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Measurement of bed load with the use of hydrophones in mountain torrents

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Abstract Sediment transport in mountain torrents is more affected by sediment production such as landslides, bank erosion and torrent bed erosion, than by water runoff. Therefore sediment transport rate cannot be estimated theoretically using sediment transport equations. This is why we have to measure sediment transport rate in the field in the mountain torrents. Wash load and suspended load can be measured using various kinds of samplers, whereas the direct measurement of bed load is difficult. Bed load samplers that have been used in mild rivers are not applicable in mountain torrents where the flow velocity is high and the bed surface is rough. Hydrophones are more appropriate for mountain torrents. Steel pipes are installed on torrent beds or on the spillways of sabo (erosion and sediment control) dams. The number of times that sand and gravel particles hit the pipes are counted by the microphones. This system has worked well in mountain torrents. The measurement system, some observed results and preliminary analysis are reported.

Key words bed load; hydrophones; measurement; mountain torrent

INTRODUCTION

Actual sediment outflow rate depends not only on sediment transport capacity, but also on movable sediment volume in the mountain streams. In most cases the amount of sediment on the torrent beds and torrent banks is limited. Torrent beds are often covered with armour coats. During low discharge periods the actual sediment transport rate is smaller than the sediment transport capacity that is estimated by the sediment transport equations for sediment grain size, torrent gradient and flow discharge or flow depth. When the flow discharge rate exceeds a certain critical condition for the incipient motion, or rainfall exceeds its critical condition for landslides or debris flow occurrence, sediment is produced and supplied to the torrent. The sediment transport rate increases sharply and approaches the sediment transport capacity. The actual sediment transport has to be observed to determine the reasonable sabo (erosion and sediment control) plan. Monitoring of the sediment transport rate is necessary to operate the sediment control gates of the sabo dams that are under development. Suspended load is relatively easy to measure because sampling with samplers or suction tubes is available. However, the measurement of bed load is difficult. Some bed load samplers have been used mainly in subcritical flow. It is difficult to set the samplers on the torrent bed, because the bed is rough with large rocks and the flow velocity is high. Hydrophones counting impacts or the sound of sand and gravels against plates or pipes are appropriate in mountain torrents, as they do not measure the absolute sediment transport rate, but the relative sediment transport rate (intensity). Hydrophones with pipes and a microphone were developed for isolated mountain torrents and were installed on the bed of slit sabo dams. The system and observed data using them are reported in this paper.

HYDROPHONE SYSTEM

Hydrophone systems have been adopted in several locations. For example, a hydrophone system with a steel plate and seismometer is used in Switzerland (Rickenmann, 1992). Our hydrophone system consists of a hydrophone sensor; a steel pipe with a microphone inside. In this case, we used a pressure-type water level gauge, a data logger, a battery charged by solar batteries and a cellular phone to transmit the data (Fig. 1). Hydrophone signals are logged after a 10 times amplification by a preamplifier. The data is recorded after amplifying 32 times at Channel 5, 16 times at Channel 6, 8 times at Channel 7, 4 times at Channel 8, 2 times at Channel 9 and once at Channel 10, respectively. The number of pulses are counted during each 5-min period.

SET-UP OF HYDROPHONE

A set consisting of a hydrophone and a pressure water level gauge was set up at a slit of a slit sabo dam. A slit sabo dam is a sabo dam with one or more vertical slits. It dams up water during high water and causes inflowing sediment to be deposited temporally at the upper reach of the dam. When the discharge decreases, the deposit

