Development of the suspended-sediment concentration measuring system with differential pressure transmitter in rivers and reservoirs

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Abstract

It is important to know quantity of wash load for the integrated sediment management from upstream through downstream river basins. Generally, both continuous turbidity measuring and bottle sampling are used for suspended-sediment concentration measurement in rivers or reservoirs. Here, we have developed a new suspended sediment concentration measuring system with differential pressure transmitter (hereafter, we call *SMDP*).

The *SMDP* has advantages in long-term and high turbidity measurement because differential pressure transmitter is measuring density of water directly. Based on measuring conditions, a submersible type and a water circulating type *SMDP* are available, and both of them have shown good performances through laboratory tests and field experiments at the *Miwa dam*, the *Tenryu river* and the *Kurobe river*.

Introduction

Reservoir sedimentation is a complex process that varies with watershed sediment production, rate of transportation, and mode of deposition. Sedimentation reduces reservoir storage capacity for flow regulation and with it all water supply and flood control benefits, plus hydropower, navigation, recreation, and environmental benefit that depend on released from storage. Besides of storage loss, many types of sediment related problems can also occur both upstream and downstream of dams. The combination of sediment trapping and flow regulation also has dramatic impacts on the ecology, water transparency, sediment balance, nutrient budgets, and river morphology. Even coastal process can be affected; accelerated coastal erosion can be occurred because of sediment trapping in far upstream reservoirs and lacking of sufficient sediment supply to downstream. Thus necessities for sediment management of reservoirs are not only for a reservoir itself but also for the integrated sediment management in the total river system.

In order to realize the integrated sediment management, it is necessary to know the total sediment load consisting of bed load, suspended load and wash load that is mainly produced and transported from upstream through downstream. If there are some storage reservoirs in the river basin, outline of the annual the sediment production can be estimated from time series of sedimentation records in those reservoirs. It is, however, relatively difficult to know total incoming wash load, since some amount of total load is easily passing thorough in case of small reservoirs.

It is general to combine continuous turbidity measurement with the turbidity meter and bottle sampling for calibration to know time variation of flowing wash load in rivers or reservoirs. However, there is a subject in stability for long time since the turbidity is measured by an optical method and, for bottle sampling, it is very difficult to collect samples without missing at the time of discharge peaks in case for small catchment areas having very short run-off times. Although the long time stability has been improved by the technology improvement in recent years, there is some limitation for extremely high turbidity measurements in case of high floods that may transport almost all sediments in the whole year or sediment flushing operations to prevent reservoir sedimentation.

This research is to develop a new suspended sediment concentration measuring system with differential pressure transmitter (hereafter, we call *SMDP*). This method measures suspended sediment concentration by the water density directly with a differential pressure transmitter, without depending on a conventional optical method for the purpose of the solution of such a problem.

This method can be applicable for the continuous measurement and the high turbidity measurement. There are two types of *SMDP*; one is the submersible type and another is the water circulation type. In order to make clear the basic performance of this system, both laboratory and field experiments at the *Tenryu* river, *Miwa* dam, and also the *Kurobe* river have been executed individually.

Measuring method

Measurement object

Objects of this measuring system are mainly wash load of 0.1～0.2 mm or less in diameter. Below, suspended sediment and SS (mg/l), suspended sediment concentration, mean this wash load and its concentration respectively. In the river management, it is required to measure SS from very low ranges of 100 mg/l or less to high ranges of 100,000 mg/l over. In other words, the maximum SS of 1,000-100,000 may occur at the flood peak in mountainous rivers or during sediment flushing operations. On the other hand, measuring SS of 50 mg/l or less is required to operate water intakes or settling basins of the power station. Measuring system should be applicable for such a wide concentration range.

Measurement principle of SMDP

Densities of water with and without suspended sediments are different. There are many types of concentration measurement method of liquid (Wren at al. 2000). Here, we have developed a new method to measure density of liquid by differential pressure between two standard points, P_H: the high-pressure side and P_L: the low-pressure side, that distance H is kept constant. Figure 1 shows the concept of this measuring system.

