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RETROFITTING AND CHANGE IN OPERATION OF CASCADE DAMS TO FACILITATE SEDIMENT SLUICING IN THE MIMIKAWA RIVER BASIN (*)

Tetsuya SUMI
Disaster Prevention Research Institute, Kyoto University

Takeshi YOSHIMURA and Katsuyuki ASAZAKI
Mimikawa Hydro Power Development Office, Kyushu Electric Power Company

Mutsuhiro KAKU
Engineering Division, Kyushu Electric Power Company

Josuke KASHIWAI
Japan Dam Engineering Center

Takahiro SATO
Central Research Institute of Electric Power Industry

JAPAN

1. INTRODUCTION

The Mimikawa River in the Miyazaki Prefecture, in the southeast of Kyushu, Japan, is flowing into the Pacific Ocean with a length of 94.8km and a watershed area of 884.1km^2. It is one of the largest ‘Class B’ rivers which are operated by prefectural government. Making use of an abundant volume of water and large water head, 7 dams and hydropower stations were developed between the 1920’s and 1960’s as shown in Fig. 1, and currently have a combined generating power of 340 MW, and an output of 900 million kWh, making it one of the most important areas in the Kyushu region for hydropower production.

(*) *Rééquipement et modification d’exploitation de la cascade de barrage pour faciliter la vidange des sédiments dans le bassin de la Mimikawa.*

In September 2005, Typhoon Nabi hit Japan, causing large scale damage in various parts nationwide, including Miyazaki Prefecture. In the Mimikawa River, rainfall and water volume flowing into dams also exceeded their designed dam flood flow discharges.

Flood damage was extensive in the central area of Morotsuka village located on the upstream edge of the Yamasubaru Dam. Moreover, flood damage was amplified by mountain slope failures in approximately 500 locations, large and small, causing a huge amount of sediment and driftwood flow into the river and dam-regulating reservoirs in the Mimikawa River Basin.

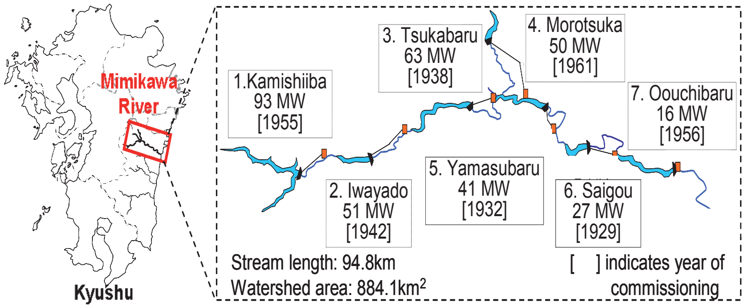

Fig.1
Mimikawa river basin, dam and power plant
Bassin de la rivière Mimikawa, barrages et centrales

In October 2011, Miyazaki Prefecture, the river administrator, compiled the “Mimikawa River Basin Integrated Sediment Flow Management Plan” which is showing the current status of the complex Mimikawa River sediment problems and possible approaches to solve these problems while balancing flood control, water usage and environmental conservation. As part of the Management Plan, the Kyushu Electric Power Company, KEPCO, which is responsible for dam installation is aiming to restore the original sediment flow which has been trapped by dam reservoirs up until now, and has drawn up a plan for sediment sluicing operation at Yamasubaru, Saigou and Oouchibaru Dams.

This paper reports on related matters including the following, 1) the necessity for sediment flow management at dams in the Mimikawa River Basin, 2) the appropriateness of choosing sediment sluicing at dams as a measure to manage sediment flow, 3) numerical simulation carried out with the objective of confirming the effect of sediment sluicing and formulating optimal rules for operation, 4) hydraulic model studies carried out to determine functional characteristics of sediment sluicing operation, 5) details of dam retrofitting work and innovative techniques to prepare for sediment sluicing operation, 6) assessment of environmental impact below dams after commencement of sediment sluicing operation and 7) adoption of auxiliary methods for sediment flow management being carried out in advance of commencement of sediment sluicing operation.

2. NECESSITY FOR SEDIMENT FLOW MANAGEMENT AT DAMS IN THE MIMIKAWA RIVER BASIN

2.1. DAMAGE CAUSED BY TYPHOON NABI

Typhoon Nabi passed slowly northwards over the sea to the west of Kyushu by maintaining its large-scale and strong power. This caused warm moist air to flow for a long period bringing heavy rainfall to mountains in Miyazaki Prefecture that exceeded 1,300mm in total. In the Mimikawa River Basin, inflow discharge exceeded previous the maximum recorded flows. Because of this extreme discharge, power plants at Kamishiiba, Tsukabaru, Yamasubaru and Saigou were flooded rendering power generation impossible, while Tsukabaru, Yamasubaru and Saigou Dams were overtopped and their dam control facilities flooded [1].

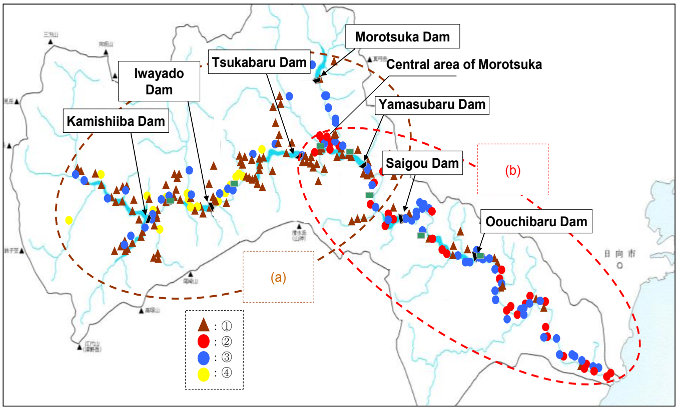

Fig. 2
Damage in the Mimikawa river basin area resulting from the Typhoon Nabi, 2005
Dégâts du typhon Nabi en 2005 dans le bassin de la rivière Mimikawa

(a) Many slope failures in upstream
(b) Extensive flood damage in downstream basin
① Slope failure
② Flood damage in residential buildings
③ Road, embankment damage
④ Other damage to residential buildings (flow of soil and rocks, etc.)

