COMMISSION INTERNATIONALE
DES GRANDS BARRAGES

VINGT TROISIÈME CONGRÈS
DES GRANDS BARRAGES
Brasilia, Mai 2009

EVALUATION OF THE IMPACT OF STREAM TYPE FLOOD CONTROL DAMS ON SEDIMENT MANAGEMENT *

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JAPAN

* *Évaluation de l'impact des barrages de contrôle des crues de type cours d'eau sur la gestion des sédiments.*

1. INTRODUCTION

Many large dams that control floods in Japan have been constructed as multipurpose dams combining water utilization and flood control functions in order to supply water to the downstream river and to maintain the river environment in excellent condition.

Recently, social conditions have increased the number of dam redevelopment projects carried out instead of new dam construction projects. The construction of stream type flood control dams, a type that stores only water discharged by floods and is called “a dry dam” in U.S.A., has similarly increased.

The reason is that at locations where the environment of the reservoir in normal circumstances is similar to the river environment, a stream type dam is better than a storage type dam from the viewpoint of the movement of sediment, the stream, and aquatic life (by securing upstream - downstream continuity) .

Sediment passes through a stream type dam comparatively easily. On the other hand, the sediment’s movement may depend on the water level, which varies greatly, resulting in impacts on the downstream river.

This thesis evaluates the stream type dam, particularly its impact on sediment management in watersheds and reservoirs.

2. BACKGROUND TO THE INCREASE IN THE NUMBER OF STREAM TYPE DAMS IN JAPAN

2.1. FEATURES OF FLOOD CONTROL DAMS IN JAPAN

2.1.1. Multipurpose and single purpose dams used for flood control

The purpose of dams is to store flowing water. A water utilization dam supplies water to downstream by storing water when the flow rate in the river is high, discharging it when the flow rate is too low, and improves the river environment. A flood control dam alleviates downstream disasters by storing a portion of the flood water in the reservoir.

Because the flood wave of rivers in Japan increases and decreases rapidly in a short time, the peak discharge of a flood can be greatly decreased by using small storage capacity. Therefore, an effective way to decrease floods in Japan is to combine reservoirs and river improvements. By fiscal 2006, 709 large dams had been constructed to control floods. (references [1] & [3])

Because suitable dam sites are limited and the flood period and non-flood period are clearly divided in Japan, 618 of the 709 dams built as flood control dams are multipurpose dams. However, dams used only for flood control have been steadily constructed according to the situation in each watershed.

2.1.2. Un-gated dam

Although various flood control rules are applied in Japan, the basic rules are the Constant Discharge Rule and the Natural Discharge Rule.

The Constant Discharge Rule stipulates that discharges that exceed the design discharge of the downstream river must not be done when the river improvement downstream is advanced. If the water level in the reservoir rises, it is necessary to close the gate according to the water level because the amount of discharge from the outlet works increases. Moreover, it is necessary to open the gate according to the inflow discharge to avoid needlessly storing water during the early stage of a flood.

To operate a dam, we operate outlet works after collecting and analyzing information, and send notifications to related organizations and warnings and other information to the downstream river region. These responsibilities are highly concentrated in short time periods during each flood, so dam operators are placed under extremely heavy work loads.

A natural regulation dam without gate control during floods greatly reduces the load on the operator and contributes to the simplification of management. This also helps decrease expenses. A natural regulation dam lowers life cycle cost, considering the life of the dam even if a bigger reservoir is necessary. However, the flexibility of the gate operation is lost, so gate operation must be carefully considered at the planning and design stages.

Until now, we have mitigated floods by proactively utilizing dams in Japan. In response to an increase in the number of managed dams, we face a demand that dams be easier to operate during floods and that facility maintenance cost be lowered. Therefore, the number of un-gated spillways has increased at dams used only for flood control and at multipurpose dams. At some dams, gates have been removed during redevelopment projects.

2.2. FEATURES OF STREAM TYPE DAMS

2.2.1. Environmental water use

Single purpose flood control dams in Japan are storage type dams because they include environmental water use capacity. They supply water to protect environmental conditions downstream from damage caused by water shortages resulting from excessive water utilization by holders of customary water rights.

Recently, the number of stream type dams which do not supply environmental use water has increased. The reason is an increase in regions where separating flood control and water utilization resolves problems with reservoir management: overcoming sedimentation and water quality problems and reducing impacts on ecosystems. Moreover, the goal of increasing un-gated dams also backs up an increase in stream type dams.

Another feature of stream type dams is that fish etc. can move up and down the river through outlet works comparatively easily. The outlet works etc. should be designed to make the best use of this advantage. For instance, some dams adopt the digging type stilling basin.

The reservoirs of stream type dams store water only for a short time during floods. And they presumably have less influence on flora and fauna than the reservoirs of storage type dams. Reservoirs should be improved to make the best use of this advantage.

It is necessary to study measures to prevent blockage by logs and slope instability because, although water is not stored in normal circumstances, the water level changes greatly during a flood.

2.2.2. Sluicing of sediment

Sedimentation capacity is provided for a storage type dam where most of the inflowing sediment is accumulated in the reservoir, and only fine sediment is discharged. Far less sediment accumulates in a stream type dam reservoir that in a storage type dam.

The movement of sediment that flows into the reservoir of a stream type dam at the flood is, in the first stage of flood, similar to its movement in a river without a dam. The sediment accumulates temporarily in the reservoir when storage begins. The accumulated sediment moves when the water level descends at the end of the flood. And it also moves during a small or medium flood after a large flood. Therefore, it is necessary to consider the change of this sedimentation to calculate the capacity of the reservoir.

It is also possible that fine sediment will accumulate in the downstream riverbed, and that turbid water will be discharged for a long period. The problem of the movement of this sediment is discussed in Chapter 3.

It is possible to more smoothly release sediment to the downstream river through a stream type dam by appropriately designing the structure of the outlet works set near the riverbed and the stilling basin. The scale and the shape of the outlet works influence the amount, the quality, and the time of the release of sediment to the downstream river. It is, therefore, necessary to design the outlet works out of consideration for sediment movement and flood control plan. And the outlet works and the stilling basin must be protected from erosion because sediment passes through them.

