Monitoring scheme for sediment bypass tunnel at Koshibu Dam

Hiroyuki Takeuchi, Katushi Ishida, Motohiko Hayashi and Chihiro Wakahara

Abstract

Koshibu Dam was built in 1969. In autumn 2016, a sediment bypass tunnel which is to prevent sedimentation of the reservoir and to increase sediment supply to downstream reaches was completed. During high flows, sediment-laden inflow is diverted from upstream of the reservoir to the downstream river directly. The tunnel is now in pre-operation before expected full operation in 2019. This paper presents an overview of the tunnel project and its monitoring scheme including operational performance during flood events in autumn 2016.

Key words: multipurpose dam, sediment control measure, sediment bypass tunnel, monitoring

1 Introduction

Koshibu Dam was built in 1969 as a multipurpose concrete arch dam 105 m high and 293.3 m long. It is located in the Koshibu River which originates in Akaishi-dake and is a left tributary of the Tenryu River (Fig. 1, left). In the 46 years operation, sedimentation in the Koshibu Reservoir has reached up to 89% of the design sedimentation capacity in 2015, and there is concern that the capacity will be filled in a few more years, critically reducing active storage volume for storing water (Fig. 1, right). At the same time, river bed armoring occurred below dam by coarser sediments are selectively deposited while finer sediment tends to be washed away (Fig. 2). To counter these problems, a sediment bypass tunnel has been built to take sediment directly from upstream to downstream of the dam during floods, controlling sediment inflow into the reservoir and maintaining continuous sediment transport (Kashiwai and Kimura 2015). Test operation started in autumn 2016. Full operation is expected to start in 2019.

This paper presents an overview of the sediment bypass tunnel (Table 1) and the monitoring scheme, and monitoring results of the test operation during two flood events in 2016.

Over 60% of sediment inflow into the reservoir consists of wash load (Fig. 2, right). Inflow is diverted into the bypass tunnel mainly during floods. Any excess inflow can be discharged through the dam's main gate if the inflow exceeds the tunnel capacity.

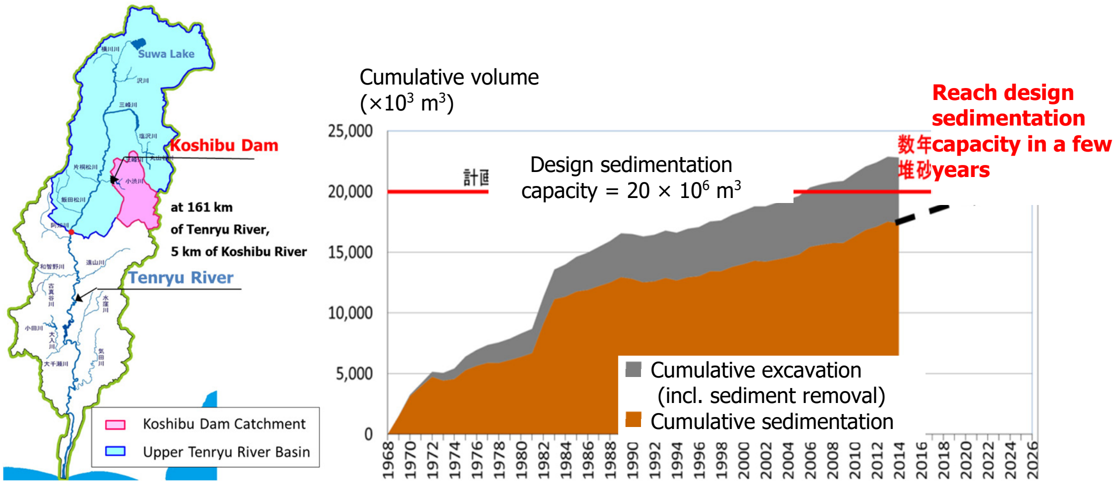

Figure 1: Location of the Koshibu Dam (left) and sedimentation in the Koshibu Reservoir (right)

