MONITORING SEDIMENT TRANSPORT IN MOUNTAIN TORRENTS

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ABSTRACT

In mountain torrents, the sediment transport rate is controlled by the sediment supply, rather than the sediment transport capacity of the flow. Thus, to control torrents, sediment monitoring is necessary. Suspended load and washload can be observed using turbidometry and/or direct sampling. However, bedload observation is difficult in mountain torrents that have supercritical flow and transport large-sized gravels. Ordinary bedload samplers cannot be used in such circumstances. We have developed a passive acoustic bedload monitoring device called a hydrophone. A steel pipe is installed on the torrent bed, and a microphone in the pipe allows the enumeration of the number of transported gravels that hit the pipe. For over 10 years, we have used this system in a number of mountain torrents to understand when and how much bedload is transported during storms. A Birkbeck-type pit bedload sampler is used to calibrate the hydrophone. To count pulses can indicate the condition of incipient motion and measure the sediment transport at low rates of transport. However, the enumeration of pulses becomes impossible when sediment transport is high. In such a situation, acoustic energy can be measured. Here, we describe these devices, focusing on the characteristics of the hydrophone and some examples of observations of mountain torrents.

Keywords: Bedload, Hydrophone, Monitoring.

INTRODUCTION

In mountain streams, the actual sediment outflow rate depends not only on the sediment transport capacity, but also on the movable sediment volume. The amount of sediment on torrent beds and banks is generally limited, torrent beds often covered by armour coats. During low-discharge periods, the actual sediment transport rate is lower than the sediment transport capacity estimated using sediment transport equations involving sediment grain size, torrent gradient and flow discharge or depth. When the flow discharge rate exceeds a certain critical condition for incipient motion or rainfall exceeds a threshold for the occurrence of landslides or debris flows, sediment is produced and supplied to the torrent. The sediment transport rate increases sharply and approaches the sediment transport capacity. Observation

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of the actual sediment transport is necessary to determine the reasonable *sabo* (erosion and sediment control) plans and to operate the sediment-control gates of *sabo* dams. Whereas the suspended load is relatively easy to measure using samplers or suction tubes, the measurement of bedload is difficult. Some bedload samplers have been used mainly in subcritical flow. However, it is difficult to place samplers on torrent beds, because they often have rough surfaces with large rocks, as well as high flow velocity. Hydrophones that count the impacts or the sound of sand and gravels against plates or pipes are appropriate for mountain torrents, these devices do not measure the absolute sediment transport rate, but rather the relative sediment transport rate (intensity). We developed a hydrophone comprising a pipe and microphone and have installed this system in isolated mountain torrents and on the crests of *sabo* dams. The method to count the number of collision to steel pipes is appropriate for low sediment transport. It, however, becomes impossible to count the pulses when sediment transport is high. Acoustic energy is measured for that situation. Here, we describe the hydrophone system and collected data.

SEDIMENT TRANSPORT MONITORING SYSTEM

Verious hydrophone systems have been devised such as a system composed of a steel plate and seismometer that was used in Switzerland (Rickenmann, 1994). Our hydrophone system consists of a hydrophone sensor made up of a steel pipe with a microphone inside. A pressure-type water-level gauge, a data logger, a battery charged by solar power, and a cellular phone are used to obtain and transmit the data (Fig. 1) (Mizuyama et al., 1996, 1998 and 2003). Hydrophone signals are logged after 10-times amplification by a preamplifier. The data are recorded after amplifying 1016 times at Channel 5, 256 times at Channel 6, 64 times at Channel 7, 16 times at Channel 8; 4 times at Channel 9; and 2 times at Channel 10; respectively. The number of pulses is counted during each 5-min period.

