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PROPAGATION AND DEFORMATION OF FLOOD FLOW HYDROGRAPHS IN RIVER WITH A SERIES OF SMALL HYDROPOWER DAMS

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***Abstract**: A series of small hydropower dams have been constructed along gorge sections of river in Japan. It is important to study propagation characteristics of flood flow associated with the hydropower dams which will be usable for the future flood control management. At first, we show the effects of the gate operation of small hydropower dams on flood propagation speed and deformation of discharge hydrographs from observed data in the gorge section of the Agano River. Secondary, we evaluate the storage function of these reservoirs by using the unsteady one dimensional flow analysis which has developed to consider the effects of the gate operation.*

***Keywords**: flood propagation; hydropower dam; gate operation; gorge; reservoir; discharge hydrograph ; flood control project*

INTRODUCTION

Frequency and scale of floods are predicted to increase due to the global warming in Japan. So, the measures for adaptation strategies of flood control against the global warming are required. Because a storage facility is the most confidential measures to protect people's life and their property against flood disasters, it is important to use existing storage facilities effectively for flood control management.

As a result of modern development of water resources, a series of small hydropower dams have been constructed along gorge sections of river in Japan. In some rivers, total length of the reservoirs occupies a large part of the gorge section. Therefore, it will be important to use these hydropower dams for future flood control management. The above requires us to understand the effects of small hydropower dams on flood propagation and to evaluate the storage function of these reservoirs.

Flood propagation in reservoirs was studied intensively in 1950's from 1970's (e.g. Yano & Adachi 1956, Akimoto & Maruoka 1968 and Ozaki & Akimoto 1979). As indicated by these studies, flood propagation in reservoirs is affected by gate operation of the dams. Ozaki &

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Akimoto (1979) illustrated the propagation characteristics of flood flow in a reservoir under the different gate operations. But, because of the lack of field observed data, most of these studies were carried out by experimental channels. So the study based on field observed data is required for the further understanding. Mitkova et al. (2005) investigated the effects of a series of small hydropower dams on flood propagation in the Danube River by the hydrological flood routing model. However, because flood propagation is a dynamic phenomenon, the hydrological flood routing model is not enough to explain the storage phenomena in reservoirs associated with gate operation of the dams.

The Agano River has a gorge section which continued about 70 km long between the Aizu Basin and Niigata Plane as shown in Figure 1. In this section, six small hydropower dams are constructed and the distance of individual dams is about 10 km long (see Figure 2). The objectives of this study are to understand the effects of the gate operation of small hydropower dams on flood propagation and to evaluate the storage function of the gorge section of the Agano River. First, we examine the effects of the gate operation of small hydropower dams on flood propagation speed and discharge hydrographs based on observed data which obtained in the reservoirs at 1982 flood, 2002 flood and 2004 flood. Next, to evaluate the storage function of small hydropower dams, we develop the unsteady one dimensional flow analysis to consider the effects of the gate operation and apply the model to the gorge section of the Agano River.

GORGE SECTION OF THE AGANO RIVER AND GATE OPERATION OF SMALL HYDROPOWER DAM

Figure 2 is the outline of the section studied. In this section, river width varies from 50 m to 200 m and small hydropower dams, as shown in Figure 3, are constructed continuously along the river. Table 1 indicates the hydraulic and topographic conditions of these dams. The

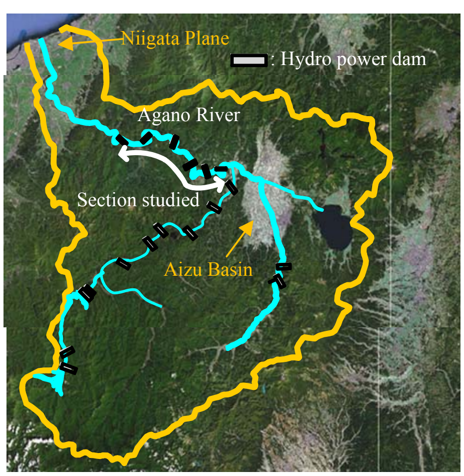


Fig.1 Agano River basin.

