



# **Measurement of high suspended sediment concentration during operations of Miwa dam sediment bypass tunnel and the Kurobe River sediment flushing with SMDP**

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## **Abstract**

From the view point of the comprehensive sediment management in the sediment routing system, monitoring of quantity and quality of sediment transport during operations of sediment bypass tunnel, sediment flushing and sediment sluicing of dams is very important. This paper shows the results of continuous measurement of high suspended sediment concentration during operations of the Miwa dam sediment bypass tunnel and during sediment flushing and sluicing operations of the Unazuki dam. These data have been obtained by the Suspended Sediment Concentration Measuring System with Differential Pressure Transmitter (hereinafter we call 'SMDP'). Measured data have good correlation with manual sampling and can be used to operate sediment bypass tunnel or sediment flushing gate to optimize sediment management under minimizing environmental impacts by extreme high suspended sediment concentration.

Keywords: Suspended-sediment concentration, SMDP, Miwa dam, Unazuki dam

## **1 Introduction**

In Japan, comprehensive sediment management in the sediment routing system has been implemented in the Kurobe River and the Tenryu River. Sediment management requires measuring the amounts of bed load, suspended load and wash load in a river. Conventional techniques such as manual bottle sampling to measure turbidity and suspended sediment (SS) concentration have been conducted to obtain transport rate of wash load and suspended load (Wren et.al, 2000, Peteil et.al, 2013). However, manual sampling has various problems, including non-continuous and burdensome measurements with respect to time and costs.

Felix et al. (2017) recently developed a method to measure high SS concentration of intake water using a vibration tube in order to manage abrasion damages on a hydraulic turbine in a hydraulic power plant. We set up a hypothesis that a change in density can be used to measure the SS concentration in river water, and developed SMDP (Suspended Sediment Concentration Measuring System with Differential Pressure Transmitter) equipment. SMDP continuously and automatically measures the SS concentration as a change in pressure. We have achieved satisfactory results using

SMDP installed in downstream of the Kurobe River (Sumi et.al, 2001, 2002, 2005, 2007, 2010) and the Miwa Dam in the Tenryu river basin.

There are two types of SMDPs which are underwater and water circulation ones. In the former, the entire measurement system is installed directly in water, while in the latter, river water is taken in by a pump and guided through a pipe to a water tank (a differential pressure sensor is installed inside). In 2010, water circulation type has been installed at the entrance of sediment bypass tunnel of Miwa dam to monitor inflow sediment concentration. A sandpump was placed in the fish ladder to intake water flowing over diversion weir and create water circulation to SMDP tank. In 2010 and 2012, we have successfully measured high SS concentration flow with this system.

In 2015, an underwater-type SMDP was also installed downstream of the Unazuki Dam in the Kurobe River. High SS concentrations during sediment flushing were successfully measured in real time basis. In 2016, we attempted to employ the SS concentration value measured by SMDP to operate the sediment-flushing gate of the dam. Coordinated sediment flushing at the Unazuki Dam requires effective discharge of the suspended load while simultaneously controlling the SS concentration (Sumi et.al, 2009). Consequently, real-time measurements of the SS concentration and its control downstream of the dam by gate operations are important. In this paper, we overview SMDP measurements in the Miwa and the Unazuki dams, and the control trials of the sediment flushing concentration from a dam utilizing SMDP measurements.

## 2 Measurement method

### 2.1 Measurement principles of SMDP

SMDP continuously monitors high SS concentrations in a river or reservoir during flooding by directly measuring the density of fluid with a highly accurate differential pressure sensor. In running water, the density of water with SS differs from that without SS. If two fixed reference points with vertical spacing  $H$  in a fluid are provided, density measurements can be carried out by detecting difference of these pressures ( $P_H$ : high pressure side,  $P_L$ : low pressure side).

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

$$\frac{P_H}{\rho g} + \frac{V_H^2}{2g} = \frac{P_L}{\rho g} + H + \frac{V_L^2}{2g} \quad (1)$$

From Eq. (1), the pressure difference  $\Delta P$  is calculated by Eq. (2).

$$\Delta P = P_H - P_L = \rho g H + \frac{\rho(V_L^2 - V_H^2)}{2} \quad (2)$$

If  $V_H=V_L$  is assumed,  $\Delta P$  is calculated by Eq. (3).

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

Since  $g$  and  $H$  are known, the average density  $\rho$  and the suspended sediment concentration (SSC) can be determined by obtaining the pressure difference.

