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# Debris flow monitoring using load cells and pressure sensors on Sakura-jima Island

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**Abstract**

Numerous debris flows have recently taken place frequently in Sakura-jima Island located at southwest in Japan due to rainfall events after ash deposition due to volcanic activities since 2010. Debris-flow measurement system with loadcell and pressure sensor (DFLP) had been applied for debris-flow monitoring (Osaka et al., 2014). In present study, a modified monitoring DELP system using load cells and a stainless-steel plate is employed. Mass density and sediment concentration are calculated using data obtained by the DFLP system and data measured by ultrasonic level meter and surface velocity by of image analyses of CCTV camera. (Results) Temporal changes of specific weight, sediment concentration and sediment volume of debris-flow in Nojiri and Arimura Rivers in 2014 were well measured using DFLP system. Sediment concentration and specific weight were calculated in both rivers, and there are at least 10 data in Arimura River and 8 data in Nojiri River for calculations of temporal changes of mass density and sediment concentration since 2012 and 2014, respectively. Averaged sediment concentration near peak discharge are calculated as 0.441 in Arimura River and 0.279 in Nojiri River, respectively. However, values of calculated concentration do not always take correlation with rainfall depth before debris-flow occurrences. Data analyses continuously need by more data collections of debris-flow events.

Keywords: Debris flow; DFLP; Sakura-jima, Loadcell, Sediment Concentration, Specific Weight

## 1. Introduction

Numerous debris flows have recently taken place frequently in Sakurajima Island, which is located at southern-west in Japan, due to rainfall events after deposition of volcanic ash by volcanic activities since 2010, and the number of debris-flow occurrences has been gradually increasing though volcanic activities were active in 1980s there and the number of debris-flows occurrences decreased in 1990s to 2000s due to decrease of volcanic activities. The numbers of debris-flow occurrences are counted by the numbers of disconnected wire sensors. Many kinds of measurements have been carried out to evaluate flow characteristics of debris flows. In those monitoring, temporal changes of flow depth, discharge and bed profiles tried to be collected using ultrasonic sensors and video camera, and profiles of bed elevations were also monitored along the channel for longitudinal deposition and near river mouth in the sea using a sounding machine, that was for measuring bed elevation due to debris-flow deposition under the sea, to evaluate sediment runoff volume from river mouth. Sediment in debris-flow bodies was measured using a sampler box produced by an iron bucket. However, it was quite difficult to obtain continuous data for sediment discharge and the runoff volume due to debris flows.

A modified debris-flow measurement system with loadcell and pressure sensor (DFLP) system, which is firstly installed in Switzerland (McArdell et al., 2007), using load cells and an iron plate was installed to evaluate flow characteristics of debris flows at the Arimura River No. 3 sabo dam in June in 2012 (Osaka et al., 2014). After the

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installation in Arimura River, a system with small size of loadcell and iron plate without accuracy change of measurements was discussed for easier maintenance, and the newly modified three systems with an iron plate (1 m in width and 1 m in length) were installed transversely at the No. 1 sabo dam in Nojiri River in March in 2013.

In present study, temporal changes of specific weight, sediment concentration and sediment volume of debris flow using DFLP systems in Nojiri and Arimura Rivers in 2014 were shown because of well measured data using DFLP system. Sediment concentration and specific weight were calculated in both rivers, and there are at least 10 data in Arimura river and 8 data in Nojiri river for calculations of temporal changes of mass density and sediment concentration since 2012 and 2014, respectively. Averaged sediment concentration near peak discharge are calculated as 0.441 in Arimura River and 0.279 in Nojiri River, respectively.

## 2. Installation and modification of the DFLP

Figures 1 to 4 show plan view and longitudinal bed profiles of Noji river and Arimura River, respectively. Nojiri River is southern-west area in Sakurajima, and is with a watershed area 2.99 km$^2$, bed slope 4.5 % measured from top of river to the river mouth and flow width 13.2 m at the Nojiri No. 1 sabo dam (see Figs. 1 and 2). Arimura River is in southern-east area in Sakurajima with a watershed area 1.35 km$^2$, bed slope 19% and flow width 20.5 m at the Arimura No. 3 sabo dam (see Figs. 3 and 4), though the information is shown in previous research (Osaka et al., 2014).

