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EVALUATION OF SEDIMENT BYPASS EFFICIENCY BY FLOW FIELD AND SEDIMENT CONCENTRATION MONITORING TECHNIQUES

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This paper evaluates the performance of the sediment bypass tunnel that diverts the suspended sediment from Lake Miwa to downstream reaches below Miwa dam. In such a complex processes during bypassing, it is difficult to predict the sediment bypassed efficiency numerically. Therefore, the digital image techniques were developed and implemented to measure the flow pattern and suspended sediment concentration SSC for the first time in Miwa dam. Where, field measurements were conducted during flood seasons in June and July 2010. Surface flow velocity and SSC were analyzed to clarify the performance before and after the commencement bypassing operation mode. The measured sediment bypassed efficiency assists the decision making on optimization of bypassing performance and validates numerical prediction. The facility proved its effectiveness in mitigating reservoir sedimentation in Miwa dam and turbidity of river water contributing towards restoration of downstream environment.

Key Words: *Miwa Dam, sediment bypass tunnel, removal efficiency, digital image techniques, LSPIV, turbiditymeter*

1. BACKGROUND

Often, the sedimentation problem is a critical element in the economic feasibility of a project, particularly when each year large quantities of sediment material have to be dredged and disposed at far-field locations. Worldwide sediment management techniques are classified and some examples of representative dams from Japan and Europe are listed[1)]. Sediment bypass tunnel in Miwa dam is the first experience for multipurpose dams in Japan, as sediment management technique which diverts mainly suspended sediment concentration.

Miwa Dam located on the Mibu River, a tributary of the Tenryu, about 20 Million Cubic Meter (MCM) of sediments were deposited by 2002 since the completion of dam. About 5 MCM of deposited sediments were excavated by gravel quarrying and 2 MCM were excavated and transported by trucks[2)]. The bypass scheme includes upstream check dam of 140 m long, a 4.3 km long sediment bypass tunnel, a 230 m long diversion weir, and some auxiliary facilities (trapping weir and two training dikes were provided). Asahi sediment bypass tunnel is another example that divert total sediment load (coarse and fine sediment). The number of bypass tunnel is expected to increase in the future, which are under construction (Koshibu and Matsukawa dams), or under planning (Yahagi, and Sakuma dams)[3)].

The issues of sediment bypass technique to be resolved in the future are the clarification of the hydraulic behavior of flow and sediment in tunnels for the purpose of designing safe and economical sediment tunnels, as well as the establishment of countermeasures for abrasion damages on channel bed surface[4)].

Several parameters were monitored namely, precipitation in the upstream, turbidity, water quality, fish, benthic animals, attached algae, and etc[2)]. These data can be used for switching operation modes as shown in **Fig.1**. The first normal mode is that all incoming flood flow will overflow the diversion weir into main reservoir (Mode 1). While the second mode is some part of incoming flood flow will be diverted to bypass tunnel after opening the bypass main gate (Mode 2). The last mode is refilling mode by closing the bypass main gate (Mode 3, **Fig.1**). Generally we can use inflow discharge to design and guide the timing for switching these operation modes. But we should pay attention to sediment concentration, because the flow discharge and sediment concentration are not linear relationship including sometime hysteresis. For example, sediment concentration during discharge increasing stage in the hydrograph is usually higher than that during decreasing stage.

Therefore, in order to increase the performance of sediment bypassing and removal efficiency, we focus on surface flow patterns and suspended sediment concentration in the approach flow area to the bypass tunnel according to different modes.