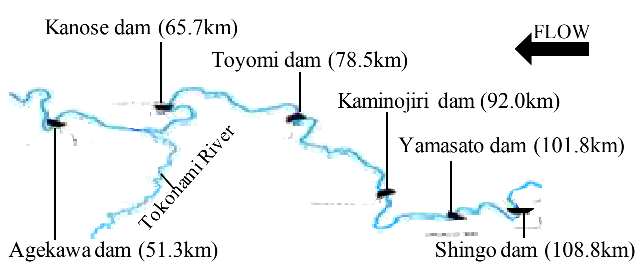


Fig.2 Outline of section studied.

Fig.3 Kanose dam.

Table 1 Hydraulic and topographic conditions of hydropower dams.

Dam name	Shingo dam	Yamasato dam	Kaminojiri dam	Toyomi dam	Kanose dam	Agekawa dam
Storage capacity	22,720 m3	7,591 m3	12,370 m3	18,667 m3	16,525 m3	13,748 m3
Hight	27.5 m	22.5 m	30.0 m	34.2 m	32.6 m	19.0 m
Normal water laevel	161.8 m	140.8 m	125.5 m	105.5 m	78.1 m	50.5 m
Spare stage	160.3 m	140.3 m	125.0 m	104.5 m	77.6 m	43.5 m
Elevation of dam crest	152.0 m	133.0 m	118.0 m	95.5 m	68.7 m	38.5 m

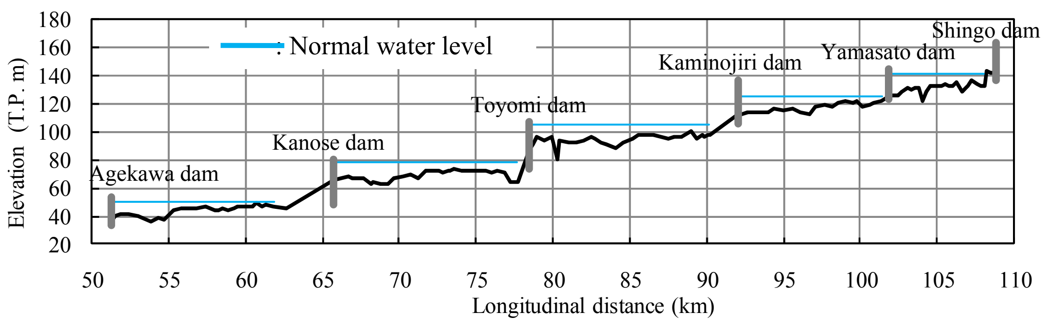


Fig.4 Longitudinal profiles of section studied and normal water level.

height of these dams is 20 m to 30 m. Figure 4 shows the longitudinal profiles of the section studied and normal water level (the water level for electricity generation) of the dams. And water level is observed at just upstream of the dam body in each reservoir shown in Figure 2.

The gate operation of small hydropower dams during flood is illustrated in Figure 5. Individual dams have the reference discharge for the gate operation called "flood discharge". In this section, flood discharge is 3000(m^3/s) at all the dams. If inflow discharge of the reservoir is increasing due to flood and predicted to exceed the flood discharge, the water level in the reservoir is lowered to spare stage (pre-lowered water level against flood). After the inflow discharge becomes larger than the flood discharge, there are two different gate operations. If the inflow discharge is smaller than the capability of the outflow discharge of

