Q. 100 – R. 25

COMMISSION INTERNATIONALE
DES GRANDES BARRAGES

VINGT SIXIÈME CONGRÈS
DES GRANDS BARRAGES
Vienne, Juillet 2018

RESEARCH ON SEDIMENT SLUICING OPERATIONS THROUGH DAM DISCHARGE OPERATIONS IN CONSIDERATION OF UPSTREAM/ DOWNSTREAM RIVERBED CHARACTERISTICS*

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JAPAN

SUMMARY

Sediment environment changes due to sedimentation in a dam reservoir not only cause changes within the reservoir but also affect a wide range of the dam's upstream/downstream. Sedimentation in a dam reservoir greatly changes the upstream/downstream riverbed environment, with effects such as increasing the flood level in the upstream area, armor coating and degradation of riverbed of the downstream riverbed, and even coastal retreat. Due to this, the importance of comprehensive sedimentation management, which includes not only sedimentation measures targeting the environments within the dam reservoir but also sediment flushing and sediment sluicing (hereinafter referred to as "sluicing") measures comprehensive sediment management, has been increasing. Sedimentation sluicing measures, which are comprehensive sediment management, have often been implemented.

* *Recherche sur les opérations d'évacuation des sédiments par le biais de déversements du barrage tenant compte des caractéristiques du lit du cours d'eau en amont et en aval*

In this paper, the authors analyze data obtained from hydraulic model experiments and results of numerical analyses regarding measures against riverbed erosion in areas downstream the Funagira Dam, and discuss sediment flushing and sluicing techniques based on dam discharge operations taking the riverbed characteristics upstream and downstream the dam into account.

The results obtained indicate that it is possible to estimate the amount of sediment outflow from the average riverbed level upstream the dam reservoir and the flood volume; to forecast changes in the flow downstream the dam from the estimated amount of sediment outflow and the average riverbed level downstream the dam; and to maintain and control the flow. On the basis of the numerical analysis results, the authors also propose adequate gate operations and discharge level operations to control dam sedimentation and sluicing as well as the flow downstream the dam.

Keywords: Dam Operation, Flood Control, Funagira Dam, Gated Dam, Hydraulic Model Test, Mathematical Model, River Bed Erosion, Sedimentation, Shear Stress.

RÉSUMÉ

Les évolutions de l'environnement relatif à la sédimentation dans la retenue ont des effets non seulement sur le lac lui-même, mais également sur une vaste zone en amont et en aval du barrage. La sédimentation dans la retenue cause des changements importants sur l'environnement du lit du cours d'eau en amont et en aval, notamment la hausse du niveau des inondations en amont, le durcissement (armor coating) et l'abaissement du lit de la rivière en aval et même l'érosion des zones côtières. C'est pourquoi, il est de plus en plus important d'adopter une gestion globale en matière de sédiments, qui porte non seulement sur les mesures relatives à la sédimentation dans le lac de retenue, mais aussi sur des mesures d'évacuation des sédiments qui tiennent compte de l'environnement en amont et en aval. On constate ainsi une fréquence croissante des mesures d'évacuation des sédiments qui prennent en compte ces conditions.

Dans cet article, nous avons analysé les données des tests réalisés à l'aide d'une maquette hydraulique relatifs aux mesures contre l'érosion du lit du cours d'eau en aval du barrage de Funagira ainsi que les résultats de l'analyse numérique, afin d'envisager des techniques d'évacuation des sédiments par le biais d'opérations de déversement prenant en compte les caractéristiques du lit du cours d'eau en aval du barrage.

Nous avons confirmé qu'il était possible d'estimer le volume de sédiments évacués en se basant sur le niveau moyen du lit du cours d'eau en amont du lac de retenue et le volume de la crue, ainsi que de prévoir les changements de

l'écoulement en aval du barrage, ainsi que de gérer cet écoulement en fonction du volume de sédiments évacués et du niveau moyen du lit du cours d'eau en aval du barrage. En outre, les résultats de l'analyse chiffrée nous permettront d'émettre des propositions concernant les méthodes d'exploitation des vannes et de niveau de déversement adaptées au contrôle de la sédimentation dans le lac de retenue, de l'évacuation des sédiments du barrage et de l'écoulement en aval du barrage.

1. INTRODUCTION

Sediment environment changes due to sedimentation in a dam reservoir not only cause changes within the reservoir but also affect a wide range of the dam's upstream/downstream. Sedimentation in a dam reservoir greatly changes the upstream/downstream riverbed environment, with effects such as increasing the flood level in the upstream area, armor coating and degradation of riverbed of the downstream riverbed, and even coastal retreat. As a result, the importance of comprehensive sedimentation management, which includes not only sedimentation measures targeting the environments within the dam reservoir but also sediment flushing and sediment sluicing (hereinafter referred to as "sluicing") measures targeting the dam's upstream/downstream environments, has been increasing. Sedimentation sluicing measures, which are comprehensive sediment management, have often been implemented.

However, the effects of these measures differ depending on the riverbed characteristics, such as the river shape and sedimentation condition, and even the flood volume, dam discharge level, and gate operation method.

In this paper, we would like to report the results of our considerations on the sluicing technology using dam discharge operations, based on the 3-dimensional hydraulic model experiment on Funagira dam reproducing the dam's shifting bed in the upstream/downstream as well as the results obtained from the numerical analysis on riverbed fluctuations.