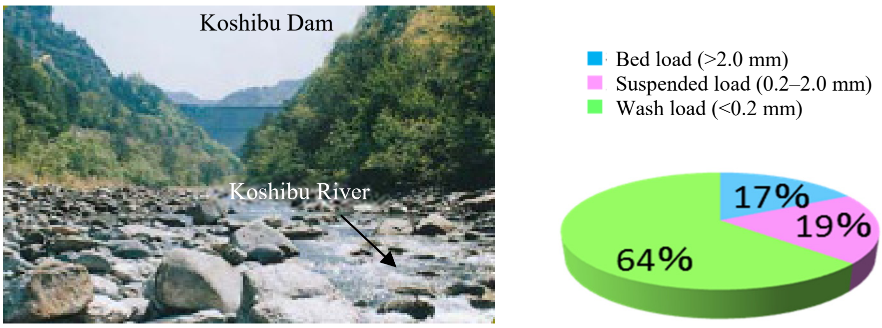

Figure 2: Riverbed at the Koshibu Dam downstream (left) and inflow sediment characteristics to the Koshibu Dam (right)

Table 1: Overview of the Koshibu Dam

Overview	Established	1969
	Name of river	Koshibu River (Tenryu River system)
	Dam type	Concrete arch dam
	Scale	H = 105 m, L = 293.3 m
	Basin area	288.0 km^2
	Reservoir capacity	58,000,000 m^3
	Capacity for water use	29,100,000 m^3
Purpose	Flood control	Starting flow: 200 m^3/s Maximum flow: 500 m^3/s Maximum inflow: 1,500 m^3/s Flood control method: fixed rate and fixed volume
	Irrigation	1.8 m^3/s (Matsukawa-town, Toyooka-village, Takagi-village, Ida-town)
	Power generation	Maximum 10,500 kW (Nagano Prefectural Gov. Enterprise Bureau)

2 Overview of sediment bypass facilities

2.1 Overview

The sediment bypass facilities consist of the sediment bypass tunnel, an inlet, and an outlet structures (Fig. 3). The target sediment is bed load, suspended load and wash load (Table 2).

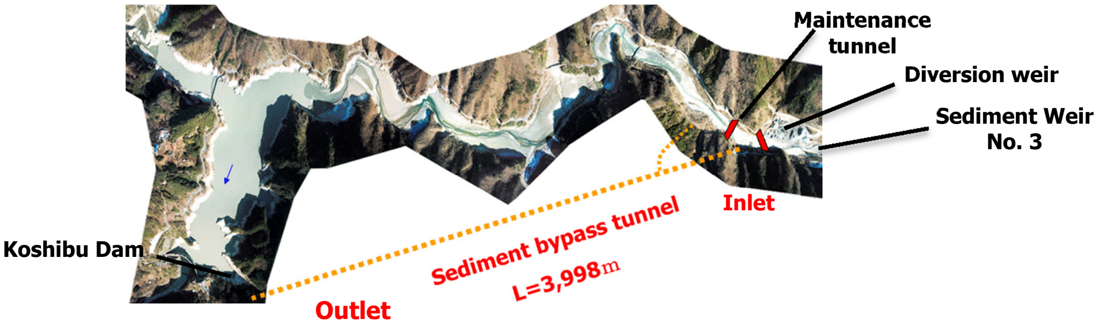

Figure 3: Components of sediment bypass tunnel facilities

2.2 Sediment bypass tunnel

The tunnel was designed as straight as possible with only one curving section at R = 1,000 m. A maintenance tunnel is installed upstream of the bypass tunnel allows access for survey and maintenance as needed. It is possible to enter the bypass tunnel from both the maintenance tunnel and the outlet.

The design discharge is 370 m^3/s, consistent with the design effluent flow of the Koshibu Dam specified in the *Basic Policy for the Tenryu River Improvement* (not the current *Koshibu Dam Basic Plan*).