Herein, in Arimura and Nojiri Rivers where debris flows take place frequently, the number of debris-flow occurrences in Arimura River exceeds 6 per year: e.g., 6 times in 2010, 6 times in 2011 and 9 times in 2012, and in Nojiri River exceeds 10 per year, e.g., 18 times in 2010, 10 times in 2011, 21 times in 2012 and 18 times in 2013 in Nojiri River. In Arimura river, debris-flow measurement system with loadcell and pressure sensor (DFLP) system was installed in June in 2012, and ultrasonic velocity meter was also set up in 2013 (Osaka et al., 2014). Measurements using a DFLP system on the bed can obtain temporal changes of data without disturbing debris-flow body. Flow discharge and depth are measured by image analyses of CCTV or ultra-sonic wave meter. Data sampling and collections system are introduced in the literature (Osaka et al., 2014).

In Nojiri River, after the installation in Arimura River in 2012, a system with small size of loadcell and iron plate without accuracy change of measurements was discussed for easier maintenance against mechanical troubles and the newly modified three systems with an iron plate (1 m in width and 1 m in length) was developed and installed transversely at the No. 1 sabo dam in March in 2013, as shown in a picture in Figure 1.

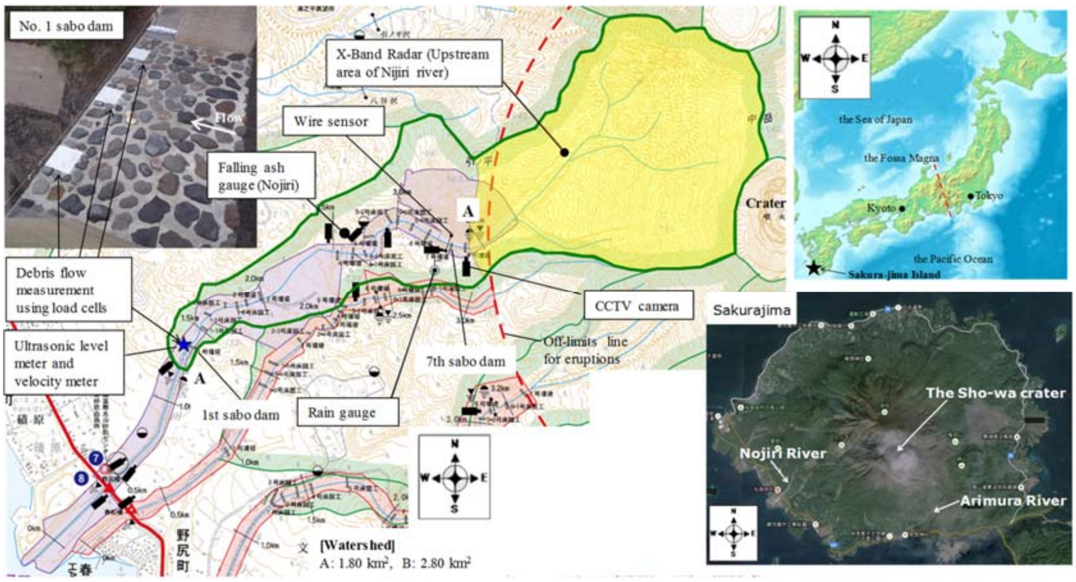


Fig. 1. Plan view of Nojiri River basin and installed various sensors for debris-flow monitoring (Osaka et al., 2014)