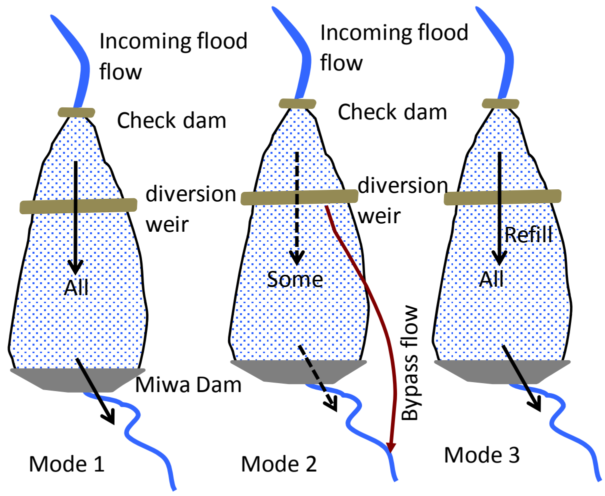

Fig.1 Switching operation modes during flood at Miwa Dam.

2. OBJECTIVES AND TARGET PROJECT

The main purposes of this paper are, to evaluate the effectiveness of sediment bypassing system, and develop digital image techniques to measure SS and flow field. These will assist in operating of sediment bypass tunnel efficiently for managing diverted flood with wash load from reservoir. The observed efficiencies of bypassed sediment reported in this paper will provide a basis for determining the best management practice for existing and future planned bypass tunnels.

3. FIELD SITE AND METHODOLOGY

(1) Outlines of Miwa dam bypass system

The multipurpose reservoir Miwa Dam is composed of a 69 m high gravity concrete dam and 29.95 MCM gross storage reservoir volumes with 311 km^2 catchment area. Since the dam was completed, several extreme runoff events caused serious disasters and sediment yield. From the view point of the eternal reservoir sedimentation management, a sediment bypass system is planned and completed in March 2004 to reduce sedimentation of the reservoir. **Fig.2** shows the schematic diagram of the bypass system components combined with the locations of the monitoring instrumentation and studied areas.

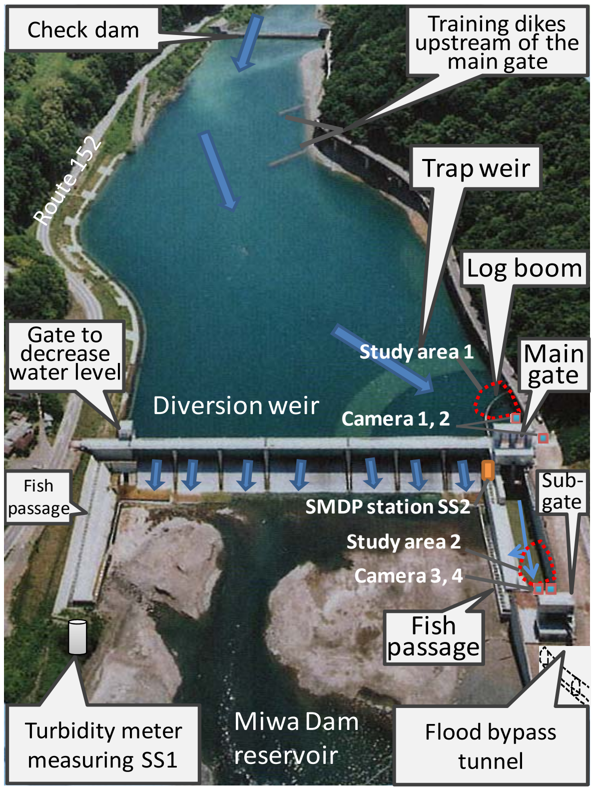

Fig.2 Sediment management facility at Miwa dam and cameras and suspended sediment measurement locations.

Based on some theoretical considerations and recorded field data, the annual sediment inflow was evaluated at an average amount of 0.68 MCM, of which 0.525 MCM is wash load and 0.16 MCM is bed load combined with suspended load. The complex sediment countermeasure system is shown in **Fig.2** and consists of the following installations:

- Check dam of 0.22 MCM sediment storage capacity; the sediment is periodically excavated and transported by private gravel agencies.
- Diversion weir of 0.51 MCM combines the functions of training and trapping the sediment. Wash load that flows down through the check dam, is directed together with the flood water from a bypass channel into a bypass tunnel. Where two cameras 3 and 4 are installed to monitor the flow velocity in the bypass channel (**Fig.2**). During high flood the facility allows the training dikes and trap weir (**Fig.2**), to trap the coarse grain sizes that overflow from the check dam, in order not to flow into the tunnel. The approach flow in front of the main gate is monitored by camera 1 and 2 for flow field analysis before and after the gate opening for

switching modes (**Fig.2**). Moreover, for SS monitoring two points with two different instruments are installed as shown in **Fig.2**.