High-strength invert concrete was used to prevent damage by bed load, and a smooth finish was created to withstand high flows by mechanical construction works (Table 2).

Table 2: Features of sediment bypass tunnel

Cross-sectional shape	Flat invert standard horseshoe (r = 3.95 m, cross-sectional area ≈ 54 m^2)
Longitudinal fall	1/50
Length	3,998 m
Design discharge	370 m^3/s
Maximum flow velocity	Approx. 15 m/s
Target sediment	Bed load, suspended sediment, and wash load
Lining material	Invert concrete constructed with high-strength composition of 50 N/mm^2 (t = 45 cm)

2.3 Inlet structure

The inlet structure consists of an inlet and a diversion weir to divert inflow, a woody debris trap to prevent blockage of the inlet, and a sediment trap weir to trap coarser sediment before diversion (Fig. 4). Originally, a small sediment trap weir was built in

1977 for sediment excavation which has been converted into the diversion weir in this project. The shape and location of each component were selected through hydraulic model experiments.

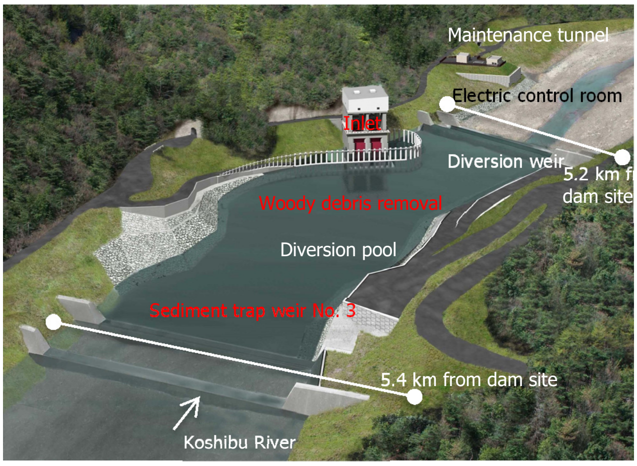

Figure 4: Layout of inlet structure

The inlet (Fig. 5, left) is a complex structure with two lower orifice gates and two crest gates designed to allow natural regulation without adjusting gate operation during flood times. To prevent abrasion damage of the inlet, a 20 m section of the tunnel inlet was covered by the rubberized steel plates and the following 30 m was lined with steel plates (Fig. 5, right).

Two sub-gates are placed upstream and two main gates are placed downstream of the inlet. The two sub-gates can operate even if the front of the main gates is blocked with sediment.

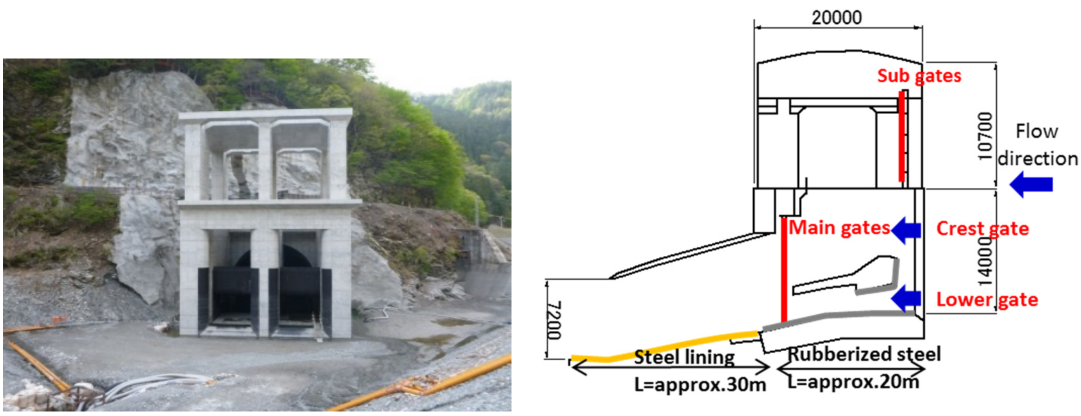

Figure 5: Inlet structure: front (left), with sub-gates above main gates, and in cross-section (right)

2.4 Outlet structure

The outlet structure is located 300 m downstream of the dam. It consists of the outlet, a discharge channel, and an energy dissipation pool (Fig. 6). The shape and location of each component were chosen through hydraulic model experiments.