From the Bernoulli's theorem, eq.(1) is derived where average density $\boldsymbol{\rho}$, gravitational acceleration g, velocity at the high pressure and low pressure points V_H, V_L respectively.

$$P_H/\rho g + V_H^2/2g = P_L/\rho g + H + V_L^2/2g \qquad (1)$$

Pressure difference ΔP is calculated by eq.(2).

$$\Delta P = P_H - P_L = \rho g H + \rho (V_L^2 - V_H^2)/2 \qquad (2)$$

If $V_H = V_L$ is assumed, ΔP is calculated by eq.(3).

$$\Delta P = P_H - P_L = \rho g H \qquad (3)$$

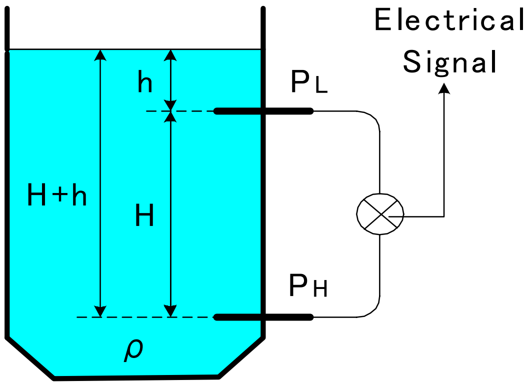

Figure 1. Measuring principle

Here, average density $\boldsymbol{\rho}$ and SS can be calculated by measuring differential pressure ΔP, since g, H are known. $V_H \neq V_L$ in general and $\rho(V_L^2 - V_H^2)/2$ may become an error if assuming $\boldsymbol{\Delta} P = \boldsymbol{\rho} g H$. In order to raise accuracy, either designing the system to be V_H V_L or measuring V_H, V_L simultaneously is considered, and the former is realistic.

Next, we can estimate the differential pressure that may occur actually. If ρ_0(g/cm^3) is defined as the density of water of SS=0 mg/l, the change of the differential pressure from SS=0 mg/l (**I**) to SS=10,000 mg/l (**II**) can be calculated by eq.(4) from eq.(3).

$$\Delta P_{II} - \Delta P_{I} = ((\rho_0 + 0.01) - \rho_0)\, g H \qquad (4)$$

If assuming H = 1,000 mm, the small pressure change of about 10mmH_2O becomes needed to be detected. Here, we are using the differential pressure transmitter of the silicon vibration type in this system to detect such a small pressure change with high accuracy. The silicon semiconductor process technology has enabled to form two oscillators on the single crystal diaphragm of silicon that are placed in the vacuum chamber. Original resonance frequencies of the two oscillators will slightly change because of those elastic strain caused by differential pressure between the top and bottom face of the silicon diaphragm. By measuring these frequency changes, differential pressure can be detected.

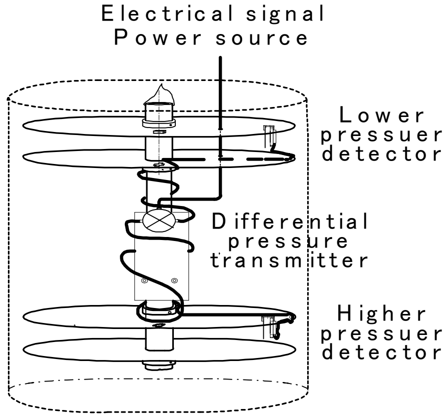

Figure 2. Schematic diagram of the measuring equipment

Measuring systems of SMDP

The schematic diagram of *SMDP* is shown in Figure 2. Two pressure detectors are placed vertically with the distance H=1,000mm and connected by small pipes filled up with water to the differential pressure transmitter mounted at the center of the system.

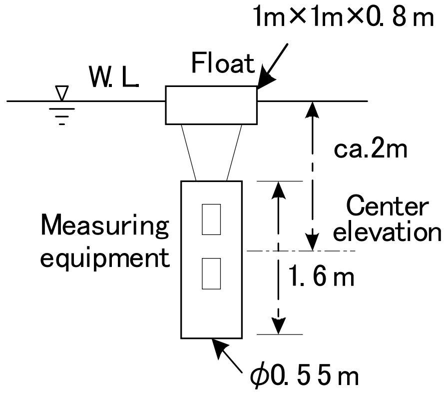

Figure 3. Schematic diagram of the submergible type SMDP

Next, we have developed two different unites to measure water with suspended sediments based on different measuring situations. One is the submersible type and the other is the water circulation type. The submersible type is shown in Figure 3. The main measuring equipment is suspended from a float and submerged in the measuring water directly. Advantages of this type are simple structure and easy maintenance. On the other hand, it is necessary to secure enough water depth over about 2.5～3.0 m for measuring, to keep almost equal velocities between the high and low pressure detectors and to protect the measuring

Figure 4. General view of the submergible type SMDP

equipment by floating debris such as gravels or driftwoods. We have solved this subject by shielding the equipment with the shell type cylinder. This submergible type is applicable for measuring such as in reservoirs. Figure 4 shows the measuring equipment for the field experiment in the *Miwa* dam reservoir, the *Tenryu* River, explained later.