Here, we can estimate the actual pressure difference to be obtained. Assuming that the water density of SSC = 0 mg/l is  $\rho_0$  ( $\text{kg/m}^3$ ), a change in the pressure difference from SSC = 0 mg/l (I) to SSC = 10,000 mg/l (II) can be calculated by Eq. (4) .

$$\Delta P_I - \Delta P_{II} = ((\rho_0 + 0.01) - \rho_0) g H \quad (4)$$

Assuming  $H = 1,000$  mm, a small pressure change of about 10 mmH<sub>2</sub>O must be detectable. To achieve such an accurate measurement, SMDP uses a silicon vibration-type differential pressure sensor with high accuracy (Sumi et.al, 2001, 2002).

### 3 Water Circulation type SMDP installed fish way of the Miwa Dam

#### 3.1 Setup of water circulation type SMDP

A system of water circulation type SMDP was installed outside the gate room at the entrance of the bypass tunnel at Miwa Dam and supplied water from a submersible pump placed at the fishladder installed in the diversion weir. The water sampled from the submerged pump is supplied to the SMDP tank through the pipeline. Figure 1 shows the installation status of the water circulation type SMDP, and on the right shows the submersible pump installed in the fishladder. In the water circulation type SMDP, a differential pressure gauge is installed in the central part in a cylindrical water tank of 800 mm in diameter and 2000 mm in height. The pressure on the high pressure side and the pressure on the low pressure side are transmitted to the differential pressure gauge via the filling liquid at intervals of 1000 mm in the vertical direction.

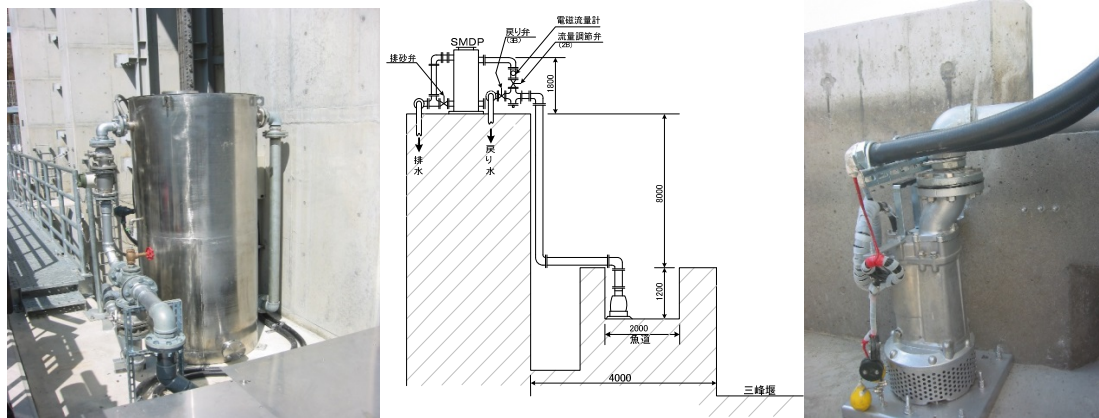


Fig. 1 Water circulation type SMDP installed in the fish ladder of diversion weir at the Miwa dam (Left: SMDP body, Center: Installation status, Right; Submersible pump in the fish ladder)

### 3.2 Measurement results in 2010

From July 11th to 16th, 2010, the Miwa Dam basin got rainfall up to total 213mm. The maximum inflow to the Miwa dam reached 229m<sup>3</sup>/s which triggered sediment bypass operation from 12th to 18th. Water also flowed to the fishladder on the side of the entrance of the diversion weir and the submersible pump supplied water to the water circulation type SMDP. Fig.2 is the SS concentration measured by SMDP. The peak value of the SS concentration was 5,200 mg/l. The SS concentration was measured by sampling water even in the weir located upstream of the fishladder, and the peak value of the sampled SS concentration was 5,160mg/l. Comparing the SS concentration of SMDP with the SS concentration of water sampling, the pattern of the total SS concentration agreed well.

After the peak value has passed, since the sampling pump stopped due to driftwood clogging, there is no measurement value by SMDP. The water supply stop of such a water sampling pump can be solved by providing driftwood removal upstream of the fishladder and further increasing the pump capacity. Nevertheless, in the case of water circulation type SMDP, there is a limitation on increasing the high concentration SS due to the relation between the pump head capability and the SS concentration. Therefore, the upper limit of the measurement of the high concentration SS by the water circulation type SMDP is about 10,000 mg/l to 30,000 mg/l depending on the pump capacity of the submerged pump.