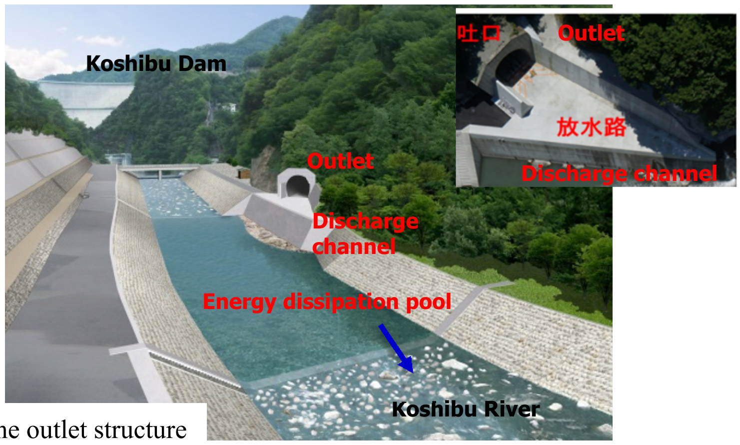

Figure 6: Layout of the outlet structure

3 Monitoring during pre-operation

3.1 Purpose and extent of monitoring

During pre-operation, the performance and environmental impacts of the tunnel are being monitored so that its full operational methods such as timing of bypass operation and appropriate riverbed elevation in front of the inlet can be determined. Three aspects are being monitored: the "structure" itself, "environment" as the environmental impacts of sediment transport, and "sediment budget" to measure sediment transport volume and its effects (Table 3). The monitoring methods are described in detail in Sections 3.2 to 3.4.

Table 3: Monitoring aspects

Monitoring area	Objective	Consideration
Structure	Structural verification including diversion characteristics. Creation of management plan	Compare and verify the diverted flow volume with model results. Monitor water and sediment transport, as well as damage to structure
Environment	Environmental impact assessment	Conduct one-dimensional riverbed fluctuation analysis, and revise qualitative analysis through technical documents
Sediment budget	Establishment of methods to calculate sediment transport for several particle size ranges	Revise current calculation method according to observation data and evaluate effectiveness of sediment bypass scheme

3.2 Structural monitoring

Structural monitoring on the tunnel's function is described in Table 4. Abrasion rate is assessed by visual inspection of painted bands every 200 m in the tunnel (Fig. 7) and by 3D laser scanning inspection using vehicle.

Table 4: Structural monitoring methods

Purpose	Monitoring location	Method	Period
Validation of diverted volume	Inside bypass tunnel	Water level survey	During tunnel operation
Measurement of flow volume	At woody debris trap, bypass gate and bypass outlet	CCTV	
Assessment of abrasion	At woody debris trap, inlet, in tunnel, and at outlet	Visual and 3D laser scanning measurement	After tunnel operation

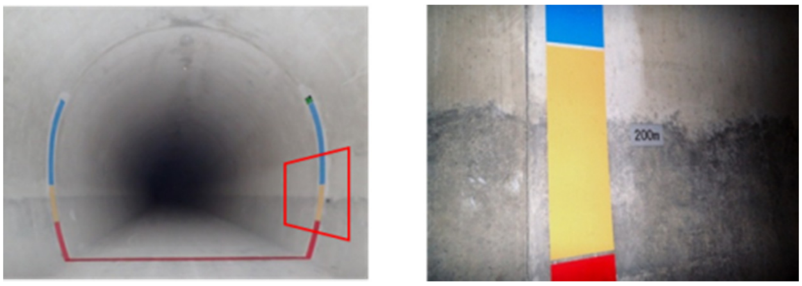

Figure 7: Painted band inside the sediment bypass tunnel

3.3 Environmental monitoring

The river environment is monitored from the dam to approximately 5 km downstream, where the Koshibu River merges with the Tenryu River. The monitoring focuses on both physical factors such as riverbed fluctuations, riverbed materials, water quality and ecological factors such as algae, benthos, fish, and rare plant species (Table 5). Surveys are conducted in non-flood season as well as after floods for riverbed material and living organisms. Attached algae on stone surfaces are surveyed monthly as seasonal variation occurs.