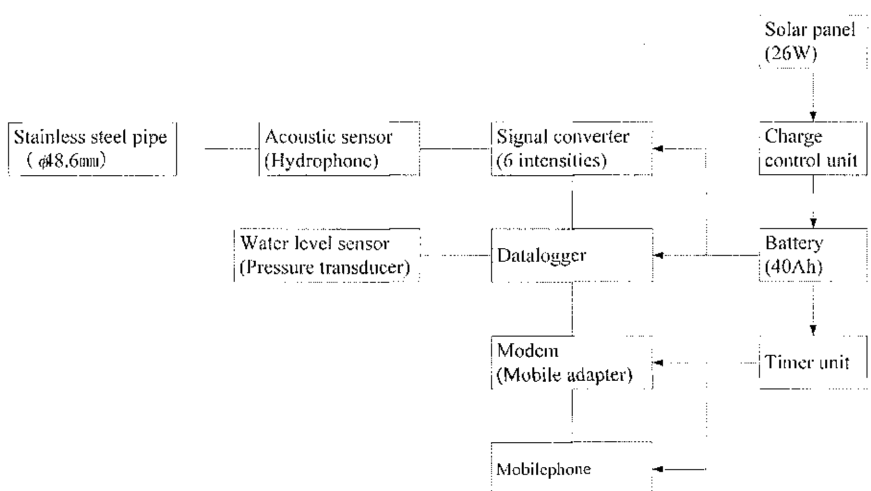

Fig. 1 Block diagram of the hydrophone system.

disappears gradually as the trapped sediment is eroded and released downstream. Although the behaviours of slit sabo dams is known through flume experiments and computer simulations, their real function must be verified in the field. The hydrophones were applied to measure the real sediment outflow from the slit sabo dams.

The hydrophone was installed at Tsuno-ura Karyu slit sabo dam (Figs 2 and 3) constructed by Tateyama Sabo Work Office in the Joganji River. The sabo dam is 13.5 m high and has two slits; 16.0 m wide and 7 m high. Channel gradient at the dam site was originally 1:28. The planned deposition gradient is 1:56. The drainage area at the dam is 131.53 km^2. A 6-m long steel pipe was set at the bottom of the slit as a hydrophone sensor. A signal was recognized by Channel 5, but not by Channel 6 when a 1.0 cm diameter stone was dropped from a height of 1.5 m. A 2-cm diameter stone dropped from a height of 0.5 m was recognized by both Channel 5 and Channel 6.

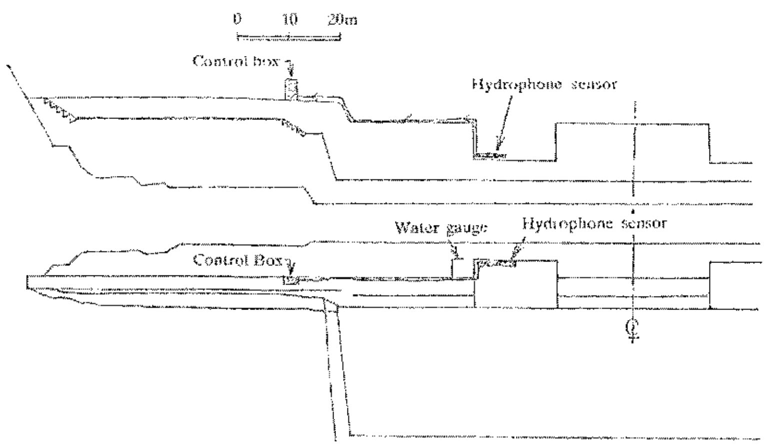

Fig. 2 Installation of the hydrophone and a water level gauge at the Tsuno-ura Karyu slit sabo dam.

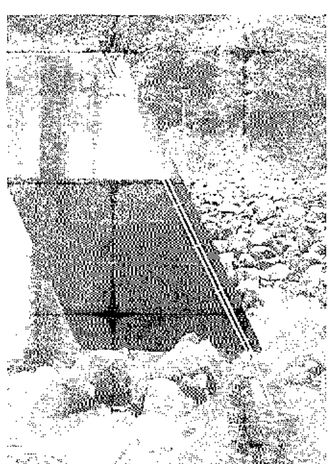

Fig. 3 Sensor pipe of the hydrophone installed on the slit of a sabo dam.

