

Numerical simulations of flow and large-scale bed variation using quasi-3D flow analysis methods in a river confluence during a large flood

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Strong flow attacking point and flow separation area due to a large flood were formed and large-scale erosion and sediment deposition occurred at the confluence of the Shinano River and Ikarashi River. In this paper, we apply the general bottom velocity computation (BVC) method to the confluence of a Shinano River and Ikarashi River to estimate three-dimensional flow and bed variation during the large flood. The general BVC model shows that the depth of the erosion and the deposition in separation area are not sufficiently reproduced, but structures of unsteady three-dimensional flow and bed variations are described on the whole.

Key words

River confluence, flood flow, flow attacking point, three-dimensional flow, bed variation, general bottom velocity computation (BVC) method , separation zone.

I INTRODUCTION

The Ikarashi River is the main tributary in the lower Shinano River that is known as a typical low-lying river in Japan. In the record-breaking flood observed in 2011, large discharge inflowing from the Ikarashi River caused large-scale erosion and sediment deposition around the confluence of the Shinano River and Ikarashi River. Therefore, it is important to establish a numerical model for investigating complex flow structures and bed variation mechanism around the confluence during the large flood. In recent years, Uchida et al. [1] have developed the general Bottom Velocity Computation (BVC) method capable of analyzing flood flows and bed variations considering the three-dimensionality of the flow. It has been shown that the general BVC method can evaluate the pressure deviation from hydrostatic pressure distribution and bottom velocity and elucidate the developing mechanism of the local scour around hydraulic structures in the laboratory experiments. However, the applicability to the river fields with a complex three-dimensional flow and large scale bed variation like the confluence of the Shinano River and Ikarashi River has been not been investigated enough. In this study, we apply the general BVC method to the river confluence and verify the reproducibility of flood flow and bed variation in the 2011 flood. In addition, we investigate the time change in flow and bed variation in the confluence area from the calculation results. These calculation results are compared with results observed during and after the flood.

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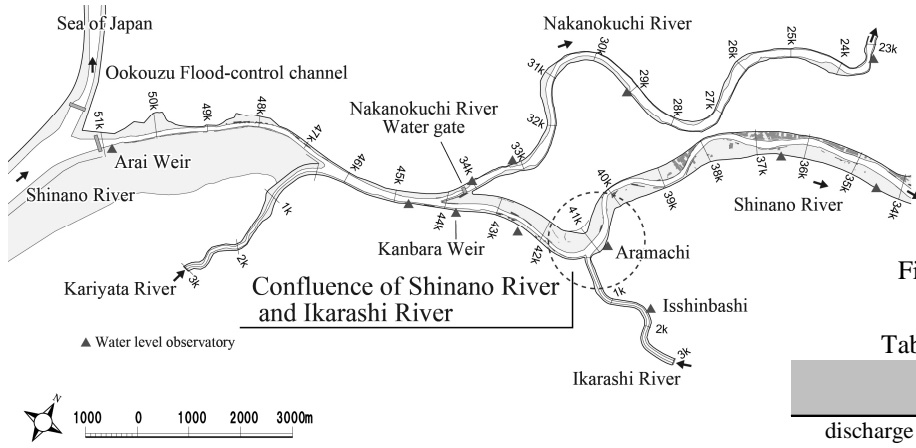


Fig.1 Plan form of the lower Shinano River and water level observation points.

II OBJECTIVE AREA AND FLOOD

Fig.1 shows the plan form of the lower Shinano River and water level observation points. There is no inflow from the Arai weir located around 51 km point of the lower Shinano River because the flood-control gates are completely closed during floods. Therefore, the flood discharge in the lower Shinano River is determined by discharges from the Ikarashi River and Kariyata River. As shown in Fig.1, the Ikarashi River joins the Shinano River at almost right angle. Three-dimensional flow structures and bed variations at the confluence change complicatedly during the floods due to the plan shape of the confluence and the inflow conditions of the Ikarashi River and Kariyata River. Table 1 shows the peak discharges observed in the Shinano River and Ikarashi River during the 2011 flood. The flood hydrograph has two peaks. The peak discharge at Isshinbashi in the Ikarashi River is over 2,000 m³/s and as large as the design flood discharge. On the other hand, the peak discharge at the Kanbara weir in the Shinano River is smaller than that of the Ikarashi River. As a result, the erosion at left bank around 41.2 km and the sediment deposition at right side in the main channel from 40.6 km to 41.0 km were seen in Fig.2.

