7th International Conference on Debris-Flow Hazards Mitigation

Monitoring of sediment runoff and observation basin for sediment movements focused on active sediment control in Jo-Gan-Ji River

Takahiko Nagayama [a,*], Tomohiko Furuya [a], Satoru Matsuda [a], Takahiro Itoh [b], Masaharu Fujita [c], Takahisa Mizuyama [d]

[a] *NIPPON KOEI Co., Ltd, 1-43, Eki Nishihon-machi 5-chome, Kanazawa-shi, Ishikawa 920-0025 JAPAN*
[b] *NIPPON KOEI Co., Ltd, 2304 Inarihara, Tsukuba, Ibaraki 300-1259 JAPAN*
[c] *Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011 JAPAN*
[d] *National Graduate Institute For Policy Studies (GRIPS), 7-22-1 Roppongi, Minato-ku, Tokyo 106-8677, Japan*

Abstract

Continuously measuring sediment runoff along multiple sections of the Jo-Gan-Ji River is necessary to understand both the propagation of sediment as well as the changing of grain sizes in order to appropriately evaluate sediment yielding from debris flows temporally and spatially. The present study proposes a combination of sediment monitoring tools and appropriate equipment to identify various sediment transport modes from wash load to bedload in mountainous torrents. As a result of monitoring runoff volume and grain sizes, sediment management can be achieved. In the Jo-Gan-Ji River basin in Japan, temporal and longitudinal sediment runoff has been measured continuously since the 1990's. Previous studies help determine the proper instrumentation suite for this type of sediment runoff monitoring. Bedload is measured with a Reid-type bedload slot sampler and by use of the hydrophone to survey acoustic waves. In addition, hydrophones and a velocity meter (vertically installed on a side wall) are used to quantify suspended loads. A turbidity meter is also used to measure wash load. Propagation of sediment particles can be observed during flooding in mountainous torrents. Specifically, bedload discharge rates of each particle are evaluated using of the hydrophone. Monitoring of the Jo-Gan-Ji river also identifies inactive bedload movements such as large boulders. Previous installations of this type monitoring equipment make it clear that the destructive nature of bedload collisions indicate a need for robust instruments. Alternate instrumentation methods, that are robust, are explored here. Moreover, in order to actively control sediment runoff in flooding, we developed a sabo dam with shutter and pilot operations that activate during flooding. Differences of those sediment transport characteristics with/without the shutter also shown through the sediment monitoring along the Jo-Gan-Ji River.

Keywords: sediment monitoring; Japanese pipe hydrophone; bedload monitoring tools; sediment management; sabo dam with shutter

1. Introduction

Sediment runoff due to floods has been continuously monitored in a small basin in a mountainous region of Japan since the 1990s to evaluate runoff properties as well as administer watershed management. Several sensors are used for this monitoring including a Japanese hydrophone, turbidity meter, pressure sensor for flow depth, bedload slot, etc. (e.g., U.S. Geological Survey, 2010). However, there are only a few examples for longitudinal measurements along a main river with a length > 10km. In the basin where sediment yield is continuously active, detection for sediment movement/runoff through monitoring is necessary for reduction of disaster. For this reason, it is necessary to rapidly monitor river channel conditions by using both longitudinal and temporal measurement tools to appropriately evaluate continuous sediment runoff and sediment sorting.

For the purpose of sediment control in basin management, information on sediment runoff and water flow in mountainous torrents has attempted to be collected using various sensors to continuously measure bedloads, suspended loads, turbidity, flow depth and so on. Relationships found through monitoring between bedload/wash loads and water

* Corresponding author e-mail address:*a4619@n-koei.co.jp*

runoff show that there is a discontinuous relationship between sediment and water runoff in mountainous regions. This further shows that direct monitoring and evaluation of suspended loads and bedloads is still quite difficult. Several members of Kyoto University, Japan have reviewed passive and direct sediment monitoring methods in mountainous regions (in Japan and abroad) and have tried to develop previous methods of evaluating sediment runoff. The following instruments were selected as a suitable monitoring apparatus: a set of pipe-hydrophones for bed loads, pressure sensors for the flow depth, turbidity meters for wash loads and an electro-magnetic velocity meter on the bed for bed shear stress (Mikami et al., 2014). These instruments are installed in several sections of the upstream reach of the Jyo-Gan-Ji River.