2. DAM'S SEDIMENTATION MEASURES AND ISSUES

2.1. Sedimentation measures within the dam reservoir

A dam reservoir accumulates sediment, which flows in over the course of many years. Although dam plans are formulated in anticipation of such deposition, some dams, in which the sedimentation has progressed beyond anticipation, require sedimentation measures. Sedimentation measures within reservoirs include methods to control the inflow of sediment (sediment trap dam/excavation), methods to flush the sediment (sediment flushing bypass, density current flushing, sluicing, and sediment flushing), and removal (dredging) of deposited sediment. There are a number of methods (Fig. 1) to countermeasure dam sedimentation, depending on the characteristics of the sediment that flows into the reservoir, characteristics of the dam, etc. [1].

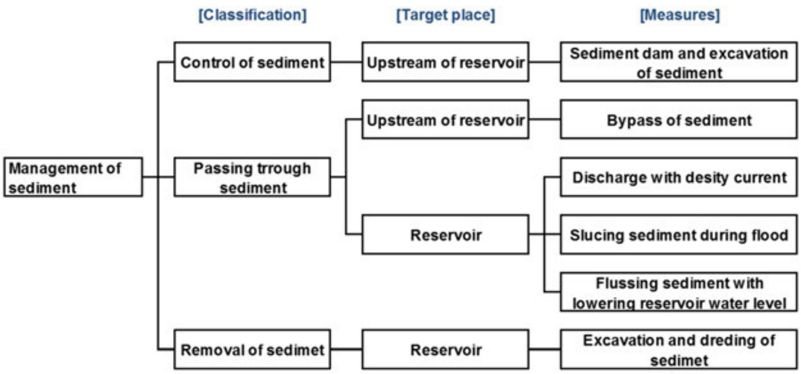

Fig. 1
Countermeasure against sedimentation of dam reservoirs
Principales mesures contre la sédimentation du lac de retenues

For low weir-type dams, some extremely effective methods include the method to flush the deposited sediment by lowering the water storage level at the time of floods as well as the sluicing method, in which the water storage level is kept low during the flood season when there is more sediment inflow in order to allow the incoming sediment to pass through.

2.2. Issues with sedimentation measures through sluicing

Many dams at the downmost-stream of the basin possess spillway gates through the entire width. In such dams, you can control the flushing volume of sediment within the reservoir to the downstream by changing the discharge gate operation sequence or changing the drawdown prior to the outflow. On the other hand, the riverbed shapes and flow conditions can be significantly changed on the downstream side of the dam due to sediment flushing, depending on the downstream sediment volume. This directly affects the river environment downstream of the dam. Especially on the dam's immediate downstream side, the flood flow must be safely and smoothly guided to the downstream river. Sophisticated sluicing technologies are required so that they don't cause drifting or affect river facilities through local sedimentation or erosion.

Sluicing technologies that integrally target dams' upstream/downstream become more complicated, depending on the river shape, sedimentation condition, riverbed characteristics as well as the difference of dam discharge operations, such as flood volume, dam discharge level, and gate discharge method. In terms of comprehensive sediment management, demands are increasing for the improvement of sluicing technologies that can efficiently perform erosion/slucing within the reservoir and supplying of the sedimentation to the downstream river.

3. CHARACTERISTICS OF THE DAM RESERVOIR UNDER CONSIDERATION

3.1. DAM PROFILE AND RIVER MORPHOLOGICAL CONDITION

Funagira dam is located approximately 30km from the river mouth of the Class A River Tenryu River in the Tenryu River system where it flows from the mountainous area out to the plain. It is a concrete gravity dam with the height of 24.50m and the crest length of 220.00m. Funagira dam is jointly owned by the Ministry of Agriculture, Forestry and Fisheries, Shizuoka Prefecture, and Electric Power Development Co., Ltd. with the aim of being utilized for power generation, agriculture, waterworks, and industrial water. More facts of Funagira dam are shown in Table 1.

Table 1
Profile of Funagira dam

Start of Construction	Nov.1972.	High water level		EL.57.00 m
Commission	Apr.1977	Low water level		EL.54.80 m
Type of dam	Concrete gravity type	Preliminary discharge level		EL.50.60 m
Height of dam	24.50 m	Spillway gate		9 roller gates
Length of dam	220.0 m	Design flood discharge		11,130 m^3/s
Volume of dam	54,000 m^3	Generation	Turbine discharge	270m^3/s
Catchment area	4,895 km^2		Maximum output	32,000 kW

The river curves to the right at the dam location toward downstream. As the flood volume increases, the difference in the water level between the right and left increases, generating secondary currents in the dam axis direction. It has a characteristic of generating a current in the direction of the left bank near the water surface and another current in the direction of the right bank near the riverbed [2]. Fig. 2 shows the river shape near the dam.