2.3. PROTECTION AGAINST EROSION

Protecting outlet works from erosion in Japan is studied using results of a study of erosion protection at the sediment flushing facility of the Unazuki Dam in the Kurobe River.

Because the amount and the particle size of the sediment are small, the amount of erosion assumed to occur in outlet works of stream type dams now planned is considerably smaller than that which occurs on the facilities of the Unazuki Dam. The water level is decreased after flood control to remove sediment at the Unazuki Dam. Because details of this erosion protection have been described in reference [2], we'll omit them here.

Erosion protection methods include lining the facilities with steel, high-strength concrete, super-high strength fiber reinforcement panels, and natural stone.

Steel material provides durability under erosion by sediment and cavitation damage. Concrete material may be severely damaged. Therefore, a steel lining is executed as protection for the discharge pipe of the control section which must maintain its shape. Moreover, because anti-corrosion coatings cannot be applied, important parts are lined with stainless steel.

Choosing the erosion protection method and appropriately controlling maintenance are considered so that the dam body around the outlet works will not be damaged when they are installed in the dam body. Because lining with stainless steel is expensive, another lining material is selected for parts of the outlet works that can be repaired assuming they will be repaired. In this case, adequate work space is secured.

Because it is comparatively easy to maintain the stilling basin , some damage is allowed. Most of the stilling basin is presumably lined with high-strength concrete considering the amount of erosion. The area where the flow concentrates and damage spreads is presumably lined with stainless steel. It is necessary to prepare a maintenance plan in advance so it can be repaired promptly when damage has occurred.

Erosion protection of the outlet works and the stilling basin must be designed so that fish can pass through the works easily.

2.4. REPRESENTATIVE STREAM TYPE DAMS IN JAPAN

In this section, we'll introduce a few stream type dams in Japan shown in Table 1 and 2. All dams except the Masudagawa Dam are now under construction.

2.4.1. Tateno Dam (MLIT)

The Tateno Dam is the first dam planned as a real stream type dam in Japan. This dam is a gravity concrete dam 87m in height and 420,000 m^3 in volume. There are 3 outlet works, each a service spillway with a different elevation. The bottom outlet is arranged to provide flood mitigation effects during small and medium floods and also functions as a sediment flushing facility.

2.4.2. Masudagawa Dam (Shimane Prefecture) Fig. 1 and 2

The Masudagawa Dam, which is the first dam completed as a real stream type dam in Japan, is based on the results of hydraulic design of the Tateno dam which was planned earlier. This dam is a gravity concrete dam 48m in height and 102,000 m^3 in volume. There are 2 outlet works: service spillways that function as sediment flushing facilities. A detailed study was done regarding blockage of outlet works by logs. Its river environment conservation capacity is transferred to another improved dam in the same watershed.

Table 1
List of Main Stream Type Dams
Liste des barrages du type cours d'eau principal

Name of Dam	Tateno	Masudagawa	Tatsumi	Asuwagawa
Owner	MLIT	Shimane Pref.	Ishikawa Pref.	MLIT
Name of River (Water System)	Shirakawa (Shirakawa)	Masudagawa (Masudagawa)	Saikawa (Saikawa)	Asuwagawa (Kuzuryugawa)
Type of Dam	Concrete gravity	Concrete gravity	Concrete gravity	Concrete gravity
Dam Height	87 m	48 m	51 m	96 m
Dam Length	197 m	169 m	195 m	410 m
Dam Volume	420,000 m^3	102,000 m^3	146,000 m^3	680,000 m^3
Catchment Area	383 km^2	87.6 km^2	77.1 km^2	105.2 km^2
Reservoir Area	0.36 km^2	0.54 km^2	0.42 km^2	0.94 km^2
Total Storage Capacity	10.1 hm^3	6.75 hm^3	6.0 hm^3	28.7 hm^3
Effective Storage Capacity	10.1 hm^3	6.5 hm^3	5.8 hm^3	28.2 hm^3
Service Spillway (Upper outlet) (Bottom outlet)	Un-gated H5.0m*B5.0m*2 H5.0m*B5.0m*1	Un-gated H3.4m*B4.5m*2	Un-gated H4.5m*B4.5m*1 H2.9m*B2.9m*2	Controlled H4.5m*B3.6m*2 H4.0m*B3.2m*1
Emergency Spillway (Surface spillway)	Free-overflow H5.0m & B105m	Free-overflow H3.3m& B80.5m	Free-overflow H3.5m & B78m	Free-overflow H3.0m & B156m
Design Flood Discharge	2,800 m^3/s	950 m^3/s	600 m^3/s	780 m^3/s
Maximum Outflow Discharge	2,250 m^3/s	640 m^3/s	460 m^3/s	180 m^3/s

MLIT: Ministry of Land, Infrastructure,Transport and Tourism

Fig. 1
Upstream face of Masudagawa Dam
Face amont du Barrage de Masudagawa

Fig. 2
Downstream face of Masudagawa Dam
Face aval du Barrage de Masudagawa

2.4.3. Tatsumi Dam (Ishikawa Prefecture)

Tatsumi Dam is a concrete gravity dam 51m in height and 146,000 m^3 in volume. There are 3 outlet works: service spillways with different elevations. The bottom outlets are provided to cut the peak discharge of a flood and to function as sediment flushing facilities. Its multipurpose effect has been improved in cooperation with the other two dams in the watershed. The river environment protection capacity is transferred to two dams in the watershed. Part of the flood control capacity of the two dams is transferred to the Tatsumi Dam.

2.4.4. Asuwagawa Dam (MLIT)

The Asuwagawa Dam is a concrete gravity dam 96m in height and 680,000 m^3 in volume. There are 2 outlet works: regular spillways and another sediment flushing facility. This dam is located on a tributary because there is no adequate dam site on the Asuwa River. And there are flood diversion channels from the main river and other tributaries to the reservoir in this project. Therefore, the control gates of the outlet works are operated to reduce the discharge rate from the dam at the peak of a flood of the main river. The sediment flushing facility is active in the initial stage and the final stage of a flood.