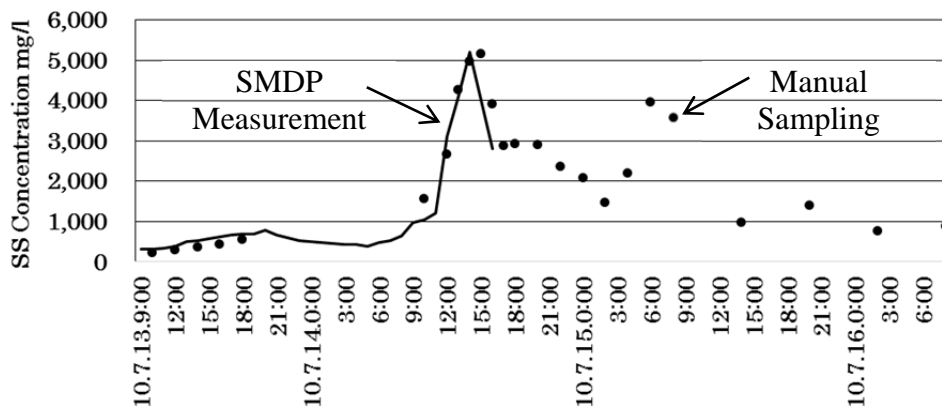


Fig. 2 SS concentration measured by water circulation type SMDP during SBT operation in 2010

## 4 Underwater-type SMDP installed downstream of the Unazuki Dam

### 4.1 Setup of underwater type SMDP

Fig. 3 (left) shows the underwater type SMDP installed downstream of the Unazuki Dam. A differential pressure transducer (SS sensor) was installed at the center in an outer cylinder, which had a 500-mm diameter and 700-mm height. The sensor transmitted the pressure difference between the high-pressure side and the low-pressure

side in 500-mm intervals in the vertical direction with a narrow tube filled with an enclosed liquid. The SMDP was installed using a concrete jetty on the right bank side about 500-m downstream of the Unazuki Dam. To avoid direct impacts of driftwood and gravel in the discharged water, a storing basket with the built-in SMDP was attached to the downstream side of the jetty using a suspension device (Fig. 3, right).

The central SMDP body was installed so that it was 1,500-mm high from the riverbed (Fig. 3, center). The measurement span of SMDP was 100,000 mg/l. For example, when the concentration of river water changed from 0 mg/l to 100,000 mg/l, a minor pressure change of about 50 mmH<sub>2</sub>O occurred from the vertical interval H=500 mm between the high-pressure and the low-pressure side outlets. The pressure change was converted into a 4–20 mA DC signal and transmitted to a recorder. The recorder saved the data every 20 seconds. In addition, the 4–20 mA DC signals were sent to the dam management office with a telemeter and the measured value was displayed on a monitor in the management office every 10 minutes.

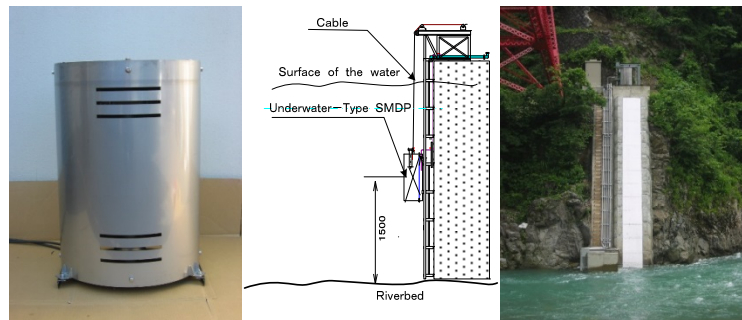


Fig. 3 Underwater SMDP installed downstream of the Unazuki Dam (Left: SMDP body, Center: Suspension device and installation status, Right: Installation location (approximately 500-m downstream of the Unazuki Dam))

## 4.2 Coordinated sediment flushing in 2016

Coordinated sediment flushing at the Unazuki Dam and the Dashidaira Dam was carried out from June 25 to 27, 2016. At the Unazuki Dam, the peak inflow amount reached 336 m<sup>3</sup>/s at 05:30 on June 25, and the reservoir water level draw down started at 06:40 from 244.6 m. About 8 hours later at 14:32, the sediment-flushing gate was opened when the reservoir water level was 234.6 m. After about 6 hours later, free flow flushing started at 20:45 when the reservoir water level was 220.4 m.

After starting the free flow around 20:45 on June 25, the inflow water flowed through the bottom of the dam in a river-like stream which erodes the sediment accumulated on the bottom of the reservoir. As a result, the SSC in the discharged water becomes the highest. The SSC measurement at this time is important to check the environmental impact on aquatic lives. Conventionally, at the observation point downstream of the Unazuki Dam, turbidity and SSC measurements were conducted by manual water sampling in one-hour intervals. Generally, since it took several days to obtain the actual

SSC after water sampling and the turbidity was indirectly monitored, and the SSC measurements could not be used directly for dam operations.

### 4.3 Measurement results and method of gate operation

The present gate operation for sediment flushing is conducted by setting an upper threshold value for the SSC downstream of the dam. When the SSC gradually increased and approached the upper limit (30,000 mg/l), the gate will be closed so as to reduce discharge amount by controlling erosion of the riverbed sediment and decreasing the SSC. As the SSC decreased and reached to the lower limit target value (20,000 mg/l), the gate will be re-opened to increase the discharge to the riverbed sedimentation is more transported. In the actual case at the Unazuki dam, the above operations were repeated several times to draw down the water level while keeping SSC within the target range before shifting into the free flow condition.