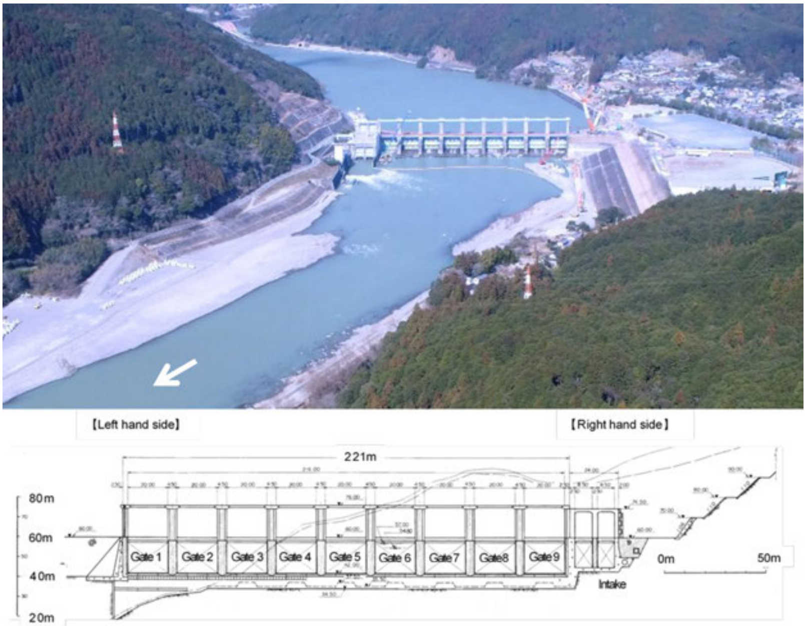

Fig. 2
Whole view of Funagira dam
Vue d'ensemble du barrage de Funagira

3.2. Sedimentation of the reservoir and riverbed characteristics

Changes in the riverbed upstream of Funagira dam are as shown in Fig. 3. Despite some fluctuations upstream of the dam, the riverbed responds to floods each year and is considered to be dynamically stable. The riverbed on the downstream side of the dam displays time-based drawdown, and the river level on the downstream side of the dam is observed to be lower than the time of dam completion. In terms of the riverbed material on the downstream side of the dam, the largest grain size is approximately 300mm, and 50% of the grain is approximately 30mm to 100mm. The grain sizes are almost the same in the dam regulating reservoir and upstream.

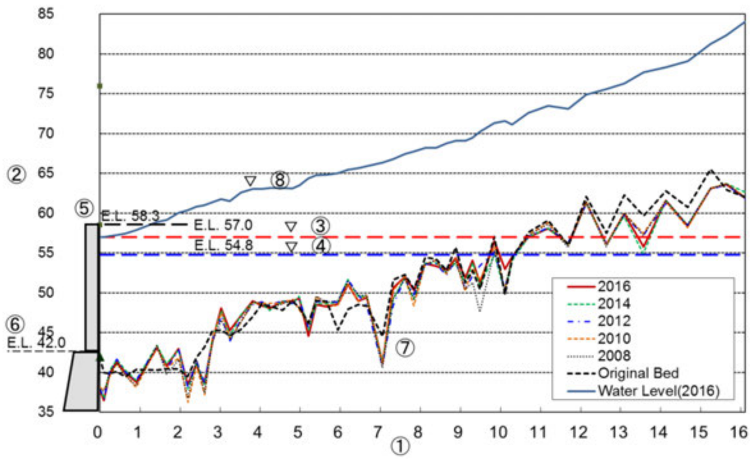

Fig. 3

Annual change of the mean riverbed level at Funagira dam upstream

Variations annuelles du niveau niveau moyen du lit de la rivière en amont du barrage de Funagira

1	Distance from upstream end of dam (10^3m)	*1*	*Distance jusqu'au point le plus en amont du barrage (10^3m)*
2	Altitude (m)	*2*	*Altitude (m)*
3	HWL: EL.57.00 m	*3*	*Niveau maximum: EL.57.0m*
4	LWL: EL.54.80 m	*4*	*Niveau d'eau bas: EL.54.8m*
5	Height of dam top: EL.58.50 m	*5*	*Hauteur au sommet du barrage: EL.58.50 m*
6	Overflow height: EL.42.00 m	*6*	*Hauteur de débordement: EL.42.00 m*
7	Mean river bed level (m)	*7*	*Niveau moyen du lit de la rivière (m)*
8	Flood water level (m)	*8*	*Niveau d'eau des inondations (m)*

3.3. Flood characteristics and the current gate discharge method

The approximate results of discharges due to floods at the Funagira dam position are as follows:

- Approximate number of days with discharges: 90/year
- Number of discharges: 10/year
- Maximum discharge volume in the past: 8,712m^3/s
- Classification of flood scale according to flood volume: 1,000 - 2,000m^3/s (55%), 2,001 - 4,000m^3/s (31%), 4,001 - 6,000m^3/s (9%), 6,001m^3/s and above (4%)

The current gate discharging method is as shown in Fig. 4. The reserve discharge level is 50.6m high, and this level is maintained up to 8,000m^3/s through gate discharges (orifice discharges). When the flood volume further increases, the gate is fully opened, resulting in free flow. In addition, the sluicing volume starts to increase at around 5,000m^3/s. The spillway gates are specified to be opened in the order of gate number 6, 7, 5, 8, 4, 9, 3, 2, 1, and the opening per gate is 0.50cm (50m^3/s).

