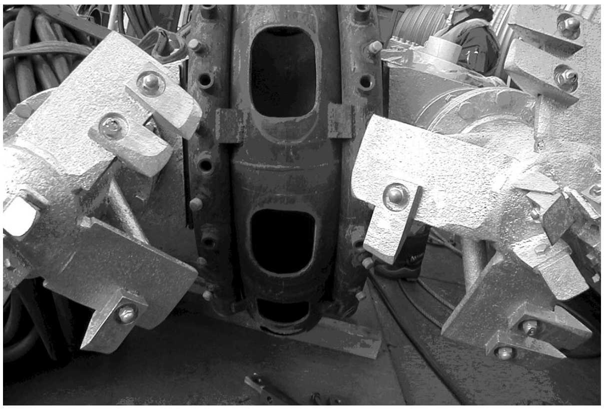
   i = hydraulic gradient of clear water

   C_v = concentration by volume of slurry.

   The value almost agreed with the calculated value.
3) The density of the discharged sand applied to the maximum water head difference of 5 meters was about 9% in terms of volumetric concentration. Taking into account of losses of in-take, discharge, bending and valve, for the slurry at this maximum point, we can assume discharge of the tested subjects could be achieved with a hydraulic gradient of about 1.8%. This may be converted to ability to transport and discharge for a distance of more than eight kilometers at the water head difference of 150 meters.
4) From 2) and 3) above, we could confirm that this method being practical with capability of dredging and discharge dense sediment materials of considerably long distance.

Photograph-1 Working barge with a crane to hang Hydro-J pipe

Photograph-2 Hydro-J Pipe



Photograph-3 Slots of Hydro-J Pipe

Photograph-4 A group of measurement instruments

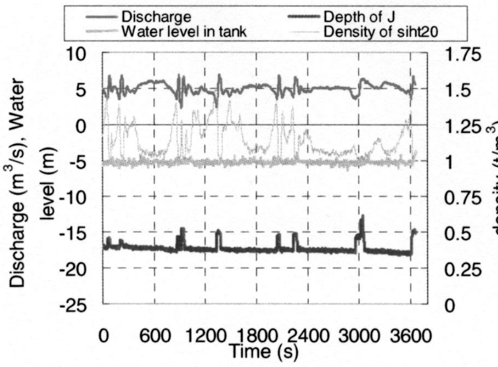


Fig.-10 Excavation Log

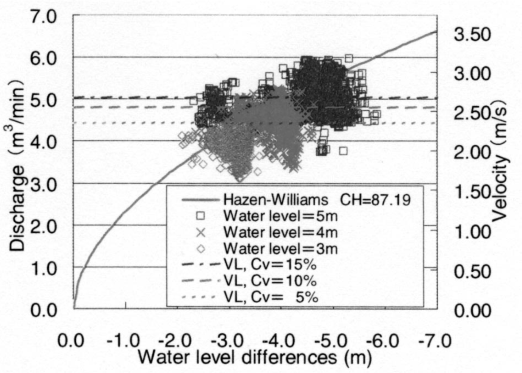


Fig.-11 Relation between the water level differences and discharge volume

5. Laboratory testing of Hydro-pipe method

Following is a summary of laboratory tests on Hydro-pipe method held at the laboratory attached to Asunaro Aoki Construction Co. Ltd.

Testing facilities:

1) A water tank of 1meter wide x 10 meters long x 1.2 meters depth.
2) A Hydro pipe, 100mm dia., 10meter long and an outlet pipe 75mm dia., 7meter long.
3) Slot size of Hydro-J pipe: 60mm wide with 180mm long
4) Difference of water levels from upstream side and outlet at downstream side was 1.3 meters.
5) Measurement instruments included an ultra sonic distance meter and load meter to measure discharge and density and measurement of pressures inside the pipe, using manometer and pressure transmitter.

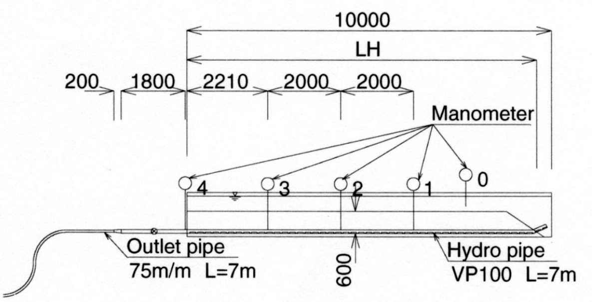


Fig.-12 General Outline of Testing Facilities

Material subjected to test:

Mountain sand with main component of medium to fine grains under particle size of 4milimeters taken from Shimodate Region, Ibaraki Prefecture, containing about 2% of silt under 75μm. d_{50}=0.7~0.8mm.

Test Method:

1) Fill the water tank with water and put test material to the height of 600mm from the bottom of Hydro-pipe and let it piling up...
2) Keep overflowing of the tank with fresh water in order to maintain consistent water level.
3) Open the main valve to operate the Hydro-pipe.

Table 2 shows the results of the measurement. Figures 13~16 are the results expressed in graphs.

t = time passed since opening the valve

L_H = Hydro Pipe's length covered with sediment material

V_H =Velocity of slurry inside the Hydro Pipe

C_v =Volumetric concentration of Slurry

I_m =Hydraulic gradient of slurry as expression of clear water

H_d =Pressure differentials between the pressure inside the pipe at the downstream end of the pipe and the static water pressure (water head as expression of clear water). It indicates the difference of manometer reading of 0-4 in Fig. 4.

