Debris Flow Detection Using LVP Sensors in Japan

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Sakura-jima Island is an active volcano in the southwest region of Kyushu in Japan. The area surrounding the volcano is impacted by significant debris flows when rainfall follows an eruption. Various studies have investigated the use of sensors including wire sensors and accelerometers to detect such events. Wire sensors typically incorporate three horizontal wires set at heights of 60, 120, and 180 cm from the river bed and can be used to quantify the magnitude of the debris flow. We have developed an LVP (load, vibration, pressure) sensor [*Itoh et al.*, 2017] and installed it at two test sites to establish its suitability for continuous detection of debris flows. The sensor consists of a load cell, an accelerometer, and a pressure meter. The sensor is mainly used for debris flow detection but also measures the load of the surge. In this paper, we present the results of an analysis of LVP and wire sensor data that were recorded at the test sites to verify the accuracy of the LVP data, and propose threshold values for debris flow occurrences which were observed using the LVP sensors.

Key words: debris flow detection, bed pressure, vibration, LVP sensor

1. INTRODUCTION

The rivers around the Sakura-jima volcano are highly susceptible to debris flows caused by the large volumes of volcanic ash that are frequently deposited across the region. The debris flows are triggered by rainfall after an eruption and contain huge volumes of sediment. The early detection of such events is therefore very important and the use of various sensors including wire sensors, accelerometers [*Osumi Construction Office*, 1988] and geophones [e.g., *Arattano et al.*, 2008] has been proposed for this purpose. Wire sensors have been used in Japan because they are cheap and easy to maintain. In addition, we have identified occurrences of debris flow on Sakura-jima Island using CCTV images and by monitoring the disconnection of the wires. This enabled for the flow to be quantified from knowledge of the separation of the wire from the river bed such as debris flow height of 60, 120 and 180 cm [*Osumi Office of River and Highway,* 2013].

LVP (load, vibration, pressure) sensors consist of a load cell, accelerometer, and pressure meter. A proposal for continuous monitoring of debris flow using a combination of wire and LVP sensors was first proposed by Itoh et al. [2017]. However, wire sensors are unable to detect further debris flow events after disconnection and wires are sometimes disconnected by random objects in the river and animal activities. In this study, we present the further development of an LVP sensor, its installation on Sakura-jima Island and the results from the field study.