- Flood bypass tunnel of 4.3 km long, 7.5 m diameter, 1% slope, and 300 m^3/s capacity.
- Auxiliary reservoir sediment discharge facility is under planning to discharge wash load that flows into the reservoir together with floodwater, into the downstream reaches as a flood control measure.

(2) Image monitoring techniques

a) LSPIV and Fx-8100

The development of image processing hardware and associated software tools has led to a revolution in the scope and quantity of quantitative information that may be gathered from laboratory and field experiments[5)]. More recently, the standard PIV method has been applied to velocity measurements for larger scales, commonly named as Large Scale Particle Image Velocimetry (LSPIV)[6)]. The optical flow Fx-8100 developed by Mitsubishi was applied during sediment flushing of Unazuki dam in July 2006[7)]. Large-Scale Particle Image Velocimetry (LSPIV) is an extension of a quantitative imaging technique to measure water surface velocities[5)]. In the present applications we utilized the CCTV (CIT-7430) camera from Mitsubishi Coro. The flow videos recorded at 30fps and 740 by 480 pixels.

The accuracy of the LSPIV method was tested using two simple test cases. First, fully developed laminar flow in the bypass approach channel with dimensions of 12 m width was measured. A comparison of the average velocity profile in the main flow direction obtained with LSPIV and Fx-8100 technique will be illustrated after. Raw pixel displacement fields were computed using a standard cross-correlation algorithm. The first step of the post-processing involved identification and correction of spurious displacement vectors using a local-median scheme.

Fx-8100 developed by Mitsubishi Electric Corporation which is a Video Front End Processor (FEP) and a multipurpose image recognition platform. This is a platform aiming to recognize the video-image, and have a lot of image processing functions logic and a network interface. FEP's function can be enhancing by updating program according to different applications. More details about the technique and some applications can be found in a previous study[8)].

b) Suspended sediment concentration by SMDP, turbiditymeter, sampling, & image processing

In case of SS monitoring, various existing SS measurement techniques were compared by Wren et al.[9)]. SS monitoring systems based on a differential pressure transmitter (SMDP) are implemented in Miwa dam and Kurobe River[10)]. The turbidimeter that uses optical backscatter and relates nephelometric turbidity unit NTU to SS is known for continuous and automated field sampling[11)].

In the present paper digital optical camera recorded the sediment-water mixture in-situ, to determine the SS. SMDP and INFINITY-Turbi by JFE-Advantech (Miniature Super-High Turbidity Data Logger with Wiper)[12)], were installed for sediment monitoring in the river as shown in **Fig.2**. Furthermore, river water samples were taken constantly to calibrate these monitoring systems. Third instrument is INFINITY-Turbiditymeter by JFE-Advantech Company. Regarding the image processing we analyzed a method to determine the concentration by measuring the reduction in the intensity of light transmitted through Mode 1, as compared to that transmitted through Mode 2. Light attenuation technique that developed by Dalziel research group[13)], were used to obtain SSC results from images. A simple calibration procedure relates the light intensity observed at each point on the layer surface to the corresponding SSC at that point.

4. RESULTS AND DISCUSSIONS

(1) Bypass operation results

In Miwa dam, there were three times of bypass operation after 2006. These data are summarized in **Table 1**. In 2010, we have two middle class flood events which are peak flows of 150 and 250 m^3/s.

Table 1 Sediment bypass operation records after 2006.