Table 5: Environmental monitoring method

Purpose	Monitoring location	Method	Period
Landscape	Koshibu Dam downstream (toward junction with Tenryu R)	Aerial photo survey	Once after annual flood season and after relatively high flows
Riverbed fluctuation	Koshibu Dam downstream (every 200 m toward junction with Tenryu R)	River survey: photo at junction with Tenryu R	Survey: after flood season Photo: monthly
Riverbed material	Koshibu Dam upstream (Koshibu R and Kashio R) and downstream (7 locations)	Sampling and laboratory testing	Once after annual flood season and after relatively high flows
Water quality	Koshibu River (inflow and outflow), Tenryu R (Tenryu Bridge and Daijo Bridge), and tributary (Katagirimatsu R)	Observation of turbidity and water temperature	Koshibu R: every month and during floods (hourly) Other points: during floods (hourly)
Attached algae	Koshibu Dam upstream (Ikuta Weir) and downstream (2 locations)	Sampling and laboratory analysis (species structure, number of cells, Chl-*a*, pheophytin, ignition loss)	Monthly
Benthos and fish	Koshibu Dam upstream (Ikuta Weir) and downstream (4 locations along Koshibu R; Tenryu and Daijo Bridges along Tenryu R)	Numeric survey	Once after annual flood season and after relatively high flows
Rare land plant species	Koshibu Dam downstream (toward junction with Tenryu R)	Numeric survey	

3.4 Sediment budget monitoring

Sediment budget is monitored by measuring the sediment transport volume for each sediment flow in the bypass inflow, bypass outflow, and dam outflow during floods (Table 6). Since it is difficult to measure the total volume of sediment transport during floods, one-dimensional riverbed fluctuation analysis is conducted and validated with hydraulic model test results.

The method for monitoring sediment budget is shown in Table 7. Suspended sediment (SS), particle size distribution, SS density, and gravel transport are monitored during floods at the inflow and outflow. Water sampling pipes are inserted in the training wall to collect samples at different depths (Fig. 8). Riverbed fluctuation and riverbed material are measured after floods. The diversion and energy dissipation pools are surveyed before and after floods to collect deposited sediment volume data at the inlet and outlet sections.

To measure gravel transport during floods, a plate microphone is mounted on the invert of the bypass outlet channel. This monitoring system is based on a collaborative study with Kyoto University.

Table 6: Methods of sediment observation and calculation

Sediment	Method	Possible to directly observe sediment mass?	Method for calculating sediment mass
Silt	Water sampling during floods	Yes	Q-QS equation (flow volume vs. sediment volume) derived from SS, particle size distribution, and SS density data
Sand	Water sampling during floods	Difficult to sample total transported sand	1-D riverbed fluctuation analysis with validation by observed data
Gravel	Riverbed measurement	Yes	By observation

Table 7: Method for monitoring sediment balance

Purpose	Monitoring location	Period	Method
SS, particle size distribution, SS density	Inflow 1 (Okeya Bridge) Inflow 2 (Matsuyoke Bridge) Gate outflow (management bridge) Dam discharge	During floods (hourly)	Surface water sampling and laboratory testing
	Bypass outflow	As above	Water sampling at different depths and laboratory testing
Riverbed fluctuation	Koshibu Dam downstream to junction with Tenryu River	After floods that result in sediment transport	3-D survey (laser or narrow multi-beam)
	Diversion pool, Energy dissipation pool	After bypass operation	ditto
Riverbed material	Around sediment weir No. 3 (2 locations)	After floods that result in sediment transport	Sampling and laboratory testing
	Diversion pool (6 locations) Energy dissipation pool (2 locations)	Before and after bypass operations	ditto
	Koshibu Dam downstream (7 locations toward junction with Tenryu River)	After floods that result in sediment transport	ditto
Gravel transport	Bypass outflow channel	During floods	Microphone