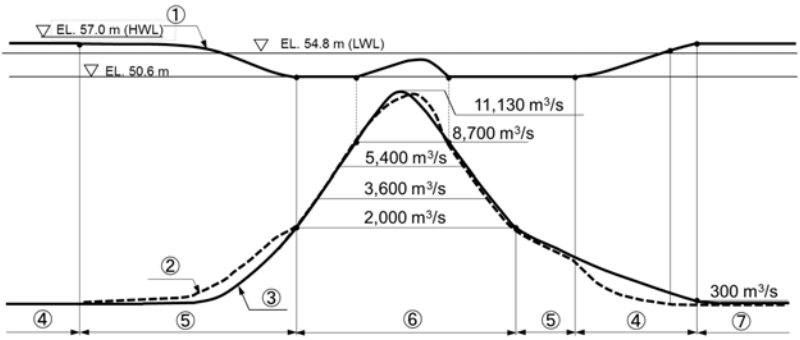

Fig. 4
Discharge operation of Funagira dam
Opérations de déversement par ouverture des vannes du barrage de Funagira

1	Water level of reservoir (m)	*1*	*Distance jusqu'au point le plus en amont du barrage (m)*
2	Discharge flow (m^3/s)	*2*	*Volume déversé (m^3/s)*
3	Inflow (m^3/s)	*3*	*Apports d'eau (m^3/s)*
4	Preliminary warning duration	*4*	*En cas d'avertissement préliminaire*
5	Flood-warning duration	*5*	*En cas d'avertissement contre une inondation*
6	Flood duration	*6*	*En cas d'inondation*
7	Normal duration	*7*	*En temps normal*

4. SLUICING EFFECT EVALUATION BASED ON HYDRAULIC MODEL EXPERIMENT

4.1. THE HYDRAULIC MODEL AND EXPERIMENT DESCRIPTION

The riverbed shape and flow condition downstream of the dam are largely affected by sluicing volume differences. We performed an experiment on the impact on the downstream riverbed, hydraulic jump positions, and average downstream riverbed level changes caused by sluicing volume changes with a 1/50-scale 3-dimensional hydraulic model (Fig. 5) by using the shifting bed in the 1.5km range upstream/downstream of the dam, including the dam [3]. Table 2 shows the experiment case.

Fig. 5
View of 3 dimensional hydraulic model
Vue d’ensemble tri-dimensionnelle de la maquette hydraulique

Table 2
Condition of experimental tests

<table>
<tr><th></th><th>Flood (m^3/s)</th><th>Dam W.L.(m)</th><th>Initial river bed condition in the model</th><th>Sediment supply</th></tr>
<tr><td>1</td><td>1,800
3,600
5,400
8,700
11,130</td><td rowspan="3">Gate flow
50.6 m

Free flow after
8,000 m^3/s</td><td rowspan="3">Reservoir:
2012-2014

In front of dam:
2015-2017

Downstream:
2013, 2014</td><td>Sediment supply was adapted by latest upstream reservoir bed level.</td></tr>
<tr><td>2</td><td>3,600
5,400</td><td>Sediment supply was controlled by upstream reservoir bed level.</td></tr>
<tr><td>3</td><td>8,700
11,130</td><td>Without sediment supply: Upstream reservoir bed was sat by lowering the bed level.</td></tr>
</table>

4.2. Sluicing volume and the impact on the dam's downstream riverbed

We performed an experiment on the impact on the dam's downstream riverbed caused by the sluicing volume that passes the dam by changing the riverbed level and flood volume upstream of the dam. As a result, we observed that sediment started to deposit from the right bank side in the dam's downstream as the sluicing volume increased, which gradually spread to the left bank side (Fig. 6). This phenomenon is prominent when the dam's upstream riverbed level is high and the flood volume exceeds 8,000m^3/s, fully opening the gate which results in free flow. This phenomenon is caused by the sedimentation on the right bank side downstream of the dam caused by the flow of the vertical secondary current formed by the horizontal alignment of the dam's upstream/downstream river curving. Furthermore, the flood flow is deviated to the left bank side due to the sedimentation on the right bank side, resulting in flow channel-type scouring on the left bank side.

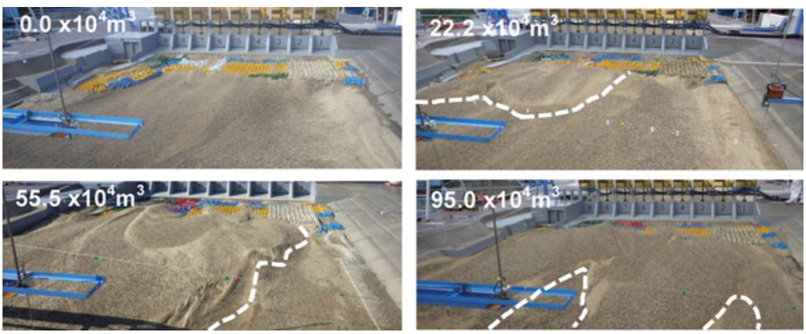

Fig. 6
Change of downstream riverbed level caused by a change of sluicing volume (after design flood discharge 11,130m^3/s)
Variations du niveau du lit du cours d'eau en aval causé par un changement du volume d'eau en amont (afteraprès la découverte des inondations 11,130m^3/s)

4.3. Energy dissipating effect at the time of sluicing

In the experiment with large sluicing volume, we observed a phenomenon in which the gate discharge water's energy dissipation greatly changed during as the flood declined after the flood peak. When the sluicing volume was small, during which time the flood volume increased, the flood flow was attenuated by the stable hydraulic jump immediately downstream of the dam (stilling basin type). When the sluicing volume increased along with the increase of the flood volume, a large volume of sediment deposited immediately downstream of the dam, resulting in hydraulic jump energy dissipation changes. Especially in the phase in which sluicing decreased during the flood decline phase, the hydraulic jump positions occurred over the sediment, which had deposited on the right bank side downstream, resulting in unstable conditions.