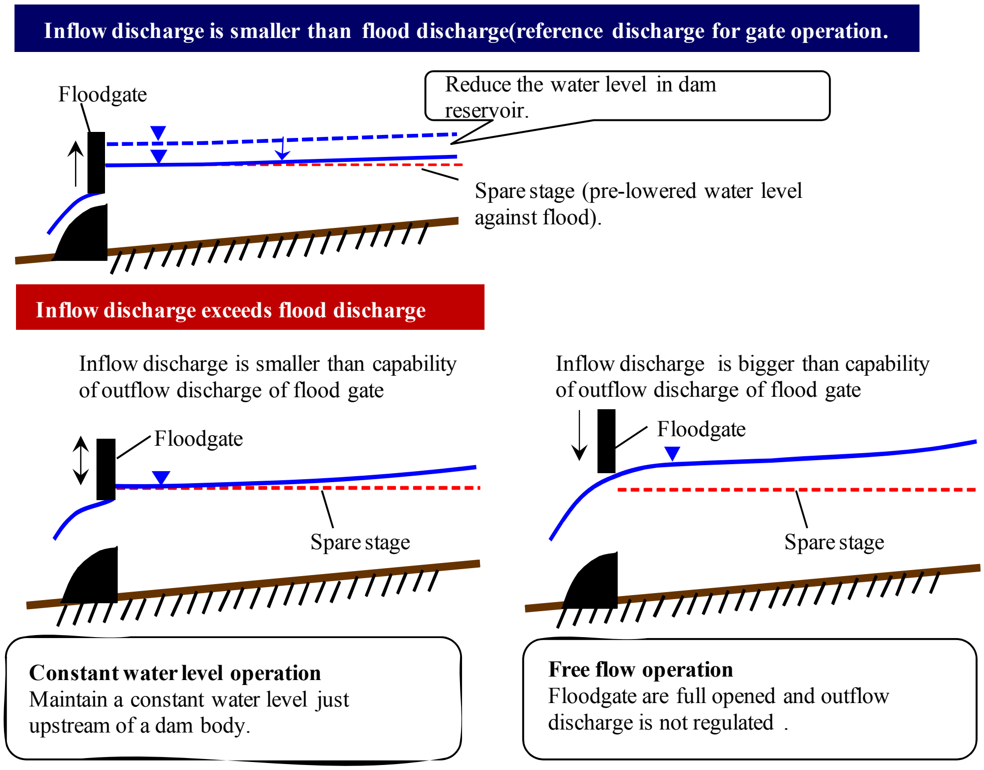
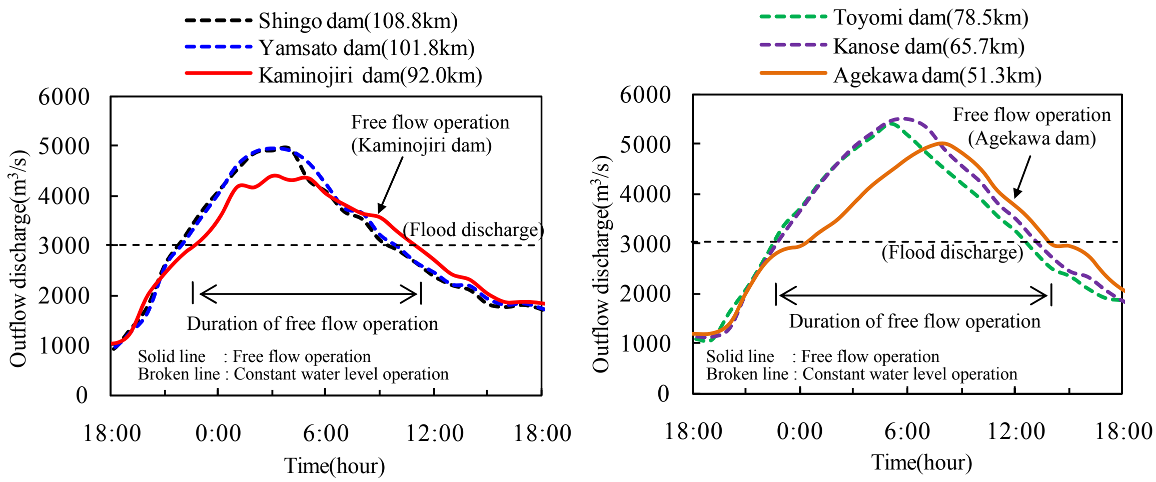


Fig.5. Sketch of gate operation of small hydropower dam.