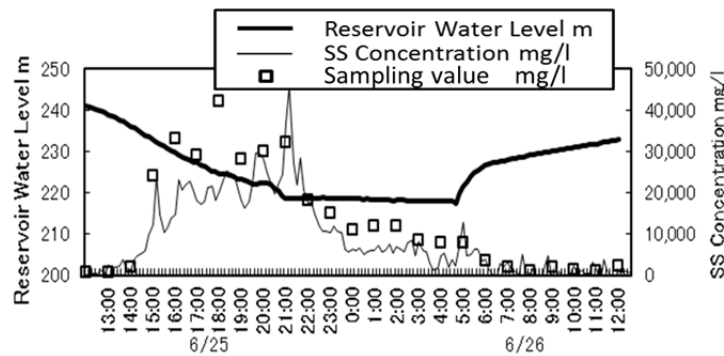


Fig. 4 Reservoir water level and SS concentration during coordinated sediment flushing in 2016

Fig. 4 shows the actual record of SSC measured by SMDP downstream of the dam during the coordinated sediment flushing in 2016. The SSC fluctuated between 10,000 mg/l and 30,000 mg/l due to the gate operations with the above mentioned method. Consequently, draw down operation shifted into free flow without any extreme peak values of SSC. SMDP could measure continuous SSC which is well fitting with the water sampling data even though there was a slight deviation. Meanwhile, during the coordinated sediment flushing in 2015, the gates were operated without using SMDP to monitor the SSC. The sediment-flushing gate was simply opened to draw down the reservoir water level and shifted into free flow flushing.

Fig. 5 compares the SSC during coordinated sediment flushing in 2015 and 2016. The graphs are normalized by setting the time that the flushing gate was opened as time 00:00. This indicates that the SSC of the peak in 2015 rapidly increased to about six times the initial concentration. Meanwhile, in the sediment flushing in 2016, increasing trend of peak SSC values is milder than that in 2015 and it is estimated that gate control by monitoring the SSC downstream of the Unazuki Dam successfully reduced the increase of SSC by limiting about 1.5 times compared to the just before the value. The target sediment flushing amount of the Dashidaira Dam was 290,000 m<sup>3</sup> in 2016, which

was larger than the 160,000 m<sup>3</sup> target in 2015. If the water level was drawn down similar to 2015 without any gate control with careful SSC monitoring, the SSC would have been several times higher than the present one because of larger amount of target sediment volume in 2016.

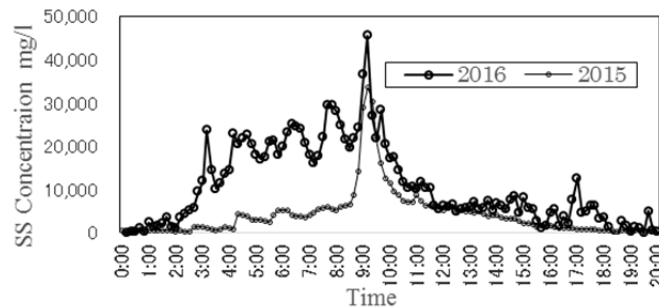


Fig. 5 Comparison of SS concentration changes during coordinated sediment flushing in 2016/2015 (The time is normalized by setting the time that the flushing gate was opened as time 00:00.)

## 5 Conclusion

This paper shows the results of continuous measurement of high suspended sediment concentration during operations of the Miwa dam sediment bypass tunnel and during sediment flushing and sluicing operations of the Unazuki dam. These data have been obtained by the Suspended Sediment Concentration Measuring System with Differential Pressure Transmitter (hereinafter we call 'SMDP'). Based on the measurement, we have obtained the following conclusions.

Measured data have good correlation with manual sampling and can be used to operate sediment bypass tunnel or sediment flushing gate to optimize sediment management under minimizing environmental impacts by extreme high suspended sediment concentration.

In the case of water circulation type SMDP, the upper limit of the measurement of the high Suspended Sediment Concentration (SSC) is about 10,000 mg/l to 30,000 mg/l depending on the pump capacity of the submerged pump.

An underwater SMDP downstream of the Unazuki Dam could measure an extreme high SSC up to a peak value of 45,000 mg/l during coordinated sediment flushing in 2016 which is hardly measured by conventional turbidity meter.

Adjusting operations of the sediment-flushing gate by monitoring the SSC with SMDP enabled to conduct draw down sediment flushing successfully while keeping the SSC downstream of the Unazuki Dam within the target range in order to minimize environmental impacts.

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