(a) *Nombreux éboulements en amont*
(b) *Dégâts considérables des crues dans le bassin en aval*
① *Éboulement*
② *Inondations dans des bâtiments résidentiels*
③ *Routes et berges endommagées*
④ *Autres dégâts aux bâtiments résidentiels (laves torrentielles, etc)*

Fig.3
Slope failure downstream of the Tsukabaru dam
Éboulement du versant en aval du barrage de Tsukabaru

Fig.4
Flooding in central area of the Morotsuka village
Inondation au centre de Morotsuka

Fig. 2 shows mountain slope failures and flood damage caused over the entire the Mimikawa River watershed. Within the watershed area, mountain slope failures occurred in 491 locations and 424 residential buildings were flooded. The cost of damage sustained over the whole of the Miyazaki Prefecture amounted to 130 billion yen (1.2 billion USD) which was the greatest amount of damage ever recorded for the prefecture. In the Mimikawa River Basin a total of 10.6 million m^3 of sediment flowed into rivers as a result of mountain slope failures, with approximately half of this amount (5.2 million m^3) being deposited in dam-regulating reservoirs. There is concern about an additional 26.4 million m^3 of sediment which is also in danger of flowing into rivers. Fig. 3 shows the largest slope failure which formed a land slide dam. In addition, as shown in Fig. 4, in the central area of Morotsuka located on the upstream edge of the Yamasubaru Dam regulating reservoir, damage caused by flooding was extensive with 70 buildings being flooded, the largest number ever recorded. Over and above the record rainfall, the large quantities of sediment flowing into the Yamasubaru Dam regulating reservoir, which caused rapid aggregation in the vicinity, contributed to further damage.

2.2. APPROACHES TO THE MIMIKAWA RIVER BASIN INTEGRATED SEDIMENT FLOW MANAGEMENT

With the opportunity that arose due to the damage by Typhoon Nabi, Miyazaki Prefecture, the river administrator, established the Mimikawa River Basin Integrated Sediment Flow Management Technical Committee, in which river basin stakeholders participate. Rather than focusing on each problem separately, the prefecture came to a proper understanding of these various sediment-related problems over the entire river basin, including the mountainous areas, dams, the river itself and the coastal areas. And with the aim of restoring the original sediment flow, while balancing flood control, water usage and environmental conservation, formulated a policy to advance integrated sediment flow management [2].

In October 2011, the Mimikawa River Basin Integrated Sediment Flow Management Plan was compiled. The plan established matters such as the work to be carried out and stakeholder roles, with the aim of resolving problems caused by sediment in the basin [3].

2.3. APPROACHES TO SEDIMENT FLOW MANAGEMENT IN DAM-REGULATING RESERVOIRS

KEPCO had repeated discussions with Miyazaki Prefecture, national and academic institutions as well as basin stakeholders, to draw up an action plan regarding reservoir sedimentation problems which had become increasingly serious. As a result, KEPCO formulated an action plan focusing on sediment sluicing operation at Yamasubaru, Saigou and Oouchibaru Dams, with the aim of restoring the original sediment flow which has been trapped by dam reservoirs up until now. Sediment sluicing operation at dams, which is carried out at times of river flooding due to typhoons, is the temporary lowering of reservoir water levels to make the flow of water in dam-regulating reservoirs close to the original, natural state of the river, thereby allowing inflow sediment to be transported below dams (Fig. 5) [2].

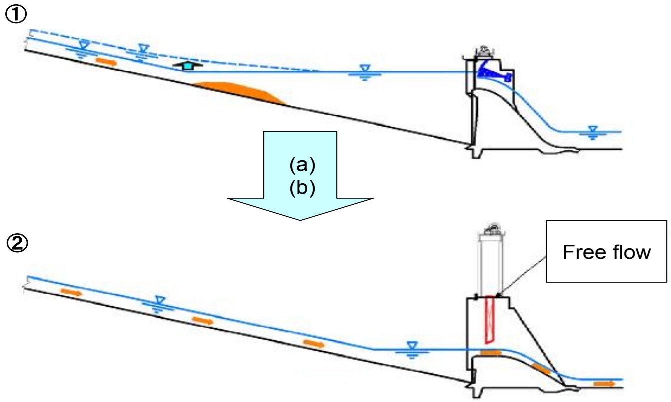

Fig .5
Sediment Sluicing
Vidange de sediments

(a) Dam modification (reservoir water level drawdown)
(b) Sluicing of sediment (early realization of flood control + environmental measures)
① Process of sediment accumulation under current operation
② Sediment sluicing operation

a) *Modification de barrage (niveau de réservoir abaissé)*
(b) *Vidange de sédiments (réalisation rapide de mesures de contrôle des crues et environnementales)*
① *Processus d'accumulation de sédiments avec l'exploitation actuelle*
② *Gestion des vidanges de sédiments*

3. SELECTION OF SEDIMENT FLOW MANAGEMENT MEASURE

In recent years, various countermeasures for sediment flow management policies have been studied. As shown in Fig. 6, it has been proposed that using CAP/MAR (Total capacity/Mean annual runoff) and CAP/MAS (Total capacity/Mean annual inflow sediment) as parameters, sediment measures can be classified, which will assist in selecting an appropriate countermeasure [4]. According to Sumi, with an increase in CAP/MAR (that is, a decrease in dam-regulating reservoir turnover rate), the appropriate sediment measure will vary between: sediment flushing, sediment bypass, sediment sluicing, sediment check dam, excavating and dredging, or no necessity for a sediment measure to be applied. The reason for this is that these various sediment measures depend largely on the amount of water that can be used for sediment management, which in turn depends on the scale of the dam-regulating reservoir.