Flood date	July 2006	July 2007	September 2007
AverageRainfall (mm)	253	117	254
Max. Inflow Discharge (m^3/s)	366	166	568
Max. Bypass Discharge (m^3/s)	242	136	264
Bypass Operation time (hrs)	47	35	48
Max. Inflow Sediment Concentration	16,900	3,610	25,000
Max. Bypass Sediment Concentration	16,900	2,810	20,200
Total Inflow Wash Load ($1000m^3$)	326	37	461
Total Bypass Wash Load ($1000m^3$)	150	14	155

(2) Flow pattern before and after bypassing

LSPIV and Fx-8100 techniques were applied for two different study areas in front of bypass tunnel approach flow in the reservoir of Miwa dam as shown in **Fig.2**. Recorded images at two modes were treated to evaluate the approach flow in three zones, considering the possibility of the vortex formations that can influence the bypass efficiency. Flow field measured by LSPIV are shown in **Figs.3,4**. The main flow is directed towards the diversion weir at Mode 1 and a circulation in front of the bypass tunnel was formed (see **Fig. 3(a))**.

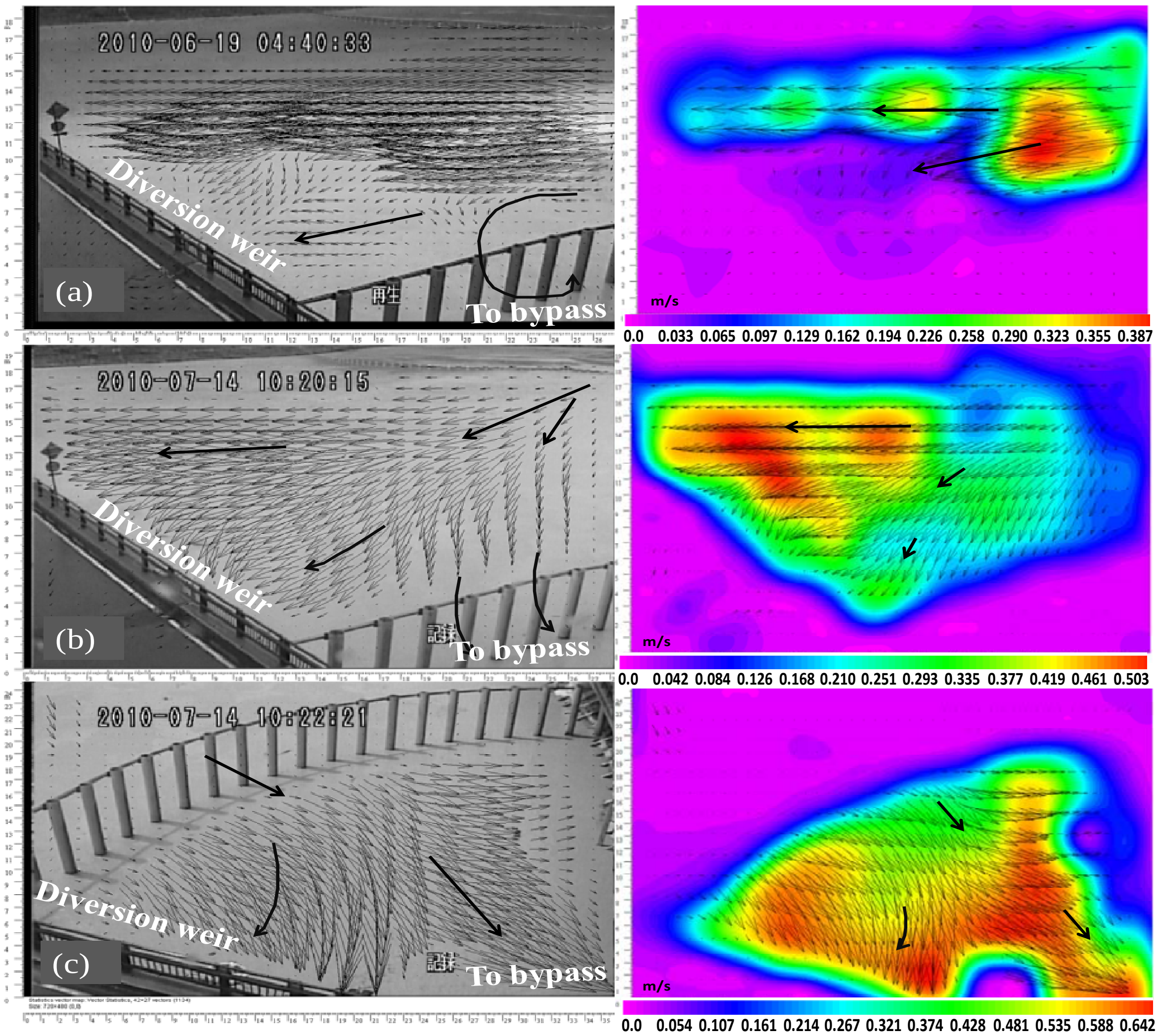

Fig.3 Stationary flow fields and corresponding velocity in the reservoir of Miwa dam for (a) Mode 1, (b, c) Mode 2.