In Jo-Gan-Ji River, longitudinal sediment monitoring for various wide sediment transport modes (from wash load) to bed load is carried out using preferable sensors for measuring sediment movement, focused on sediment discharge rates for each component of grain size. Moreover, those sensors are robust to protect from sediment collision by large boulders. In the Jo-Gan-Ji River basin, a sabo dam with a shutter is proposed and installed for smoothing sediment runoff with open-type concrete slit dam. An effective control of sediment runoff is attempted using of the silt dam along with sediment monitoring tools and sensors. The results are an active sediment management system in the basin. In the present study, monitoring data and trial runs with a shutter on the dam are shown for management of water and sediment runoff in a mountainous basin. Sabo dam (a dam with a movable shutter) is an effective tool in the basin when combined with the applied monitoring system.

2. Bed load to wash load and related hydraulic quantities monitoring

2.1. Study basin and installed sensors for monitoring

The monitoring system installed in the Jyo-Gan-Ji River, prepared by the Tateyama Sabo Office, consists of a data collection network and an optical cable network. Temporal and longitudinal monitoring for water and sediment runoff is conducted continuously to evaluate the spreading of sediment discharge, the effects of sabo facilities, and the confluence of tributaries on the sediment runoff.

Fig. 1 shows the observation stations in the Jyo-Gan-Ji River, and Fig. 2 are the longitudinal bed profiles of the river. Sabo dams and weirs are indicated from (A) to (F) in Fig. 1. Because sabo facilities work well for maintaining bed elevation, from a macroscopic view the longitudinal bed profiles are almost level. The optical network for monitoring data collection has been set up in the basin and data is collected at the Sabo Office (Mikami et al., 2014).