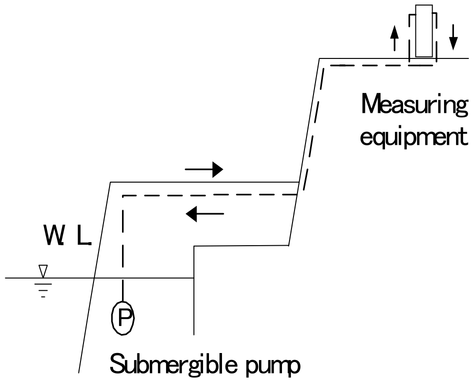

Figure 5. Schematic diagram of the water circulation type SMDP

On the other hand, adopting the submergible type *SMDP* becomes difficult in the case that the water depth changes largely depend on time like a natural river. Then, we have also developed the water circulation type *SMDP* as shown in Figure 5. Here, the main measuring equipment is installed in a water tank that is placed in land and two pipes are connected. One is to intake measuring water from a river and another is to drain from the tank. An intake pipe is connected to a submergible pump in river water.

Figure 6. General view of the water circulation type SMDP

This type can be applicable to anywhere, if the minimum water depth for intake is secured, and is more safety than the submersible type at the time of the flood. On the other hand, pump operation is needed for continuous measurement and constant discharge of accumulated sediment from the bottom of the water tank. The system has the electromagnetic flow meter to measure quantity of water, and the accumulated sediment can be discharged periodically from the valve installed at the bottom of the tank. This water circulation type is applicable for even at the natural rivers and we are doing field experiment in the *Kurobe* River, as shown in Figure 6.

Figure 7. General view of the Miwa dam reservoir and the bypass tunnel

Field experiment of the submersible type SMDP at the Miwa dam

Test outline

We are doing the field experiment to measure inflowing suspended sediment concentration to the *Miwa* dam reservoir, completed in 1959, 69m high and 29.95 million m^3 of the total storage capacity and 311km^2 of the total catchment area. This dam is very famous for severe reservoir sedimentation. At the flood time, high suspended sediments flow into the reservoir and the *Miwa* dam has been already silted up to 60 % of total storage. Now, a new sediment bypass tunnel, 4,300 m length, 47m^2 in cross section and 300m3/s of the discharge capacity is under construction for reservoir sedimentation management. Figure 7 shows general view of the *Miwa* dam reservoir and the bypass tunnel.

