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PLAN AND OPERATION RESULTS OF THE KOSHIBU DAM SEDIMENT BYPASS TUNNEL*

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JAPAN

SUMMARY

In order to prevent sedimentation in the reservoir and ensure the continuity of sediment transport at the river, the Koshibu dam sediment bypass tunnel was planned and completed in September 2016. From the viewpoint of structure, environment and sediment budget, monitoring plan was examined by the monitoring committee and several trial operations have been carried out.

** Plan et résultats d'exploitation du tunnel de dérivation des sédiments du barrage de Koshibu*

Since the purposes of the Koshibu dam is including flood control, irrigation and power generation, the sediment bypass tunnel is planned to operate during the flood control. In order to adapt to the flood control rule, two crests placed on the two orifices is designed for the inlet structure. The target bypassing sediments are gravel having a grain size of about 100 mm or less, sand and silt (clay). As a countermeasure against abrasion damage caused by the sediment transport, around the gate with a relatively low flow velocity was protected with "rubber steel" and the downstream section with high flow velocity was protected with steel lining.

In the monitoring plan, the objectives of monitoring at each viewpoint were arranged by selecting suitable methods. In sediment budget monitoring, as the first case of the sediment bypass tunnel in Japan, sediment observation devices were installed on the bottom of the tunnel outlet part.

After completion of the bypass facility, several trial discharge operations were carried out. Even though the trial discharge was a small scale compared with the planned maximum bypass discharge and comparatively short time, as a result of monitoring, it was confirmed that there was no problem in gate operation, and no significant abrasion damage and environmental changes in the downstream river. Moreover, it was able to estimate the sediment budget and sediment transport characteristics during bypass operations. Regarding abrasion damages, long-term monitoring is needed since the flow rate and operation time in the trial discharge was limited.

Keywords: Sedimentation, Reservoir Capacity, Reservoir Operation, Flood Diversion, Effect Of Dams On Environment, Koshibu Dam.

RÉSUMÉ

Afin de prévenir la sédimentation dans le réservoir et assurer la continuité du transport des sédiments dans la rivière, le tunnel de dérivation des sédiments du barrage de Koshibu a été planifié, et terminé en septembre 2016. Du point de vue de l’ouvrage, de l'environnement et du bilan sédimentaire, un plan de suivi a été examiné par un comité ad-hoc et plusieurs essais d’exploitation ont été effectués.

Étant donné que les objectifs du barrage de Koshibu comprennent le contrôle des crues, l'irrigation et la production d'électricité, le tunnel de dérivation des sédiments fonctionne pendant le contrôle des crues. Afin de s'adapter à la règlementation de contrôle des crues, deux crêtes placées sur les deux orifices sont prévues pour l’ouvrage d'entrée. Les sédiments devant être dérivés sont des graviers ayant une granulosité maximale d'environ 100 mm, des sables et des limons (argile). En tant que mesure contre l’abrasion causée par le transport des sédiments, l’écoulement de vitesse relativement faible au niveau de la vanne s’effectue sur un « acier caoutchouté » et la section aval à grande vitesse d'écoulement est protégée par un revêtement en acier.

Dans le plan de surveillance, les objectifs de suivi pour chaque point ont été définis en sélectionnant des méthodes appropriées. Dans le cadre de la surveillance du bilan sédimentaire, en tant que premier tunnel de dérivation des sédiments au Japon, des dispositifs d'observation des sédiments ont été installés au fond de la galerie de fuite.

Après l'achèvement de l'installation de dérivation, plusieurs essais de déchargement ont été effectués. Même si cet essai de décharge était à petite échelle comparé au débit de dérivation maximum prévu, et relativement court, à la suite de la surveillance, il a été confirmé qu'il n'y avait aucun problème dans le fonctionnement des vannes et pas de dommages significatifs dus à l'abrasion, ni changements environnementaux dans la rivière en aval. De plus, il a été possible d'estimer le bilan sédimentaire et les caractéristiques de transport des sédiments lors des opérations de dérivation. En ce qui concerne les dommages dus à l'abrasion, une surveillance à long terme est nécessaire étant donné que le débit et le temps de fonctionnement pour l'essai de décharge étaient limités.

1. INTRODUCTION

The Koshibu dam was built in 1969 at the Koshibu river, one of the branches of the Tenryu river system in Japan. At the dam, a sediment bypass tunnel was planned with the aim of preventing sedimentation in the reservoir and ensuring the continuity of sediment transport at the river. The bypass facility was completed in September 2016. Regarding the operation of the sediment bypass tunnel, a monitoring committee consisting of academics and experts was established in 2014. From the viewpoint of structure, environment, and sediment budget, monitoring plans have been examined, and analysis and evaluation of trial operation results were carried out [1]. In this paper, the characteristics of the facility of the Koshibu dam sediment bypass tunnel, the monitoring plan and the monitoring results of the trial operations are reported.