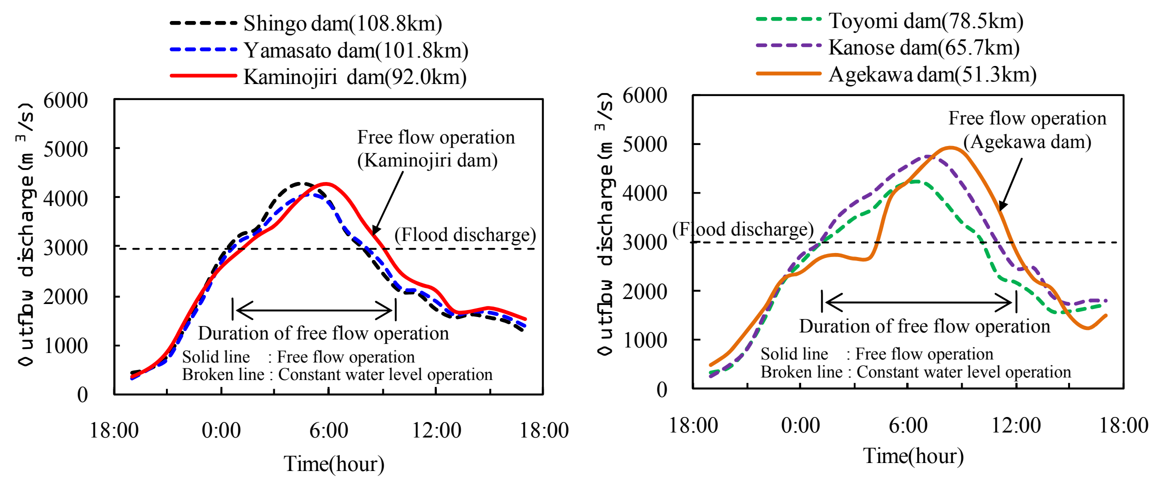
the dam, the water level just upstream of the dam body is maintained at spare stage. When the inflow discharge becomes larger than the capability, the flood gates are full opened. In this case, flood flow in the reservoir is no longer regulated. In this paper, we call the former operation “constant water level operation” and the latter “free flow operation”.

EFFECT OF GATE OPERATION OF SMALL HYDROPOWER DAM ON FLOOD PROPAGATION

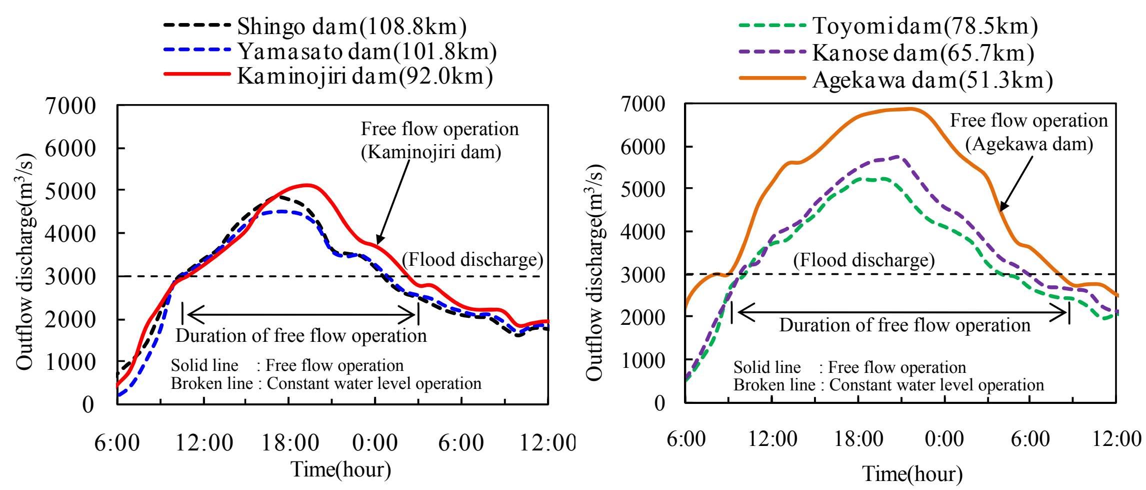
For the section shown in Figure 2, large floods in 1982, 2002 and 2004 are investigated in this paper. Figure 6 shows the outflow discharge hydrographs from the hydropower dams in these floods. The duration of the free flow operation are indicated by arrows in Figure 6. The free flow operation was conducted (i.e. flood gates were full opened) at Kaminojiri dam (92.0 km) and Agekawa dam (51.3 km) in all the floods. In the duration of the free flow operation, deformation of the discharge hydrographs is emphasized between Yamasato dam (101.8 km) and Kaminojiri dam (92.0 km), Kanose dam (65.7 km) and Agekawa dam (51.3 km). However, deformation of the outflow discharge hydrographs is relatively small between



(a) 1982 flood (left : Shingo dam□Kaminojiri dam , right : Toyomi dam□Agekawa dam).