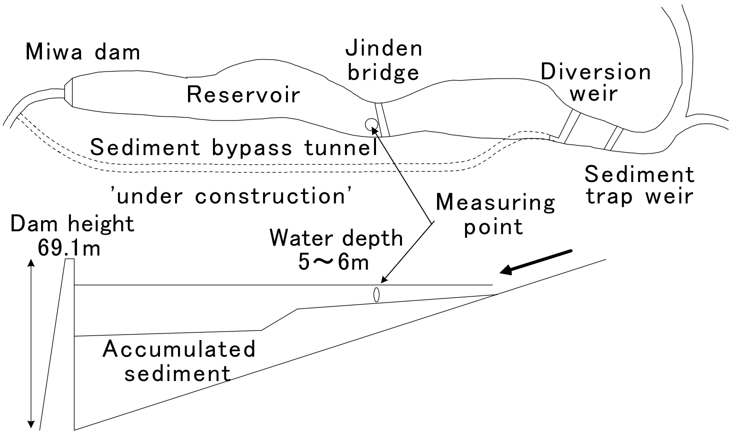

Figure 8. Field experiment of the submersible type SMDP at Miwa dam

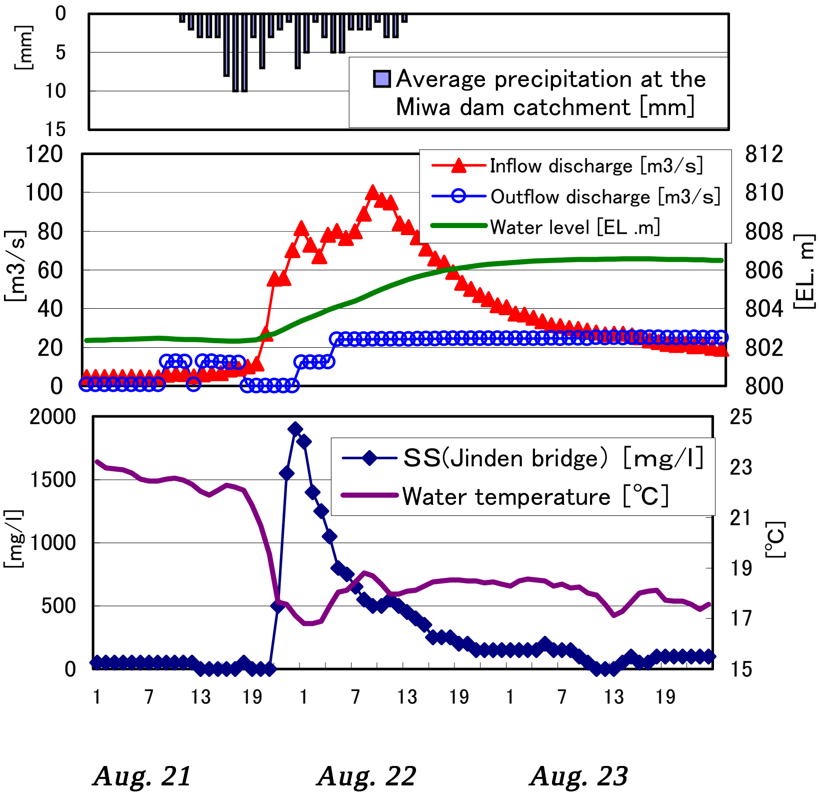

Figure 9. Field experiment at the Miwa dam ’Typhoon No.11, 2001’

The measuring equipment is moored at the bridge pier, located at the middle of the reservoir with about 5-6 m water depth as shown in Figure 8. Figure 4 shows the equipment that connected by an electric cable and a signal line to the recording unit placed on the bridge.

Measuring results

In 2001, there were two major floods caused by the typhoon No.11, August 21 to 22, and No.15, September 10 to 11. Figure 9 shows measured records by *SMDP* at the typhoon No.11. Sampling data is collected per second and recorded per minute as the average, maximum and minimum value.

Water temperature have also dropped from 21°C to 17 °C at the peak hydrograph. Figure 10 shows the maximum and minimum value in every minute data during SS is rising up. It became clear that high-suspended sediment flow have entered to the reservoir upstream and passed through the measuring point in a very short period from 21:40 to 21:50 P.M. *SMDP* has important advantages in such a real-time and high-suspended sediment concentration measurement.

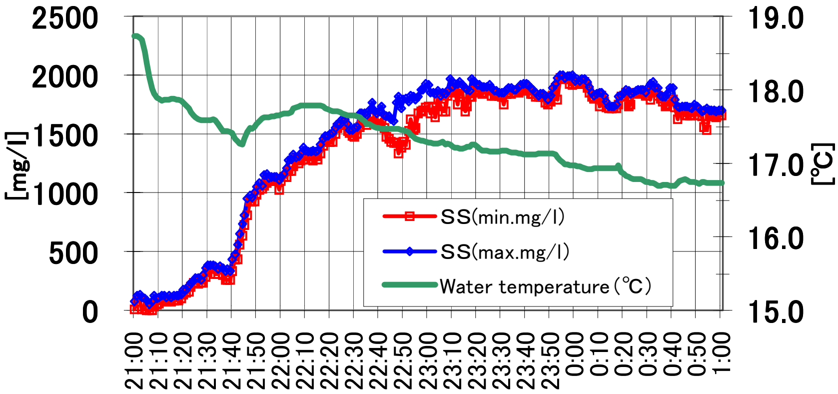

Figure 10. SS and water temperature change in every minute 'Typhoon No.11'