2. OUTLINE OF THE KOSHIBU DAM AND SEDIMENT BYPASS TUNNEL PROJECT

The Koshibu dam was built in 1969 in the Koshibu river, the left branch of the Tenryu river flowing through Nagano Prefecture and Shizuoka Prefecture in Honshu Island, Japan. The Koshibu dam is managed by the Ministry of Land, Infrastructure and Transport. The location of the dam and the outline is shown in Fig.1 and Table 1. The purposes of the Koshibu dam are flood control, irrigation and power generation, which is an important infrastructure facility for the watershed area.

Fig. 2 and Fig. 3 show the trend of sedimentation volume and the thalweg profile of sedimentation in the reservoir. At the Koshibu dam, the planned sedimentation volume was defined by estimating the amount of sediment accumulated during the 50 years at the time of dam planning. Sedimentation capacity of 20,000,000 m^3 to store the planned sedimentation volume is prepared in the storage capacity.

Fig. 1
Location of the Koshibu Dam (left) and the airial photo (right)
Emplacement du barrage de Koshibu (à gauche) et de la photo aérienne (à droite)

Table 1
Overview of the Koshibu Dam

<table>
<tr><td>Completion year</td><td colspan="2">1969</td><td>Catchment area</td><td>288.0 km²</td></tr>
<tr><td>Dam type</td><td colspan="2">Concrete arch dam</td><td>Reservoir capacity</td><td>58,000,000 m³</td></tr>
<tr><td>Dam height</td><td colspan="2">105 m</td><td>Capacity for water use</td><td>29,100,000 m³</td></tr>
<tr><td>Crest length</td><td colspan="2">293.3 m</td><td>Design flood flow</td><td>2,160 m³/s</td></tr>
<tr><td rowspan="3">Purpose</td><td>Flood control</td><td colspan="3">Flood control method: constant ratio - constant discharge
Flood control starting discharge: 200 m³/s,
Planed the Maximum discharge: 500 m³/s,
The maximum inflow discharge: 1,500 m³/s</td></tr>
<tr><td>Irrigation</td><td colspan="3">1.8 m³/s</td></tr>
<tr><td>Power generation</td><td colspan="3">The maximum 10,500 kW</td></tr>
</table>

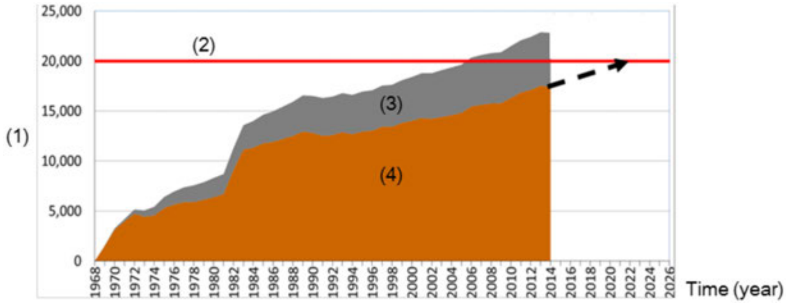


Fig. 2
Trend of sedimentation in the Koshibu Reservoir
Tendance de la sédimentation dans le réservoir Koshibu

(1) Cumulative volume ($\times 10^3$ m^3)
(2) Design sedimentation capacity = 20×10^6 m^3
(3) Cumulative excavation
(4) Cumulative sedimentation

(1) Volume cumulatif
(2) Conception de la capacité de sédimentation
(3) Excavation cumulative
(4) Sédimentation cumulative

After the dam construction, since the progress of sedimentation was faster than planned, several countermeasures for sedimentation have been implemented. For example, about 5,000,000 m^3 of sediment accumulated in the reservoir due to large-scale floods in 1982 and 1983. As a countermeasure, excavation was adopted and carried out from the beginning of the dam operation. After that, in order to carry out excavation more efficiently, three sediment trap weirs have been installed such as No.1 in 1978, No.2 downstream in 1990 and No.3 upstream in 2006, respectively. On average, about 105,000 m^3 of sediment have been excavated and removed annually which are most effectively used for aggregate and so on.

However, the average value of annual sedimentation volume in recent years is up to about 280,000 m^3, and it is difficult to prevent the increase of sedimentation volume even if continuing excavation. As of 2014, 87% of the planned sedimentation volume was deposited and there was concern that the amount of sediment exceeded the planned amount in the near future. At the downstream of the dam, since the amount of sediment flowing down after construction of the dam has decreased, influence on the riverbed environment such as bed armoring has been observed.