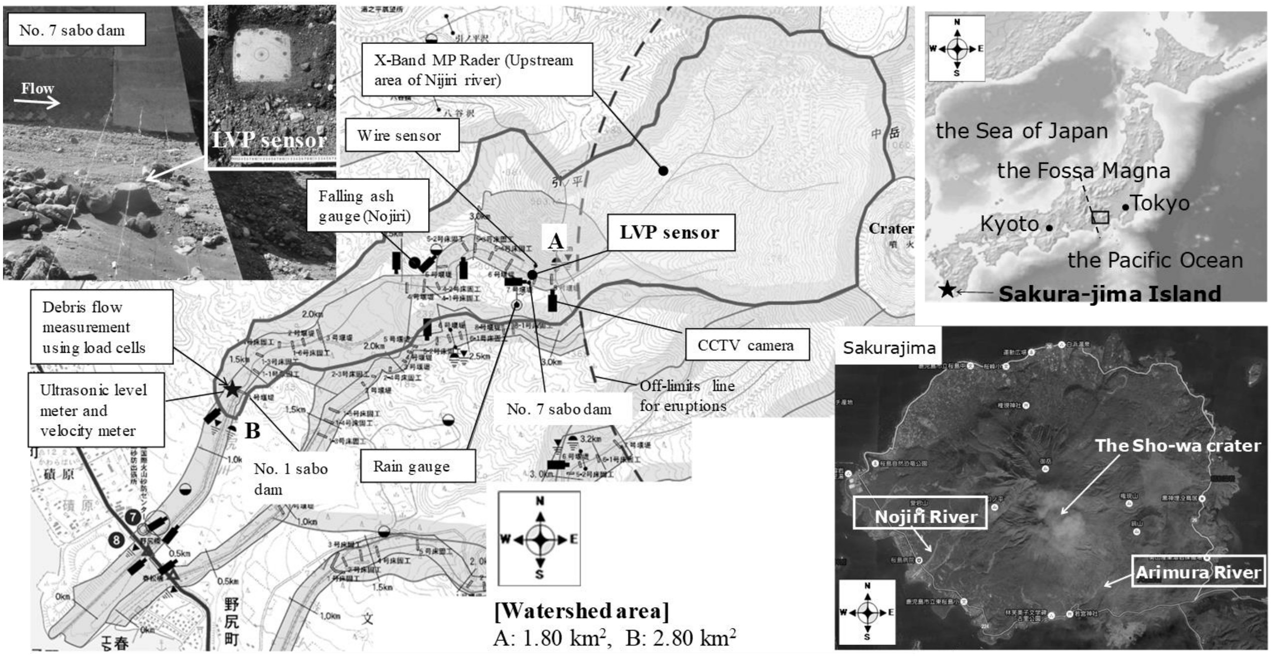

Fig. 1 Several kinds of sensors for debris flow monitoring in Sakura-jima Island

2. EXISTING DEBRIS FLOW DETECTION SENSORS

Various sensors have been used to detect debris flow including wire sensors, optical beams and accelerometers [e.g., *Okuda et al.*, 1980; *Hirano et al.*, 1999; *Suwa et al.*, 2011]. Wire sensors have been widely used after the applicability was confirmed by field surveys at Kami-Kami-Hori Creek in Japan [*Okuda et al.*, 1980]. Surface velocity sensors and spatial filter velocimetry were also used at the study site [*Itakura et al.*, 1985; *Itakura and Suwa*, 1989]. However, the sensor was not used at other sites. Other studies have looked at various sensors for debris flow monitoring [e.g., *Arattano et al.*, 1999 & 2008; *Scott et al.*, 2011]. Wire sensors identify the occurrence of debris flow by monitoring the disconnection of the wires and the magnitude of the flow is estimated using knowledge the height of wire from the riverbed, which is usually 60 cm, 120 cm, and 180 cm from the bed surface. However, they require intervention to reconnect the wires after each event. CCTV cameras are also used but cannot observe night-time surges. Therefore, there is a need for a new type of sensor that will mitigate against the drawbacks of the existing technology.