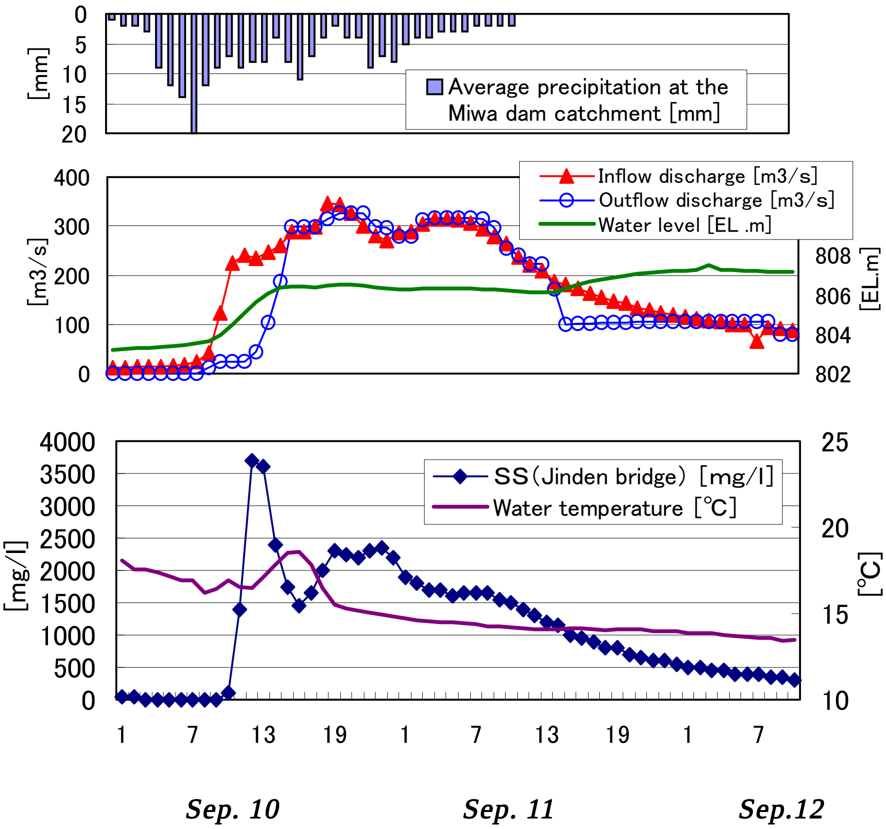

Figure 11. Field experiment at the Miwa dam ' Typhoon No.15, 2001'

SS was also measured as shown in Figure 11 at the typhoon No. 15. This flood, peak discharge exceeded 300m3/s, was larger than the typhoon No.11 and SS also rose up to the highest 3,700 mg/l. Figure 12 also shows the every minute data, and it is clear that the instantaneous maximum SS was up to 4,600 mg/l. Figure 12 also shows the maximum and minimum value in a minute, and fluctuation of SS is admitted after the flood peak around 19 PM. As for this fluctuation, the destruction of the thermal stratification in the reservoir by this large flood is estimated as the main cause.

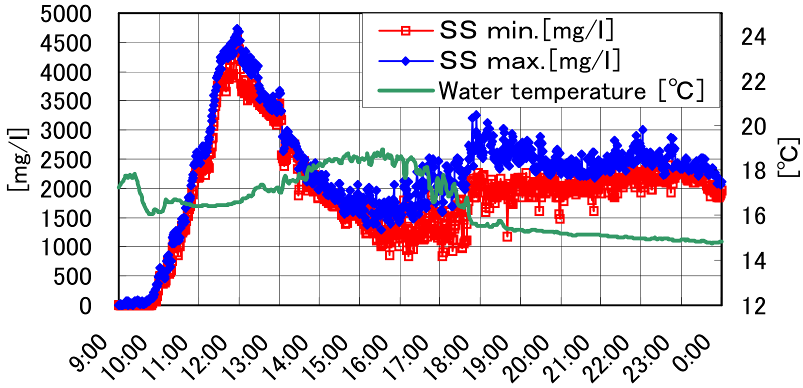

Figure 12. SS and water temperature change in every minute 'Typhoon No.15'

Field measurements in the *Miwa* dam showed that the submersible type *SMDP* can be used for SS monitoring in reservoirs with advantages of real-time and high-suspended sediment measurement.