III NUMERICAL ANALYSIS METHOD

The general BVC method [1] is able to evaluate non-hydrostatic pressure distributions and bottom velocities by not using the assumption of the shallow water flow. A set of governing equations as shown in Fig.3 are solved for the following unknown quantities: water depth h , depth averaged (DA) horizontal velocities U_i , DA horizontal vorticities Ω_i , horizontal velocities on water surface u_{si} , DA vertical velocity W , bottom pressure deviation from hydrostatic pressure distribution dp_b and bottom velocities u_{bi} . The bottom velocity equations (Eq.(1)) is derived by integrating horizontal vorticities respect to depth.

$$u_{bi} = u_{si} - \varepsilon_{ij3} \Omega_j h - \left(\frac{\partial W h}{\partial x_i} - w_s \frac{\partial z_s}{\partial x_i} + w_b \frac{\partial z_b}{\partial x_i} \right) \quad (1)$$

Where, z_s : water surface level, z_b : bed level, w_s , w_b : vertical velocities on water surface and bottom.

The bed variation analysis is calculated by the continuity equation for sediment and grain sizes (Hirano, 1971) using bed load formula (Ashida and Michiue, 1972) and suspended load formulas (Itakura-Kishi, 1980 and Lane-Kalinske, 1972). The transport of the suspended sediment is calculated by 3D advection and diffusion equations in this study.

IV ANALYSIS OF THE FLOOD FLOW AND BED VARIATION IN THE RIVER CONFLUENCE DURING THE 2011 FLOOD

IV – 1 Conditions of the numerical analysis

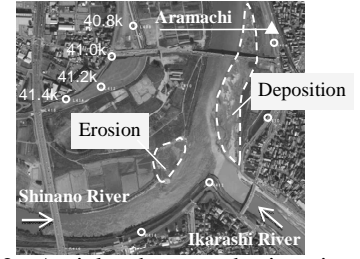


Fig.2 Aerial photograph in river confluence after 2011 flood.

Table 1. 2011 flood discharge.

		Shinano River	Ikarashi River
discharge in	first peak	439	2,088
2013 flood (m ³ /s)	second peak	1,035	2,292
design flood		800	2,400
discharge (m ³ /s)			

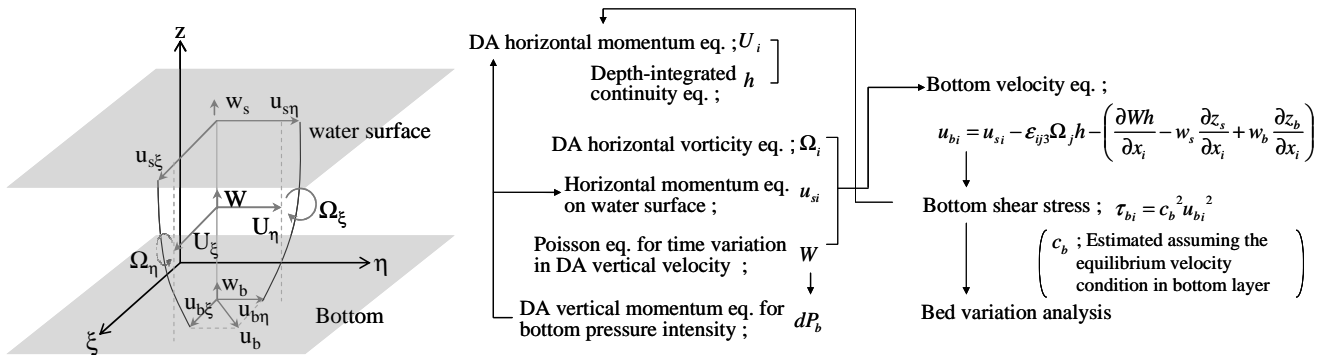


Fig.3 Flow of calculated method.

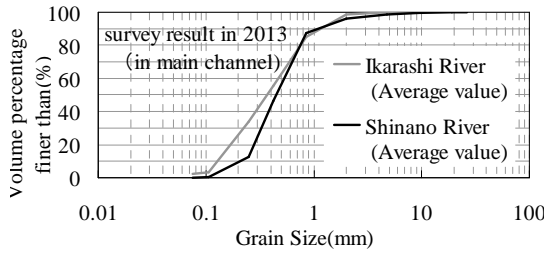


Fig.4 Grain size distribution.