2.4.5. Small stream type dams

Table 2 shows representative small stream type dams: the Tsuzuki Dam (Iwate Prefecture), Mogami-ogunigawa Dam (Yamagata Prefecture), Kitagawa No.1 Dam (Shiga Prefecture) and Nishinotani Dam (Kagoshima Prefecture). Because the necessary outflow discharge rate of these dams is small, the section of the outlet work is also small. Therefore, the discharge pipe is shortened for maintenance, and the section of the downstream open channel in the dam body is enlarged. Moreover, at one dam, large outlet works are operated in the non-flood season.

Table 2
List of Small Stream Type Dams
Liste des barrages du type cours d'eau secondaire

Name of Dam	Tsuzuki	Mogami-ogunigawa	Kitagawa No.1	Nishinotani
Owner (Prefecture)	Iwate	Yamagata	Shiga	Kagoshima
Name of River (Water System)	Omatagawa (Kesengawa)	Mogami-ogunigawa (Mogamigawa)	Asougawa (Yodogawa)	Shinkawa (Shinkawa)
Type of Dam	Concrete gravity	Concrete gravity	Trapezoidal CSG	Concrete gravity
Dam Height	48.6 m	46 m	51.2 m	21.5 m
Dam Length	165 m	166 m	167 m	135.8 m
Dam Volume	105,000 m^3	46,600 m^3	217,000 m^3	33,000 m^3
Catchment Area	50.3 km^2	37.4 km^2	23.2 km^2	6.8 km^2
Reservoir Area	0.37 km^2	0.28 km^2	0.57 km^2	0.13 km^2
Total Storage Capacity	5.6 hm^3	2.6 hm^3	10.4 hm^3	0.793 hm^3
Effective Storage Capacity	5.35 hm^3	2.2 hm^3	10 hm^3	0.793 hm^3
Service Spillway (Bottom outlet)	Un-gated H1.9m*B1.9m*1	Un-gated H2.5m*B2.5m*1	Un-gated H1.3m*B1.3m*1	Un-gated H1.65m*B1.95*1
Emergency Spillway (Surface spillway)	Free-overflow H2.5m & B96m	Free-overflow H2.5m & B70m	Free-overflow H1.8m & B101m	Free-overflow H2.3m & B48m
Design Flood Discharge	240 m^3/s	330 m^3/s	320 m^3/s	95 m^3/s
Design Outflow Discharge	65 m^3/s	80 m^3/s	32 m^3/s	30 m^3/s

CSG: Cemented Sand and Gravel

3. EVALUATION OF CONTINUITY OF SEDIMENT MOVEMENT AT STREAM TYPE FLOOD CONTROL DAMS BASED ON A SEDIMENT TRANSPORT SIMULATION

3.1. STUDY METHOD

To clarify the sediment supply properties of stream type flood control dams with outlet works at the riverbed elevation, hypothesizing typical reservoir specifications and river basin conditions, a numerical simulation of sediment movement was performed using the 10 year flow regime. (reference [4]) The model used for the study was a mixed particle size-one-dimensional movable bed model. This model, which was developed by the Public Works Research Institute, can reproduce a mixed flow combining a sub critical flow and a super critical flow, and it can be used to consider the non-equilibrium transport of suspended sediment. (reference [5])

3.2. SETTING THE CALCULATION CONDITIONS

The reservoir shape was the trapezoidal section shown in Fig. 3. The values concerning reservoir shape were decided with reference to values for existing dams managed by the Ministry of Land, Infrastructure and Transport (MLIT) of the Government of Japan. The riverbed slopes were set at two values: 1/100 and 1/50. Table 3 shows the reservoir specifications and the river basin conditions. As explained below, the specific inflowing sediment load (annual quantity of inflowing sediment per unit area of the river basin) was set at the same level for the two reservoir shapes. Reservoir shape 2 has a larger catchment area and smaller reservoir storage capacity than reservoir shape 1. In other words, reservoir shape 1 was set as the average condition in Japan and reservoir shape 2 was set as the condition where sediment is deposited more quickly.

Table 3
Reservoir shape parameters for simulation
Paramètres concernant la forme du réservoir pour la simulation

Item	Reservoir shape 1	Reservoir shape 2
Height of dam (m)	100	
Length of dam (m)	300	
Reservoir capacity ($\times 1000 m^3$)	56,000	28,000
Riverbed slope	1/100	1/50
Riverbed width (m)	20	
Catchment area (km^2)	100	200
Reservoir surface area (km^2)	1.6	0.8
Turnover frequency	2	10

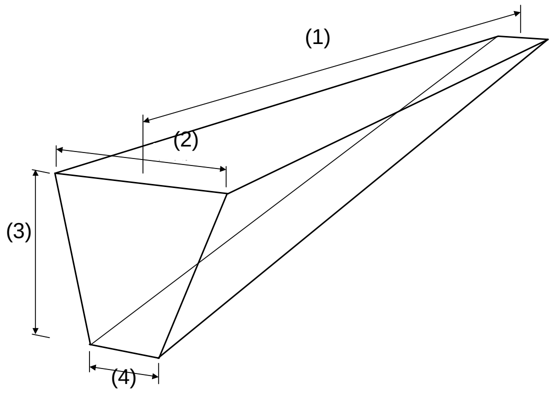

Fig. 3
Reservoir shape for simulation
Forme du réservoir pour la simulation

(1) Reservoir length — *(1) Longueur du réservoir*
(2) Length of dam — *(2) Longueur du barrage*
(3) Height of dam — *(3) Hauteur du barrage*
(4) Riverbed width — *(4) Largeur du lit de la rivière*

The inflow hydrographs used for calculation were made by extending a ten year wave form from 1983 to 1992 at the Futase Dam in the Kanto Region where the flood period is relatively clear. These 10-year inflow hydrographs were extended so that the average of each 10-year reservoir turnover frequency was 2 for shape 1 and 10 for shape 2. And for normal periods, the calculation was done using average daily data, while for flood periods, it was done using hourly data.