(b) 2002 flood (left : Shingo dam□Toyomi dam , right : Toyomi dam□Agekawa dam).



(c) 2004 flood (left : Shingo dam□Toyomi dam , right : Toyomi dam□Agekawa dam)

Fig.6. Discharge hydrographs of hydropower dams in 1982, 2002 and 2004.

Table 2. Flood propagation speed in 2002, 2004 floods.

		CASE1	CASE2	
Section Studied		Shingo dam(108.8km)□ Agekawa dam(51.3km)	Shingo dam(108.8km)□ Toyomi dam(78.5km)	Shingo dam(108.8km)□ Kanose dam□65.7km)
Distance		57.5 km	30.3 km	43.1 km
Flood propagation time	2002 flood	220 min	100 min	150 min
	2004 flood	230 min	110 min	
Flood propagation speed	2002 flood	4.36□m/s	5.05□m/s	4.79□m/s
	2004 flood	4.17□m/s	4.59□m/s	

Shingo dam (108.8 km) and Yamasato dam (101.8 km), Toyomidam (78.5 km) and Kanosedam (65.7 km).

Next, we investigate the effects of these gate operations on flood propagation speed in reservoirs in 2002 and 2004 floods. The flood propagation speed is examined in the section long as possible, because it is difficult to examine in short section. The flood propagation speeds in each section are indicated in Table 2. In Table 2, CASE 1 indicates the flood propagation speed in the section which includes both Kaminojiri dam (92.0 km) and Agekawa dam (51.3 km) (i.e. include two dams conducted free flow operation). CASE 2 indicate the speed in the section which includes Kaminojiri dam (92.0 km) and doesn't include Agekawa dam (51.3km) (i.e. include one dam conducted free flow oeperation). Flood propagation speed in each section indicated in Table 2 is calculated by the following process. First, we examine the time lag of the occurrence of a maximum discharge between the upper end and lower end of each section from the time series data of the outflow discharge and record of the gate operation. And we define the time lag as the flood propagation time in each section. Also, because it is difficult to determine a maximum discharge at Kanose dam (65.7 km) in 2004 flood from the data, the flood propagation time and flood propagation speed between Shingo dam (108.8 km) and Kanose dam (65.7 km) in 2004 flood are excluded from this investigation (diagonal lines are drawn in Table 2). As shown in Table 2, flood propagation speed of CASE 1 is smaller than that of CASE 2. It means that the free flow operation delays flood propagation in the reservoirs compare with the constant water level operation.

UNSTEADY ONE DIMENSIONAL FLOW ANALYSIS IN THE RIVER WITH SERIES OF HYDROPOWER DAMS

To evaluate the storage function of the gorge section of the Agano River, we develop the unsteady one dimensional flow analysis to consider the effects of the gate operation of small hydropower dams and apply the model to the 2004 flood in the section shown in Figure 7.

The section-integrated continuity and momentum equation are shown as equation (1) and equation (2), respectively. And equation (3) is the force acting on a dam body and flood gates as defined in Figure 8.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \tag{1}$$

$$\begin{cases} \dfrac{\partial Q}{\partial t}+\dfrac{\partial QV}{\partial x}=-gA\dfrac{\partial H}{\partial x}-gA\dfrac{n^2V^2}{R^{4/3}} & (x\neq x_i) \\ \dfrac{\partial Q}{\partial t}+\dfrac{\partial QV}{\partial x}=-\dfrac{\partial}{\partial x}\int_B\left(\dfrac{1}{2}gh^2\right)dy-gA\dfrac{n^2V^2}{R^{4/3}}-\dfrac{F}{\rho} & (x=x_i) \end{cases} \tag{2}$$

$$F=K_P\cdot\int_B\left(\frac{1}{2}\rho g(H-H_u)^2+\frac{1}{2}\rho g(H^2-(H-H_d)^2)\right)dy \tag{3}$$

Where A = cross-sectional area, V = section-averaged velocity, Q = discharge, H = water level, h = water depth, R = wetted perimeter, B = river width on water surface, ρ = water density, g = gravity acceleration, n = Manning's roughness coefficient, F = force acting on dam body and flood gates, x_i = position of dam body.