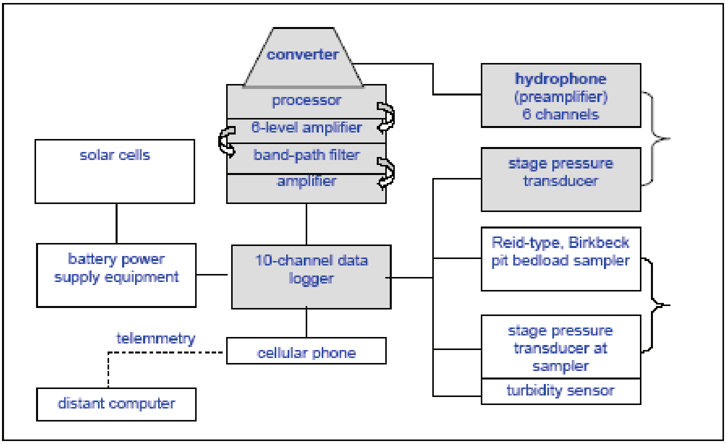

Fig. 1: Block diagram of the hydrophone system.

SET-UP OF THE HYDROPHONE

A hydrophone pipe, 48.6 mm in diameter and 1 m long made of SUS304 steel, was installed in June 2004 at the downstream end of a 15 m long concrete channel of Ashiarai-dani (drainage area 6.5 km^2), a tributary of the Gamata River in the Jindu River system (Fig.2). The channel was constructed for water-flow measurement and sediment observation by the Disaster Prevention Research Institute of Kyoto University in 1972 and has a gradient of 1/20. Cumulative pulse data are logged every 5 min, and water level and the weight of the trapped sediment in the pit are recorded every 1 or 5 min. These data are transmited through a cellular phone to a remote computer on demand from time to time. Scince 2007, these data have been directly recorded on a computer of the Hodaka Sabo Obsevatory. The pit is cleaned after it fills with sediment.

Fig.2: The hydrophone and pit sediment sampler at Ashiarai-dani. The pipe hydrophone was installed 20 cm upstream of the pit.

EXAMPLE OF PULSE DATA OBTAINED USING THE HYDROPHONE

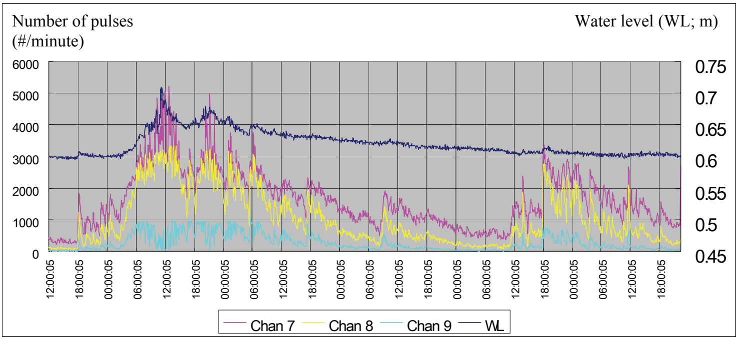

Fig. 3: Example of observed data at Ashiarai-dani starting from 12:00 on 3 July, 2005.

Figure 3 shows an example of the pulse data, through different amplifiers, detected using the hydrophone and the water level measured using a pressure gauge. The sediment discharge fluctuated and did not correspond to the flow discharge. Interestingly the sediment discharge increased from 12:00 on 7 July 2005, although the flow discharge decreased continuously. New sediment may have been produced and discharged in an upstream area, possibly by bank erosion or a break in the armour coat.

PIT BEDLOAD SAMPLER

Hydrophones give the sediment discharge intensity qualitatively, rather than quantitatively. To convert the pulse data collected using the hydrophone to the sediment discharge rate, the direct measurement of the sediment discharge is required. One method is to install a Birkbeck-type bedload sampler (referred to here as a pit bedload sampler) on a bed downstream from the hydrophone. Another meathod is to measure the sediment in *sabo* (“check“) dams before and after events to estimate the total sediment discharge. In the latter case, total pulses are compared to total sediment discharge. Some bedload samplers can be used in rivers with less rapid flow. In Ashiarai-dani, a pit bedload sampler (210 cm long, 110 cm wide, and 68 cm deep) was established just downstream of the hydrophone. The sediment drops through a slit and is deposited on a steel plate situated on water-filled pressure pillows. The width of the entry slit was changed from 50 to 20 cm in October 2004 because the large sediment discharge had been filling the pit too rapidly. The pit is cleaned after becoming filled with sediment. The grain-size distributions of the trapped sediment are observed and measured by sieving before cleaning.