In the hydraulic model experiment using the design flood volume of 11,130m^3/s, the hydraulic jump positions shifted upstream/downstream at 3,600m^3/s during the flood decline phase, demonstrating a phenomenon in which the energy dissipation effect is weakened and high flow rate is generated (Fig. 7). Based on the experiment, attention must be paid to changes in the energy dissipation effect downstream of the dam during the flood decline phase if the sluicing volume is to be increased.

Fig. 7
Change in hydraulic jump on flood reduction (at 3,600m^3/s)
Variations du ressaut hydraulique en cas de baisse du niveau d'eau après une Inondation (à 3,600m^3/s)

4.4. Sluicing volume and the average bed level in the dam' reservoir

In the experiment with large sluicing volume, we observed a phenomenon in which the gate discharge water's energy dissipation greatly changed during the flood decline phase after the flood peak. When the sluicing volume was small, during which time the flood volume increased, the flood flow was attenuated by the stable hydraulic jump immediately downstream of the dam (stilling basin type). When the sluicing volume increased along with the increase of the flood volume, a large volume of sediment deposited immediately downstream of the dam, resulting in hydraulic jump energy dissipation changes. Especially in the phase in which sluicing decreased during the flood decline phase, the hydraulic jump positions occurred over the sediment, which had deposited on the right bank side downstream, resulting in unstable. As shown in 4.2, the dam's downstream environment changes due to sedimentation and flow condition changes caused by the deposition, depending on the sluicing volume fluctuations. Due to this, attention must be paid to the impact on the dam's downstream environment, such as local scouring, stability of downstream banks, etc. The sluicing volume also increased in the experiment, and local scouring and damage to the banks, etc. were observed when the riverbed rose. Fig. 8 shows the impact level on the dam's downstream environment in relation to the flood volume, sluicing volume, and the average riverbed downstream of the dam (150m across). According to this figure, the average riverbed level changes downstream of the dam can be utilized as the maintenance/management standard for the dam's downstream environment [4].

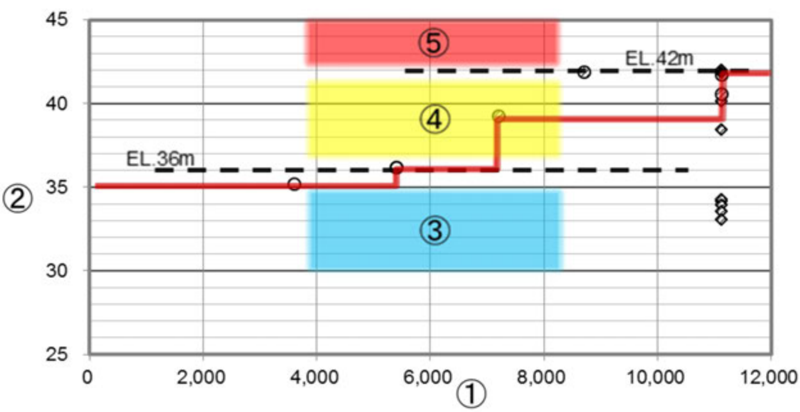

Fig. 8
Change of mean riverbed level caused by a change of discharge volume at 150m downstream from dam axis
Variations du niveau moyen du lit du cours d'eau causées par un déversement à 150 m en aval dans l'axe du barrage

1	Discharge volume (m^3/s)	*1*	*Volume déversé (m^3/s)*
2	Mean riverbed level after flooding at 150m downstream of dam axis (m)	*2*	*Niveau moyen du lit du cours d'eau après un déversement à 150m en aval dans l'axe du (m) barrage*
3	Level 1 (Regular control level) < EL.36.0m	*3*	*Niveau 1 (niveau de contrôle normal) < EL.36.0m*
4	Level 2 (Caution level) < EL.42.0m	*4*	*Niveau 2 (niveau nécessitant un contrôle vigilant) < EL.42.0m*
5	Level 3 (Warning level) > EL.42.0m	*5*	*Niveau 3 (niveau d'alerte) > EL.42.0m*

In addition, the relationship between the flood volume, the average riverbed in the 1.5km range directly upstream of the dam prior to the experiment, and the sluicing volume is shown in Fig. 9. The sluicing volume was calculated based on the changes of the dam's upstream riverbed before and after the experiment. Based on the experiment result, we were able to organize the relationship between the 4 types of flood volume, average riverbed upstream of the dam (1.5km range), and the sluicing volume. According to this figure, we can predict the sluicing volume for each flood volume due to the increase in the average riverbed upstream of the dam, namely the dam reservoir's sedimentation. This figure also shows that sediment slucing starts at approximately 5,000m^3/s if the average riverbed height is 46m.