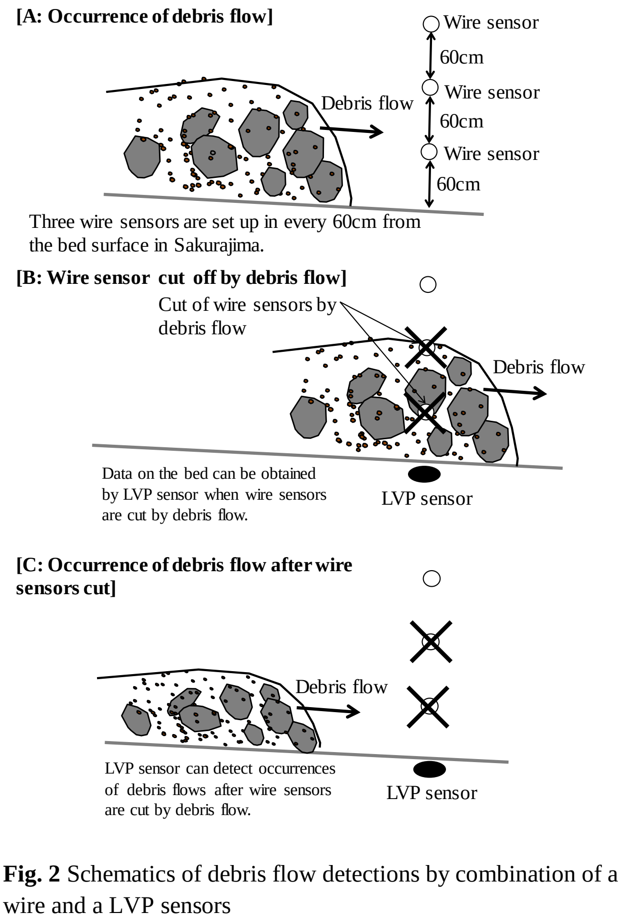

Fig. 2 Schematics of debris flow detections by combination of a wire and a LVP sensors

3. DEVELOPMENT OF THE LVP SENSOR

3.1 Monitoring sites

Fig. 1 shows the location of the study site on the Nojiri River on Sakura-jima Island. Several types of sensors in addition to the LVP sensor were installed, including rainfall gauges, falling ash gauges, CCTV cameras, wire sensors, ultrasonic level sensors, and velocity meters. Continuous direct debris flow measurement using loadcell and pressure meters (DFLP) [*Osaka et al.*, 2014] was

Table 1 Debris flow detection by wires and the LVP sensor that has a round small force plate of 60 mm in diameter

No.	Date	Disconnected wires			Detection by a LVP sensor		
		1st (60cm above from the bed)	2nd (120cm)	3rd (180cm)	Flow depth	Vibration	Weight
1	March 19th, 2015	○	○	○	○	○	○
2	April 6th, 2015	○	−	−	○	○	○
3	April 19th, 2015	○	−	−	(○) *1	(○) *1	(○) *1
4	May 3rd, 2015	○	○	−	○	○	○
5	May 12th, 2015	○	○	−	○	○	○
6	June 3rd, 2015	○	−	−	○	○	○
7	June 8th, 2015	○	○	−	○	○	○
8	June 14th, 2015	○	−	−	○	○	○
9	Augus 16th, 2015	○	○	−	○	○	○
10	August 30th, 2015	(○) *2	−	−	○	○	○
11	September 6th, 2015	○	−	−	○	○	○
12	October 1st, 2015	○	−	−	○	○	○
13	December 10th, 2015	○	○	−	○	○	○
14	April 21st, 2016	○	○	−	○	○	○
15	May 9th, 2016	○	−	−	○	○	○
16	June 13th, 2016	○	−	−	○	○	○
17	June 16th, 2016	○	−	−	○	○	○
18	June 19th, 2016	○	○	−	○	○	○
19	June 27th, 2016	○	—	—	○	○	○
20	June 27th, 2016	○	○	—	○	○	○
21	July 11th, 2016	○	—	—	○	○	○
22	July 2oth, 2016	○	—	—	○	○	○
23	September 17th, 2016	○	○	—	○	○	○
24	September 20th, 2016	○	○	○	○	○	○

also performed to evaluate mass density and sediment concentration.

3.2 Development LVP sensor and detections of debris flows

The LVP sensor consists of a load cell [e.g., *McArdell et al.*, 2007; *Osaka et al.*, 2014], accelerometer, and pressure meter. The sensor was modified by trial and error at the study site [*Itoh et al.*, 2017] and installed on the river bed to directly measure debris flow.

Fig. 2 shows the arrangement of the wire and LVP sensors used for the detection of debris flow. **Fig. 3** shows the longitudinal bed profile of the Nojiri River. The bed slope at the Nojiri No. 7 sabo dam test site is 1/7.6 (7.50 degrees) and the supposed equilibrium sediment concentration for the bed slope is 0.147 for a specific weight of 2.65 and an interparticle friction angle of the sediment particles of 34 degrees.

The No. 2 sensor, which was installed on the bed on February 6th, 2015, was modified to minimize the risk of direct impact from large boulders by fitting a smaller 6 cm diameter force plate [*Itoh at al.*, 2017]. The advantage of the smaller plate is that the risk of damage due to a direct impact from a boulder is reduced. However, the accuracy of the load reading is also reduced as a result [e.g., *Scott et al.*, 2011]. The data sampling rate was 10 Hz.