GRAIN SIZE DISTRIBUTION OF THE TRAPPED SEDIMENT

Figure 4 shows an example of the grain-size distributions of sediment trapped in the pit. Sediment is fine-grained at the beginning of sediment discharge and becomes coarse as discharge continues.

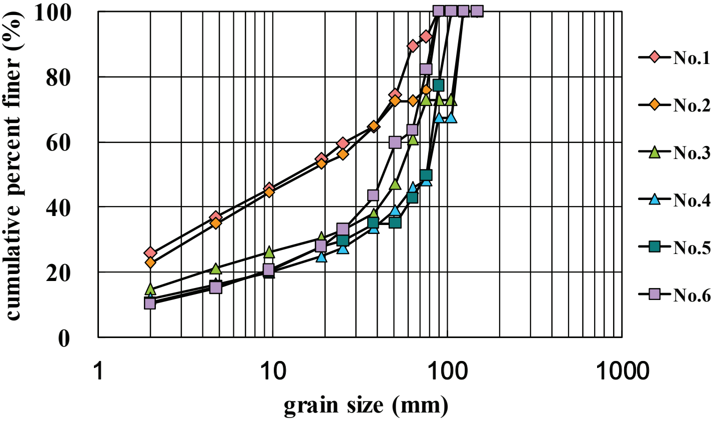

Fig.4: Grain-size distributions of sediment trapped in the pit, measured on 6 June 2006. The samples were taken at the following depths from the deposited surface: No.1, 55-60 cm; No.2, 45-55 cm; No.3, 35-45 cm; No.4, 25-35 cm; No.5, 10-25 cm; and No.6, 0-10 cm.

CALIBRATION OF PULSE DATA TO THE SEDIMENT TRANSPORT RATE

The pit data and hydrophone pulse data were compared, and the results were used to calibrate the hydrophone. Figure 5 presents a calibration chart for channel 7 (amplification rate = 64). The data were widely scattered. The extent of scattering may depend on changes in the grain size. Data for a sandy torrent showed good relationships between pulses and bedload discharge (Hoshino et al., 2004).

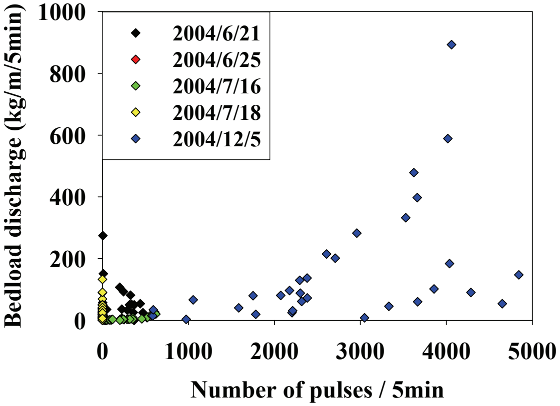

Fig.5: The relationship between the number of pulses recorded by the hydrophone and the bedload discharge measured in the pit (width of slit = 20 cm). Data measured in 2004 are shown with pulse data are for Ch. 7 (amplification rate = 64 times).