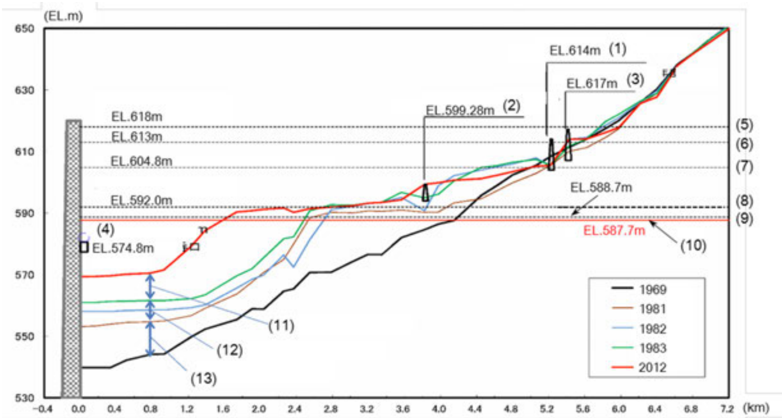


Fig. 3
Thalweg profile of sedimentation in the Koshibu Reservoir
Profil thalweg de la sédimentation dans le réservoir de la Koshibu

(1) Sediment weir No.1
(2) Sediment weir No.2
(3) Sediment weir No.3
(4) Conduit gate intake
(5) Surcharge water level
(6) Normal water level
(7) Limiting water level in rainy season (7/21-10/5)
(8) Limiting water level in rainy season (6/10-7/20)
(9) Low water level
(10) Planed sedimentation level
(11) Deposited for 30 years
(12) Deposited during floods in 1982 and 1983
(13) Deposited for 12 years

(1) Déversoir de sédiments No.1
(2) Déversoir de sédiments No.2
(3) Déversoir de sédiments No.3
(4) Entrée des conduits
(5) Surcharge du niveau d'eau
(6) Niveau d'eau normal
(7) Limitation du niveau d'eau en saison pluvieuse (7/21-10/5)
(8) Limitation du niveau d'eau en saison pluvieuse (6/10-7/20)
(9) Faible niveau d'eau
(10) Niveau de sédimentation planifiée
(11) Déposé depuis 30 ans
(12) Déposé pendant les inondations en 1982 et 1983
(13) Déposé depuis 12 ans

To cope with these problems, a sediment bypass tunnel project was launched in 2000 with the aim of reducing sediment inflow into the reservoir and ensuring continuity of sediment transport in the river. The project period was 17 years up to 2016 which costed about 14.4 billion yen (about 128 million US dollars). Construction of the major facilities took 8 years, and the sediment bypass tunnel was completed in September 2016. It has taken 4 years for the main tunnel about 4 km in length to break through and another 4 years for facilities such as the inflow facility, the energy dissipator and so on.

3. OUTLINE OF SEDIMENT BYPASS TUNNEL FACILITY

The outline of the Koshibu dam sediment bypass tunnel facility is shown in Fig.4 and Table 2. In the Koshibu dam, target bypassing sediments are gravel having a grain size of about 100 mm or less, sand and silt (clay). Annual average sediment budget plan of the Koshibu dam sediment bypass project as of 2014 is shown in Fig.5 which bypasses about 310,000 m^3 of sediment per year to downstream river out of the average annual inflow volume of about 570,000 m^3. Also, about 140,000 m^3 of sediment trapped in the sediment trap weirs is planned to be excavated per year after starting the bypass operation. The sediment bypass facility consists of an inlet part, a tunnel part and an energy dissipator part. The outline of each part is written below.

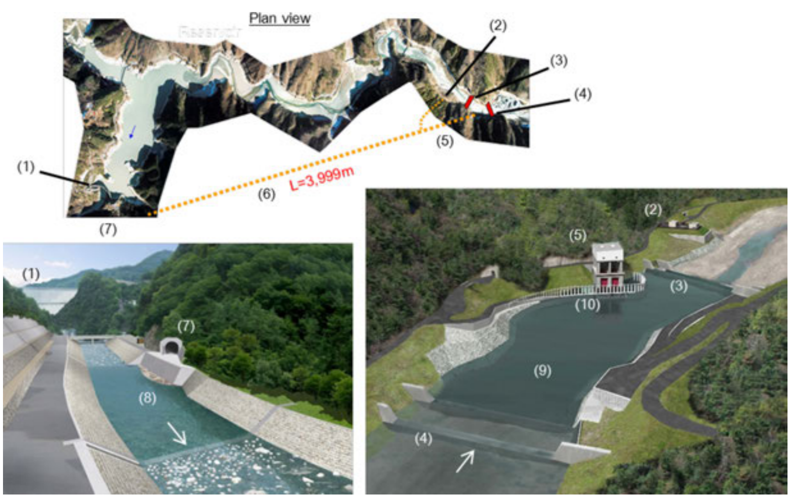


Fig. 4
Sediment bypass tunnel facility
Installations du tunnel de dérivation des sédiments

(1) The Koshibu dam, (2) Maintenance tunnel
(3) Diversion weir, (4) Sediment weir
(5) Inlet, (6) Sediment bypass tunnel
(7) Outlet, (8) Energy dissipator
(9) Diversion pool
(10) Driftwood guard piles