The derivation of equation (2) and (3) are shown in Figure 8. First, we assume that river bed is flat and set the control volume as Figure 8. Equation (2) is derived from the assumption of hydrostatic pressure distribution and uniform velocity in cross sections. The force acting on a dam body and flood gates are given by hydrostatic pressure distribution and dimensionless parameter K_p as shown in Figure 8. K_p means the deviation of pressure distribution from hydrostatic pressure distribution on the dam body and flood gates. Where P = pressure, H_d = elevation of dam crest, H_u = bottom elevation of flood gates.

The calculation process is shown in Figure 9. Upstream and downstream boundary conditions are given by the time series data of the outflow discharge from Shingo dam (108.8 km) and observed water level just upstream of Toyomi dam body, respectively. Dimension less parameter K_p is adjusted as the calculated water level correspond to the observed water level at the points indicated by open dots in Figure 7. In this study, K_p varies from 1.0 to 1.35

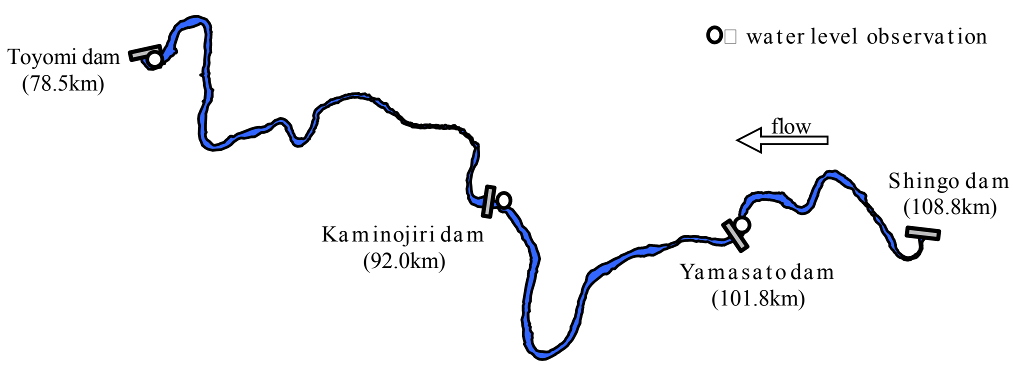


Fig.7 Plan form of section analyzed and observed points of water level

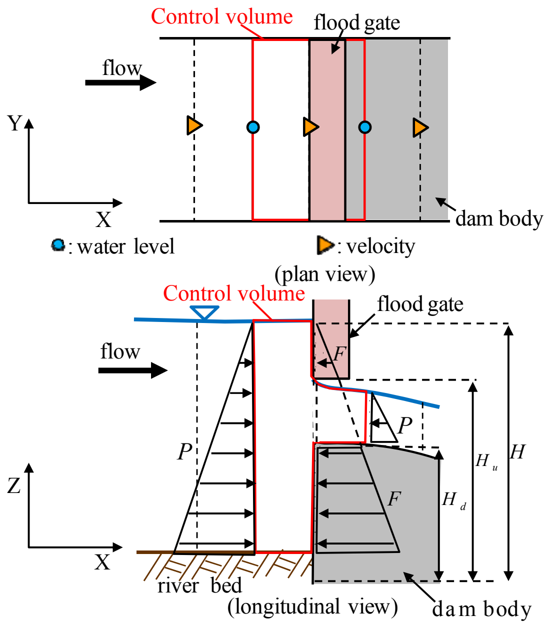


Fig.8 Concept of analysis for flow over the dam.

