Long-term monitoring of sediment runoff for an active sediment control in Joganji River

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Abstract. There were huge sediment yielding and deposition due to debris flows by breaking natural landslide dams which were formed by earthquake in 1858 at upstream reach of Joganji River. Sediment transportation is still active by debris flow and flow with bedload due to rainfall, though a lot of erosion control dams have been constructed. Continuously measuring sediment runoff for long term along a main river is necessary to evaluate the propagation of sediment after the huge events for sediment management in the basin using well hydrological information. Appropriate tools are selected and applied to monitoring in the area managed by Tateyama Mountain Area Sabo Office along Joganji River, using a Reid-type bedload slot sampler, robust-type hydrophone and velocity meter on the bed for bedload and turbidity meter for washload. Monitored data is concentratedly collected at the office to apply risk management for sediment movement due to heavy rainfall and so on. Several typical data and problems to solved were shown because it passed around twenty years since sediment monitoring started, and those are reported in present study.

1 Introduction

Discontinuous relationships between sediment and water runoff frequently appear in mountainous regions, through long-term sediment monitoring, and those show the necessity of sediment monitoring there [1]. Following sensors have been selected and installed as appropriate tools such as a set of hydrophones for bedloads, pressure meter for the flow depth, turbidity meter for washloads and an electro-magnetic velocity meter on the bed for bed shear stress for sediment monitoring in Japan [2]. In Joganji River, longitudinal sediment monitoring is carried out using robust-type sensors, that could prevent from collisions by boulders along a main river. Because there is huge volume of deposited sediment due to debris flows and landslides by earthquake in 1858 at upstream reach of Joganji River. Sediment transportation is still active by debris flows, flow with bedload and so on, though a lot of erosion control works have been constructed.

Additionally, a sabo dam with a movable shutter was installed for smoothing sediment runoff from a slit dam and for an effective control of sediment runoff in the basin. Because it will be important recently for long-term usage of sabo facility and sediment environment to run out debris from up- to down-stream. Pilot operations were tried to conduct in flood to flood, and some examples of sediment controls were obtained with/without shutter operations during floods [3, 4].

Present study reports monitored data obtained along a main river of Joganji River such as continuous measuring and the related system for sediment runoff along a main river. Hydrological and sediment information is also applied to sediment management in the basin. Several matters to be solved are shown through sediment monitoring such as the limitation for bedload measurements using acoustic wave and the difficulty of suspended load in steep torrents of Joganji River.

2 Monitoring stations and related information

Figure 1 shows the observation stations, which are arranged as (A) to (F) from upstream reach and Fig. 2 show sensors installed at Tsunoura-Karyu sabo dam ((D) in Fig. 1). Figure 3 is the longitudinal bed profiles

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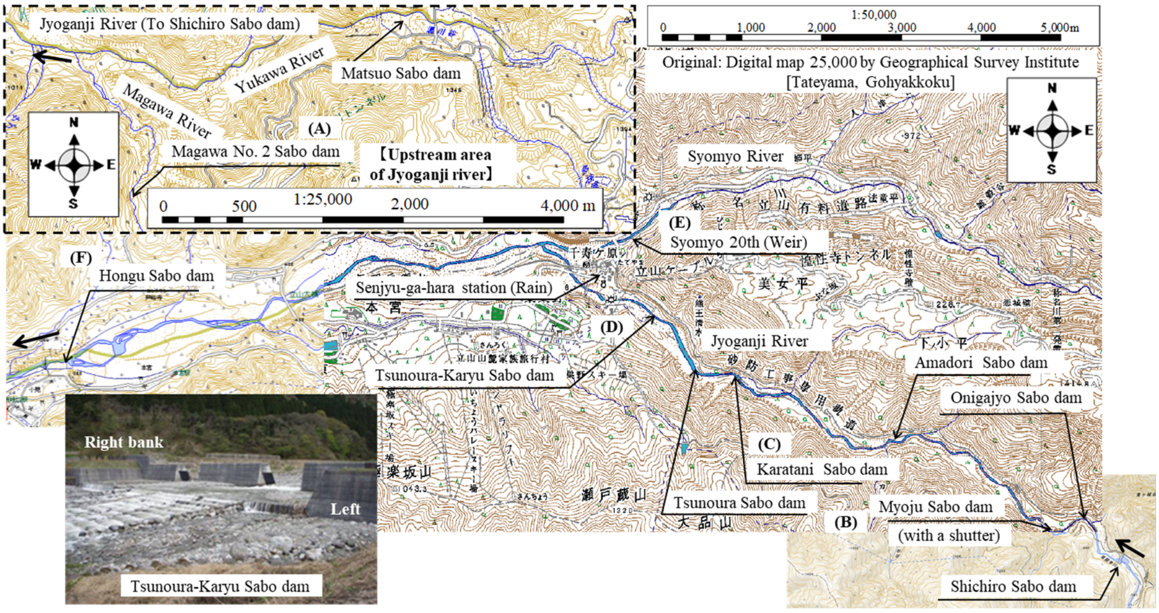