(1) Barrage de Koshibu, (2) Tunnel de maintenance
(3) Déversoir de dérivation, (4) Déversoir de sédiments
(5) Entrée, (6) Tunnel de dérivation des sédiments
(7) Sortie, (8) Dissipateur d'énergie
(9) Bassin de dérivation
(10) Piles de garde à bois flottant

Table 2
Overview of the Koshibu Dam Bypass Tunnel

Completion year	2016	Outlet energy dissipator	Yes
Design velocity	15.8 m/s	Target Grain Size	d_m: 10 mm, d_{90}: 70mm
Tunnel specifications	Cross section shape		Horseshoe shape 2r = 7.95 m
	Length		3,999 m
	Longitudinal slope		2.0% (1/50)
	Curved section		Yes
Flow discharge	Design discharge		370 m³/s
	Design flood return period		1/6.2 year
Intake specifications	Intake position in reservoir		Upstream end
	Flow control		Gate
	Reservoir operation during sediment discharge		Flood control

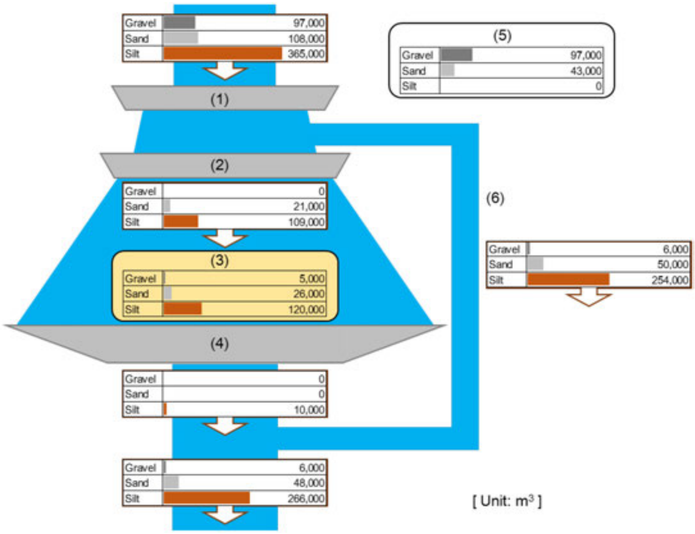


Fig. 5
Annual average sediment budget plan of the Koshibu dam sediment bypass project
Plan budgétaire annuel moyen des sédiments du projet de dérivation des sédiments du barrage de Koshibu

(1) Sediment Weir
(2) Diversion weir
(3) Reservoir sedimentation
(4) The Koshibu dam
(5) Excavation
(6) Sediment bypass tunnel

(1) Déversoir de sédiments
(2) Déversoir de dérivation
(3) Sédimentation des réservoirs
(4) Barrage de Koshibu
(5) Excavation
(6) Tunnel de dérivation des sédiments

3.1. Outline of the inlet part

The inlet part is composed of “sediment trap weir” installed upstream to capture coarse sediment, “driftwood guard piles” to prevent clogging inlet by driftwood, “inlet structure” and “diversion weir” to divert flood water to the bypass tunnel. “Sediment trap weir” and “diversion weir” were constructed by remodeling existing “sediment trap weir No.3” and “sediment trap weir No.1”, respectively.

In order to minimize the gate operation by adapting to the Koshibu dam’s flood control rule of constant rate - constant discharge, two crests placed on the two orifices is designed for the inlet structure where two sub gates on the upstream and two main gates on the downstream are installed (Fig. 6) [2]. The sub gates are designed to be operated even if the upstream side is covered by deposited sediment.

As a countermeasure against abrasion damage caused by the sediment flow, the 20 m section around the gate with a relatively low flow velocity was protected with “rubber steel” which is the composite structure of the steel plate and the hard rubber, the downstream 30 m section with high flow velocity was protected with steel lining (Fig. 6).

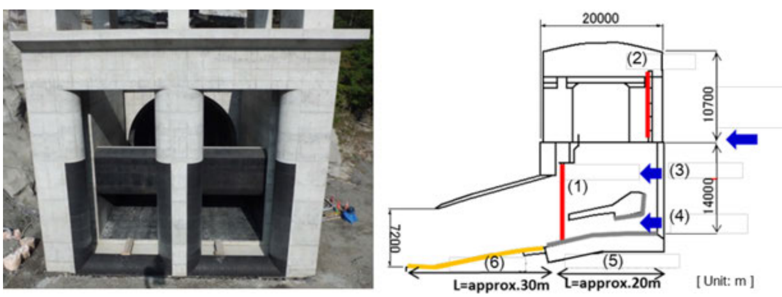


Fig. 6
Inlet structure front view (left) and longitudinal section shape (right)
Vue frontale de la structure d’entrée (gauche) et de la coupe longitudinale (droite)

(1) Main gates, (2) Sub gates
(3) Crests, (4) Orifices
(5) Rubber steel, (6) Steel lining

(1) Portes principales, (2) Sous-portes
(3) Crêtes, (4) Orifices
(5) Acier en caoutchouc, (6) Doublure en acier

3.2. Outline of the tunnel and energy dissipator parts

Since the abrasion damage due to sediment flow was concerned, the high strength concrete with the target strength of 50 N/mm^2 was applied for the tunnel invert concrete where the thickness was designed to 45 cm including the abrasion margin of 16 cm. Considering the maintenance management, the structure was made possible to allow vehicles to enter the tunnel from both the maintenance tunnel installed upstream and the downstream end of the tunnel.