Field experiment of the water circulation type SMDP at the Kurobe river

Test outline

In the *Kurobe* river, there are two dams, the *Unazuki* and *Dashidaira* dams that are periodically emptied to flush out accumulated sediments from reservoirs. Figure 13 and 14 shows the schematic diagram of the *Kurobe* river, and the *Unazuki* and *Dashidaira* dams. During those flushing operations, monitoring of SS in the downstream river is needed for the environmental assessment, and the field experiment of the water circulation type measuring system is planned as shown in Figure 5 and 6.

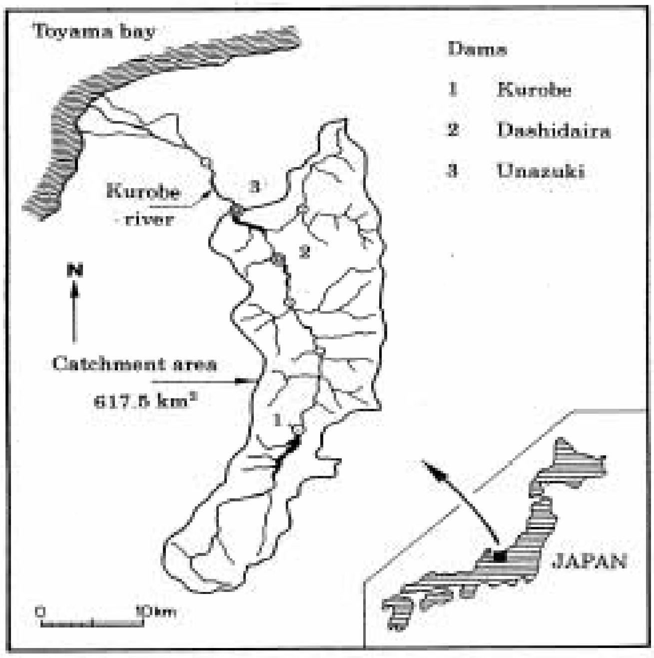

Figure 13. Kurobe river system

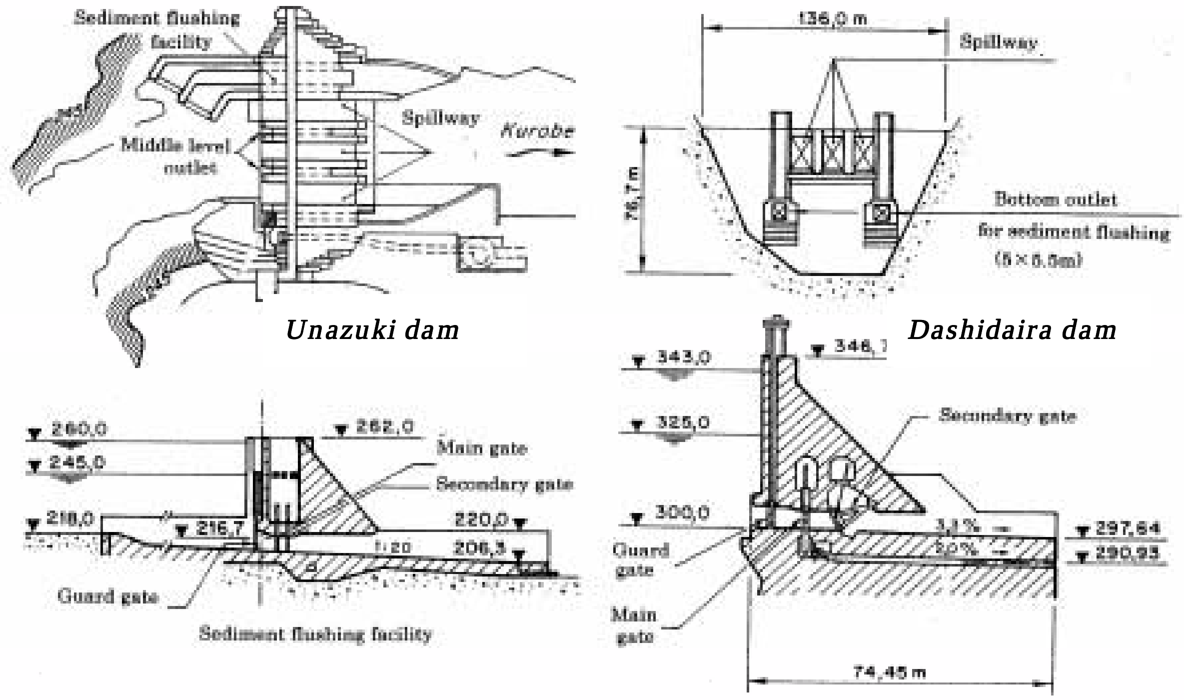

Figure 14. Schematic diagram of the Unazuki dam(left) and the Dashidaira dam(right)