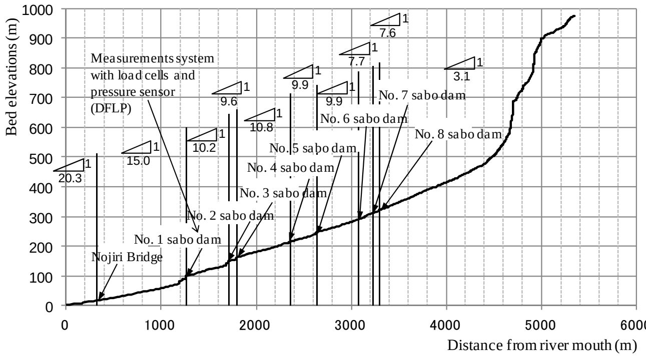


Fig. 2. Longitudinal bed profile of Nojiri River

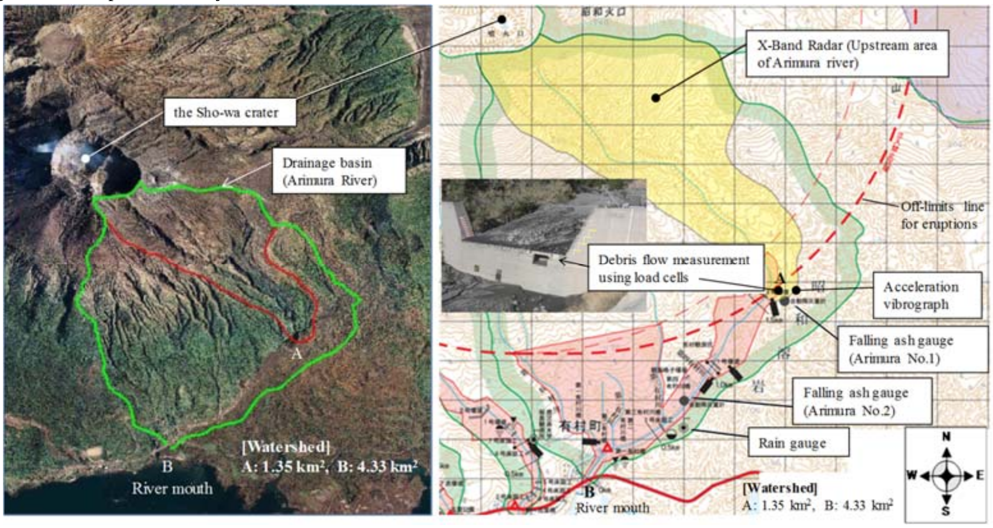


Fig. 3. Plan view of Arimura River basin and installed sensors for debris-flow monitoring (Osaka et al., 2014)

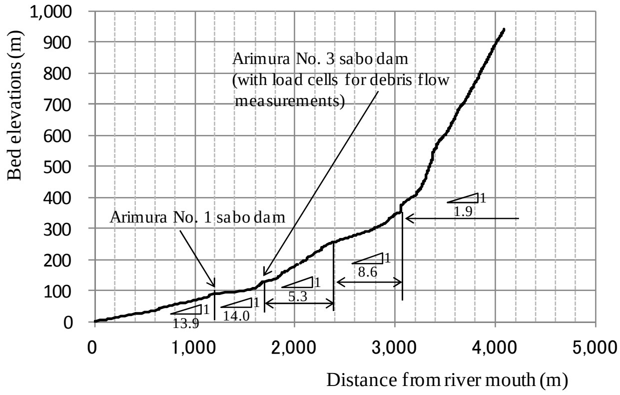


Fig. 4. Longitudinal bed profile of Arimura River

## 3. Typical debris flows monitored by the DFLP

### *3.1. Temporal changes of flow discharge, weight and pressure*

Many sensors have been installed (see Figures 1 and 3) to measure occurrence and runoff of debris flow, and those are as follows: Rain gauge on the bed, X-band MP Radar, ultrasonic water level meter, wire sensor, falling ash gauge, acceleration vibrograph (in only Arimura River) and CCTV camera in Arimura and Nojiri River. In Sakurajima Island, the number of debris-flow occurrences are counted by the numbers of disconnected wires of wire sensor and wires are installed at the position of 60 cm, 120 cm and 180 cm on the bed surface to define debris-flow magnitude. In Arimura River, debris flow took place 13 times in 2014, and debris flows with middle magnitude were observed on June 27th, July 30th, August 29th and November 1st, among these events debris flows on June 27th were observed by the DFLP systems. While, in Nojiri River, debris flow took place 17 times in 2014, and debris flows with middle magnitude were observed on May 14th, June 21st, June 27th, July 9th, August 1st and November 1st. Debris flows on June 21st and 27th were measured by three DFLP systems in Nojiri River. In Arimura River, debris flows are observed by the DFLP system as shown in Figure 3, and sediment concentration of both coarse sediment and suspended & liquid phase can be estimated by data measured by the DFLP system and calculations (Osaka et al., 2014) as shown in Figure 5.