The outlet of the tunnel is located about 300 m downstream of the dam. The energy dissipator was designed to reduce the water flow energy by spreading flow from the tunnel end into the downstream water channel and flowing into the river.

3.3. Outline of the bypass operation method

In case of the Koshibu dam, the sediment bypass facility was planned to discharge sediment during flood events as follows in 2014. Specifically, as shown in the hydrograph shown in Fig. 7, when the inflow discharge exceeds 60 m^3/s, the bypass gate will be opened to start discharging from the bypass. During the flood peak, the bypass will discharge as far as possible within the range of the outflow discharge in the flood control rule. After the flood, the bypass gate will be closed when the inflow discharge decreases below 60 m^3/s. This planned operation method will be examined and modified based on the monitoring results of trial operations in the future.

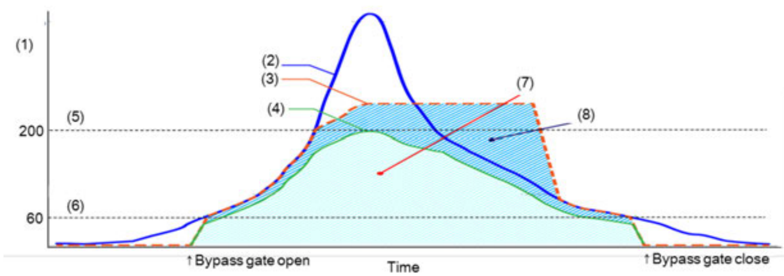


Fig. 7
Planned hydrograph of the Koshibu dam sediment bypass project
Projet de dérivation des sédiments du barrage de Koshibu

(1)	Discharge rate (m^3/s)	*(1)*	*Taux de décharge (m^3/s)*
(2)	Inflow (Dam)	*(2)*	*Apport (barrage)*
(3)	Outflow (Total)	*(3)*	*Sortie (Total)*
(4)	Outflow (Bypass)	*(4)*	*Sortie (dérivation)*
(5)	Flood control starting discharge	*(5)*	*Déclenchement du contrôle des inondations*
(6)	Bypass operation starting discharge	*(6)*	*Déclenchement de l'opération de dérivation*
(7)	Discharge from bypass	*(7)*	*Décharge à partir de la dérivation*
(8)	Discharge from dam conduit	*(8)*	*Décharge à partir du conduit du barrage*

4. MONITORING PLAN

The purpose of monitoring is to confirm the facility performance, environmental impacts and others by implementing trial operation of the sediment bypass and to finalize the formal operation method. The monitoring is categorized into the following three aspects: "structural monitoring" to verify the discharge facility, "environment monitoring" to assess the environmental impacts by the sediment flow to the downstream river and "sediment budget monitoring" to clarify the amount of bypassed sediment to check the effect of bypass facility. Specific monitoring methods are described below.

4.1. Structural monitoring

In consideration of the functions required for each part of the sediment bypass facility, a monitoring plan was prepared to confirm the diverted water volume, the flow condition and the abrasion damages on the tunnel invert. The monitoring methods are shown in Table 3. In order to easily detect the abrasion damage condition inside the tunnel, both visual inspection of the painted band at 200 m intervals and periodical survey by the vehicle with the 3D Laser Scanner will be conducted.

Table 3
Structural monitoring methods

PURPOSE	MONITORING LOCATION	METHOD	PERIOD
Validation of diverted water volume	Inside bypass tunnel	Water level survey	During tunnel operation
Observation of flow condition	At driftwood guard piles, bypass gate and bypass outlet	CCTV	
Assessment of abrasion damages	At driftwood guard piles, inlet, tunnel inside and outlet	Visual inspection (painted belt) and 3D Laser Scanner	After tunnel operation

4.2. Environmental monitoring

The river 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 landscape, riverbed fluctuations, riverbed materials, water quality and environmental factors such as attached algae, benthos, fish, and rare land plant species (Table 4). Surveys are conducted during non-flood season as well as just after floods for riverbed material and living organisms. Attached algae will be surveyed monthly considering seasonal variation.