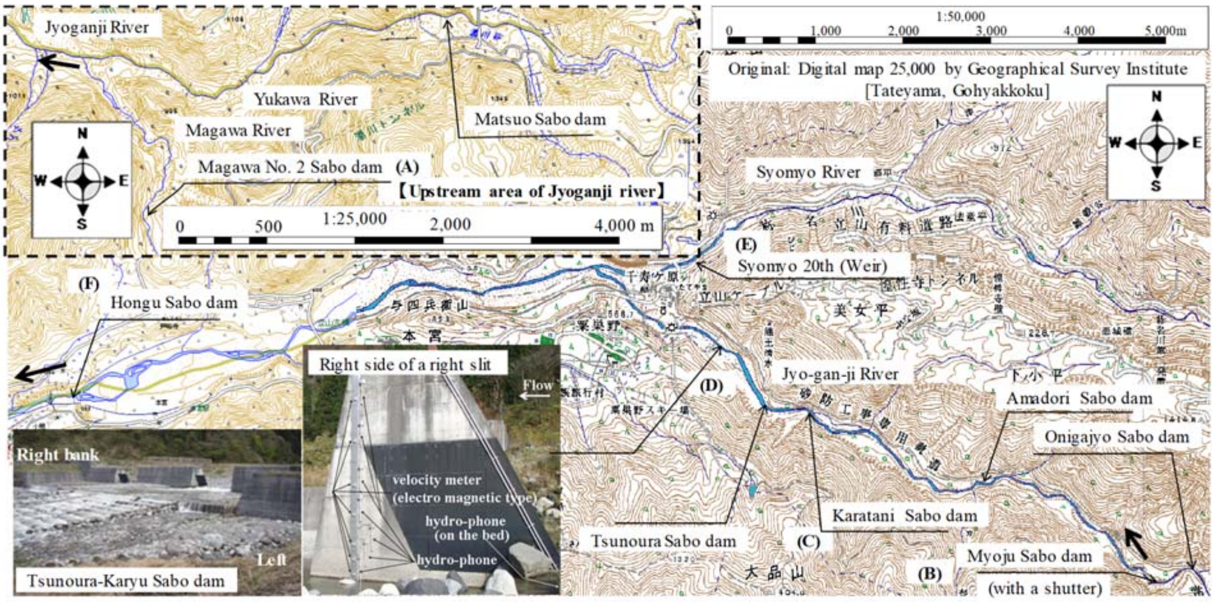

Fig. 1. Observation station in Jyo-Gan-Ji River

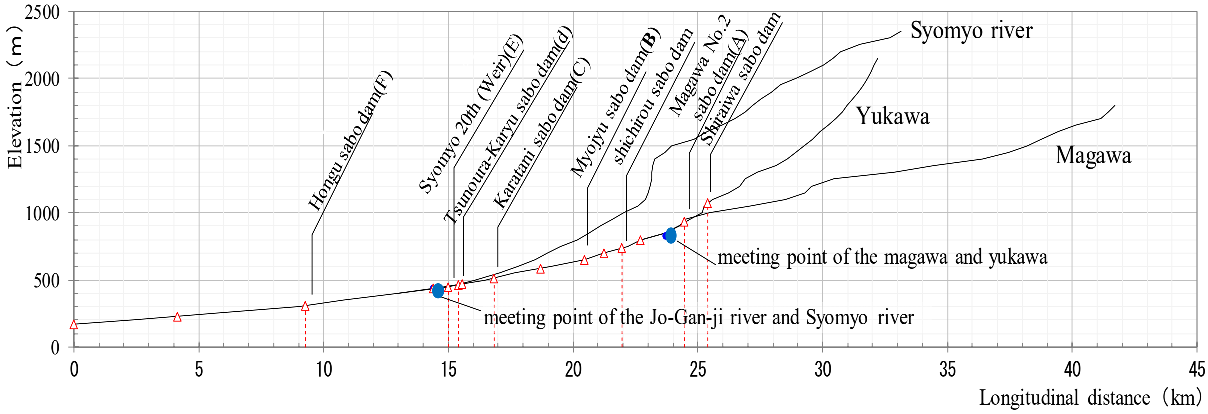

Fig. 2. Longitudinal bed profile of Jo-Gan-Ji River

2.2. Measured data

Bed load monitoring at the Hongu sabo dam ((F) in Fig.1) using a Japanese pipe hydrophone and pressure meter for the flow depth started on 15th of December in 2009. Modified measurements using the pipe hydrophone for bedload, pressure meter for flow depth and turbidity meter for wash load began on the17th December in 2012. At the Hongu sabo dam, flow width is 52 m and bed slope is 1/90(0.0111). Water discharge is calculated using a relationship between flow depth, H, and discharge, Q, estimated by surface velocity measurements in floods (*H*-*Q* curve). Bed sediment has a wide range of diameters: d_{60}= 30 mm and d_{95}= 150 mm. At the Tsunoura-Karyu sabo dam ((D) in Fig. 1), concentrated monitoring has been conducted at the slit part in right bank site of the sabo dam since June of 2001 (U.S. Geological Survey, 2010). The watershed area of the dam is 139.49 km^2 and the bed slope near the dam is 1/56(0.0179), which is measured in 2007. In the Tsunoura-Karyu sabo dam, monitoring of water and sediment started with a combination of Reid-type bedload slot, a flow depth meter, and a pipe hydrophone. Temporal changes indicated around 70 events that occurred between the installation in June of 2001 until March of 2013. Rainfall is measured at Senjyu-ga-hara Station. The monitoring was started using the pipe hydrophone and pressure meter for the flow depth. In January of 2008, a Reid-type bedload slot was installed to obtain the correlation between impulses of the Japanese pipe hydrophone and bedload discharge recorded by the bedload slot. At this station, flow width is 110 m and bed sediment also has a wide range of diameters: d_{60}= 20 mm and d_{95}= 200 mm.

Fig. 3 shows the calibration line between impulses by Japanese pipe hydrophone and bedload discharge measured by the bedload slot at the Tsunoura-Karyu sabo dam. This relationship is used of estimation for bedload discharge at several observatories in the Jo-Gan-Ji River. Several equilibrium bedload formulas for d_{60} are compared with previously measured data (e.g., Japan Society of Civil Engineering, 1999). Fig. 4 shows the relationship between water discharge and bedload discharge at Hongu sabo dam. Water discharge is calculated using the *H*-*Q* curve and bedload discharge is calculated using Fig. 3. Fig. 3 is the correlation between the amount of sediment transport measured by the bedload slot and the impulse number of the Japanese hydrophone. Fig. 5 shows the relationship between water discharge and fine components of sediment discharge measured by a turbidity meter at several observatories in the Jo-Gan-Ji River. The two dashed lines identify the range of fine components of sediment discharge in Japan (Japan Society of Civil Engineering, 1999) to compare to the monitored data in the Jo-Gan-Ji River. Although fine components of sediment discharge have large values, bedload transportation is not active because there has not been a large magnitude of sediment yielding as a result of large events, such as a landslide and a debris flow, in the past 50 years.