Fig. 1. Sabo dams and monitoring stations along Joganji River.

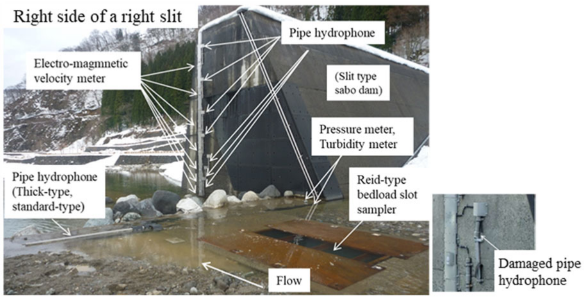

Fig. 2. Sensors installed at Tsunoura-Karyu sabo dam.

of Joganji River. Bedload monitoring at Hongu sabo dam ((F) in Fig.1) started using a pipe hydrophone and pressure meter for the flow depth started on 15th December in 2009 and the measurement by turbidity meter began on 17th December in 2012 [3, 4]. At Hongu sabo dam, width of spillway is 85 m, flow width is 52 m, bed slope is 1/90 and drainage area, A, is 193.1km^2. Bed material has a range of diameters such as d_{60}= 30 mm and d_{95}= 150 mm [2]. At Tsunoura-Karyu sabo dam, concentrated monitoring was carried out at the slit of the sabo dam since June in 2001. The catchment area of the dam, A, is 139.49 km^2 and the bed slope near the dam is 1/56 which is measured in 2007. Flow width is 110 m and bed sediment have a range of diameters such as d_{60}= 20 mm and d_{95}= 200 mm [2]. Rainfall is measured at Senjyu-ga-hara Station as shown in Fig. 1. Sediment monitoring started with a combination of sensors and Reid-type bedload slot there, that was installed in

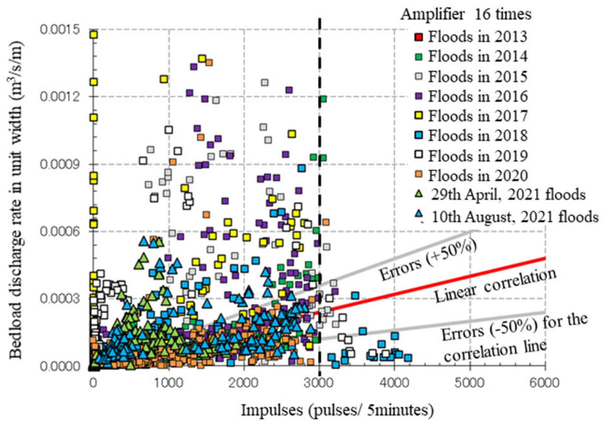

Fig. 4. Linear line between impulses of the pipe hydrophone and bedload discharge by the bedload slot at Tsunoura-Karyu sabo dam.

January 2008. The size is 2.0m X 2.0m in plane, 1.5m in deep and the slit is 0.6m on the bed. Other sensors are a pressure meter, a pipe hydrophone (since 2001) and a turbidity meter (since December in 2012).