CAP/MAR and CAP/MAS data for each of the 7 dams in the Mimikawa River Basin is shown in Table 1. According to this, it can be seen that compared to Kamishiiba, Tsukabaru, and other dams upstream, Yamasubaru, Saigou and Oouchi Dams 1) have low CAP/MAS and therefore have a substantial need for sediment measures and 2) dam-regulating reservoir turnover rate is high (CAP/MAR is low), making sediment flushing and sediment sluicing appropriate. Based on this, the retrofitting of dams for sediment sluicing operation was initiated.

Table 1
Reservoir sedimentation of dams in the Mimikawa River Basin

Dam Name	Total Storage Volume CAP (10^3m^3)	Annual Runoff Volume MAR (10^6m^3)	Total Sedimentation Volume (10^3m^3)	Year of Operation	Annual Sedimentation Volume MAS (10^3m^3)	CAP/MAR	CAP/MAS
Kamishiiba	91600	672	12600	58	217.8	0.136	420
Iwayado	8310	876	5560	72	77.2	0.00948	108
Tsukabaru	34300	1071	6890	75	91.8	0.032	374
Morotsuka	3480	151	1060	52	20.3	0.0231	172
Yamasubaru	4190	1410	2590	81	32	0.00297	131
Saigo	2450	1610	1010	84	12	0.00152	204
Ouchibaru	7490	1830	1930	57	33.8	0.00409	222

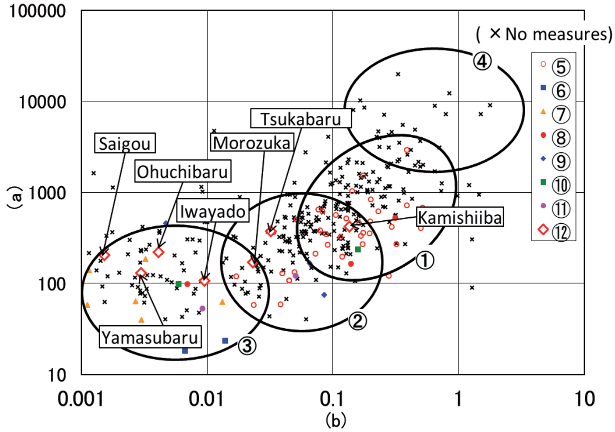

Fig. 6
Selection of sediment management options and dams in the Mimikawa River Basin
Sélection des options de gestion des sédiments et barrages dans le bassin de la rivière Mimikawa

(a) Reservoir Life=CAP/MAS
(b) Capacity-inflow ratio=CAP/MAR
① Sediment check dam
Sediment replenishment
② Sediment bypass, Sluicing
③ Sediment flushing, Sediment scoring gate
④ Impoundment option
⑤ Check dam
⑥ Flushing
⑦ Scoring gate
⑧ Scoring pipe
⑨ Bypassing
⑩ Excavating
⑪ Dredging
⑫ Mimikawa

(a) *Vie d'un réservoir=CAP/MAS*
(b) *rapport capacité/débit entrant = CAP/MAR*
① *Barrage de contrôle*
Remplissage en sédiments
② *Dérivation/vidange de sédiments*
③ *Chasses de sédiment, vanne dégraveur*
④ *Option d'endiguement*
⑤ *Barrage de retenue*
⑥ *Chasses*
⑦ *Vanne dégraveur*
⑧ *Tuyau dégraveur*
⑨ *Dérivation*
⑩ *Excavation*
⑪ *Dragage*
⑫ *Mimikawa*

4. NUMERICAL SIMULATION OF SEDIMENT FLOW

In the study of sediment management measures for dam-regulating reservoirs and river channel sections, as well as optimal rules for operation of sediment measures, it is vital to understand sediment flow in the river basin, which is affected by factors such as the relationship between river flow volume and amount of fluctuation in the river. In order to do this, one-dimensional analysis of riverbed variation was carried out, and the effect of sediment sluicing at dams verified for the approximately 58km stretch of the main river, covering the three dams where sluicing is to be carried out, from the area upstream of the Yamasubaru Dam regulating reservoir down to the river mouth. Table 2 shows investigation conditions for an analysis of a 33 years period. Fig. 7 shows a comparison between riverbed elevation for Yamasubaru Dam after 33 years under current operation (Case 1) and sediment sluicing operation (Case 2). Fig. 8 shows the effect of calculation for annual inflowing and outflowing sediment volume under sediment sluicing operation.