Table 4
Environmental monitoring methods

PURPOSE	MONITORING LOCATION	METHOD	PERIOD
Landscape	Dam downstream	Aerial photo survey	After flood season and after bypass operation
Riverbed variation	Dam downstream (every 200 m)	Riverbed survey, photo at junction with Tenryu R	Survey: after flood season Photo: monthly
Riverbed material	Dam upstream and downstream (7 locations)	Sampling and laboratory analysis	After flood season and after bypass operation
Water quality	Dam inflow and outflow, Tenryu R (2 locations), and tributary	Observation of turbidity and water temperature	Koshibu R: every month and during floods (hourly), Other points: during floods (hourly)
Attached algae	Dam upstream and downstream (2 locations)	Sampling and laboratory analysis (species, number of cells, Chl-a, pheophytin, ignition loss)	Monthly
Benthos and fish	Dam upstream and downstream (4 locations)	Numeric survey	After flood season and after bypass operation
Rare land plant species	Dam downstream	Numeric survey	

4.3. Sediment budget monitoring

In order to understand the sediment budget in the sediment bypass operation during flood, it is necessary to confirm the sediment quantity by each particle size with regard to “Dam inflow”, “Bypass outflow” and “Dam outflow”.

Generally, the budget of the gravel is estimated from the riverbed survey upstream and downstream of the bypass tunnel, before and after floods, and from the riverbed material investigation. Survey will be also conducted after the flood season. Since it is necessary to get data in more detail at the diversion pool and the energy dissipator, precise surveys will be conducted before and after the bypass operation. In addition, as the first case of the sediment bypass tunnel in Japan, sediment observation devices (plate type sensor etc. [3]) were installed on the bottom of the tunnel outlet part. The plate type sensor consists of a steel plate (0.5 m long side, 0.36 m short side and 15 mm thickness), an acoustic sensor (hydrophone) and a vibration sensor installed on the back side. These measurements have been already started during flood events (Fig.8 left).

With regard to the sand, it is difficult to observe all amount of the sand transport during flood. Therefore, using the observed data as a verification data, the amount of the sand transport is estimated from the one-dimensional river bed variation model. For water sampling at the tunnel outlet, water intake pipes were installed on the training wall surface (Fig.8 right), in order to collect the discharged water at different water depths.

The amount of the silt transport is estimated by combining the discharge rate data with the suspended sediment concentration and the particle size distribution obtained by water sampling at the tunnel upstream and downstream points. The monitoring methods are summarized in Table 5.

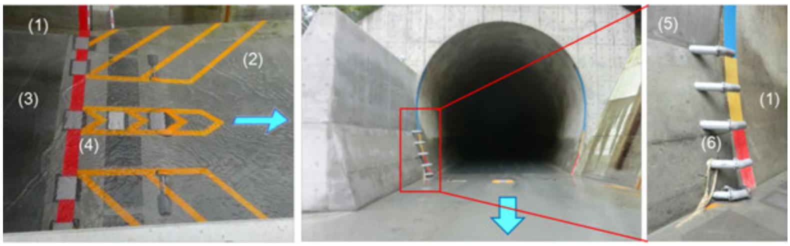


Fig. 8
Plate type sensors (left) and Water sampling pipes (right)
Capteurs de type plaque (gauche) et tuyaux d'échantillonnage d'eau (à droite)

(1) Tunnel
(2) Outlet channel
(3) Bottom invert
(4) 7 plate type sensors
(5) Training wall
(6) Water sampling pipes

(1) Tunnel
(2) Canal de sortie
(3) Radier inférieur
(4) 7 capteurs de type plaque
(5) Mur d'entrainement
(6) Tubes d'échantillonnage d'eau

Table 5
Sediment transport monitoring methods

Purpose	Monitoring location	Period	Method
SS, particle size distribution, SS density	Inflow (2 locations) Conduit outflow Dam discharge	During floods (hourly)	Surface water sampling and laboratory analysis
	Bypass outflow		Water sampling at different depths and laboratory analysis
Riverbed variation	Dam reservoir	After flood season	3-D survey (laser or narrow multi-beam)
	Diversion lake, Energy dissipator	Before and after bypass operations	
Riverbed material	Sediment weir No. 3 upstream (2 locations)	After flood season and after remarkable riverbed change	Sampling and laboratory testing
	Diversion lake (6 locations) Energy dissipator (2 locations)	Before and after bypass operations	
	Dam downstream (7 locations)	After flood season and after remarkable riverbed change	
Gravel transport	Bypass tunnel outlet	During floods	Plate type sensor

5. TRIAL OPERATIONS AND MONITORING RESULTS

In August 2016 just after completion of the sediment bypass tunnel facility, the bypass flow test up to the maximum 20 m^3/s discharge was carried out for the purpose of examining the measuring method of the sediment transport rate. Trial operations during flood times were also conducted in September 2016, July and October 2017. The maximum discharges from the bypass were about 100 m^3/s on July 4 and 180m^3/s on October 23, 2017.