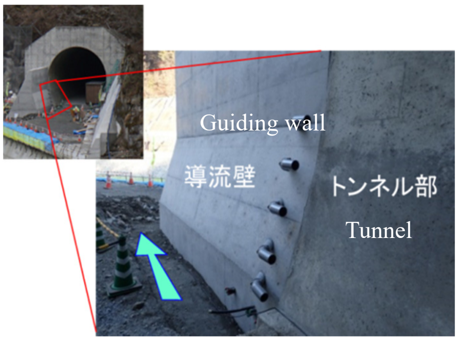

Figure 8: Water sampling pipes installed in guiding wall

3.5 Monitoring committee

A monitoring committee comprising professors with experience or academic background has planned and evaluated the monitoring program since 2014. The committee will oversee further studies.

4 Test operation of sediment bypass tunnel in 2016

4.1 Overview of test operation

Test operation of the sediment bypass tunnel were conducted during two events, Typhoon No. 16, on 20–21 September 2016, with the maximum flow of 80 m^3/s (Fig. 9), a rainy front on 23 September, with the maximum flow of 60 m^3/s. Operational data during two floods is shown in Fig. 10.

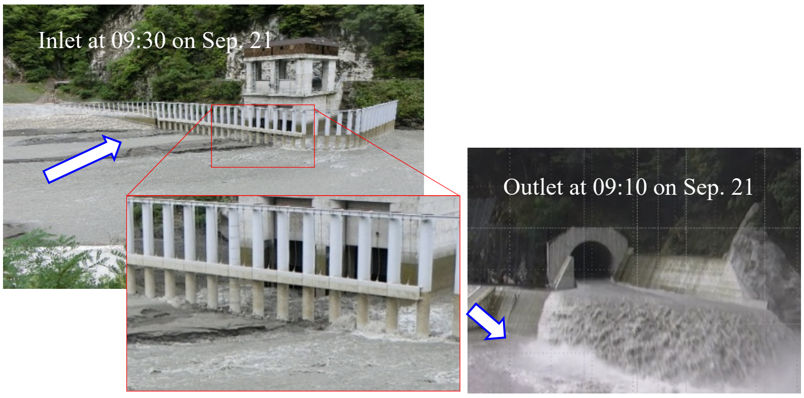

Figure 9: Inlet (left) and outlet (right) during test operation on 21 September 2016