MEASUREMENT OF ACOUSTIC ENERGY OF HIGH SEDIMENT TRANSPORT

Thus far, the sediment transport rate has been measured by counting the number of collisions (or “pulses“) on the steel pipes. This method is appropriate to detect the condition of incipient motion and measure the sediment transport at low rates of transport. However, the enumeration of pulses becomes impossible for high sensitivity channels when sediment transport is high though low-sensitivity channels count pulses correctly (Fig.6), because the sound data of high-sensitivity channels stay high level. The data was obtained at the Ashiarai-dani with a hydrophone and a pit. Verious ways were tested in an experiment flume to know the relationships between obtained pulses and the characteriscs of hydrophone. To use low amplified outputs, to install shorter pipes and/or to apply low sensitive microphones may solve the problem. Another way for such a situation is to measure acoustic energy instead of counting pulses. This method has been tried in the Wari-dani, a upstream branch of the Ashiarai-dani and it was successful (Fig.7), although it required a larger-capacity data logger. Both or one of these methods can be used, depending on the purpose of the measurement and the sediment transport rate.

In the Wari-dani,. turbidity of the flow is observed to know the occurrence of new sediment production; landslides, debris flows, bank erosion and/or aggradation (Fig.7).

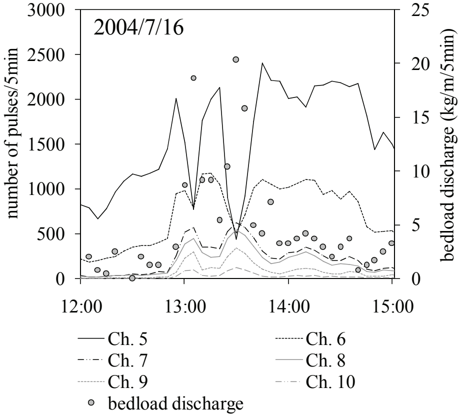

Fig. 6: Example of a decrease in the number of pulses during an increase in bedload discharge. The bedload discharge is based on data from the pit sediment sampler. The highly amplified pulse data decreased, although the actual sediment transport rate was increasing.

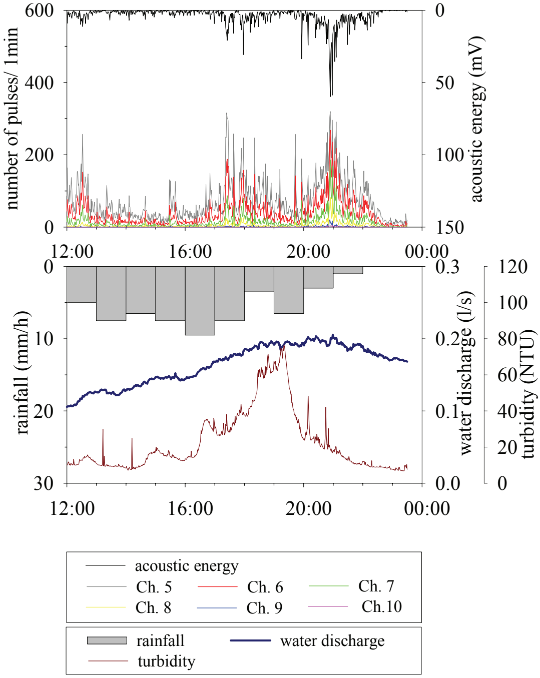

Fig. 7: Monitoring data: number of pulses, acoustic energy (top), and hourly rainfall, water discharge, and turbidity (bottom) on 22 June 2007.

CONCLUSIONS

Through trial and error, we have developed a hydrophone system that is appicable to field situations, although improvements to the calibration systems are still necessary. *Sabo* dams have been used to control erosion and sediment discharge. Because they do not have gates, their sediment control depends on the natural change of inflow sediment concentration. So far real-time information on sediment discharge has been unavailable. If actual sediment transport conditions can be determined, *sabo* dams with sediment control gates (called "shutter" *sabo* dams in Japan) can be used. The gates of such dams are usually open to allow for unobstructed water and sediment outflow and the free movement of fish, insects, and other fauna. However, when new landslides, debris flows, and bank erosion occur, raising the risk of flooding associated with sediment aggradation downstream, the gates can be closed to check sediment discharge downstream. The sediment deposited in *sabo* dams can later be excavated artificially or released through the gates.

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