Table 2
Investigation conditions

Investigation conditions			Yamasubaru Dam upstream	Saigou Dam upstream	Oouchibaru Dam upstream	Oouchibaru Dam downstream river
Initial riverbed conditions			Riverbed survey after Typhoon 0514			
River flow rate conditions			Actual flow rates at each dam 1994-2004			
Post-calculation conditions			Calculation until dam-regulating reservoir riverbed stabilization confirmed			
Sediment inflow conditions	First 10 years ($m^3/km^2/year$)		1,092	1,056	791	791
	From year 11 ($m^3/km^2/year$)		606	742	521	521
Water level conditions	Case1	Existing operation case	Reflects dam operation results			
	Case2	Sluicing of sediment case	Using actual flow rates, while flow rate at each dam exceeds $200m^3/s$, calculate water level during sluicing of sediment (all gates free flow)			

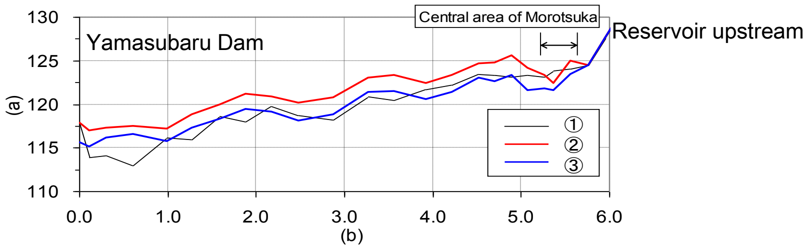

Fig.7
Results of riverbed fluctuation analysis (Yamasubaru Dam)
Résultats des analyses au niveau du lit de fleuve

(a)	Elevation (EL.m)	(a)	*Hauteur (EL.m)*
(b)	Distance from dam (km)	(b)	*Distance du barrage (km)*
①	Initial elevation of riverbed	①	*Hauteur initiale du lit du fleuve*
②	Case1 : Riverbed under continued existing operation	②	*Cas 1 : Lit du fleuve avec continuation de l'exploitation actuelle*
③	Case2 : Riverbed under sediment sluicing operation	③	*Cas 2 : Lit du fleuve en cas de vidange de sédiments*

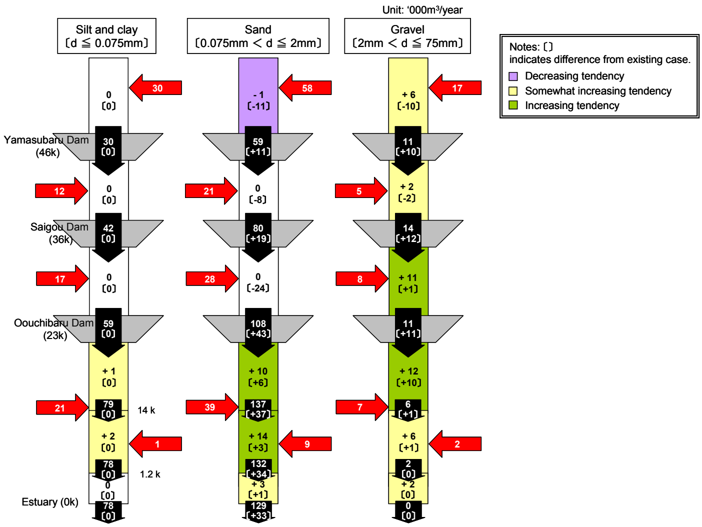

Fig. 8

Results of calculation for inflowing and outflowing sediment volume in Case 2

Résultats des calculs des sédiments entrant et sortant dans le cas 2

As a result, it has been confirmed that if current operations are continued, sediment will continue to be deposited in the reservoirs and aggregation will occur. Whereas if sediment sluicing operation is carried out, sediment upstream of regulating reservoirs will be transported downstream, which will cause riverbed forms upstream of regulating reservoirs to be stabilized at lower than existing levels. In particular, it was confirmed that there would be improvement in the feeding of sediment below dams, which have been accumulated in reservoirs up to now. Therefore, it is expected that this will lead to mitigation of the flood risks associated with rapid aggregation of dam-regulating reservoirs in upstream areas during river flooding. Also, it is expected that it will contribute to creating a healthier river environment, including the ecosystem, by controlling degradation and beach erosion in the dam downstream and in littoral areas, as well as by promoting diversification of riverbed materials. Using the tools mentioned, sediment flow simulations are being conducted under the assumption of various future risks, and specific methods for sediment sluicing at dams is being studied.

5. EXPERIMENTAL INVESTIGATIONS USING HYDRAULIC MODEL

For dam retrofitting to be carried out with the objective of sediment sluicing it is necessary to understand details such as the relationship between the form of a modified dam and sediment sluicing functions. Additionally, changes in the riverbed with time associated with the three-dimensional flow in the area immediately upstream of a dam, which is difficult to represent by numerical simulation, should be clarified. For this reason, a 1:50 scale model that recreated topographical form approximately 1.3 km up- and downstream from dams was used to conduct hydraulic experiments related to sediment sluicing functions for these dams. Fig. 9 shows the plan and cross-sectional views of the model together with a photograph taken while an experiment was in progress.