The particle diameter of the sediment was set as nine representative grain-diameters ranging from 0.005mm to 25.4mm in order to reproduce all sediment transportations from clay to sand or gravel. The diameter ranges and representative grain-diameters of sediment are shown in Table 4.

Table 4
Representative grain-diameters
Diamètres représentatifs des grains

Classification	Number of grain-diameter	Diameter range (mm)	Representative grain-diameter (mm)
Gravel	1	9.5200 ～	25.4000
	2	2.0000 ～ 9.5200	4.3630
Sand	3	0.8400 ～ 2.0000	1.2960
	4	0.2500 ～ 0.8400	0.4580
	5	0.0750 ～ 0.2500	0.1370
Shilt	6	0.0339 ～ 0.0750	0.0504
	7	0.0129 ～ 0.0339	0.0209
	8	0.0050 ～ 0.0129	0.0080
Cray	9	～ 0.0050	0.0050

The inflow sediment discharge was provided by the following equation. (reference [6])

$$Q_{sj} = \alpha_j Q^{\beta_j} \quad (Q > Q_c) \tag{1}$$

Where,
Q_{sj} : sediment discharge of grain size j (m^3/s)
Q : disharge (m^3/s)
α_j, β_j : constants
Q_c : sediment inflow limit discharge (m^3/s) (It is hypothesized that sediment does not flow in at a discharge below this value).

To set these parameters, large inflowing sediment load was set as a condition so that it would be easy to clarify differences in sediment supply properties from the dam. In other words, the specific sedimentation was set so it would be about $800m^3/(year \cdot km^2)$ with reference to past measured specific sedimentation values for reservoirs in Japan.

The value of β_j of the fine sediment particle was decided with reference to results of past studies of existing dams. The value of β_j of the coarse sediment particle was decided with reference to the relationship between the sediment discharge by grain-diameter and the discharge calculated by a non-uniform sediment discharge formula using the grain-diameter distribution obtained from measurements of past reservoir sedimentations in Japan.

The value of α_j was decided by performing a 10 year simulation calculation using β_j as obtained above under conditions at a storage type dam with reservoir shape 1 that is operated to maintain a constant reservoir water level. The value of α_j was set so that the specific sedimentation would be approximately $800m^3/(year \cdot km^2)$, and so that the grain-diameter distribution of the deposited sediment would be about equal to the average distribution obtained from the results of surveys of sedimentation at existing dams. (reference [7]) At this time, the sediment inflow limit discharge was assumed to be $5m^3/s$, and for periods when the discharge was lower than this, the calculation was omitted, reducing the computation time.

The value of α_j for reservoir shape 2 was set so that the specific inflowing sediment load would be equal to that of reservoir shape 1. Table 5 shows the parameters of inflow sediment discharge finally obtained under each set of reservoir conditions.

Table 5
Parameters of inflow sediment discharge
Paramètres concernant les sédiments apportés

Number of grain-diameter	Grain-diameter (mm)	Reservoir shape 1		Reservoir shape 2	
		α_j ($\times 10^{-7}$)	β_j	α_j ($\times 10^{-7}$)	β_j
1	25.4000	335.23	1.1	192.25	1.1
2	4.3630	1,340.92	1.1	769.01	1.1
3	1.2960	293.05	1.4	142.87	1.4
4	0.4580	35.11	2.0	10.95	2.0
5	0.1370	32.61	2.0	10.17	2.0
6	0.0504	5.72	2.3	1.38	2.3
7	0.0209	7.99	2.3	1.92	2.3
8	0.0080	16.83	2.3	4.05	2.3
9	0.0050	145.29	2.3	34.95	2.3

As the outlet work, a single un-gated spillway with foundation height equal to the initial riverbed elevation was installed. Its outlet shape was square with height and width of 4m. Its discharge capacity was obtained by the following equations.

Open channel flow: $Q = C_o B h^{1.5}$ [2]

Pipe flow; $Q = C_p B D \sqrt{2gh}$ [3]

Where,
Q : discharge (m^3/s)
B : outlet width (m)
D : outlet height (m)
h : acting water head (m)
C_o : discharge coefficient in the open channel flow (assumed to be 1.6)
C_p : discharge coefficient in the pipe flow (assumed to be 0.8)

And the discharge in the transition flow condition is obtained based on linear interpolation, assuming the transition range is the range: $1.3 \leqq h/D \leqq 1.8$.

Other calculation conditions are shown in Table 6.

Table 6
Calculation conditions
Conditions concernant la méthode de calcul

Item	Unit	Reservoir shape 1	Reservoir shape 2
Interval time of calculation	sec	1～3	0.3～3
Grid size of stream direction	m	100	100
Number of grid of stream direction	—	111	61
Grid size of vertical direction in cross section	m	0.5	0.5
Number of grid of vertical direction in cross section	—	200	200
Exchange layer thickness	m	0.05	0.05
Manning's coefficient of roughness	$m^{-1/3}\cdot sec$	0.03	0.03
Kinematic viscosity coefficient of water	m^2/s	0.000001	0.000001
Density of water	kg/m^3	1,000	1,000
Density of sediment particle	kg/m^3	2,650	2,650
Porocity	—	0.4	0.4

3.3. STUDY RESULTS

3.3.1. Sediment supply properties

From among the 10-year calculations, the result of the calculation for one flood hydrograph was selected and presented.

It is shown in Fig. 4 for the reservoir shape 1 case and in Fig. 5 for the reservoir shape 2 case.

In the figure, the top-left graph shows changes in the reservoir water level, inflow discharge, and outflow discharge while the other graphs show inflow sediment discharge and outflow sediment discharge for total, gravel, sand, silt, and clay respectively.

For reservoir shape 2, the inflow discharge is large in relation to the reservoir capacity, so the change of the reservoir level is great and the outflow discharge changes more slowly than the inflow discharge.

In Fig. 4 that shows the calculation results for reservoir shape 1, the peak inflow discharge is about $175m^3/s$.

The reservoir water level only rose a little, so that the inflow discharge and outflow discharge were almost equal.

The total outflow sediment discharge was a little lower than the inflow sediment discharge during the peak of the flood, and in the last stage of the flood, inversely, it was higher than the inflow sediment discharge. The wave form of the outflow sediment discharge is almost identical to the wave form of the inflow sediment discharge.