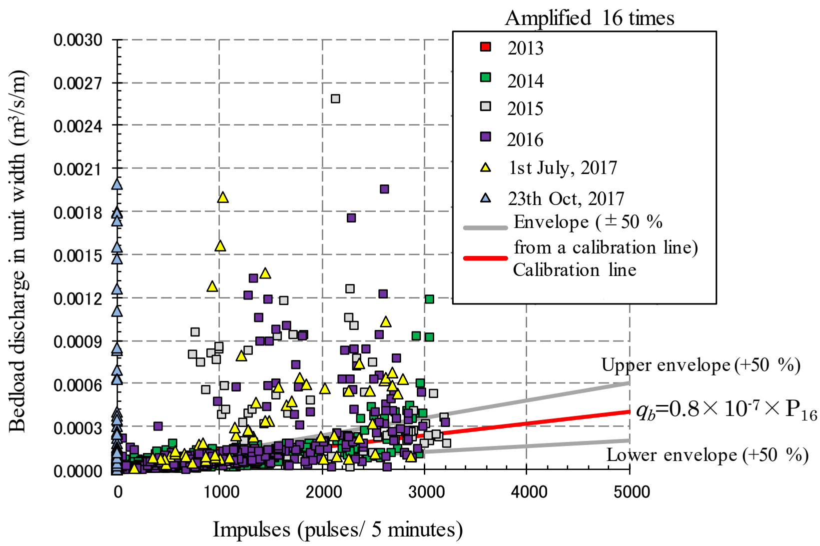

Fig. 3. Calibration line between impulses by Japanese pipe hydrophone and bed load discharge measured by a bedload slot