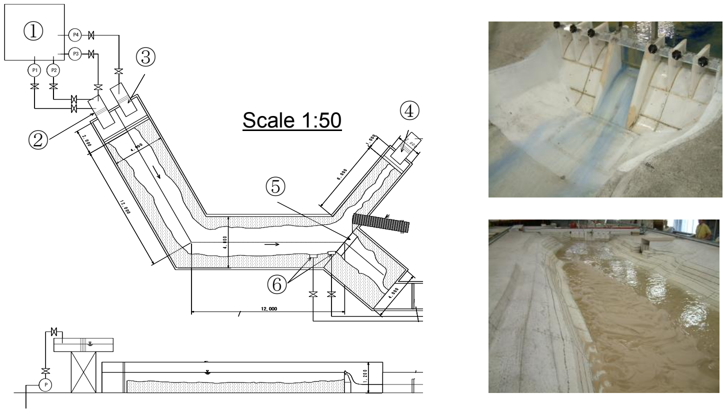

Fig. 9
Plan and cross-sectional views of hydraulic model, and photographs of experiment in progress (Yamasubaru Dam)
Plan et vue en coupe du modèle hydraulique et photos d’expérimentations en cours

①Pit	① *Fosse*
②Suppress weir	② *Déversoir sans contraction latérale*
③Right-angle triangular weir	③ *Déversoir triangulaire*
④Right-angle triangular weir	④ *Déversoir triangulaire*
⑤Dam model radial gates	⑤ *Vannes segments du modèle*
⑥Sluice gates	⑥ *Écluses*

As a result of experiment, it was confirmed that 1) differences in the effect of sediment sluicing depended on the height of the cut in the dam body, 2) when there was a transition in spillway gate flow from orifice flow to free flow and 3) a phenomena occurred in which there was a massive flow of sediment downstream from the area immediately upstream of a dam. Fig.10 shows one example of experimental results. In addition, based on these results and as mentioned later in this paper, it was confirmed that it is necessary to carry out auxiliary sediment management work, for example to remove accumulated sediment in the area immediately upstream of a dam in advance of initial sediment sluicing operation.

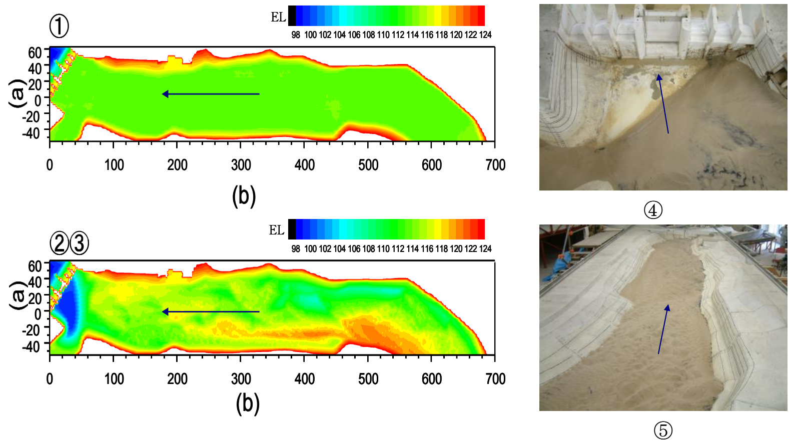

Fig.10
Example results for hydraulic model experiment for Yamasubaru Dam
(Riverbed before and after sediment sluicing)
Exemples des résultats de l'expérimentation sur modèle hydraulique
(lit de la rivière avant et après la vidange des sédiments)

(a) Transverse direction
Distance from reference point (m)
(b) Longitudinal direction
Distance from reference point (m)
① EL.114 Initial form of sand surface before sediment sluicing
② Form of sand surface after sediment sluicing
③ Q=2,000m³/s, with sand feeding
④ Immediately upstream of dam (after sediment sluicing)
⑤ Condition of riverbed upstream of dam (after sediment sluicing)

(a) Direction transversale
Distance du point de référence (m)
(b) *Direction longitudinale*
Distance du point de référence (m)
① *EL.114 Forme initiale de la surface de sable avant la vidange de sédiments*
② *Forme de la surface de sable après la vidange de sédiments*
③ *Q=2 000m³/s, avec alimentation en sable*
④ *Immédiatement en amont du barrage (après la vidange de sédiments)*
⑤ *État du lit de la rivière en amont du barrage (après la vidange de sédiments)*

6. DAM RETROFITTING PLAN AND INNOVATIVE RETROFITTING TECHNIQUES

For Yamasubaru and Saigou Dams, with the existing structure it is not possible to do the necessary drawdown in order to carry out sediment sluicing operation. For this reason, sluicing functions are now being added to these dams by partially cutting down their overflow spillway sections without causing structural damage. It will be the first time in Japan that an existing dam, 80 years after commissioning, will be modified by the addition of a new sluicing function. For Oouchibaru Dam, which is the furthest downstream, dam height is low, and by changing dam operation, sediment sluicing will be possible with the existing structure, so the dam will not be retrofitted.

6.1. FORM OF DAM RETROFITTING

For Yamasubaru Dam, retrofitting will be carried out by removing the existing two central spillway gates, cutting down spillway crest height by approximately 9.3 m, and installing a single large spillway gate. For the form of dam retrofitting chosen, the amount of sediment flow will be comparable to removal of the dam, and it was also confirmed that this method is the optimal measure by which sediment flow management cost will be minimised. For Saigou Dam, removing the four central spillway gates and then cutting down spillway crest height by approximately 4.3 m was confirmed to be the optimal measure. Fig. 11 shows the final appearances of Yamasubaru and Saigou Dams after retrofitting.

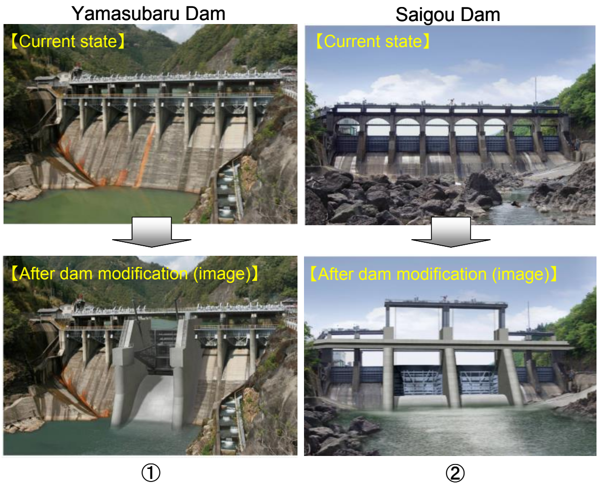

Fig. 11
Dam retrofitting
Modernisation des barrages

① Of the eight existing radial gates, two in the center will be removed, and the overflow section cut down by approx. 9.3m to install one radial gate.