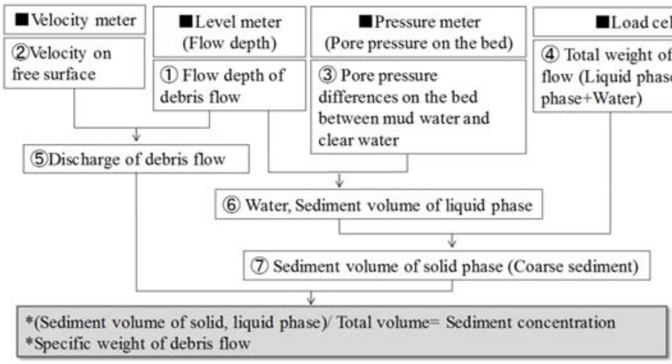


Fig. 5. Flow chart for calculations of mass density and sediment concentration using data obtained by the DFLP system (Osaka et al., 2014)

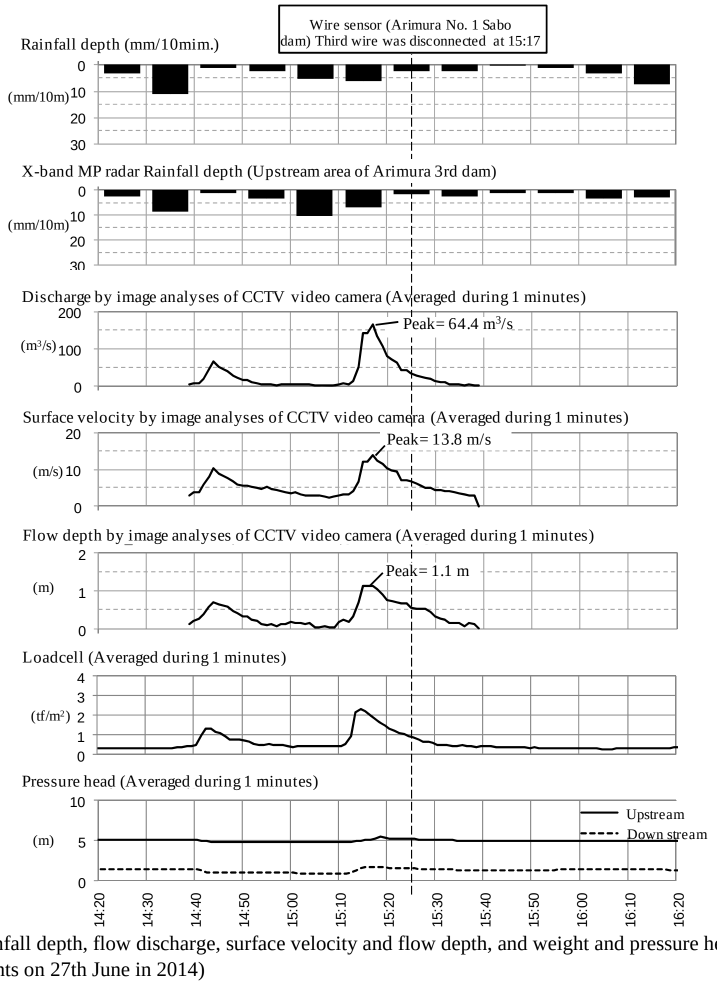


Fig. 6. Temporal changes of rainfall depth, flow discharge, surface velocity and flow depth, and weight and pressure head on the bed, observed at Arimura River (Debris-flow events on 27th June in 2014)