The No. 2 sensor detected 23 of 24 occurrences of debris flow events as shown in **Table 1**. In the table, “O” denotes a successful debris flow detection, and “*1” and “*2” denote an estimation of debris flow occurrences. These estimated events occurred on April 15th and August 30th, 2015. The 24 events detected between February 6th, 2015 and March 31st, 2016 were observed by both the wires and CCTV camera. A wire also detected only 23 occurrences of debris flows, because the disconnected wire could not be maintained due to active eruption during the middle to the end of August in 2015, while the LVP sensor detected debris flows around 60 cm in depth, and because the LVP sensor could not detect debris flow surges due to transverse flow shifting on April 19th, 2015.

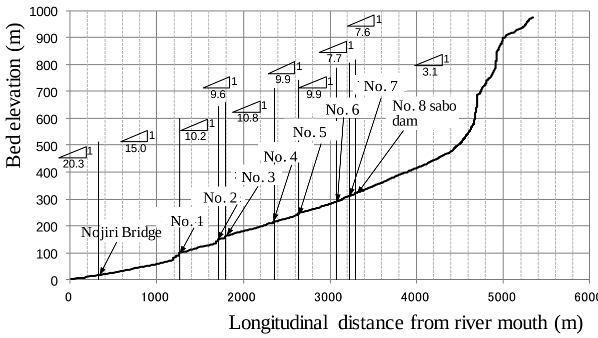

Fig. 3 Longitudinal bed profiles and sabo dam layout the Nojiri River in Sakura-jima Island

Data typical of a debris flow event were observed using the LVP sensor on June 8th, April

6th, and April 19th, 2015 and on June 27th, June 19th, and September 20th, 2016. The events were observed by the wire and LVP sensors at approximately the same time and the LVP sensor also detected several surges after the wires had been disconnected. However, at the Arimura No. 3 sabo dam test site on the Arimura River, the sensors and cables were destroyed by debris flow surges on April 16th, 2017, so data could not be recorded at that site.

Fig. 4a and **4b** show typical data from the LVP sensor. The load was calculated from the differences in the force plate area between 10,000 cm^2 and 28.3 cm^2 (ϕ= 6cm in diameter). As shown in **Fig. 4**, there are several patterns of data. For example, the LVP sensor detected several surges