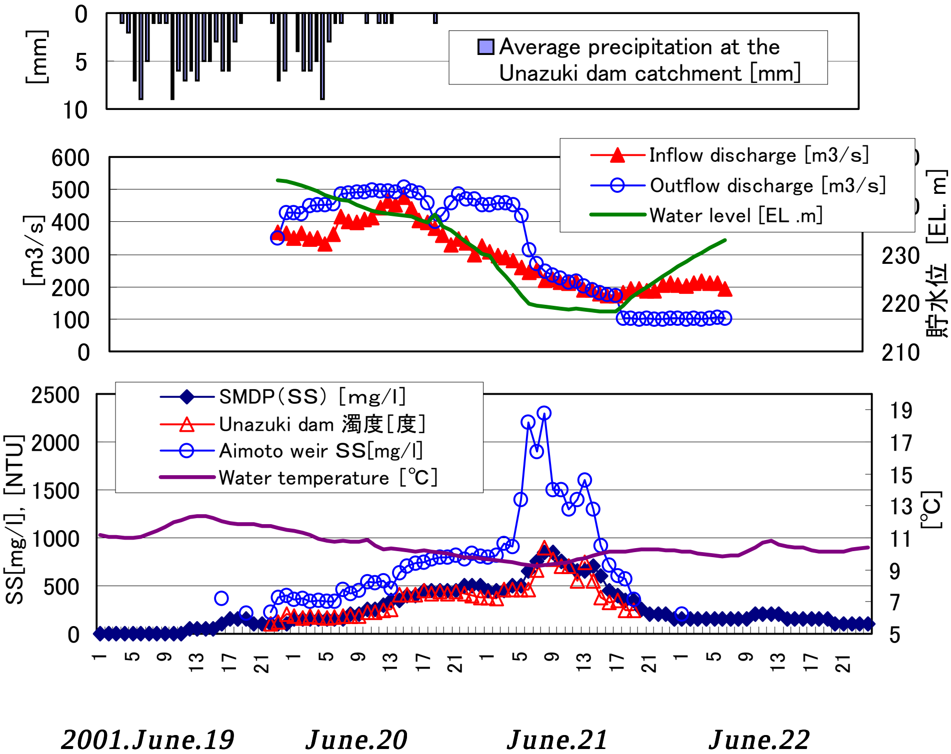

Figure 15. Field experiment at the Kurobe river

Measuring result

From June 19 to 22, 2001, high-suspended sediment concentration has been recorded at the measuring point downstream from these dams during the flushing operation. Figure 15 shows the record of SS by *SMDP* compared with the conventional turbidity measurement and the bottle sampling. The maximum of SS, 900 mg/l, was recorded at 8 A.M. June 21 immediately after the start of free flow flushing in the *Unazuki* dam. It is clear that the SS change by *SMDP* coincides with other data, but SS values are slightly different from them by bottle samplings. The main cause of this gap may come from the limitation of the submersible pump capacity. It became clear that the SS measurement by the water circulation type *SMDP* is applicable for the monitoring of the natural rivers effectively.

Conclusions

We have developed the system, *SMDP*, that continuously measures suspended sediment concentration by using the differential pressure transmitter, and carried out the field test about the submersible type and also the water circulation type corresponding to measurement environment. The result that was obtained can be summarized as follows.

(1) At the field experiment in the *Miwa* dam, SS during natural flood flows passing through the reservoir have been measured stably, and the submersible type *SMDP* can be used for SS monitoring in reservoirs with advantages of real-time and high-suspended sediment measurement.

(2) At the field experiment in the *Kurobe* river, SS during sediment flushing operation from reservoirs have been measured, and the water circulation type *SMDP* can be used for SS monitoring in natural rivers where enough water depth is hardly secured constantly.

References

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