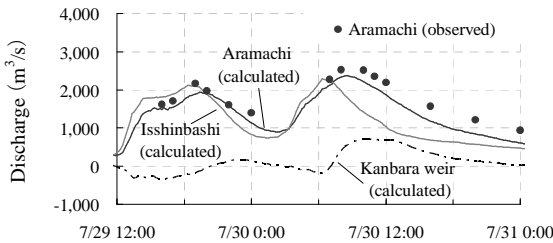


Fig.6 Discharge hydrographs in Shinano River and Ikarashi River.

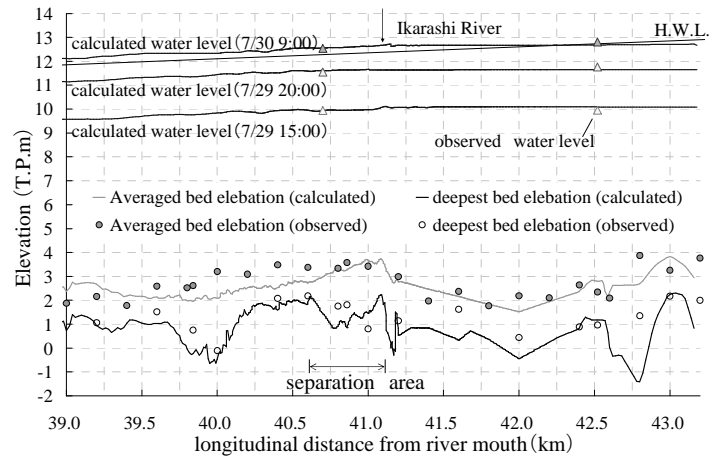


Fig.5 Comparison between calculated and observed water surface profiles and longitudinal distribution of the averaged and deepest bed elevation in Shinano River.

We apply the general BVC method to the 2011 lower Shinano River flood shown by Fig.1. The grid size of the confluence is set sufficiently small to calculate the three-dimensional flow structures. Boundary condition of the upstream end of the Shinano River is given by no-flux condition. Inflow discharge hydrographs from the upstream ends of the Ikarashi River and Kariyata River are provided so that the calculated water surface profiles coincide well with the observed ones in the objective area. The boundary conditions at the downstream ends are given by the observed water level hydrographs at 34.5 km point in the Shinano River and 23 km point in the Nakanokuchi River (see Fig.1). Fig.4 shows the grain size distributions to be used as the initial condition in the Shinano River and Ikarashi River. The bed material is composed of silt and sand and average diameter is about 0.5 mm. The Manning roughness coefficient is determined by the trial so as to explain the observed water surface profiles and bed variation in the 2011 flood. The eroded area around the left bank in 41.2 km point as shown in Fig.2 is treated as movable bed condition in this analysis.

IV – 2 Results and consideration of the numerical analysis

Fig.5 shows the comparison between the calculated and observed water surface profiles and longitudinal distributions of the averaged and deepest bed elevations in the lower Shinano River (39.0-43.2 km). The calculated results can elucidate the observed water levels, average and deepest bed elevations on the whole, while the bed elevation is estimated lower than the observation in the section indicated by an arrow in Fig.5 where the large separation area is formed due to the inflow from the Ikarashi River. The calculated discharge hydrograph at Aramachi in the Shinano River is in good agreement with the observed result as shown in Fig.6. Fig.7 shows the bed variation contour and depth averaged velocity vectors, and Fig.8 shows main flow velocity contour and secondary flow velocity vectors at 41.0 km and 41.2 km cross sections at the first and second peaks of the 2011 flood. Here, dark color corresponds to the velocity for downstream direction and light color indicates the velocities for upstream direction in Fig.8. The flow attacking point is seen at the left bank in 41.1km point and

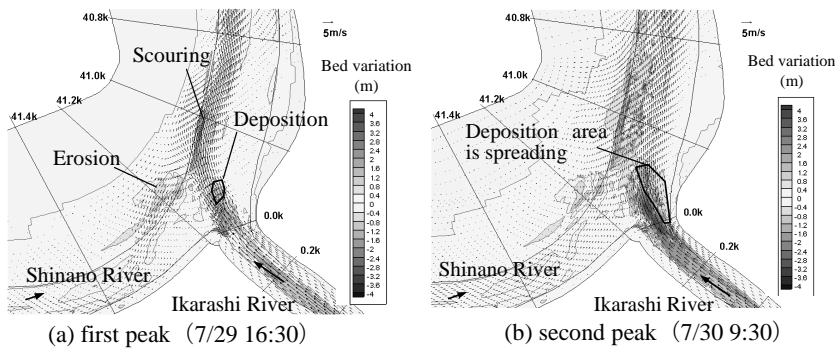


Fig.7 Calculated bed variation contours and DA velocity vectors in river confluence.