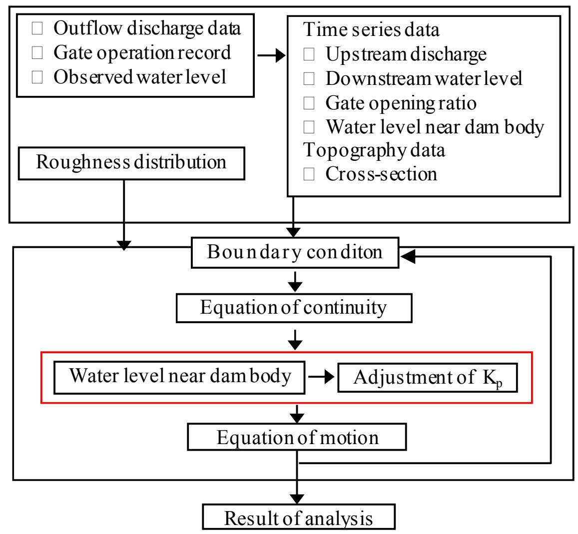


Fig.9 Flowchart of the analysis.

during flood. And, we give the Manning's roughness coefficient 0.04 uniformly in the section shown in Figure 7.

RESULTS OF ANALYSIS AND DISCUSSION

Figure 10 shows the observed and calculated outflow discharge hydrographs from the hydropower dams in 2004 flood. In Figure 10, the calculated outflow discharge becomes smaller than the observed discharge during the flood. It is the main reason that the lateral inflow in the section shown in Figure 7 is neglected in this analysis. However, deformation of the calculated discharge hydrographs are relatively large between Yamasato dam (101.8 km) and Kaminojiri dam (92.0 km) in the duration of free flow operation indicated by allows in Figure 10 and relatively small in the other duration. This tendency agrees with that of the observed discharge hydrographs shown in Figure 6.

Figure 11 shows the temporal changes of the calculated water level profiles in the reservoirs in the rising-discharge phase. In the reservoirs with constant water level operation (Yamasato dam (101.8 km) and Tyomi dam (78.5 km)), the water level is rising as discharge increase in the upstream part of the reservoirs, but remained almost constant at the downstream as shown in Figure 11. So, flood flow is stored only in the upstream part of the reservoirs with constant water level operation. On the other hands, in the reservoir with free flow operation (Kaminojiri dam (92.0 km)), the water level profiles become relatively mild due to the backwater effects of the dam body and change almost in parallel as shown in Figure 11. This indicates that the storage volume of flood flow in the reservoir with the free flow operation is larger than that with the constant water level operation.

Table 3 is the attenuation ratio of the maximum discharge in each reservoir. The attenuation ratio is defined the ratio of the attenuation of a maximum discharge in each reservoir to the