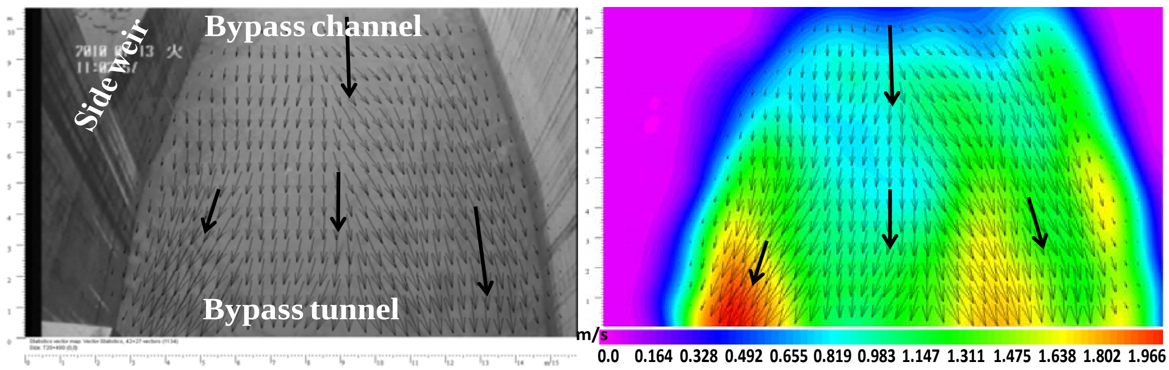

Fig.4 Actual field measurements by LSPIV, surface velocity vectors in the bypass channel and tunnel of Miwa dam.

The velocity magnitudes with vectors shows a low velocity inside the reservoir around 30 cm/s as shown in **Fig.3(a)** right. Two zones in front of the bypass were measured, before and after the log boom. The flow field of zone 1 (see **Fig.3(a)** on the left), reveals the effect of the bypass operation in Mode 2. The separation of the flow in the reservoir leads to a small retention in the immediate upstream part of the reservoir and therefore to high turbidity. This process is localized in the left side of the reservoir. This result in the flow separation on the right and left to the weir and bypass can be illustrated clearly in **Fig.3(c)**. Interesting effects of the flow separations in front of the bypass, such as concentration of inflow to the bypass and increase of velocities up, can be detected by the measurements **Fig.3(c)** on the right. The LSPIV measurements in zone 2 (see **Fig.3(c)** on the right) reveal the impact of the contraction due to the trap weirs.