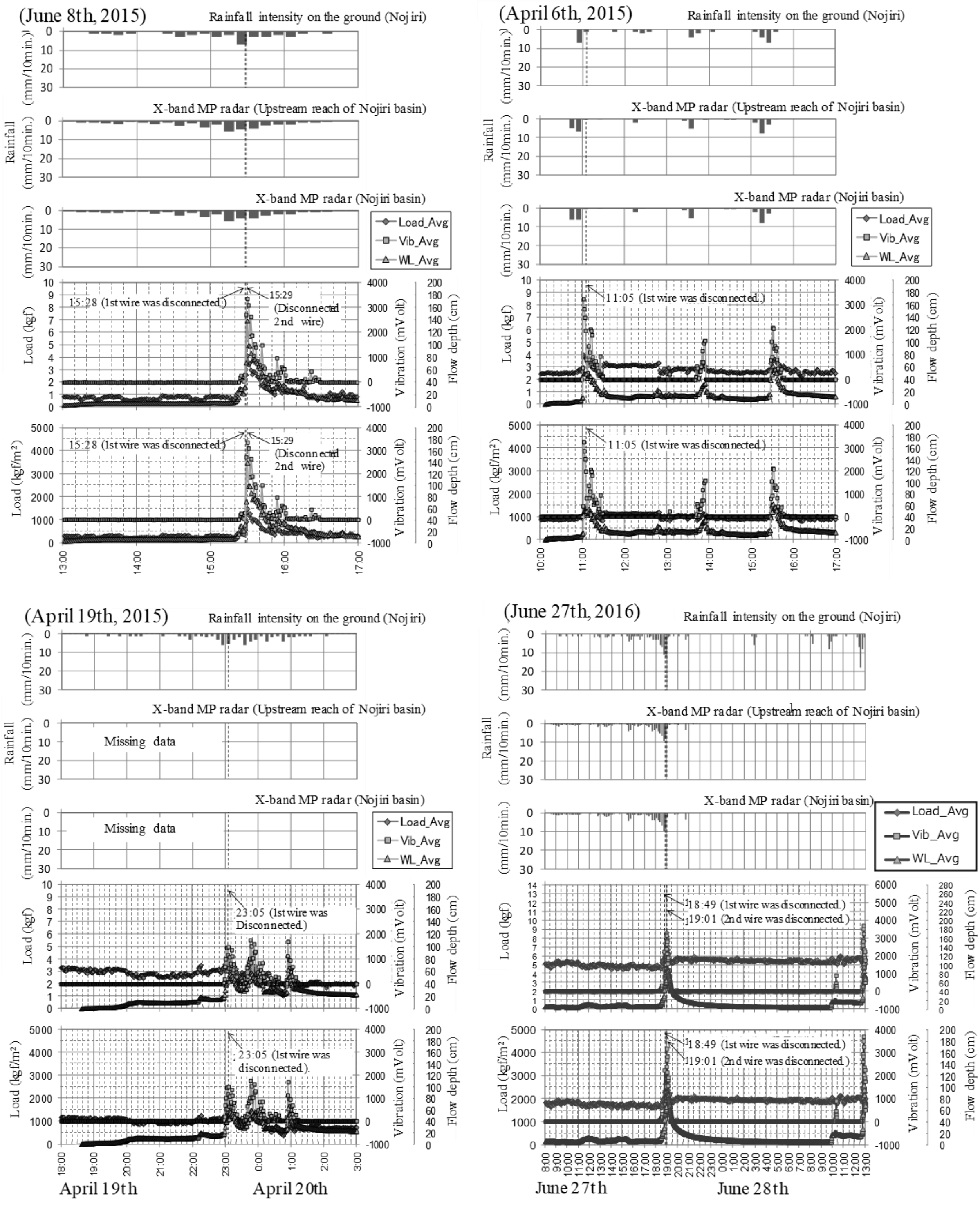

Fig. 4a Typical debris flows detected by LVP sensor on June 8th, April 6th and April 19th in 2015 and on June 27th in 2016