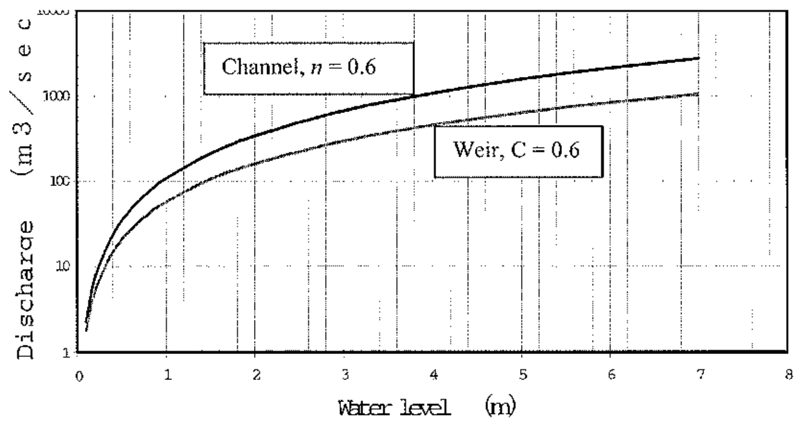

Fig. 4 Stage–discharge curve at Tsuno-ura Karyu slit sabo dam.

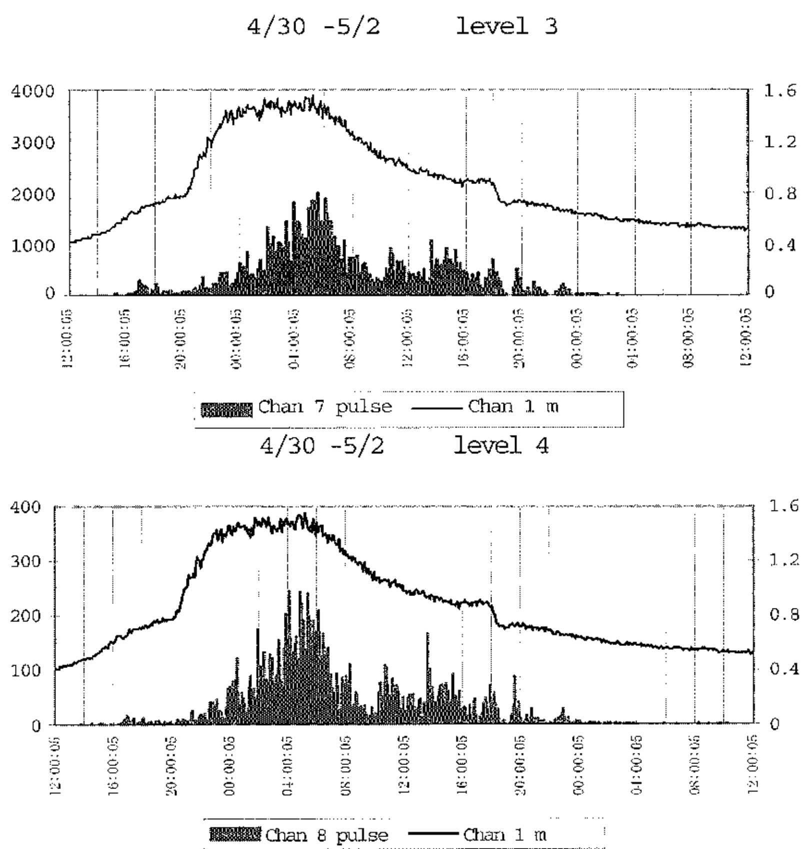

Fig. 5 Records of water level and input pulses of the hydrophone every 5 min on 30 April 2002.

The water level can be converted into flow discharge rate (Fig. 4, where Manning's n and a discharge coefficient are assumed as 0.04 and 0.6, respectively).

Measurements are necessary to obtain an accurate stage–discharge (H-Q) curve. The data obtained is stored in the data logger and is then transmitted to the work office through a cellular phone. The power for the system is supplied from a solar battery.