The calibration line, as shown in Fig. 4, is obtained and modified year to year between impulses of the hydrophone and bedload discharge by the bedload slot [3, 4]. Water discharge rate is calculated using a relation between flow depth, H, and discharge rate, Q, estimated by surface velocity measurements in floods. Data in Fig. 4 is obtained from pipe hydrophone, and a linear correlation can be used until 3,000 to 3,500 impulses/5 minutes due to saturation of acoustic wave. In Joganji River basin, there are a lot of boulders transported by

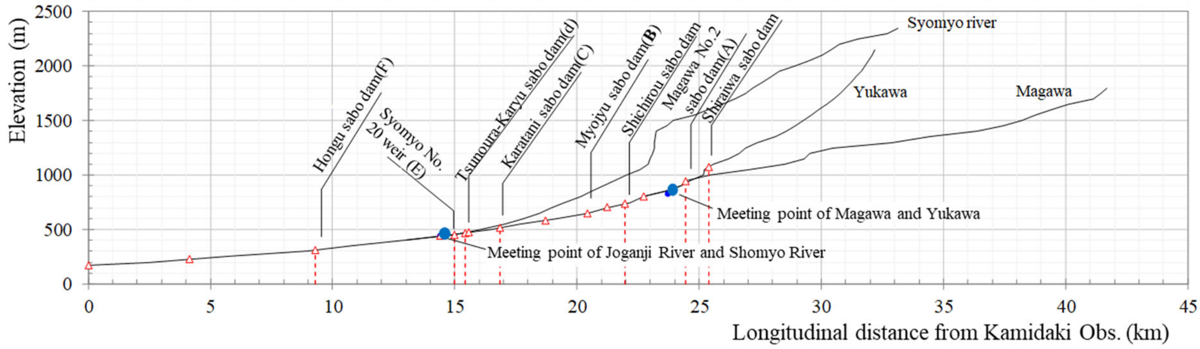

Fig. 3. Longitudinal bed profiles along Joganji River.