② Of the eight existing roller gates, four in the center will be removed, and the overflow section cut down by approx. 4.3m to install two roller gates.

① *Des huit vannes segments existantes, deux au centre seront éliminées et la crête de déversoir réduite de 9,3m approximativement pour installer une vanne-segment.*

② *Des vannes wagon existantes, quatre au centre seront éliminées et la crête de déversoir réduite de 4,3m approximativement pour installer deux vannes wagon.*

6.2. RETROFITTING WORK PLAN

Dam retrofitting work on Yamasubaru and Saigou Dams was commenced in November 2011. The work is in principle being carried out between November and May, outside the flood season. While work is being carried out, a temporary cofferdam is installed upstream of each dam, and the river diverted through a headrace to allow power generation to be continued. In addition, there is the issue that while retrofitting work is in progress, it is necessary to discharge water from dams safely during flooding, in the same way as up until now. As shown in Fig. 12, to resolve this, a 4 m high steel-rubber gate (SR gate) has been installed in the upper part of the temporary cofferdam, the first instance of such a measure being taken in Japan. Fig. 13 shows the state of progress in work being carried out on Saigou Dam, and the SR gate during current operation. Up to 2014, operations had continued for 2 years, and in that period, the SR gate had been operated for 9 times.

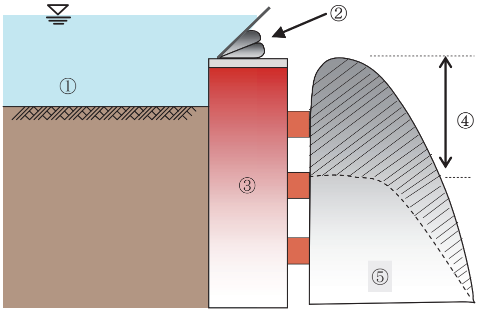

Fig. 12
Temporary cofferdam installed upstream during dam retrofitting work
Bâtardeau provisoire installé en amont pendant les travaux de modernisation

①	River water	①	*Eau de la rivière*
②	SR (Steel-Rubber) gate	②	*Vanne hybride en acier et caoutchouc*
③	Temporary cofferdam	③	*Bâtardeau provisoire*
④	Cut down by approx. 9.3 m (Yamasubaru)	④	*Découpe de 9,3 m approximativement (Yamasubaru)*
⑤	Existing dam	⑤	*Barrage existant*

Fig.13
Coffer dam installed upstream for period of dam retrofitting work (Saigou Dam)
Bâtardeau installé en amont pendant les travaux du barrage de Saigou

7. ASSESSMENT OF ENVIRONMENTAL IMPACT DOWNSTREAM FROM DAMS AFTER COMMENCEMENT OF SEDIMENT SLUICING

It is assumed that in response to the change in the amount of flow of sediment due to sediment sluicing operation at dams, that there will changes in the river environment and it is therefore necessary to make an assessment of the impact. However, there are no specific guidelines to assess the impact of sediment sluicing on the river environment. Therefore, at first it is necessary to implement adaptive management based on an initially adopted plan that is subject to review while monitoring is carried out, during which time a new plan for an assessment method appropriate to the characteristics of sediment sluicing at dams on the Mimikawa River will drawn up.

When drawing up a plan for assessment methods, it is important to appropriately set both the impact of sediment sluicing at dams, and the response. The setting for impact is based on calculated fluctuations in sediment flow, using a one-dimensional analysis of riverbed variation. The setting for the assumed response has been made based on the setting for impact. The monitoring to be used in assessing the impact of sluicing sediment has been carried out continuously for the river since 2007, and for coastal areas since 2009, and covers items needed to assess the assumed response. An assessment of the impact of sediment sluicing operation at dams will be made by making comparisons before and after sluicing, as well as by making comparisons between impact and control areas.

8. ADOPTION AUXILIARY METHODS BEING CARRIED OUT IN ADVANCE OF SEDIMENT FLOW MANAGEMENT

In the transition to dam sediment flow operation, after completion of dam retrofitting work, proper consideration must be given to flood control and sudden changes in the river environment. As a measure to deal with this, after appropriately assessing factors such as future riverbed form and riverbed grain size within dam-regulating reservoirs through model experiments and numerical simulations, relocation of existing accumulated sediment in reservoirs will be carried out as shown in Fig. 14, in parallel with dam retrofitting work.