Fig. 9 shows the result of trial operations in September, 2016. There were two flood peaks which were the maximum bypass discharge rates of 80 m^3/s and 60 m^3/s caused by the typhoon on Sept. 20-21 and the autumn rainy front on Sept. 23, respectively. On Sept. 23, three times of gate opening and closing operation were carried out to confirm the gate system function. Fig. 10 shows the flow conditions of the bypass tunnel inlet and outlet parts. Monitoring data will be reported to the monitoring committee on the Koshibu Dam Sediment Bypass Tunnel and analyzed to improve the bypass operation method.

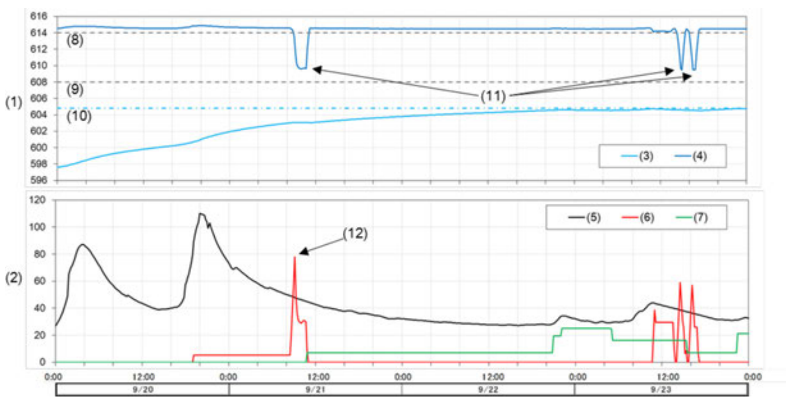


Fig. 9

Hydrographs of trial operation on September 2016

Hydrographies de l'opération d'essai en septembre 2016

(1) Water level (EL.m)
(2) Discharge rate (m^3/s)
(3) Dam Reservoir
(4) Diversion weir upstream water level
(5) Inflow (Dam)
(6) Outflow (Bypass tunnel)
(7) Outflow (Dam conduit)

(1) Niveau d'eau (EL.m)
(2) Taux de décharge (m^3/s)
(3) Réservoir de barrage
(4) Niveau d'eau amont du déversoir de dérivation
(5) Apport (barrage)
(6) Sortie (tunnel de dérivation)
(7) Sortie (canalisation du barrage)

(8) Diversion weir top elevation
(9) Bypass tunnel inlet elevation
(10) Limiting water level in rainy season
(11) Free flow bypass
(12) Bypass outflow at maximum (about 80m^3/s)

(8) Élévation supérieure du déversoir de dérivation
(9) Elévation d'entrée du tunnel de dérivation
(10) Limitation du niveau d'eau en saison pluvieuse
(11) Dérivation en flux libre
(12) Débit de dérivation au maximum (80m^3/s)

Fig. 10
Flow conditions of the bypass inlet (left) and outlet (right)
Condition de débit de l'entrée de dérivation (gauche) et de la sortie (droite)

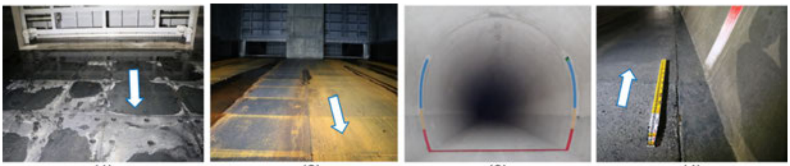
(1) 14:50 Sep. 23, 2016 (about 50m^3/s)
(2) 9:00 Sep. 21, 2016 (about 50m^3/s)

(1) 14:50 23 Sep. 2016 (environ 50m^3/s)
(2) 9:00 21 Sep. 2016 (environ 50m^3/s)

5.1. Results of structural monitoring

It was assumed that one of the challenges was to operate the gate safely without clogging sediment during closing under the coarse sediment transport condition. In order that, the following operation method was proposed: (1) Set the opening of the sub (upstream) gate to about 0.1 m, (2) flush sediment or debris at the main (downstream) gate slot, (3) Close the main gate, and finally, (4) Close the sub gate.

There was no significant abrasion damage to rubber steels and steel lining around the gates (Fig. 11 (1), (2)). In addition, the bottom of the painted belt was fully peeled off, and minor damages around the concrete joint and the mortar on the concrete surface were observed without any other significant damages (Fig.11 (3), (4)).



(1) (2) (3) (4)

Fig. 11
Surface situation around gates and tunnel invert after trial operation
Situation de surface autour des portes et du radier du tunnel après l'opération d'essai

(1) Rubber steel after operation
(2) Steel lining after operation
(3) Tunnel invert before operation
(4) Tunnel invert after operation

(1) Acier en caoutchouc après l'opération
(2) Doublure en acier après l'opération
(3) Radier du tunnel avant l'opération
(4) Radier du tunnel après l'opération

5.2. Results of environmental monitoring

The field survey of the dam downstream river revealed patchy deposition of sand or silt, but did not show any significant changes in attached algae, benthic organisms, fish, or rare land plants (Fig. 12).