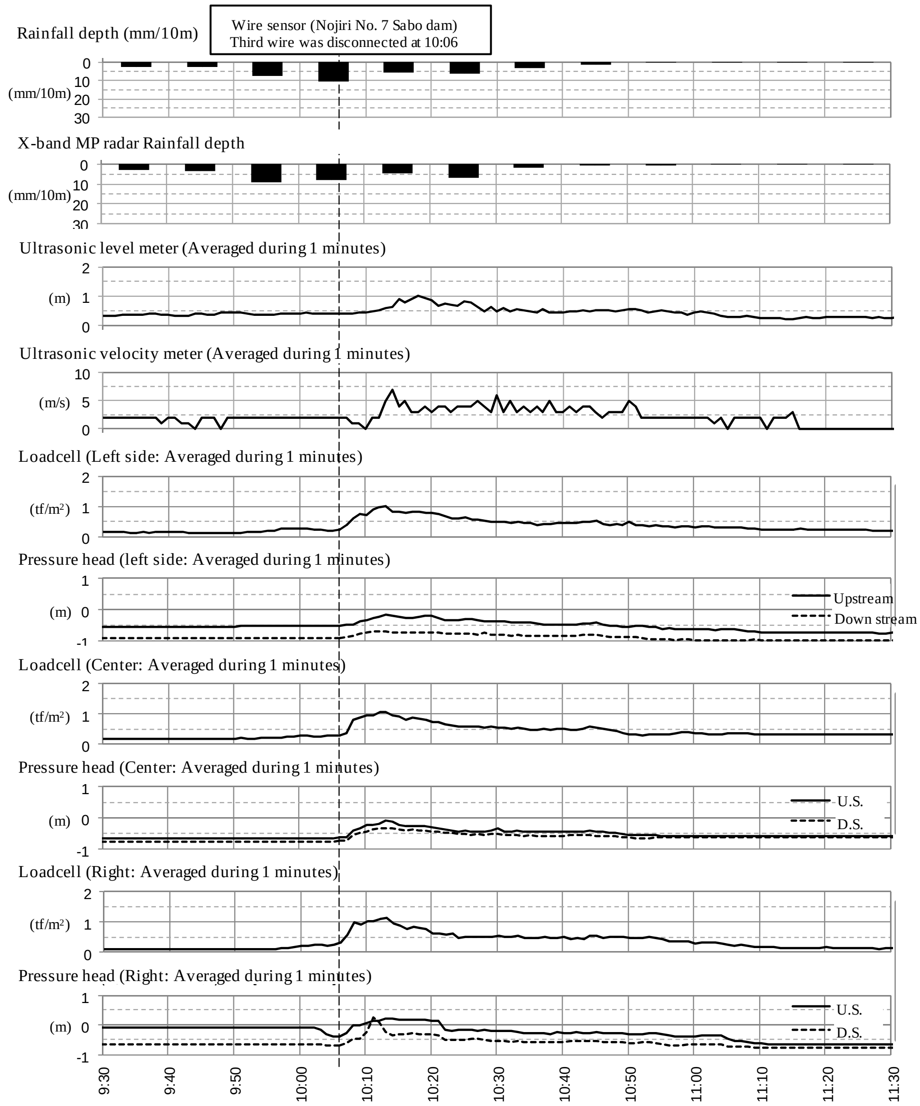


Fig. 7. Temporal changes of rainfall depth, surface velocity and flow depth measured by ultra-sonic meters, pressure head and weight on the bed by the DFLP system in Nojiri River (Debris-flow events on 27th June in 2014)

In present paper, monitored data and the related knowledge are introduced for debris-flow events measured well by the DFLP system in 2012 to 2015. In debris-flow events on 27th June in 2014, two debris-flow surges were observed with magnitude of 64.4 $m^3/s$ in peak discharge, 1.1 m in a depth and 13.8 m/s in surface velocity at Arimura River, because the flow width was not full in spill way of the sabo dam (around 4 m). Debris flows with one surge took place with magnitude of 1.0 m in peak flow depth at Nojiri River in the day. The velocity and flow depth are analyzed by image analyses of CCTV video camera in Arimura River, and by data of CCTV video camera and ultrasonic meter in Nojiri River.

Figure 6 shows temporal changes of rainfall depth, surface velocity and flow discharge, as well as pressure head and weight on the bed, which are observed at Arimura River. Figure 7 shows temporal changes of rainfall depth, surface velocity and flow depth measured by ultra-sonic meters, pressure head and weight by the DFLP system at Nojiri River. In addition, two pressure gauges on the iron plate are set longitudinally with 50 cm in a distance, and the pressure differences are measured though the value of zero for each pressure meter is moving before events. Those debris surges can be observed well, and temporal changes of those data are compared with time of disconnected wires. Wire sensors are at downstream of the monitoring section in Arimura River and, whereas, wire sensors are at upstream of the monitoring section in Nojiri River. Differences between arrival time of peak values and disconnected time of wire appear clearly, and travel time of debris flow is also measured with several sensors.

### *3.2. Specific weight and sediment concentration*

Temporal changes of specific weight, sediment concentration and sediment volume of debris flow using data obtained by DFLP systems are calculated as flow chart shown in Figures 5, in Nojiri and Arimura Rivers in 2014, because of well measured data using DFLP system. Detail explanation for calculations of specific weight and sediment concentration are introduced in Osaka et al. (2014). Specific weight is the ratio of mass density of debris flow to clear water without a dimension and sediment concentration is volumetric concentration.

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 bed slope at the Arimura No. 3 sabo dam is 1/5.3 (10.7 degrees) and recently 1/14 (4.1 degrees). The supposed equilibrium sediment concentration for the bed slope is 0.235 and 0.0721, respectively, for same values of physical parameters of sediment particles in Nojiri River.