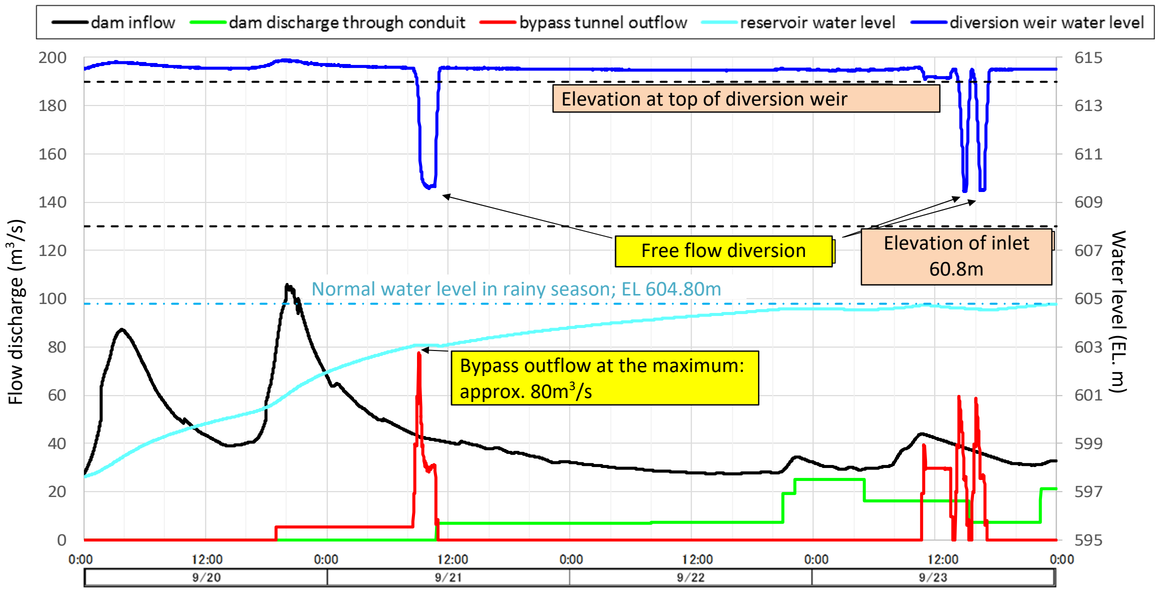

Figure 10: Operational data during the test operation in 20-23 September 2016

4.2 Structural monitoring

During the tests, the gates were successfully and firmly closed without taking in any sediment or woody debris. Although the painted bands were completely abraded at the base of the tunnel, notable abrasion did not occur throughout the tunnel (Fig. 11).

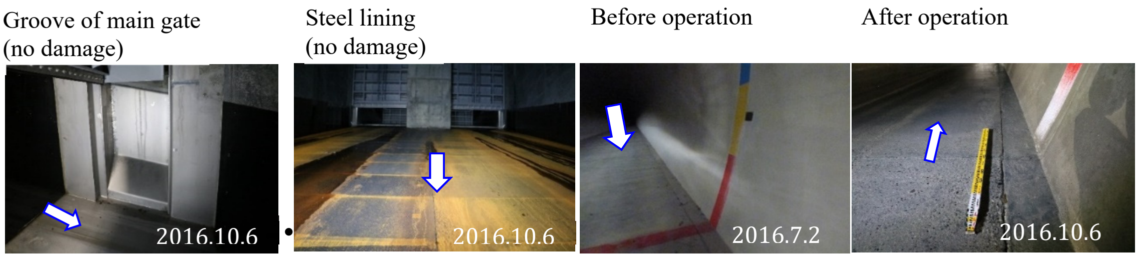

Figure 11: Surface integrity around gates after operation (left) and painted bands (right)

4.3 Environmental monitoring

The following field survey revealed patchy deposition of sand or silt (Fig. 12), but did not show any significant changes on attached algae, benthic organisms, fish or rare land plants (Fig. 13).

4.4 Sediment budget monitoring

The volume of sediment transported in the bypass tunnel was estimated from data collected before and after the test operation, from water sampling data collected during operation, and from riverbed fluctuation analysis (Fig. 14). During both events, about 10,000 m^3 of sediment was transported downstream.