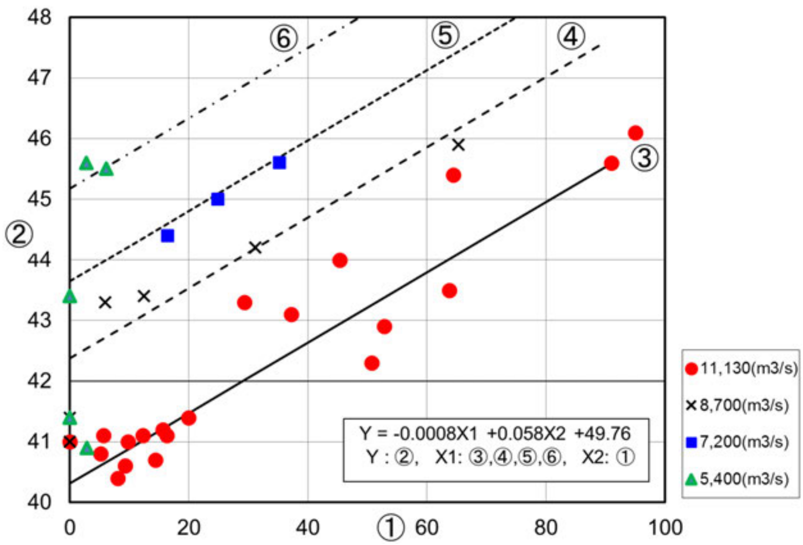

Fig. 9
Relation of sluicing sediment volume and mean riverbed level at upstream dam
Logo Autriche Relation entre le volume de sédiments évacués et le niveau du lit du cours d'eau en amont

1	Volume of sluicing sediment (10^{4}m^3/s)	*1*	*Volume de sédiments évacués (10^{4}m^3/s)*
2	Elevation of the average bed level of the river upstream of the dam (m)	*2*	*Élévation du niveau moyen du lit du cours d'eau en amont du barrage (m)*
3	11,130 flood (m^3/s)	*3*	*Volume de l'inondation: 11,130 (m^3/s)*
4	8,700 flood (m^3/s)	*4*	*Volume de l'inondation: 8,700 (m^3/s)*
5	7,200 flood (m^3/s)	*5*	*Volume de l'inondation: 7,200 (m^3/s)*
6	5,400 flood (m^3/s)	*6*	*Volume de l'inondation: 5,400 (m^3/s)*

5. SLUICING EFFECT EVALUATION THROUGH NUMERICAL ANALYSIS

5.1. CONTENTS OF THE NUMERICAL ANALYSIS

One effective sedimentation measure is the sluicing in which the sedimentation within the reservoir is moved through the dam by using the flow force and supplied to the downstream river. To increase the sluicing volume from the dam, the bed shear stress must be increased. Due to this, the water level is reduced lower than the normal water storage level. Furthermore, the bed shear stress changes as the flood volume and sediment volume change. As a result, we analytically considered the sluicing volume, changes to bed shear stress upstream/downstream of the dam, and changes in the riverbed fluctuations upstream/downstream of the dam in response to dam discharge level and gate operation method changes by using the Delft3D, which is the modeling software to investigate hydrodynamics, sediment transport and morphology for fluvial of reservoirs and rivers, and developed by the Deltares institute in the Netherlands [5].

5.2. SLUICING VOLUME DUE TO THE DISCHARGE WATER LEVEL REDUCTION

Funagira dam operates at the reserve discharge level (50.6m high), which is lower than the normal level, during floods. We analyzed the sluicing effect due to the reduction of water level with floods between 1,000m^3/s and 3,000m^3/s, which occur more often. We used 3 levels, including the reserve discharge level (50.6m high), 48.5m (approximately 2m lower), and 47.0m (3.5m lower) through flood processing.

Fig. 10 shows the results of 3-dimensional riverbed fluctuation analysis on the erosion/sedimentation volume within the reservoir due to reduction of water level and the sluicing volume for the downstream of the dam. In this figure the erosion/sedimentation volume are shown for each 3 water levels with 1,000m^3/s, 2,000m^3/s and 3,000m^3/s. The erosion/sedimentation volume is shown at reservoir up to 1.5km as blue bar graph, and the same volume at the downstream with 1.5km as gray bar graph. The erosion/sedimentation volume is shown as plus and minus volume in the horizontal axis.

As a result, almost no sluicing effect was seen in the normal operation height of 50.6m in any flood volume. However, the sluicing volume can increase even at 1,000m^3/s - 2,000m^3/s as the level decrease becomes greater. In addition, the sluicing volume is balanced with the erosion/sedimentation volume within the reservoir. However, at 3,000m^3/s, the scoured sedimentation is accumulated within the reservoir without flowing down and cannot be thoroughly sluiced. At 5,000m^3/s, this phenomenon becomes more prominent. In order to balance the erosion/sedimentation volume and the sluicing volume within the reservoir, it must be performed in floods exceeding 5,000m^3/s.

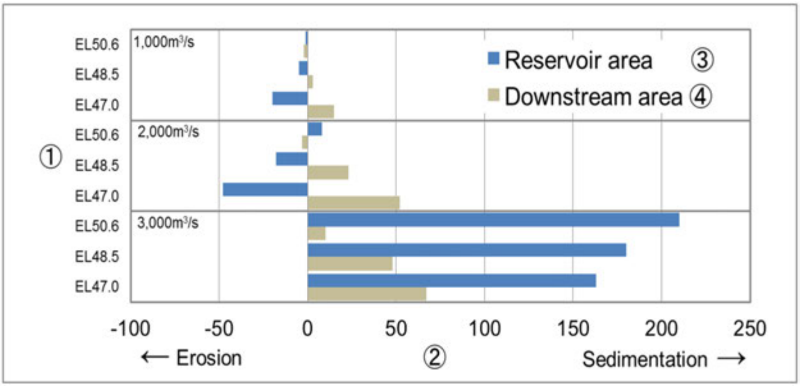

Fig. 10
Different sediment flushing water levels impacts to sediment releases (1,000-3,000m^3/s flood)
Impact des différents niveaux d'eau de rinçage sur l'évacuation des sédiments (1,000-3,000m^3/s volume de l'inondation)