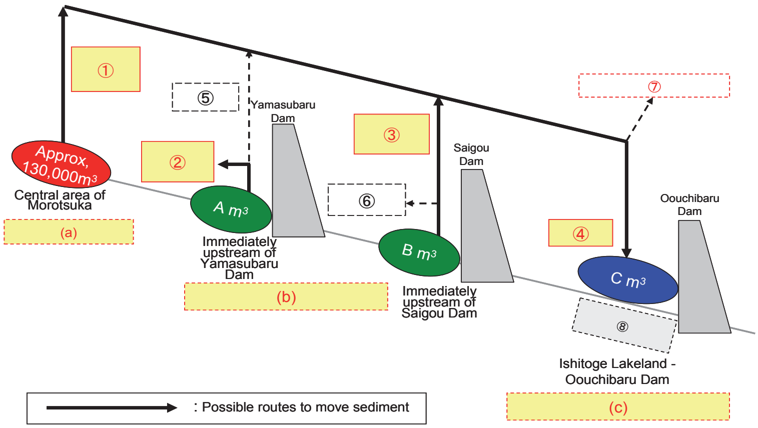

Fig. 14
Sediment relocation plan in dam-regulating reservoirs
Plan de délocalisation des sédiments dans les réservoirs de régulation

(a) Condition 1: Early demonstration of flood control effect
(b) Condition 2: Preventing flow of existing sediment at early stage of sediment sluicing (measure for localized scouring)
(c) Condition 3: Preventing flow of existing sediment at early stage of sediment sluicing (measure for resuspension of silty sediment)

① Move outside reservoir
② Move within reservoir
③ Move outside reservoir
④ Cover sand
⑤ Move outside reservoir
⑥ Move within reservoir
⑦ Other effective uses, damping at disposal sites
⑧ Silty sediment accumulation

(a) *Condition 1: Démonstration rapide de l'effet de contrôle des crues*
(b) *Condition 2: Empêcher l'écoulement de sédiments existants aux premiers stades de vidange de sédiments (contre l'affouillement localisé)*
(c) *Condition 3: Empêcher l'écoulement de sédiments existants aux premiers stades de vidange de sédiment (mesure contre la remise en suspension de sédiments limoneux)*

① *Déplacement hors du réservoir*
② *Déplacement dans le réservoir*
③ *Déplacement hors du réservoir*
④ *Sable de couverture*
⑤ *Déplacement hors du réservoir*
⑥ *Déplacement dans le réservoir*
⑦ *Autre usages effectifs, dépôt dans des sites dédiés*
⑧ *Accumulation de sédiments limoneux*

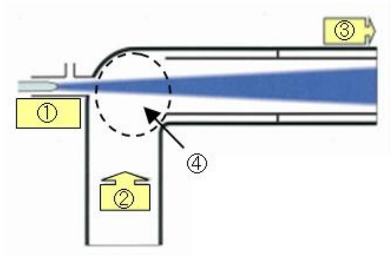

Fig.15
Mechanism of special ejector pump system and high pressure water injection
Mécanisme du système de pompe avec éjecteur spécial et injection d'eau

① High pressure water
② Suction
③ Discharge
④ Generation of negative pressure

① *Eau à haute pression*
② *Aspiration*
③ *Décharge*
④ *Génération de pression négative*

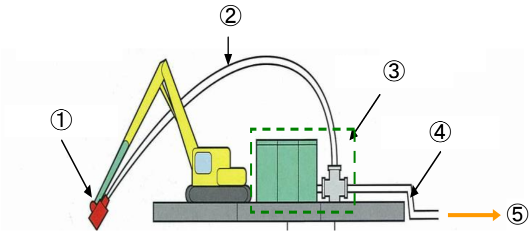

Fig.16
Schema of special ejector pump system
Schéma du système de pompe avec éjecteur spécial

① Sediment intake (Crusher)
② Sediment suction pipe
③ Ejector pump
④ Sediment conveying pipe
⑤ Discharge outlet

① *Alimentation en sédiments (concasseur)*
② *Tuyau d'aspiration de sédiments*
③ *Pompe d'éjecteur*
④ *Tuyau de transport de sédiments*
⑤ *Décharge de sédiments*

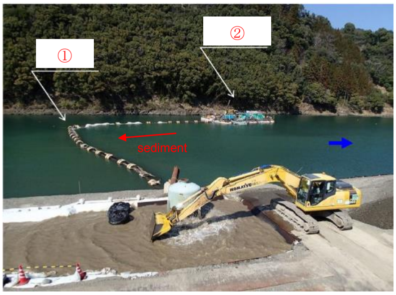

Fig.17
Work being carried out at Saigou Dam in 2013
Travaux en cours au barrage de Saigou en 2013

①Sediment conveying pipe
②Special ejector pump

① *Tuyau de transport de sédiments*
② *Pompe avec éjecteur spécial*

Concerning the method for relocation of sediment, for sites characterized by for example sediment composed mainly of coarse sand and gravel and buried driftwood, or confined work spaces, it is difficult to apply conventional submersible pump or grab dredging methods. For this reason, attention is being given to a special ejector pump system as the most applicable technology. With this system, using an ultrahigh-pressure pump, water is injected through a pipe at high pressure. This generates negative pressure that draws in sediment, which is then conveyed by the pressure produced by the ultrahigh-pressure pump (Fig.15). More specifically, as shown in Fig. 16, using a long arm backhoe aboard a barge to maneuver an intake and suction pipe, submerged deposited sediment is drawn in and then conveyed through a series of pipes. In addition, in the suction section, scree is broken down by a crusher into pieces around 150mm in diameter before being drawn in. The suction pipe structure is simple, making it resistant to blockage and internal wear. The system makes possible what could not be tackled by dredging with a conventional submersible water pump, which is limited to sediment particle size equivalent to that of sand. Fig. 17 shows the system in actual operation, which in practice has conveying capacity of approximately 25 m^3/h (over an average distance of 300 m).

9. CONCLUSION

This paper covers the background to implementation of sediment management at dams in the Mimikawa River System, and explains the use of numerical simulation and a hydraulic model for predicting sediment flow. The paper also provides an overview of specific retrofitting work for sediment sluicing at dams, adoption of auxiliary sediment management work being carried out in advance of commencement of sluicing, and methods for assessment of environmental impact in the downstream. Main conclusions are follows.