Figure 12: Riverbed at junction with Tenryu River after test operation

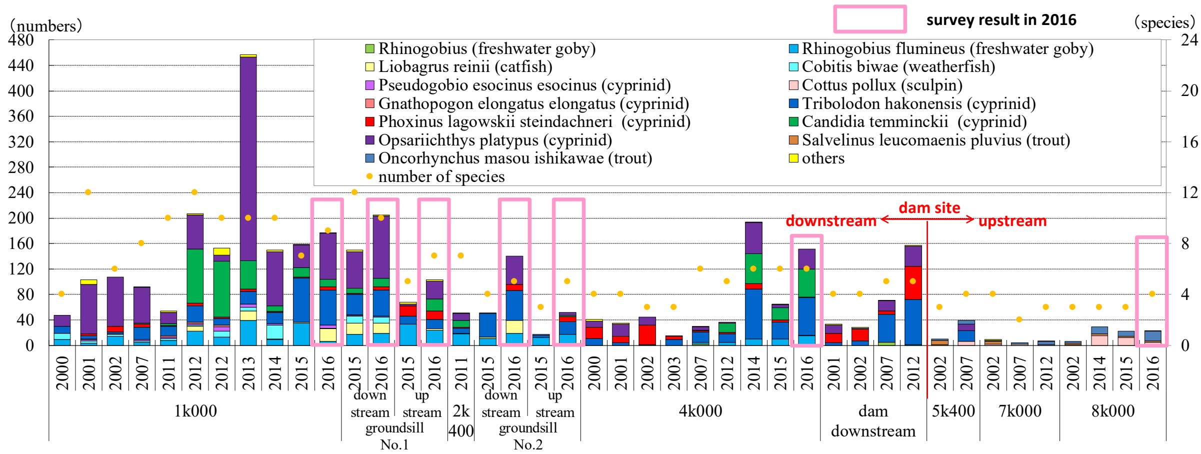

Figure 13: Fish survey results before and after test operation

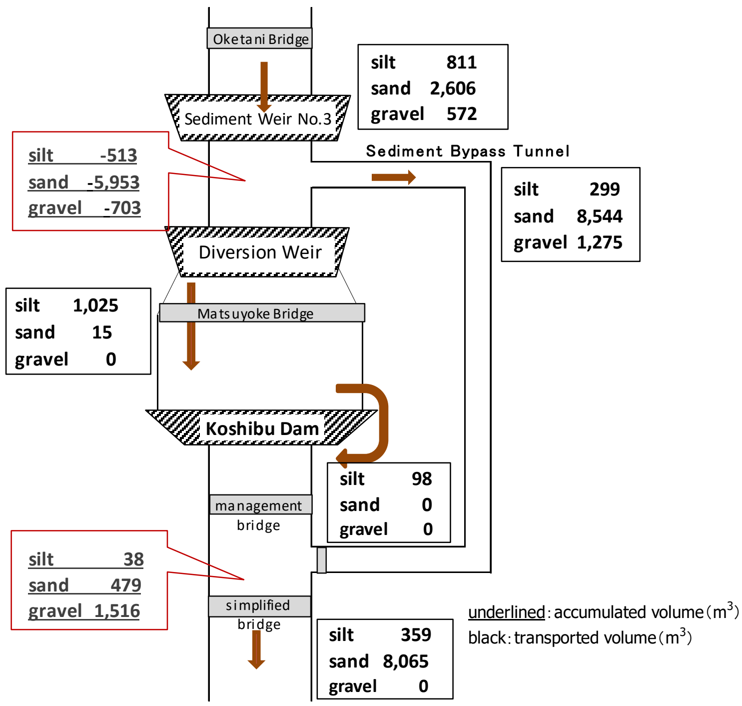

Figure 14: Estimated sediment budget during test operation on 20–21 and 23 September 2016

5 Conclusion

Sediment bypass scheme has been started very successfully. Although the test operation in 2016 is limited water discharge, sediment budget and other environmental monitoring data has been obtained. Since much uncertainty remains in regard to the operation of the sediment bypass facilities, further continuous and long-term monitoring is necessary.

Acknowledgements

The author thanks all who participated in the sediment bypass project, the monitoring surveys and the preparation of this paper.

References

Kashiwai J., Kimura S. (2015). Hydraulic examination of Koshibu dam's intake facilities for sediment bypass, Proc. First International Workshop on Sediment Bypass Tunnels, VAW-Mitteilungen 232 (R. M. Boes ed.), Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Switzerland, 45-54.

Author

Hiroyuki Takeuchi (corresponding author)
Katushi Ishida
Motohiko Hayashi
Chihiro Wakahara
Tenryu River Integrated Dam Management Office, Chubu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan
Email: takeuchi-h85aa@mlit.go.jp