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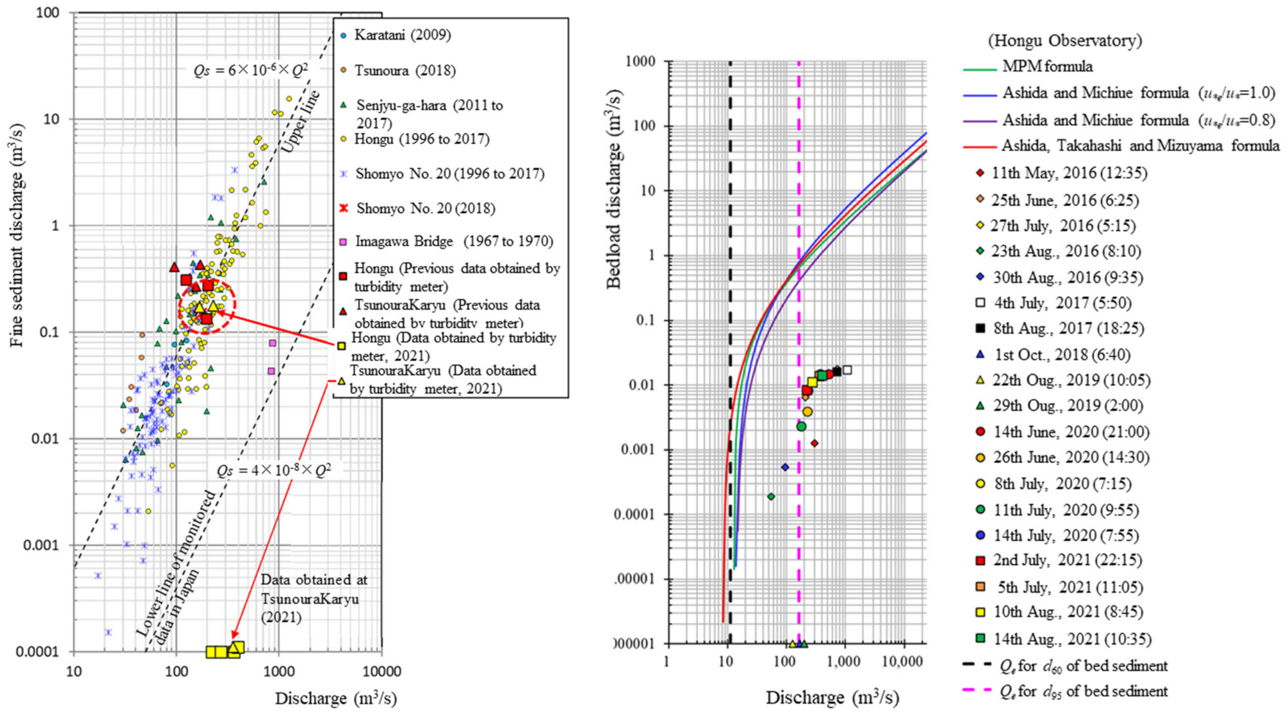
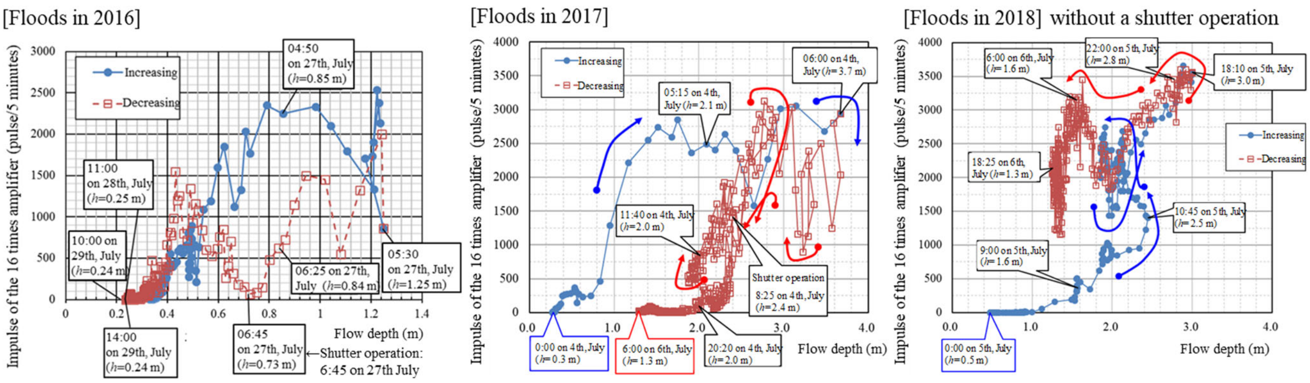


(a) Fine sediment discharge (b) Bedload discharge at Hongu sabo dam

Figs. 5. Relation between flow discharge rate and sediment discharge rate at specified stations in Joganji River.



Figs. 6. Relation between flow depth and bedload discharge, that is shown by impulses during 5 minutes, at Karatani sabo dam

floods from sources related to previous landslide. A pipe hydrophone is always destroyed due to collisions by those boulders, and the plate type is mainly used there. The value increases 4,500 impulses in case of the plate type hydrophone (the thickness is 12 mm) through sediment monitoring at Tsunoura-Karyu sabo dam, though the detection for fine component of bedload becomes dull in comparison with pipe hydrophone.

3 Measured data by sensors

3.1 Bedload and washload

Figure 5(a) shows the relation between water discharge rate and fine components of sediment discharge measured by a turbidity meter and direct water sampling at several observatories. Data measured by turbidity meter at Hongu and Tsunoura-Karyu sabo dams is also plotted in the figure, and the data is for the peak stage in a flood. The linear calibration line is obtained between the output of turbidity meter (Voltage) and volumetric concentration with Kaolin and water mixture [4]. In 2021, monitored data does not take normal values due to failure of turbidity meter at Tsunoura-Karyu sabo dam. Two dashed lines identify the range of fine components of sediment discharge in Japan. Measured value is close to be relatively large in Japan.