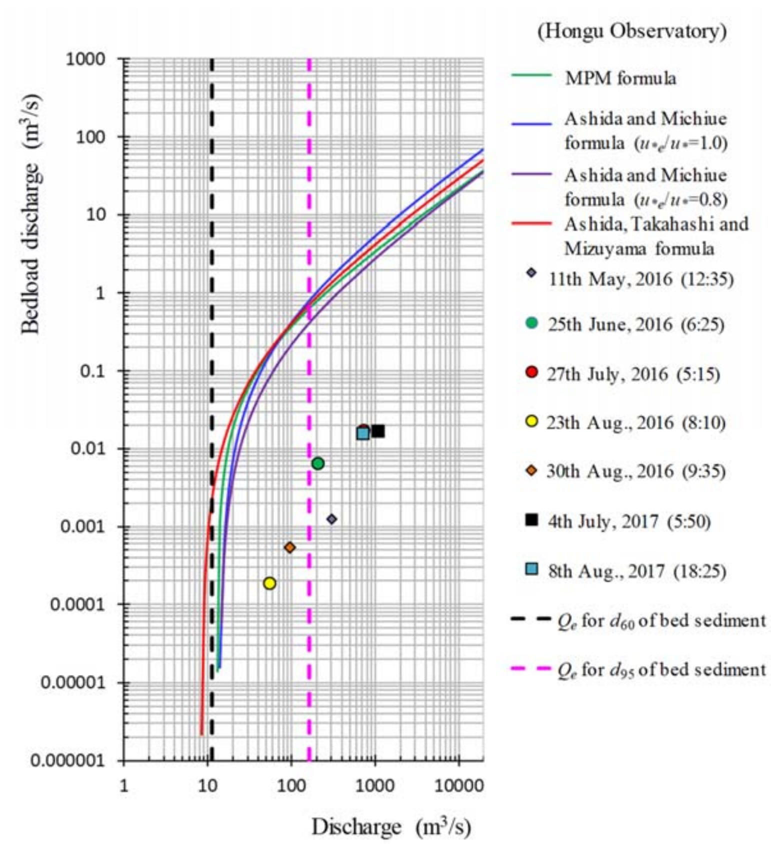

Fig. 4. Relationship between water discharge and bedload discharge

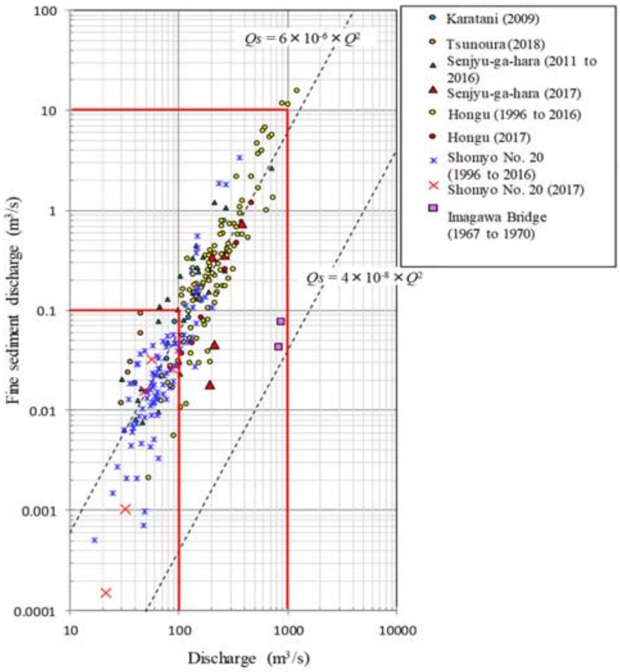

Fig. 5. Relationship between water discharge and fine components of sediment discharge measured by a turbidity meter

2.3. Development of robust sensors in mountainous region

Continuous longitudinal sediment observation such as bedload and wash load started in Jo-Gan-Ji River since 2013. However, damage to sensors often occurred, especially the Japanese pipe hydrophone, which has a pipe of 3 mm thickness. As a result, continuous measurements of bedload discharge could only be obtained in small/medium sized floods. During large-sized floods, pipes on the bed surface experience physical damages such as indentation and deformation.

In order to prevent the Japanese pipe hydrophone from having physical damage during continuous bedload monitoring, two different robust solutions were compared. One is thick pipe (e.g., 10.2 mm) and the other is a plate-type (thickness is 12 mm), ideally to help withstand heavy collisions by large boulders. Figs. 6 show the relationships between impulses recorded by the robust-type hydrophones (thick pipe and plate) and the bedload discharge measured by the bedload slot. The data is measured at the Tsunoura-Karyu sabo dam ((D) in Fig. 1). A similar correlation was found between the bedload discharge measured in the bedload slot and the standard type of hydrophone (thickness is 3 mm), but there is variation at the small impulse number. These data show that it is difficult to measure sediments of small particle size. for that reason, impulses from the hydrophone must be measured with a higher amplification than that of standard type of hydrophone (thickness is 3 mm). More data collection is needed for further discussion of general applicability using robust-type hydrophones.

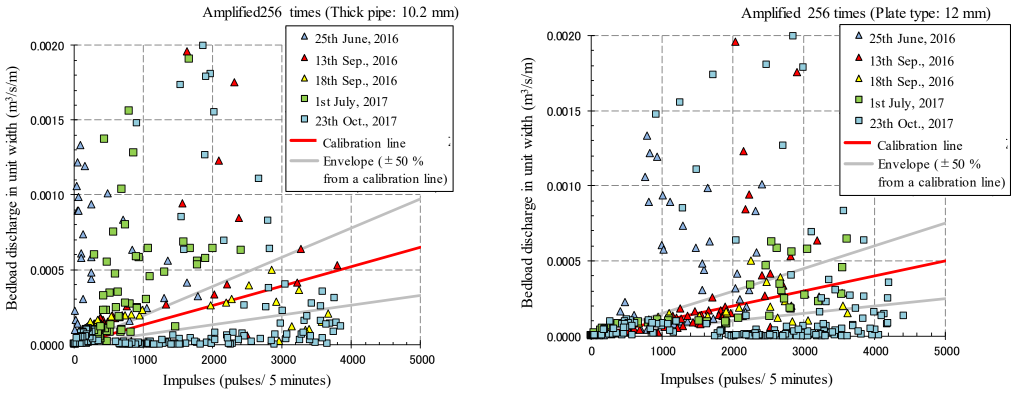

Fig. 6. Relationship between impulses by robust type hydrophone and bed load discharge measured by bedload slot, (a) Thick pipe; (b) Plate type

3. Effective sediment control tool and their applicability

3.1. Installation of sabo dam with a shutter

A sabo dam with a shutter is installed in the middle region of the Jo-Gan-Ji River ((B) in Fig. 1). The purpose of the shutter is to actively control sediment runoff during floods. The shutter has a structure in which the lower part of the slit dam is opened and closed by oil hydraulic pressure, as shown in Fig. 7. The slit with a shutter has two important roles, one being sediment runoff control, and the other being shutter movement control.