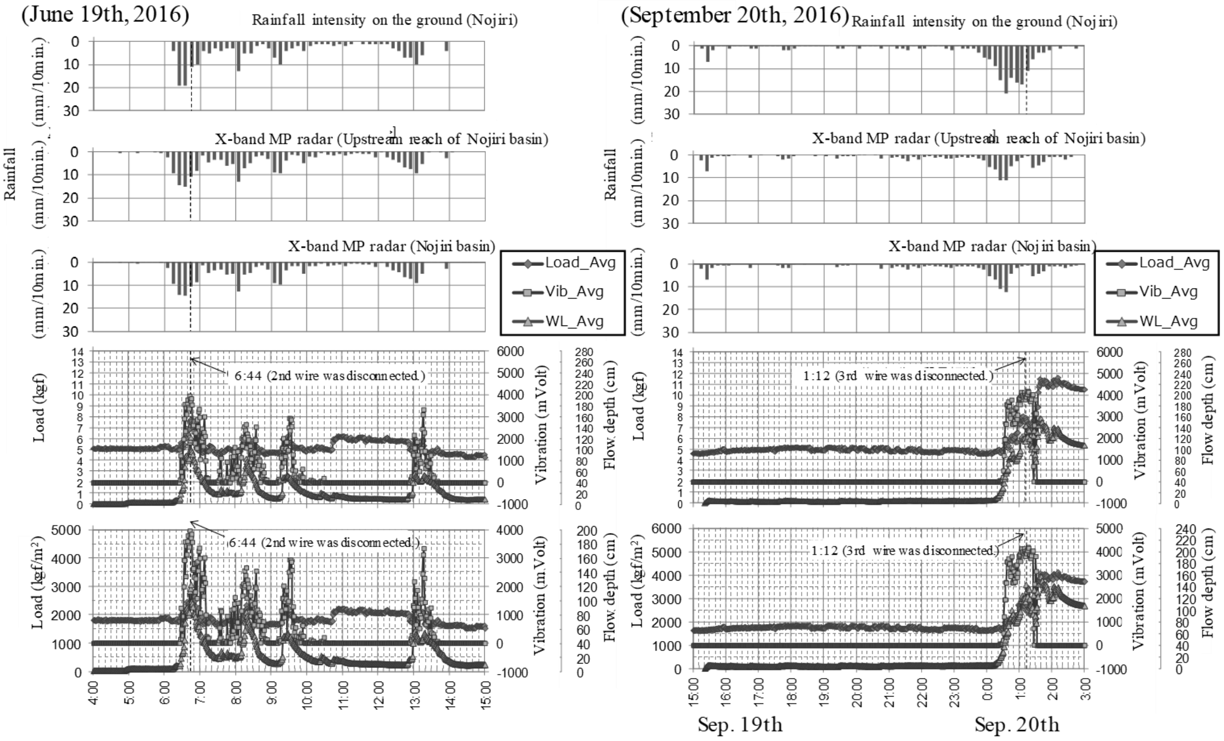

Fig. 4b Typical debris flows detected by LVP sensor on June 19th and September 20th in 2016

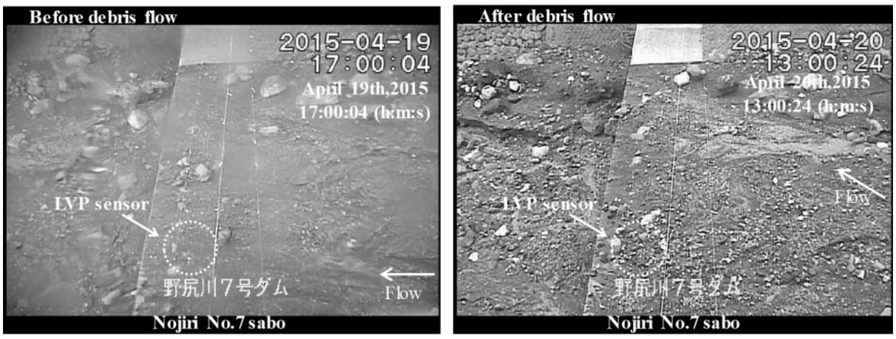

Fig. 5 Debris flow events with transvers flow shifting on April 19th in 2015

after wires were disconnected. Debris flows on September 20th, 2016 cut the 1st to 3rd wires, and were of a relatively large magnitude. Debris flows detected by both the wire and the LVP sensors after wires were disconnected were observed on April 6th, 2015 and June 19th, 2016. However, the LVP sensor did not detect the debris flows on April 19th, 2015 because of transverse flow shifting.

Fig. 5 and **6** show data from debris flow events that occurred on April 19th, 2015, and transverse installation of the LVP sensor could minimize the effects of transverse flow shifting of debris flows, but further investigation of this proposal is required.

4. EMPIRICAL EVALUATION OF DEBRIS FLOW OCCURRENCES

The relationships between flow depth and load and between flow depth and vibration at the time of wire disconnect were evaluated using the measured data.