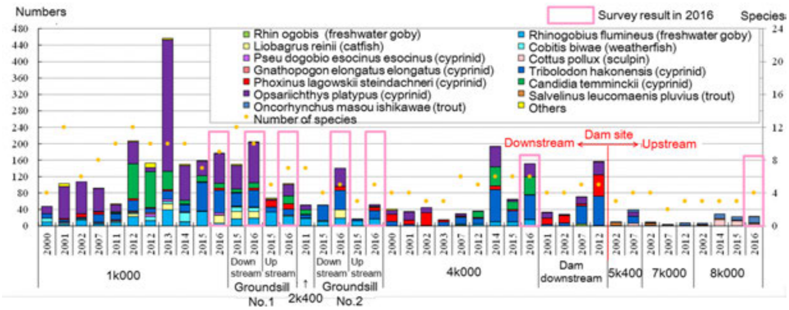


Fig. 12
Fish survey results before and after trial operation
Résultats de l'enquête sur les poissons avant et après l'opération d'essai

5.3. Results of sediment budget monitoring

As a result of examination by combining survey results before and after the trial operation, riverbed material investigation, water sampling analysis during the trial operation and river bed variation model, the sediment volume passed through the sediment bypass tunnel in two operations during September 2016 was estimated about 10,000 m^3.

Fig.13 shows the budget of sediment for each sediment size classification. Because of the erosion of sediment accumulated in the diversion pool, the

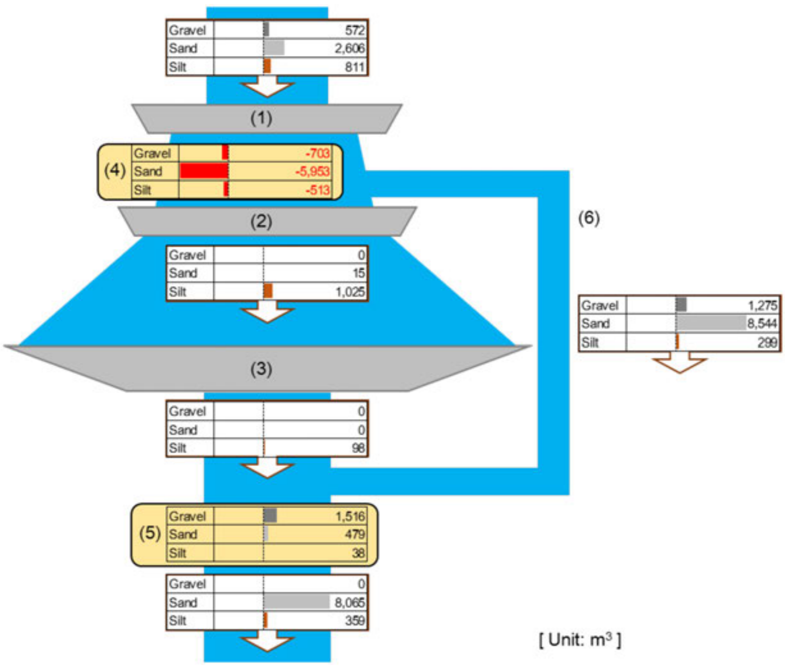


Fig. 13
Sediment budget during the trial operation in September 2016
Budget des sédiments lors de l'opération d'essai en septembre 2016

(1)	Sediment Weir	*(1)*	*Déversoir de sédiments*
(2)	Diversion weir	*(2)*	*Déversoir de dérivation*
(3)	The Koshibu dam	*(3)*	*Barrage de Koshibu*
(4)	Diversion pool deposition	*(4)*	*Dépôt du Bassin de dérivation*
(5)	Energy dissipator deposition	*(5)*	*Dépôt de dissipateur d'énergie*
(6)	Sediment bypass tunnel	*(6)*	*Tunnel de dérivation des sédiments*

sediment volume more than the inflow amount was bypassed through the tunnel. Moreover, as compared with the annual average sediment budget plan of Fig. 5, bypassed sediment volume was quantitatively small since the flood scale and the bypass operation time were small.

From the observation results by the plate type sensor during the test discharge and trial operation, it was confirmed that a large amount of gravels of about 10 mm or more will start to flow down when the bypass inlet part becomes a free flow (open channel flow) condition. Other interesting point was that the gravel tends to flow downward toward the inner side of the tunnel curvature (on the right bank side) [4], [5].

6. CONCLUSION

The bypass tunnel of the Koshibu dam was completed in 2016 and several trial discharge operations have been carried out. Compared with the planned maximum bypass discharge 370 m^3/s, the trial discharge was a small scale less than 100 m^3/s and comparatively short time.

Even though the limited conditions, as a result of monitoring, it was confirmed that there was no problem in gate operation, and no significant abrasion damage and environmental changes in the downstream river were observed. Moreover, it was able to estimate the sediment budget and sediment transport characteristics during bypass operations. Regarding abrasion damages, long-term monitoring is needed since the flow rate and operation time in the trial discharge was limited.

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