1 Water level operations (m)
2 Volume of sluicing sediment (10^4m^3)
3 Sedimentation and erosion at reservoir
4 Sedimentation and erosion at downstream

1 Opérations relatives au niveau d'eau (m)
2 Quantité de sédiments évacués (10^4m^3)
3 Sédimentation et érosion dans le lac de retenue
4 Sédimentation et érosion en aval

5.3. Changes in the bed shear stress due to reduction of water level and gate operation order changes

We studied the model flood waveform of 3,600m^3/s in order to check the erosion/sedimentation effects upstream of the dam and the sluicing effect toward the downstream of the dam due to the reduction of water level and gate operation changes. The analysis was performed in 3 cases: One was using the normal operation level, one was operation using the reduction of water level at 48.5m, and one was using gate discharges with the focus on the right bank side gates (gates number 6 through 9) after the flood peak at the normal operation level. In addition, discharges were made evenly through all the gates used in these cases with normal operation water level and reduction of water level operation in principle.

Fig. 11 shows the bottom surface bed shear stress upstream of the dam during the decline phase. Although the bed shear stress distribution diagram shows barely any effects of gate operation relative to the right bank side, the bed shear stress upstream of the dam greatly increased due to the reduction of water level, demonstrating the sluicing effect. In this figure the bed shear stress vectors through transverse direction are shown for each cross sections, and the magnitude of bed shear stress is shown with contour lines.

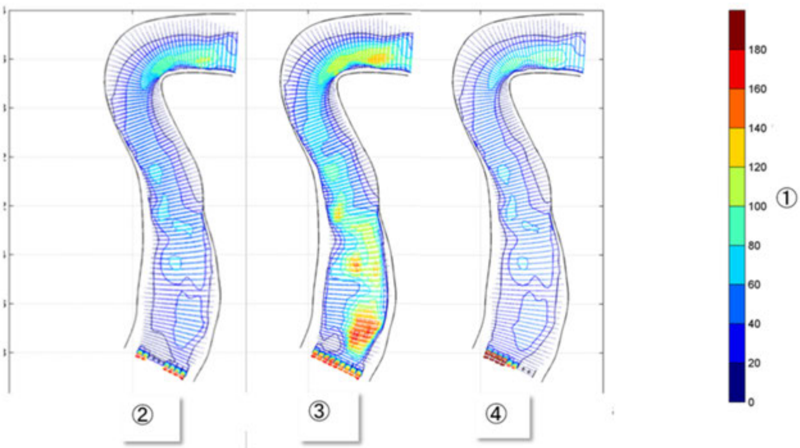

Fig. 11
Bed shear stress map at reservoir after the flood peak (3,600m$^{3/}$s)
Carte de la contrainte de cisaillement sur le fond du lac de retenue après le pic de l'inondation (3,600m^3/s)

1	Bed shear stress magnitude (N/m^2)	*1*	*Magnitude de la contrainte de cisaillement sur le fond (N/m^2)*
2	Operation with normal operation level at 50.6m	*2*	*Fonctionnement au niveau normal à 50.6m*
3	Operation with reduction at 48.5m	*3*	*Fonctionnement avec réduction à 48.5m*
4	Operation with normal operation level (50.6m) and focus on the right bank side gates	*4*	*Fonctionnement au niveau normal (50.5m) avec attention portée sur les vannes de la rive droite*

On the other hand, in the downstream of the dam, the range with great bed shear stress in the case with discharging closer to the right bank side, compared to normal operation, is closer to the dam than that in the case with large reduction of water level (Fig. 12). This change in the discharge method can enhance the sluicing effect on the right bank side in the downstream of the dam.

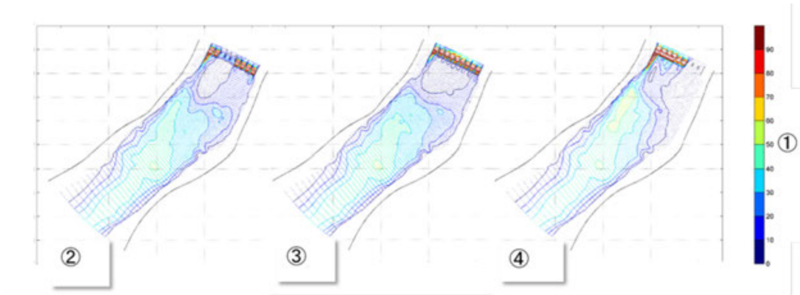

Fig. 12
Bed shear stress maps at downstream of dam after the flood peak (3,600m^3/s)
Carte de la contrainte de cisaillement sur le lit de la rivière en aval du barrage après le pic de l'inondation (3,600m^3/s)

1	Bed shear stress magnitude (N/m^2)	*1*	*Magnitude de la contrainte de cisaillement sur le lit de la rivière (N/m^2)*
2	Operation with normal operation level at 50.6m	*2*	*Fonctionnement au niveau normal à 50.6m*
3	Operation with reduction at 48.5m	*3*	*Fonctionnement avec réduction à 48.5m*
4	Operation with normal operation level and focus on the right bank side gates	*4*	*Fonctionnement au niveau normal avec attention portée sur les vannes de la rive droite*

5.4. DAM'S UPSTREAM/DOWNSTREAM RIVERBED MORPHOLOGY DUE TO GATE OPERATION CHANGES IN MAJOR FLOODS

Furthermore, we performed an analysis on upstream/downstream riverbed fluctuations regarding the discharge method that enhances the erosion/sedimentation/sluicing effects. The analysis was performed on 2 cases, in which discharging was performed under normal operation and with the focus on the right bank side gates after the peak of the flood (in the same manner as the previous paragraph), using the model free flow flood of 8,000m^3/s. The analysis results are as shown in Fig. 13. As a result, greater floods showed greater erosion/sedimentation effects within the reservoir with decreased sedimentation volume and greater sluicing volume. Toward the downstream side of the dam, the case using the right bank side showed a depletion effect due to the erosion/sluicing of the sediment, which is deposited on the right bank side of the dam.