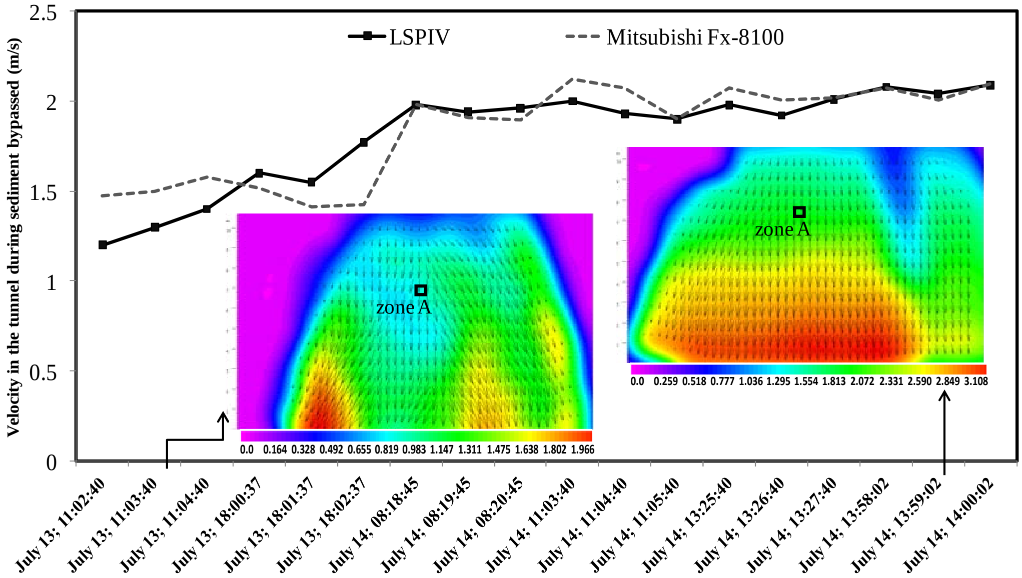

Fig.5 Average velocity measured at zone A during sediment bypassing operation in the Miwa dam bypass tunnel at selected periods

The area between the dikes on the left bank forces the main flow to the right and increases the main velocity. In the area between the dikes, the highest flow velocities are detected on the border of the dike. As a result, sedimentation occurs in before this reach. **Fig.4** shows the surface velocity vectors and corresponding velocity magnitudes obtained by LSPIV in the bypass channel.

To compare and validate the LSPIV ability, a small zone area A of 40 by 50 pixels (**Fig.5**) in middle of the bypass channel, is measured by FX-8100 as well. Image analysis for video recorded from 13th of July at 11:02 to 14th of July at 14:00, and the results of averaged velocity of 1 minute at zone A are shown in **Fig.5**. Both techniques represented and are able to monitor the behavior of average surface velocity during bypassing (mode 2). The surface velocity has accelerated in two or more from about 1.25 m/s to 2.5m/s along the center of the bypass channel at zone area A. The flow is almost uniform as illustrated by the velocity magnitude and vectors at July 14, 13:59.

Due to the increase of water surface profile at different periods, the channel surface area covered with water is reduced. Two examples of LSPIV flow field and velocity magnitudes on July 13th and 14th are shown in **Fig.5**. By comparing velocity measured by LSPIV and FX-8100, it can be said that results are in a good agreements and LSPIV can be applied within reservoir as well.

(3) Suspended sediment concentration

Inflow suspended sediment concentration is recorded as **Fig.6**. Peak concentration is almost equal to inflow discharge peak and turbid flow of from 2500 to 1000 mg/l was bypassed. Turbidity trend is well monitored by several measurement data and very much helpful to switching from Mode 1, Mode 2 and Mode 3.

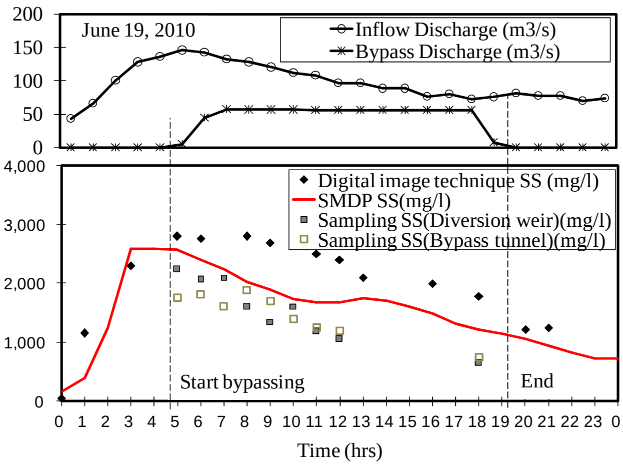

Fig.6 Comparison of monitored SSC measured by four different techniques during bypassing on 19 June 2010, Miwa dam.