Figure 5(b) shows the relation between water discharge rate and bedload discharge, that is obtained by hydrophone, at Hongu sabo dam. The bedload discharge is calculated by correlation line shown in Fig. 4. Several bedload formulas for d_{60} are compared with previously measured data. The value of bedload has the limitation as 0.01 to 0.02 m^3/s because the saturation of the acoustic wave takes place for pipe hydrophone.

Runoff of the fine sediment discharge is still active because a lot of the fine component of sediment is yielded from debris fans, side bank and bed that are formed by previous landslides. However, bedload discharge is inactive in present bed condition in Joganji River. Bedload and boulders yielded by previous landslides are captured by sabo dams along the main river, and result in inactive transport.

3.2 Hysteresis curves

A sabo dam with a shutter is installed at Myoju sabo dam ((B) in Fig. 1) [2, 3, 4] to carry out advanced sediment runoff control, and that means runoff control of bedload and boulders during floods. A shutter operation has almost two roles: One is active sediment runoff control, and the other is shutter movement control during operations. Trial attempts for preferable operation were conducted during floods since 2016.

Figures 6 shows the relation between the flow depth and bedload discharge measured at Karatani sabo dam ((C) in Fig. 1), which is at 3,645 m downstream of Myoju sabo dam. Those data were obtained during a shutter operation except floods in 2018 without the operation. Currently, there could be the hysteresis curve for wash load and bedload through sediment monitoring using hydrophone [3, 4]. Interesting data is obtained for bedload monitoring such as hysteresis curves, though the theoretical understanding needs to evaluate those curves. There were the clockwise curves for the flow depth versus the wash load in floods in 2016, 2017 and 2018. There were clockwise curves for the flow depth versus the bedload with the shutter operation in 2016 and 2017. However, there was counterclockwise curve without the shutter operation in 2018, because the deposited sediment in the storage area of the Myoju sabo dam was almost transported during the flood [4]. The data means that rapid sediment runoff took place in the decreasing stage of the flood at the slit of Myoju sabo dam without shutter operation. There are two possibility that one is sediment runoff deposited in the storage area of the dam from the slit during the flood, and the other is unusual sediment transport due to debris flows occurred somewhere in upstream reach. The hysteresis curve could be preferable tools to evaluate rapid bedload runoff in a flood. For example, the curve takes counterclockwise pattern if sediment transport such as debris flows takes place during a flood. The data could be useful for risk management against unusual sediment transport.

Bedload and wash load could be monitored well by sediment monitoring using sensors such as hydrophone and turbidity meter. However, suspended load is still difficult in mountainous stream. One trial has been carried out at Tsunoura-Karyu sabo dam as shown in Fig. 2, using vertical installed hydrophones and velocity meter [2]. Several data were obtained since those sensors were installed in November 2009. However, the vertical hydrophone was also damaged by collisions of suspended sediment particles as shown in Fig. 2.

4 Conclusions

At upstream reach of Joganji River, there were huge sediment yielding and deposition due to debris flows by breaking natural landslide dams formed by earthquake in 1858. Sediment transportation is quite active by debris flow and flow with bedload due to rainfall, though a lot of erosion control works have been constructed.

In Joganji River, continuously measuring during over twenty years and the related system for sediment runoff along a main river has been carried out to evaluate magnitude of sediment transport since about 150 years after huge sediment disasters according to development of recent sensors for measurements. The knowledge through long-term monitoring will be connected to applied sediment management in the basin using hydrological information in future sabo management there. Then, one tool was proposed through sediment monitoring, and that is hysteresis curve for fine components of sediment and bedload. Unusual sediment transport could be detected by clockwise and counterclockwise hysteresis curves, due to debris yielding somewhere. Fine components of sediment transport are still active, but bedload transports are inactive due to sabo countermeasure such as sabo dams. The several matters to be solved are found through sediment monitoring such as the limitation for bedload measurements using acoustic wave and the difficulty of suspended load in steep torrents.

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