Studying the results by grain-diameter shows that a wave form of the outflow sediment discharge of gravel was far behind the inflow sediment discharge. Gravel is not discharged from a dam while the reservoir water level is rising, then is discharged all at once when the water level has fallen.

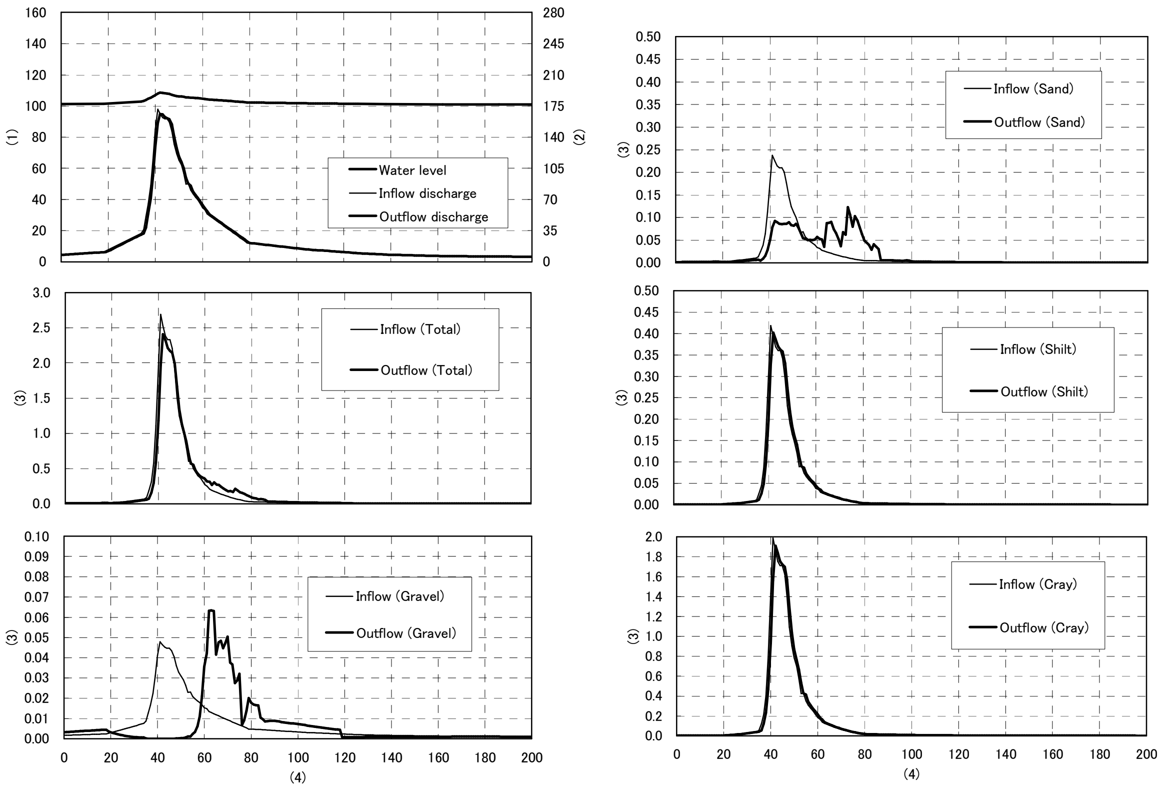

Fig. 4
Example of calculation results of reservoir shape 1
Exemple des résultats des calculs effectués pour un réservoir de forme 1

(1) Reservoir water level (EL.m)	*(1) Niveau d'eau du réservoir (EL.m)*
(2) Discharge (m^3/s)	*(2) Débit (m^3/s)*
(3) Sediment discharge (m^3/s)	*(3) Débit des sédiments (m^3/s)*
(4) Time (Hour)	*(4) Durée (en heures)*

The difference between the inflow and outflow sediment discharge of sand is not as wide as in the case of gravel. The outflow sediment discharge at the peak of the flood is about half of the inflow sediment discharge. In the last stage of the flood, the outflow sediment discharge exceeds the inflow sediment discharge.

The outflow sediment discharge of silt and clay is almost identical to that of the inflow sediment discharge. It is considered that much of the silt and clay passes through the reservoir in suspended state. In this runoff, for all grain sizes, the total inflow sediment volume is almost equal to the total outflow sediment volume.

In Fig. 5 which shows the results of the calculations for reservoir shape 2, the peak discharge is about 400m^3/s.

The reservoir level rises about 40m, and the difference between the peak outflow discharge and peak inflow discharge is about 80m^3/s.