(4) Efficiency of sediment bypass system

The operation record for flood event in July was also well monitored as shown in **Fig.7**. Moreover, to evaluate the removal efficiency of Miwa dam bypass tunnel the measured rainfall, inflow and bypass discharges, and SSC measured by three methods are depicted in **Figs.7(a,b,c)**, respectively. The calculated efficiency is defined as mass ratio of sediment bypassed to sediment inflow. The sediment discharges are the product of water discharge and SSC measured by turbiditymeter. In **Fig.7(b)** the bypass discharge is equal to inflow discharge. Suspended sediment concentration was up to 10,000 mg/l and high turbid flow was almost diverted effectively through the tunnel. In this case, bypass efficiency was estimated up to about 80 %.

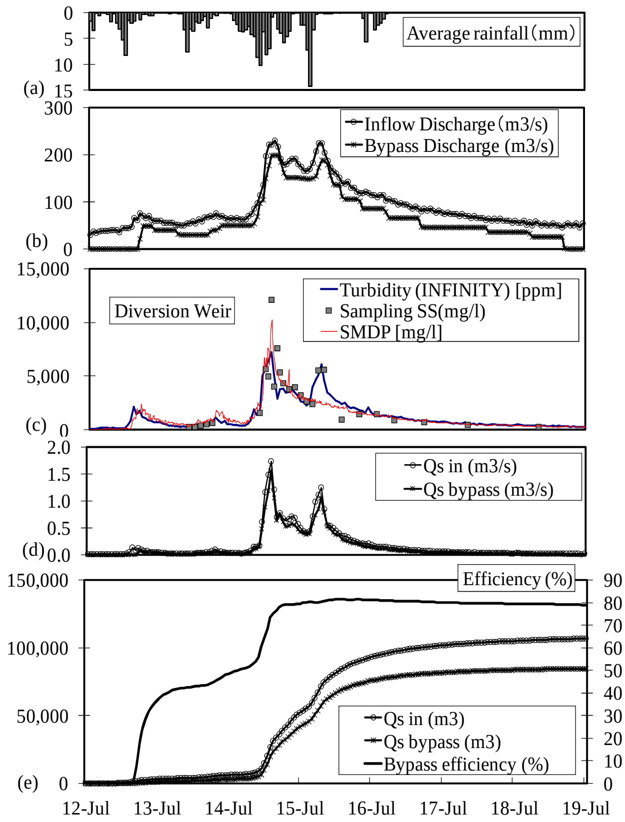

Fig.7 (a) Rainfall, (b) inflow and bypass discharges, (c) SSC measurements, (d) Calculated inflow and bypassed sediment, (e) calculated removal efficiency for Miwa dam bypass scheme on flood events of 13 and 14 July.

5. CONCLUSIONS

Sediment bypass system in Miwa dam is effectively routing incoming fine sediment directly to reservoir downstream. The measured efficiency of sediment bypassed by optical turbidity meter was up to 80% of the total inflow sediment. This efficiency was also measured at selected events by image processing which is a very useful tool in characterizing the performance of bypass tunnel operation. Moreover, the measured surface flow velocities and suspended sediment concentrations in the context of sediment management in reservoirs are important for the validity of the numerical analysis of Miwa dam.

The image technique methods were improved in order to obtain flow pattern and suspended sediment concentration despite water surface elevation variations, windy, rainy and foggy weather conditions. The described methods can be used to evaluate other sediment bypass systems.

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