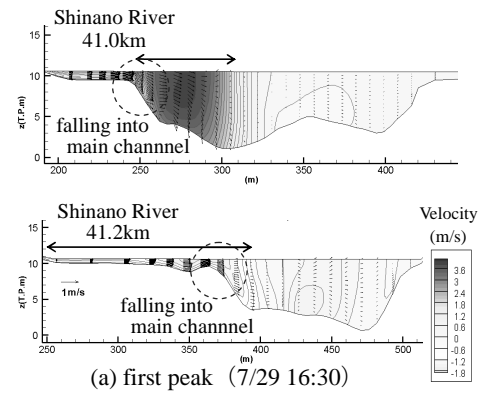


Fig.8 Calculated main flow velocity contours and secondary velocity vectors in cross sections.

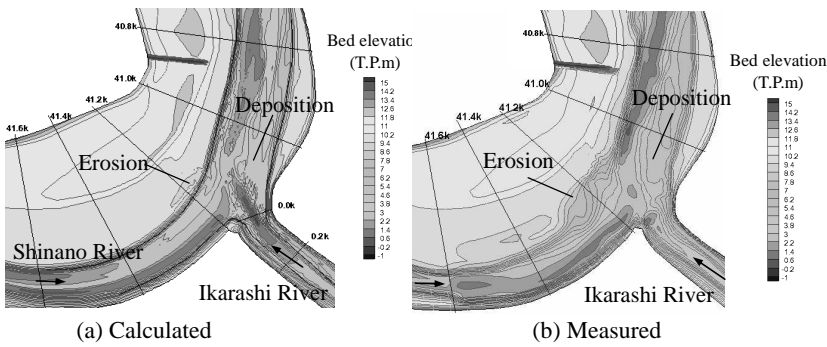


Fig.9 Comparison between calculated and observed riverbed elevation contours in river confluence.

the large separation area is formed at the downstream of the confluence at the first peak as shown in Fig.7(a) since the inflow discharge from Ikarashi River is very large compared with that from the Shinano River. Flood flows on the flood channel proceed to the upstream direction and fall into the main channel around 41.2 km point (see Fig.8(a)). Flow attacking to the river bank causes the bank erosion as shown in Fig.7(a). The bed scouring occurs along the left bank of the main channel around 41 km point (see Fig.7) where the inflow from the Ikarashi River concentrates, and the sediment deposition occurs along outer edge of the separation area. However, the lateral distribution of DA velocities in the main channel becomes mostly uniform at the downstream of the confluence at the second peak (see Fig.7(b)) as the discharge from the Shinano River increases, and the sediment deposition area shifts slightly to downstream. Fig.9 shows comparison between the calculated and observed riverbed elevation contours after the 2011 flood. As shown in Fig.9, the general BVC method can not elucidate the depth of the bed scouring at the flow attacking point and sediment deposition area in separation zone sufficiently. The eroded area is a rice field where the soil is very loose. But in this study, the bed material on the floodplain is assumed to be the same as that of the main channel. This is one of the reasons why the eroded area of the flood channel was estimated small.

V CONCLUSIONS

We apply the general BVC method to the confluence of the Shinano River and Ikarashi River for estimating the three-dimensional flow structures and large bed variations in the 2011 flood. The general BVC method cannot reproduce the depth of the bed scouring at the flow attacking point and sediment deposition at the flow separation area sufficiently. But it can describe the three-dimensional flow structures and bed variations on the whole during the flood.

VI REFERENCES

- [1] Uchida, T. and Fukuoka, S. (2012) – Bottom velocity computation method by depth integrated model without shallow water assumption, *Journal of JSCE, Ser.B1 (Hydraulic Engineering)*, Vol. 68, No. 4, I_1225-I_1230.