Fig. 7 shows examples of attempts to identify threshold values of debris flow load using data from the LVP sensor and **Fig. 8** shows the threshold values for acceleration due to vibration. The threshold values are estimated to be 400 kgf/m^2 and 200 mV although it is suggested that further data are required to verify the accuracy of this information. **Fig. 9** shows a comparison of observed data and expected load measurements using the LVP sensor. Calculations for load for specific mass densities of 1.50 (c= 0.3), 1.83 (c= 0.5), and 2.65 are shown,

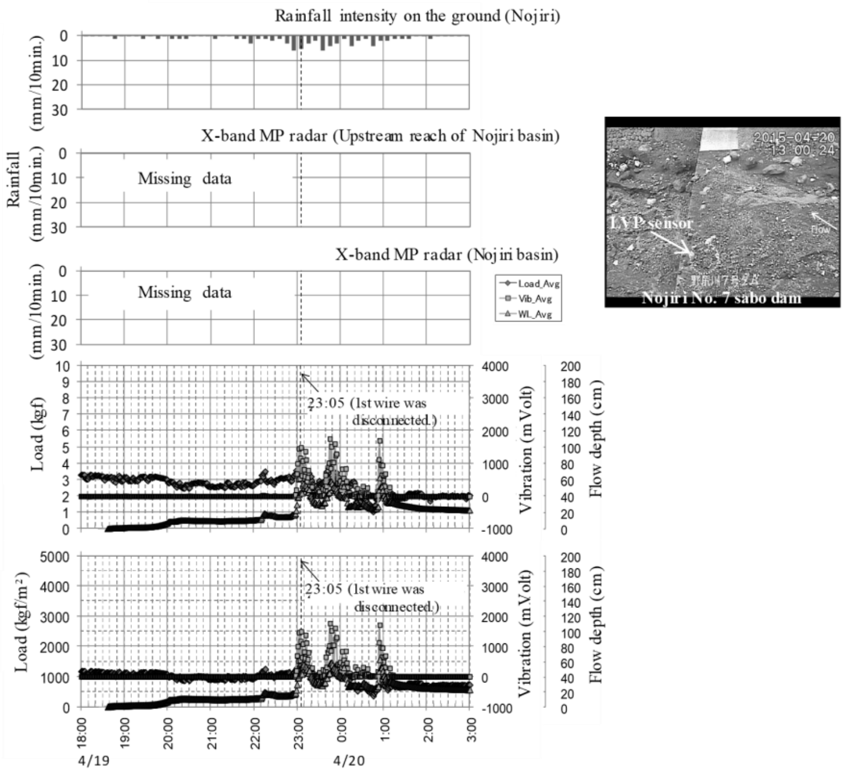

Fig. 6 Measured data obtained by the LVP sensor for debris flow events with transverse flow shifting (April 19th in 2015)

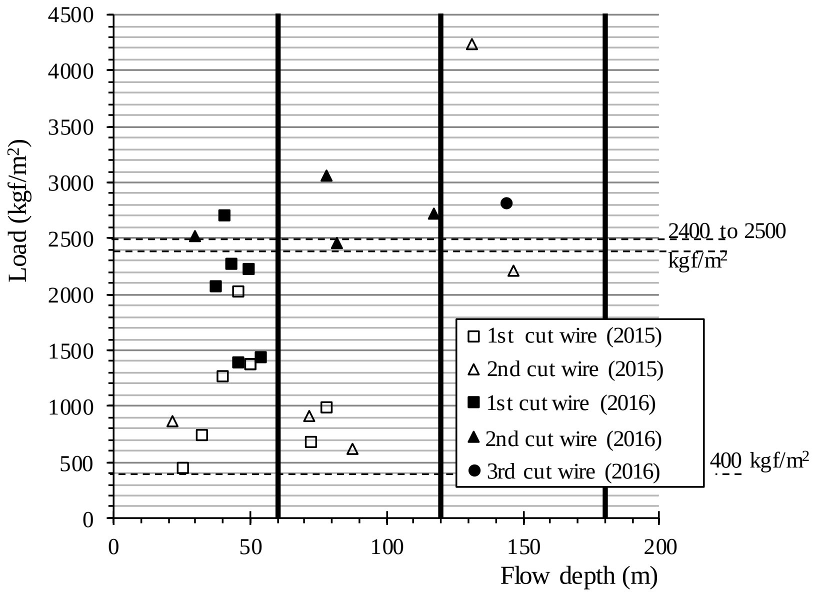

Fig. 7 Threshold values for debris flow occurrences by the relationship between flow depth and load

where c is the volumetric sediment concentration of debris flow and the specific weight of the solid particles is 2.65.