V_s =Discharged volume of sediment materials (true volume)

Table-2 Results of Laboratory Tests

t (s)	L_H (m)	V_H (m/s)	C_v	i_m (mH_2O/m)	H_d (mH_2O)
1200	9.0	0.92	0.025	0.070	0.75
4200	7.0	0.95	0.045	0.089	0.68
5700	5.0	0.87	0.050	0.108	0.65
7200	2.5	1.08	0.080	0.148	0.43
8340	1.3	0.76	0.045	0.128	0.28

Note: When L_H =1.3 meters, the valve was closed to half-opening to avoid possibility of excessive velocity.

From these results, we could find the followings:

1) When the LH decreases, the concentration of the slurry proportionately increases (Fig.-13). This fact forms the basis of similar trend in the relation between the LH and the hydraulic gradient. (Fig. -14)
2) The time and the coverage length represent the functional relations on upward convex (Fig.-15). It shows the discharge is accelerated with the passage of time.
3) H_d is the pressure differences of inside and outside of the outlet. This is one of the elements affecting the continuity of discharge operation and the stabil-

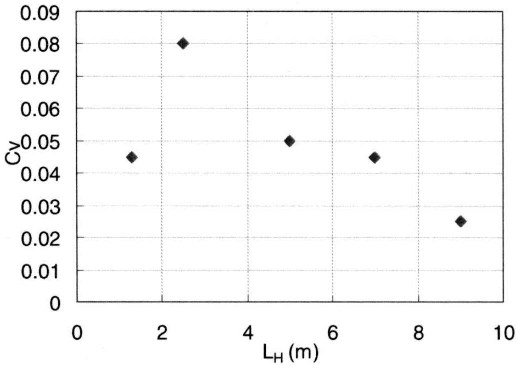


Fig.-13 Relations of L_H and C_v

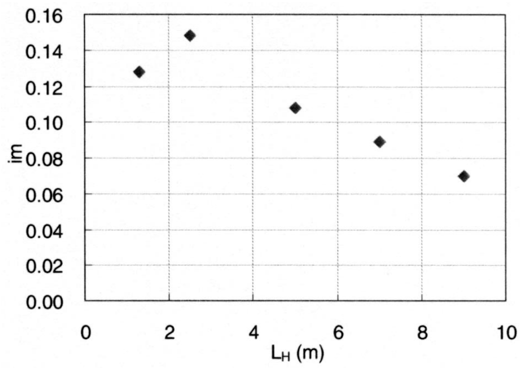


Fig.-14 Relations of L_H and hydraulic gradient

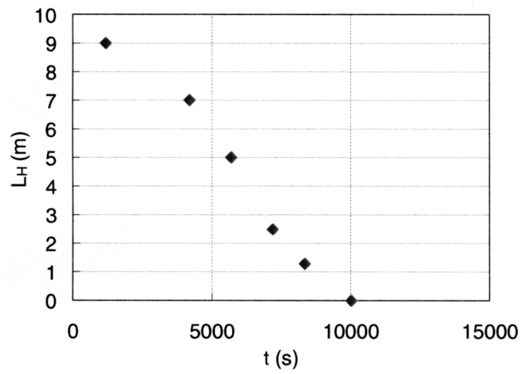


Fig.-15 Relations of time and L_H

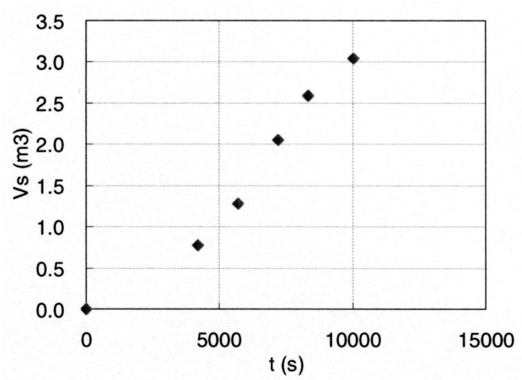


Fig.-16 Relations of time and Aggregated volume of discharges

ity of the sediment at the bottom of Hydro-pipe. The test results showed that Hd was maximum at the start of the operation but it decreased with the passage of time. (Table 2)

These test results tell that if the continuity of the operation could be maintained, then the work efficiency would be appreciated in the hydro-pipe technology and, therefore, it is very important to find the relation of pressure difference and of sediment at the bottom of pipe.

While these tests were performed under single and simple condition (pipe diameter and the material subjected to the tests), they were helpful for us to predict the qualitative character of the technology and that the hydro-pipe technology is an indicative method for displacing sediment in considerably wide area with simple facilities and operations.

Further research would be necessary to pursuit the discharging capability and maintaining continuity of the operation in the future. The quantitative aspects of this technology should be introduced from the actual work results under various conditions and circumstances and researches and analysis in the actual works and achievements.

Conclusion

Hydro-Technology which has many epoch-making features enables to discharge sediments more effectively and economically with optimum combination with various other facilities. And this technology has been confirmed on its effectiveness and practicability of dredging and discharging in experiments both on site and in laboratory. Therefore, Hydro-Technology would be mighty available method to solve the problems of sediment at reservoirs that have been growing serious year by year.