Trial operations have been conducted by floods, and the preferable timing of the shutter operation is found through trial operations.

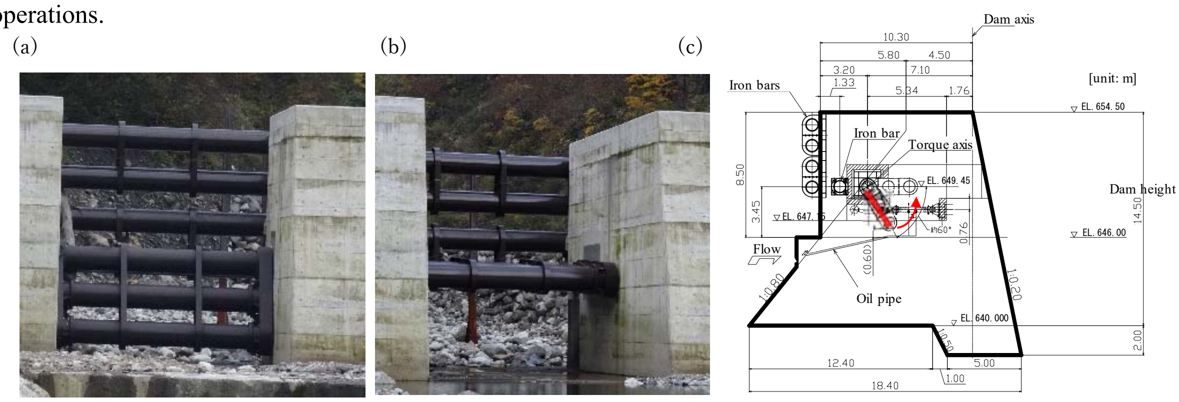

Fig. 7. A shutter at Myoju sabo dam ; (a) closed; (b) open in usual operation ; (c) longitudinal structure of a shutter

3.2. Trial control with a shutter and its sediment control

In 2016, we started pilot operations by measuring sediment traps. As a result of when shutter operation was performed in the latter half of the flood, sediment transport was controlled. Floods large enough for significant sediment transport were observed twice, once on July 27th, 2016 and again on July 4th, 2017, because sensors for water and sediment measurement are longitudinally installed along the Jyo-Gan-Ji River. When both of these floods occurred, the shutter responded appropriately and closed. Sediment transport after installation, sediment transport was first observed on July 27th, 2016, as shown in Fig. 8. Several amplifier such as 16,64,256 and 1024 times the Japanese pipe hydrophone detected movements of sediment articles during the flood. Low magnitude of the amplifier can detect coarse sediment paticles. As shown in Fig.8, coarse and fine bedload articles take characteristics temoral changes of impulses in the increasing/decreasing stage of the flood. As the beginning of the flood, bedload discharge decreases, and then the value took almost constant. After operation of a shutter at the Myoju sabo dam, coarse components of bedload decreased. And then fine component of bedload also decreased gradually in the decreasing stage of the flood. The rapid sediment run-off can be controled by the shutter opeation. Moreover, when focusing on the flow depth and impulses of the Japanese pipe hydrophone, the sediment transportation is delayed after the shutter operation at the Karatani sabo dam, which is located downstream of the Myoju sabo dam, as shown in (C) in Fig.1. As shown in Fig.8, sediment transportation can be detected between Myoju sabo dam and Karatani sabo dam, focused gradually on the shapes of temporal changes of impulses by hydrophones.