The measured load does not exhibit a linear relationship with flow depth because the force plate of the LVP sensor is too small to obtain absolute values. However, the purpose of the LVP sensor is to detect debris flows and evaluate threshold values. As seen in **Fig. 7** and **8**, the values are 2400 to 2500 kgf/m^2 and 2800 to 3000 mV at the second wire level (120 cm from the bed), while the threshold values for debris flow occurrences are 400 kgf/m^2 and 200 mV. The results show the possibility of estimating the magnitude of debris flow surges.

5. CONCLUSIONS

This study investigated the use of both LVP and wire sensors for debris flow detection and identified threshold values for occurrences of debris flow. The

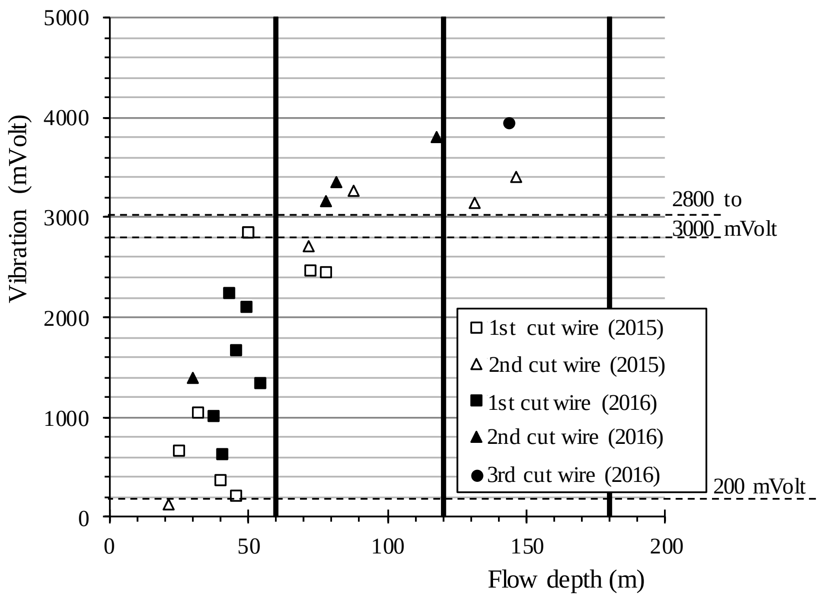

Fig. 8 Threshold values for debris flow occurrences by the relationship between flow depth and vibration

results indicate that the threshold load and vibration values for debris flow occurrences are 400 kgf/m^2 and 200 mV, respectively. Additionally, the values are 2400 to 2500 kgf/m^2 and 2800 to 3000 mV at the second wire level. Continuous data collection will be performed for several years to identify more accurate threshold values.

In addition, an optimal installation method needs to be identified to ensure reliable readings are obtained. In addition, the number of LVP sensors installed at each site needs to be considered if the effects of transverse flow shifting are to be minimized.

ACKNOWLEDGMENT: The authors are grateful to the Osumi Office of River and National Highway, Kyushu Regional Development Bureau and the Ministry of Land in Japan (MLIT) for their advice and to Dr. Koji YOKOYAMA for his advice on the development of the sensor. Additionally, the authors are grateful for research grant (KAKENHI: Scientific Research C, No. 15K07502) from the Japan Society for the Promotion of Science (JSPS) which was used to fund aspects of the present study.

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