RESULTS OF MEASUREMENTS

The measurement at Tsuno-ura Karyu slit sabo dam started from 16 June 2001. It will be continued except during snow seasons. Measured data of incoming signals and water level of a storm on 30 April 2002 are shown as examples (Fig. 5). Pulses are counted every 5 min. The storm was not large enough to dam the flow. The recorded impulses correspond well to the flow level. The data on Channel 5 may include some noise.

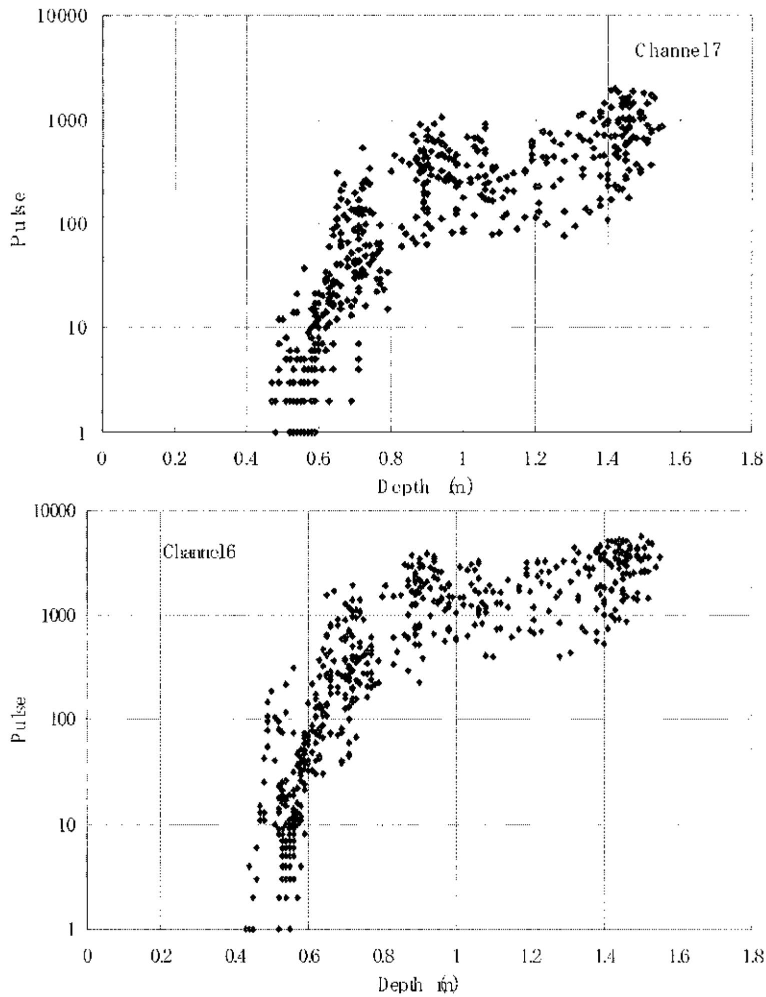

Fig. 6 Relationship between water level and recorded pulses.

PRELIMINARY ANALYSIS OF THE OBSERVED RESULTS

The relationship between the flow depth and the number of pulses are shown in Fig. 6. It indicates that sediment starts to move when the flow depth is larger than 50 cm. When impulses start to be recorded the water level changes with the gain of channels. Grain size of sediment could be estimated by analysing recorded signals.

CONCLUSIONS

It can be demonstrated that the hydrophone is appropriate for measuring bed load transport rates in mountain torrents, although the method does not indicate absolute values. As the record of the hydrophone is in proportion to sediment discharge rate (Rickenmann, 1992), absolute values can be estimated if the total sediment discharged volume is surveyed downstream. The hydrophones are planned to be set along several sections of the main river and the mouths of the branches of the Joganji River. Turbidity meters will also be installed.

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