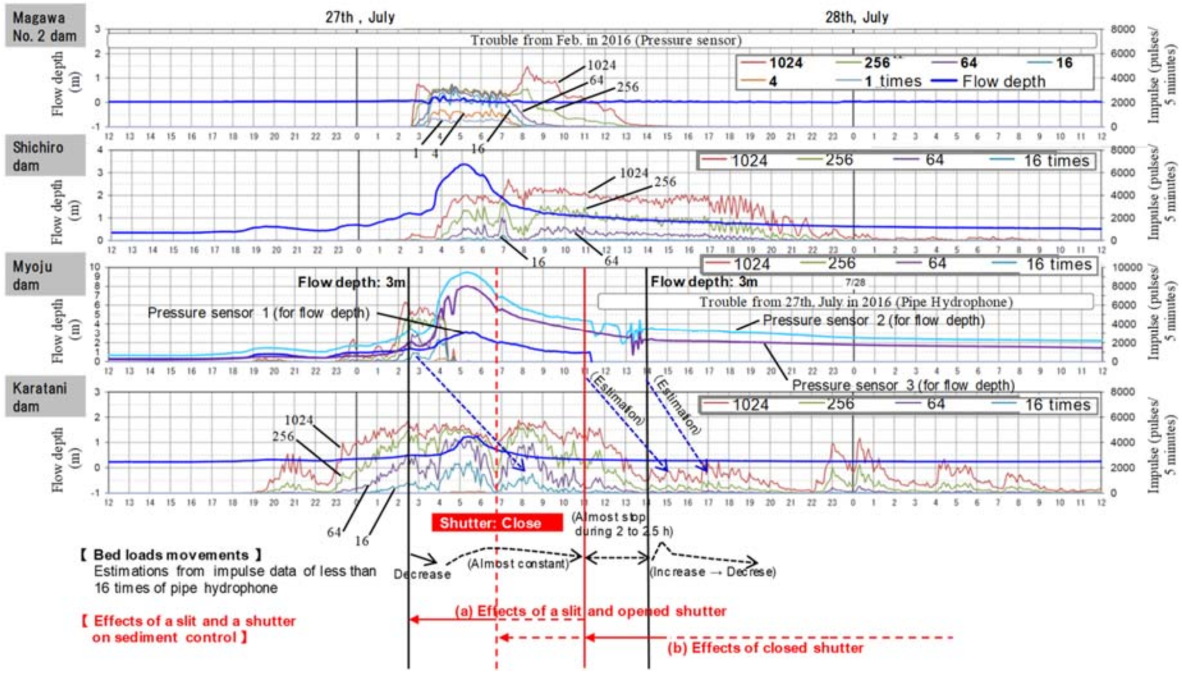

Fig. 8. Effects of shitter operation on longitudinal sediment transportation

Along with this, the operation of opening the shutter can be triggered in a stage of lower water level. However, in order to decide to trigger the opening of the shutter, further test operations must be conducted as well as water use downstream must be considered. Therefore, the preferable timing of closing and opening operations without adverse effects will be addressed in the future.

4. Conclusion

In the Jo-Gan-Ji River Basin, continuous sediment monitoring is performed longitudinally and temporally. Sediment runoff monitoring is performed simultaneously with hydrological monitoring. Present bed conditions do not allow for significant sediment runoff because of bed armor and large gravels. On the other hand, during floods, large components of bed sediment are transported along the river, including wash load and suspended load. Robust solutions tried to be conducted for the Japanese hydrophone against heavy collisions by large boulders. Those trials will be continued for further discussions of general applicability.

For the purpose of actively controlling the sediment transport during floods, a sabo dam with a shutter is proposed and the effective control function is evaluated through the test operation. The preferable timing of the shutter operation can be evaluated using longitudinal sediment monitoring with passive sensors for bedload to wash load measurements.

References

Japan Society of Civil Engineering. 1999, Handbook of Hydraulic Engineering, Maruzen (in Japanese).

Mikami, K., Koshino, M., Okui, J., Nagayama, T., Tagata, S., Miyamoto, K., Fujita, M., Itoh, T and Mizuyama, T., 2014, Install of a Movable shutter in Myo-Jyu Sabo Dam and Longitudinal Bedload Monitoring in Jyo-Gan-Ji River, Proceedings of the Interpraevent 2014 Pacific Rim (edited by Fujita, M. et al.), November 25-28, Nara, Japan, 2014, P-36.pdf in DVD.

U.S. Geological Survey, 2010, Bedload-Surrogate Monitoring Technologies, Scientific investigations Report 2010-5091, 37p.