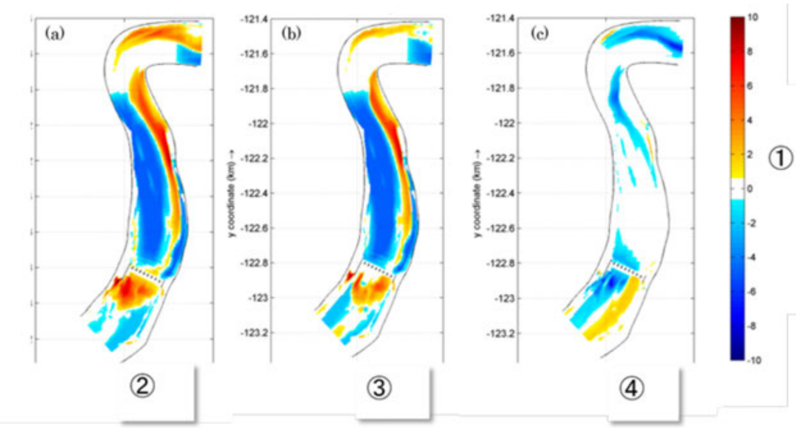

Fig. 13
Total cumulative deposition and erosion map (8,000m^3/s)
Carte des dépôts cumulés totaux et de l'érosion (8,000m^3/s)

1 Erosion (-) and sedimentation (+) (m)
2 Operation with normal operation level at 50.6m and gates
3 Operation with normal operation and focus on the right bank side gates
4 Difference of bed level with two different operations

1 Érosion (-) et sédimentation (+) (m)
2 Fonctionnement au niveau normal à 50,6m
3 Fonctionnement au niveau normal avec attention portée sur les vannes de la rive droite
4 Différence du niveau du lit du cours d'eau selon deux différents fonctionnements

6. CONCLUSION

In this paper, we analyzed the experiment data and numerical analysis results obtained from the hydraulic model experiment on riverbed scouring measures in Funagira dam downstream and reported the technical findings on the sluicing technology using dam discharge operations with considerations to the dam's upstream/downstream riverbed characteristics. The major conclusions are as follows:

(1) In the dam's downstream area where the river shape curves, local deposition of sediment occurs due to increased sluicing volume, resulting in drifting of the flood flow. The hydraulic jump positions also change as the sluicing

volume increases, and unstable phenomena occur especially in the flood decline phase. Attention must be paid to the impact on the dam's downstream environment, such as local scouring and stability of downstream banks.

(2) By using the average riverbed level at a certain length (1.5km, for example) upstream of the dam, we can estimate the sluicing volume corresponding to the flood volume to some extent. Furthermore, we can estimate the average riverbed level downstream of the dam based on the estimated sluicing volume (flood volume), allowing us to maintain/manage the dam's downstream environment.

(3) In small to medium-scale floods, you can greatly increase the dam's sluicing effect from reduction of discharge water level by reducing approximately 2m to 3m from the normal operation level. On the other hand, the erosion/sluicing effects within the reservoir tend to be reduced, resulting in sedimentation within the reservoir.

(4) Effects of changing the gate operation method are not significant in small to medium-scale floods, in terms of the erosion/sluicing effects within the reservoir and the effect of sluicing downstream of the dam. On the other hand, this method is effective for erosion/slicing of deposited sediment downstream of the dam.

(5) In major floods, the method to change the gate operation is effective to slucing the sediment within the reservoir. Furthermore, in the flood's decline phase, you can control the riverbed downstream of the dam by changing the gate operation.

In the future, we must operate the dam based on thorough considerations through hydraulic model experiments and numerical analyses. Moreover, it is important that we perform checks/reviews as we promote the appropriate sluicing method. It is important to evaluate the performance on site after sluicing and to take measures in accordance with the results. The key to solving this issue is to accumulate data.

REFERENCES

[1] ONDA C., SUMI T. Effects of sediment sluicing operation in hydropower dams considering properties of reservoir sedimentation. *Journal of JSCE, Ser. B1, Vol,73, No.4, JSCE*, 2017.

[2] KITAMURA Y., TAKAGI S. Hydraulic study on scouring downstream of Funagaira Dam. *Proceedings of 8th ICSE*, 1981.

[3] KITAMURA Y., TAKAGI S. Study on scouring phenomena at downstream of dam during flood control. *Proceedings of 85th Annual meeting of ICOLD*, 2017.

[4] TAKAGI S., SATO M., KITAMURA Y. Dvelopment of new maintenance program for scouring measures at downstream of dam. *Proceedings of 85th Annual meeting of ICOLD*, 2017.

[5] OMER A., HUISMANS Y., SLOFF K., KITAMURA Y. Optimization of operation to maximize flushing during low flood peak. *Proceedings of 85th Annual meeting of ICOLD*, 2017.