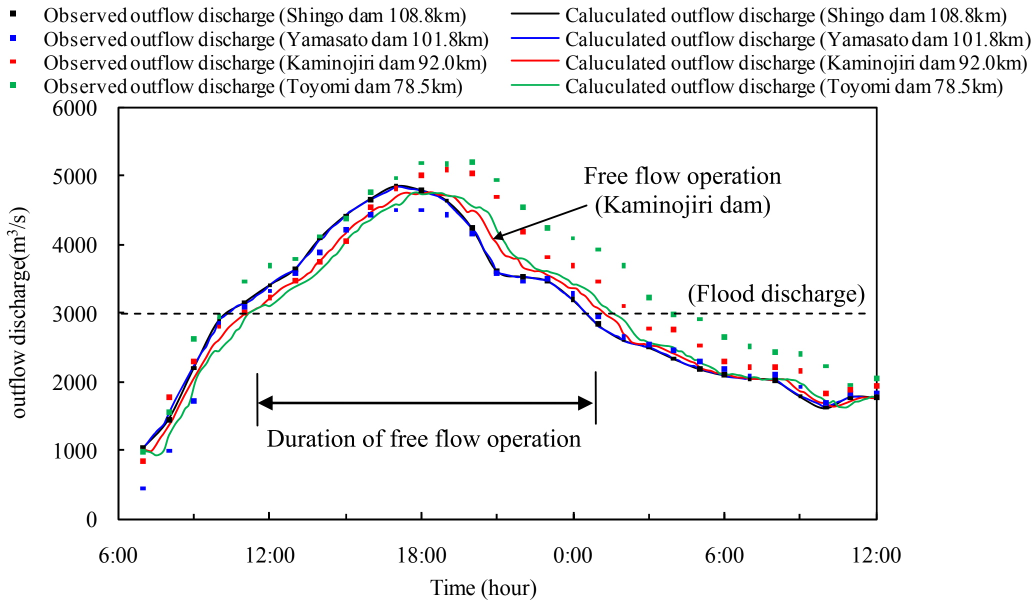


Fig.10 Observed and calculated outflow discharge hydrographs.

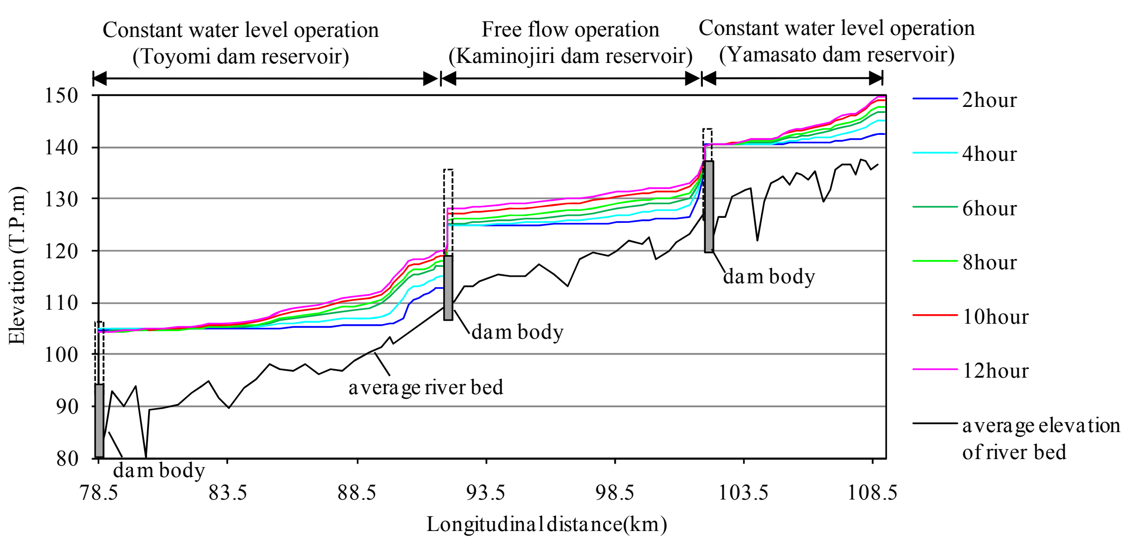


Fig.11 Temporal changes of water level profiles in reservoirs.

Table 3. Attenuation Ratio of maximum discharge in reservoirs.

Attenuaton ratio of maximum discharge		
Yamasato dam(101.8km)	Kaminojiri dam(92.0km)	Toyomi dam(78.5km)
Constant water level	Free flow	Constant water level
0.1	1.46	0.14

maximum discharge of Shingo dam. As shown in Table 3, the attenuation ratio in Yamasato dam (101.8 km) and Kanose dam (78.5 km) is only about 0.1 %. On the other hand, the attenuation ratio in Kaminojiri dam (92.0 km) reaches about 1.46 %. Because the effects of these hydropower dams are integrated and propagate to downstream, it is important to consider the effective use of the hydropower dams.

CONCLUSIONS

There are two different gate operations for small hydropower dam during flood. We investigated the flood propagation in the reservoirs associated with these gate operations. The primary conclusions are indicated below.

1 It was shown that the free flow operation delays the flood propagation and deforms the discharge hydrographs in the reservoirs compare with the constant water level operation from the observed data in the large floods in the gorge section of the Agano River.

2 We investigated the effect of the gate operation of small hydropower dams on temporal changes of longitudinal water level profiles and the attenuation ratio of a maximum discharge in the reservoirs by using the unsteady one dimensional flow analysis method which had developed to consider the gate operations.

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