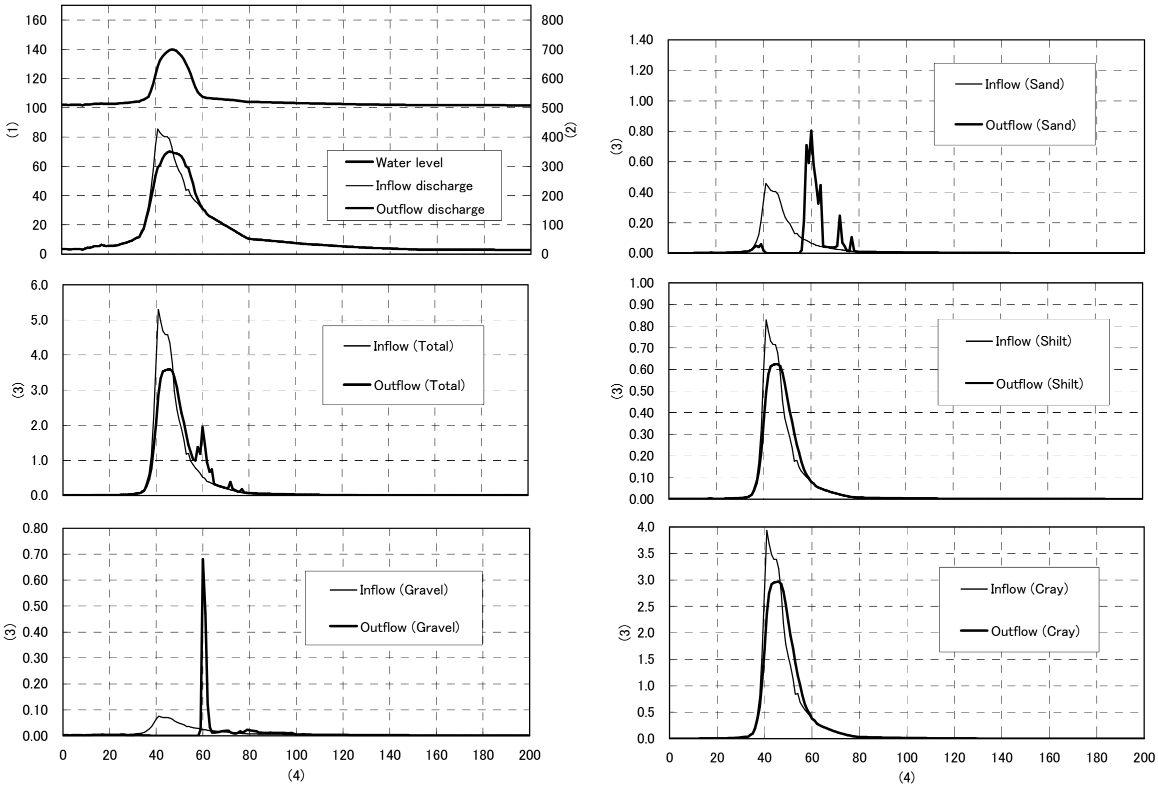

Fig. 5
Example of calculation results of reservoir shape 2
Exemple des résultats des calculs effectués pour un réservoir de forme 2

(1) ~ (4) are the same in Fig. 4

(1) ~ (4) Sont identiques sur la Fig. 4

The outflow sediment discharge of total reaches its first peak near the peak reservoir water level, and its second peak after the reservoir water level falls.

A study by grain diameter shows that in reservoir shape 2, the rise of the reservoir water level is larger, and during the flood, not only gravel, but sand outflow discharge stops. The peak value of the outflow sediment discharge after the reservoir water level falls is about 10 times and 2 times the peak value of the inflow sediment discharge for gravel and for sand respectively.

The outflow sediment discharge that is silt and clay is a little behind the inflow sediment discharge, and the peak value of the outflow sediment discharge is about 3/4 of the peak value of the inflow sediment discharge.

If the reservoir water level rises only a little, although the outflow discharge properties of sand and gravel are changed, the wave form of outflow sediment discharge of total is almost identical to the inflow sediment discharge wave form.

If the reservoir water level rises greatly, the outflow discharge of sand and gravel stops. Later when the reservoir water level has fallen, it discharges at high concentration in a short time. And because almost all the silt and clay has been discharged in suspended state, the outflow sediment discharge wave form is almost identical to the wave form of the outflow discharge. So the wave form of outflow sediment discharge of total shows two peaks: one near the reservoir water level peak and another after the reservoir water level falls.

3.3.2. Impact on the downstream river channel

The impact on the downstream river channel was studied comparing outflow sediment discharges and the sediment discharges calculated by the relational equation [1] with the outflow discharges, based on the calculated sediment discharges are assumed to be sediment discharges in natural state after dam completion.

Fig. 6 shows the results of calculations for reservoir shape 1 in which the reservoir water level remains almost unchanged (does not rise). The left side shows the results of the calculation of the flood used for the study in Section 3.3.1, and the right side shows the results of the calculation for another flood with a high inflow quantity and complex hydrograph.

Because the inflow discharge and the outflow discharge are almost identical in both cases, the inflow sediment discharge and the sediment discharge calculated from outflow discharge are almost identical.

An examination of sediment discharge of total shows that the sediment discharge calculated from outflow discharge and the outflow sediment discharge were identical during both floods. But the outflow sediment discharge that is gravel and sand is far behind the sediment discharge calculated from outflow discharge. In the case of the large flood on the right, the peak value of the outflow sediment discharge of gravel is a value more than double the sediment discharge calculated from outflow discharge.

Fig. 7 shows the result of the calculations for reservoir shape 2. These are results of the calculation of the same two flood wave forms shown in Fig. 6. In the case of reservoir shape 2, because the inflow discharge is large in comparison with the reservoir capacity, the reservoir water level changes greatly and the outflow discharge falls behind the inflow discharge, and this delay has an impact on the outflow sediment discharge.

Gravel and sand are not discharged while the reservoir water level is rising, but they are discharged rapidly when the water level has fallen. The outflow sediment discharged at the time reaches 10 times the sediment discharge calculated from outflow discharge in some cases.

The wave form of the outflow sediment discharge of silt and clay is similar to that of the sediment discharge calculated from outflow discharge. A condition for this calculation is the time period when the outflow sediment discharge reaches a maximum of 1.5 times the sediment discharge calculated from outflow discharge. It can be predicted that if it is possible for the outflow sediment discharge during this period to flow down under the tractive force of the downstream river channel, it will have a small impact on the downstream river channel. When the tractive force of the downstream river channel is small, it is possible for more silt and clay to be deposited downstream.