1) Based on the expected sediment load into reservoirs after Typhoon Nabi in 2005, drastic change of reservoir sediment management strategy is indispensable for reservoir sustainability in the Mimikawa River Basin.
2) Among several countermeasures, sediment sluicing option by installing high spillway gates and introducing patricianly drawdown operation during flood flows is suitable for three dams in the basin. This selection has been guided by two guiding parameters, CAP/MAR (Total capacity/Mean annual runoff) and CAP/MAS (Total capacity/Mean annual inflow sediment) (Sumi, 2013).
3) One dimensional numerical simulation has been carried out to clarify the effect of sediment sluicing by obtaining optimal operation rule including target flood events and threshold discharges for starting and ending reservoir drawdown. Differences in the effect of sediment sluicing depended on the height of the cut in the dam body.
4) Physical model experiments have been carried out to confirm three dimensional sediment transport phenomena such as scouring and depositing within reservoir area and to determine efficiency of sediment sluicing. It was also confirmed that it is necessary to carry out auxiliary sediment management work, for example to remove accumulated sediment in the area immediately upstream of a dam in advance of initial sediment sluicing.
5) Unique retrofitting work on two dams have been started such as installing temporary cofferdam, 4m high steel-rubber gate (SR gate), which can keep reservoir water level for power generation in normal time and discharge flood water by falling down the gates. .
6) Environmental impact assessment downstream from dams after commencement of sediment sluicing have been started by taking field data such as turbidity, river bed change, bed grain size and aquatic species and so on.
7) In order to prevent fast sediment bed change during the first drawdown operation causing large impacts on downstream by discharging high sediment concentration, adoption of auxiliary methods for sediment flow management being carried out in advance of commencement of sediment sluicing.

With sluicing planned to commence in 2016, this project is the first in Japan to incorporate large-scale dam retrofitting work and to investigate specific operational methods for sediment sluicing at dams. Following the commencement of sluicing, investigation of optimal sluicing with consideration for flood control, water usage and environmental conservation is scheduled to continue.

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SUMMARY

With the huge sediment production in mountainous areas due to the Typhoon Nabi disaster in the Mimikawa River Basin in 2005, full-scale countermeasures to deal with reservoir sedimentation became necessary. To that end, the “Mimikawa River Basin Integrated Sediment Flow Management Plan”, which took into consideration the entire river basin from the mountainous areas to the sea, was compiled in 2011 by the Miyazaki Prefecture. Sediment sluicing operation at a group of dams in the main river in the Mimikawa River Basin will play a central role in this plan, and is scheduled to commence in FY2016. Sediment sluicing operation is planned for Yamasubaru, Saigou and Oouchibaru Dams in the Mimikawa River, which are administered by Kyushu Electric Power Company (KEPCO). In order that water level can be lowered sufficiently at times of river flooding during typhoon period, crest gate retrofitting work on Yamasubaru and Saigou Dams is currently being carried out.

This paper reports on related matters including the following, 1) the necessity for sediment flow management at dams in the Mimikawa River Basin, 2) the appropriateness of choosing sediment sluicing at dams as a measure to manage sediment flow, 3) numerical simulation carried out with the objective of confirming the effect of sediment sluicing and formulating optimal rules for operation, 4) hydraulic model studies carried out to determine functional characteristics of sediment sluicing operation, 5) details of dam retrofitting work and innovative techniques to prepare for sediment sluicing, 6) assessment of environmental impact below dams after commencement of sediment sluicing operation and 7) adoption of auxiliary methods for sediment flow management being carried out in advance of commencement of sediment sluicing operation.

RÉSUMÉ

Avec l'énorme afflux de sédiments dans les zones montagneuses en raison du typhon Nabi dans le bassin de la Mimikawa, des mesures de grande envergure sont devenues nécessaires pour faire face à la sédimentation des barrages. À cette fin, le «Plan intégré de contrôle des flux de sédiments dans le bassin de la Mimikawa», qui a pris en considération l'ensemble du bassin fluvial des régions montagneuses à la mer, a été conçu en 2011. La vidange des sédiments dans un groupe de barrages sur la rivière principale dans le bassin de la Mimikawa jouera un rôle central dans ce plan, et il est prévu de commencer en 2016. La vidange des sédiments est planifiée sur la Mimikawa pour les barrages Yamasubaru, Saigou et Oouchibaru, administrés par Kyushu Electric Power Company (KEPCO). Pour que le niveau de l'eau puisse être abaissé suffisamment lors de crues de la rivière, la modernisation des vannes de crête est actuellement en cours aux barrages Yamasubaru et Saigou.

Ce article rend compte des questions associées, notamment : 1) nécessité d'une gestion des flux de sédiments dans les barrages du bassin de la Mimikawa, 2) pertinence du choix de vidange de sédiments dans les barrages en tant que mesure pour gérer les flux de sédiments, 3) simulation numérique effectuée dans le but de confirmer l'effet de vidanges des sédiments et la formulation des règles optimales de fonctionnement, 4) essais de modèles hydrauliques réalisés pour déterminer les caractéristiques fonctionnelles de vidange des sédiments qui résultera de travaux de modernisation, 5) détails des travaux de modernisation des barrage et techniques de pointe de réaménagement pour la vidange des sédiments, 6) évaluation de l'impact environnemental en aval des barrages après le début de vidange des sédiments et 7) adoption de méthodes auxiliaires pour la gestion des flux de sédiments devant être réalisée avant le début des vidanges de sédiments.