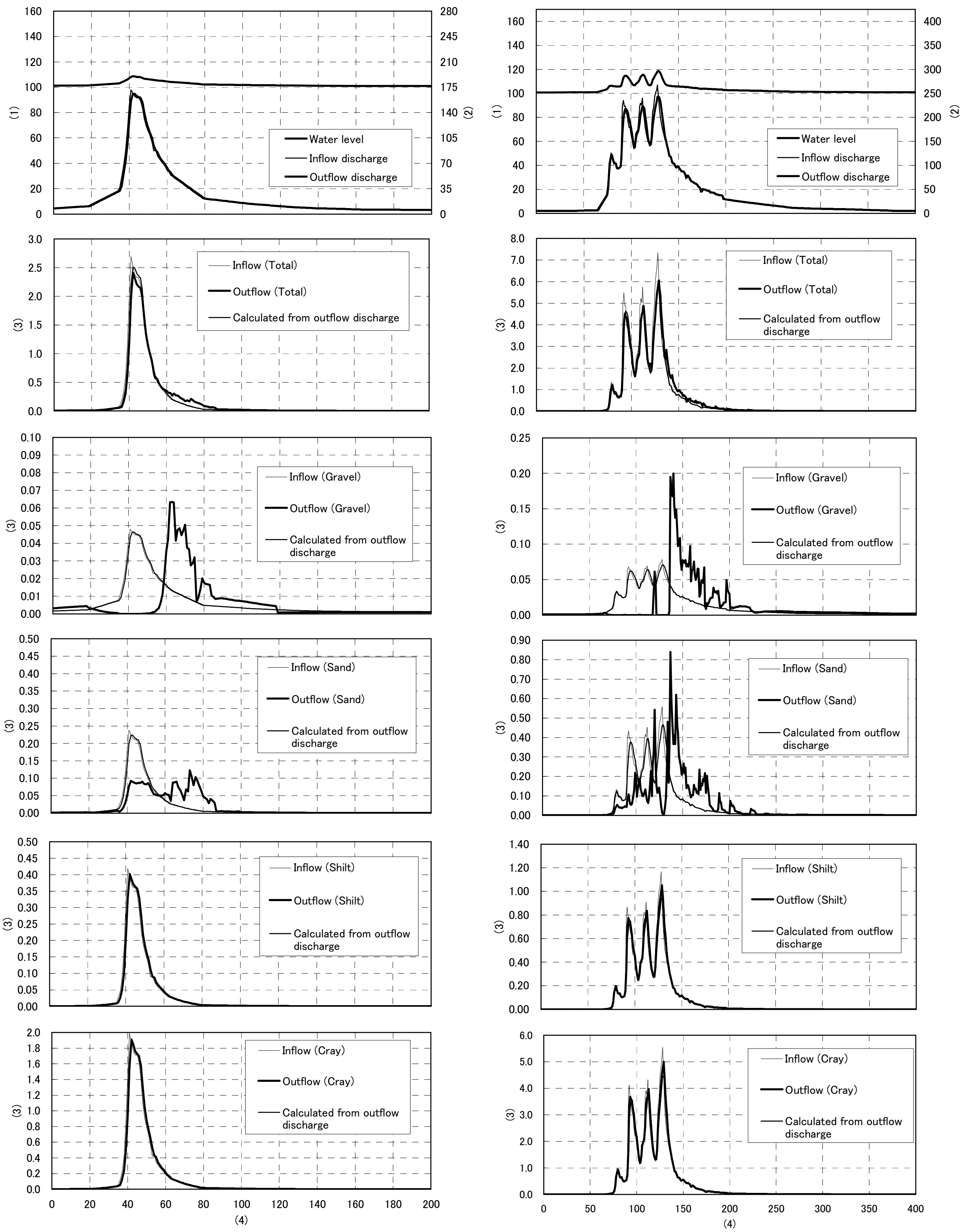

Fig. 6

Calculation results of reservoir shape 1

Résultats des calculs effectués pour un réservoir de forme 1

(1) ~ (4) are the same in Fig. 4

(1) ~ (4) Sont identiques sur la Fig. 4

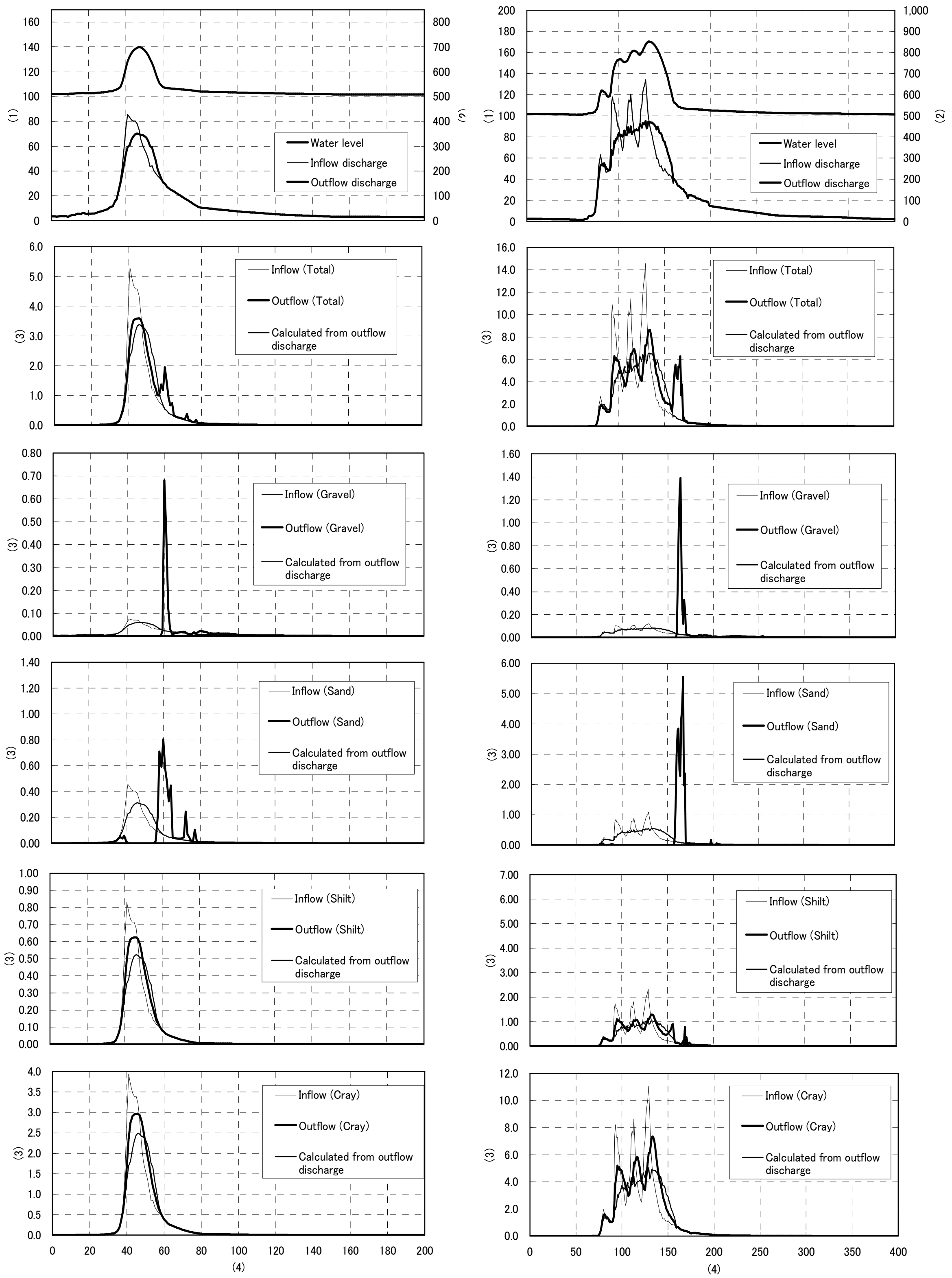

Fig. 7
Calculation results of reservoir shape 2
Résultats des calculs effectués pour un réservoir de forme 2

(1) ~ (4) are the same in Fig. 4

(1) ~ (4) Sont identiques sur la Fig. 4

A big gap in gravel and sand appears between the outflow sediment discharge and the sediment discharge calculated from outflow discharge, and gravel and sand are discharged only when the reservoir water level is low. It is predicted that, although it will differ according to the flood scale, gravel and sand will be easily deposited on the downstream riverbed because the outflow sediment discharge is larger than the sediment discharge calculated from outflow discharge at the end of the flood period. In a case where gravel and sand that have been deposited on the downstream riverbed are carried off during the next flood, the flood is large scale, and the reservoir water level has risen, they are repeatedly deposited at the end of the flood period.

4. CHALLENGES AND FUTURE DIRECTIONS TO SEDIMENT MANAGEMENT

When a stream type flood control dam stores a flood discharge, the properties of the outflow sediment discharge, which is mainly sand and gravel, unavoidably change more than the natural state. The degree of change varies according to flood control plans, inflow sediment properties, and scale of the flood, so dams must be studied individually.

As measures to mitigate changes of sediment transport properties, the shapes of the outlet works and energy dissipators are studied in order to smooth the sediment discharge at the end of the flood period, but the measure counted on to be most effective is to raise the reservoir water level less frequently within a range that satisfies flood control plans.

By expanding the cross-section of outlet works installed on the elevation of riverbeds, it is possible to raise the reservoir level less frequently. But, in Japan, the peak cut rate of flood at dam site is generally large, so in order to achieve a flood control plan, it is necessary to make the outlet works section small when the reservoir water level is raised. The measure that is considered at this time is to install large outlet works for sediment discharge and separate small outlet works for flood control, and switch over from the former to the latter during flood control.

To rationalize equipment and simplify its operation during a flood, at normal times, a large cross-section ensures the movement of sediment, stream, and aquatic life, but for flood periods, discharge equipment that permits the operation of gates to reduce the flow section, thereby controlling the flood discharge, should be developed.

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SUMMARY

Many large dams in Japan have been constructed as multipurpose dams combining water utilization and flood control functions in order to supply water to the downstream river and to maintain the river environment in excellent condition. Recently, social conditions have increased the number of dam redevelopment projects carried out instead of new dam construction projects. The construction of stream type flood control dams, a type that stores only water discharged by floods has similarly increased.

The reason is that at locations where the environment of the reservoir in normal circumstances is similar to the river environment, a stream type dam is better than a storage type dam from the viewpoint of the movement of sediment, the stream, and aquatic life (by securing upstream - downstream continuity) .

This thesis summarizes characteristics of the stream type dam and introduces some actual projects of it in Japan. It also evaluates the stream type dam, particularly its impact on sediment management in watersheds and reservoirs by numerical simulation of sediment transport in typical stream type dams.

From the results of simulation, it is confirmed that gravel and sand are not discharged while the reservoir water level is rising, but they are discharged rapidly when the water level has fallen. When a stream type dam stores a flood discharge, the properties of the outflow sediment discharge unavoidably change more than the natural state. The degree of change varies according to flood control plans, inflow sediment properties, and scale of the flood, so stream type dam projects must be studied individually.

RÉSUMÉ

De nombreux grands barrages japonais ont été construits comme des barrages polyvalents à buts multiples, combinant des fonctions d'utilisation de l'eau et de maîtrise des crues afin de fournir de l'eau à la rivière en aval et de maintenir l'environnement de la rivière en excellent état. Récemment, les conditions sociales ont fait multiplier le nombre des projets de réaménagement des barrages par rapport aux projets de construction de barrages neufs. La construction de barrages de contrôle des crues du type "au fil de l'eau," un type de barrage qui ne stocke que l'eau déversée lors des crues a également augmenté.

La raison en est que sur les sites où l'environnement du réservoir dans des circonstances normales est similaire à l'environnement de la rivière un barrage de type sans stockage est préférable à un barrage de type stockage/accumulation du point de vue du déplacement des sédiments, du cours d'eau et de la vie du milieu aquatique (en assurant la continuité entre les secteurs en amont et en aval).

Cette thèse fait la synthèse des caractéristiques du barrage de type au fil de l'eau et présente certains projets de ce type en cours au Japon. Elle évalue également les barrages de ce type, et notamment leur impact sur la gestion des sédiments au niveau des bassins versants et des réservoirs au moyen d'une simulation numérique du transport/déplacement des sédiments dans les barrages caractéristiques de type au fil de l'eau.

D'après les résultats de la simulation, on a pu confirmer que le gravier et le sable ne sont pas évacués lorsque le niveau d'eau du réservoir s'élève mais sont évacués rapidement lorsque le niveau d'eau s'abaisse. Lorsqu'un barrage de type au fil de l'eau stocke le débit provenant d'une crue, les propriétés des sédiments produits changent de manière inévitable comparés à la situation normale. Le degré du changement varie en fonction des consignes de contrôle des crues, des propriétés des sédiments apportés et l'importance de la crue. Par conséquent, les projets de barrage de type au fil de l'eau doivent être étudiés individuellement.