Figures 8 (a) to (b) are calculation data for sediment concentration, specific weight of debris flow, and sediment discharge rate for events on June 27th, 2014 in Arimura River. Figures 9 (a) to (c) also show calculation data in Nojiri River.

In Arimura River, sediment concentration and specific weight are calculated as 0.463 and 1.76, respectively, on June 27th, 2014, and sediment discharge is totally calculated as 46,073 m$^3$ in total surges and 22,656 m$^3$ in second surge as shown in Figures 8. Temporal changes of specific weight and sediment concentration can be calculated during debris flow events using DFLP system. In addition, data for sediment concentration of debris flow is obtained by eight debris-flow events, and the averaged sediment concentration, which is averaged near peak of debris-flow surge, is 0.441 during June in 2012 to September 2016 in Arimura River (see Table 1).

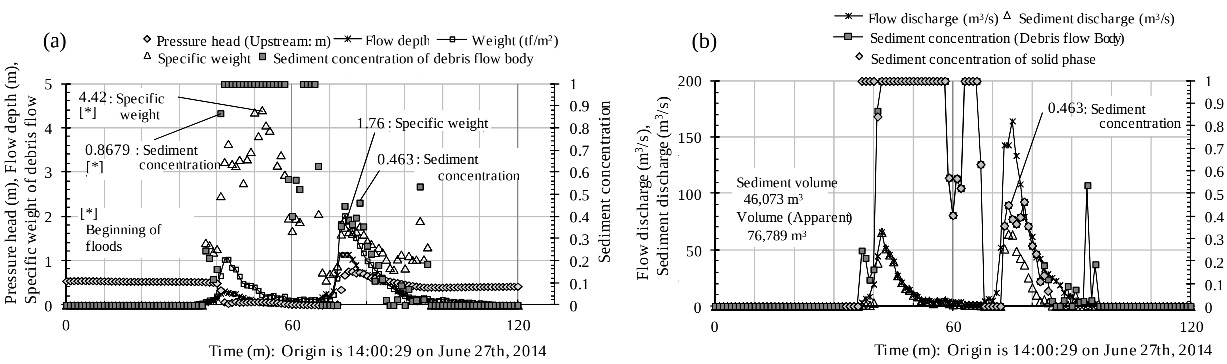


Fig. 8. Calculated sediment concentration, specific weight of debris flow, and sediment discharge rate for events on June 27th, 2014 in Arimura River

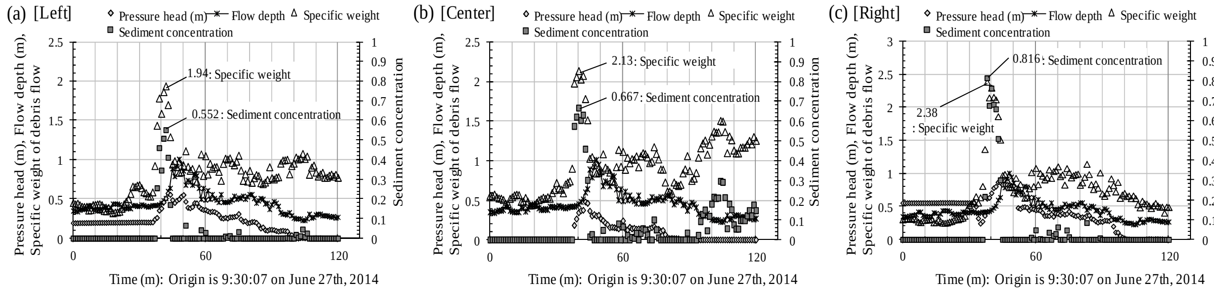


Fig. 9. Calculated sediment concentration and specific weight of debris-flow measured at left, center and right side, respectively (Debris-flow events on June 27th, 2014 in Nojiri River)

In Nojiri River, sediment concentration and specific weight (Fig. 9) were calculated such as 0.552 (left side), 0.667 (center), 0.816 (right side) and 1.94 (left side), 2.13 (center), 2.38 (right side), respectively, in Nojiri River (on 27th in June, 2014). Effects of channel shifting on mass density and sediment concentration are clearly shown in measurements in Nojiri River, though the characteristics could depend on flow magnitude of debris flow. Sediment volume for solid and liquid phase is calculated using data in Figure 9. Total runoff sediment volume is 1,920 $m^3$, and sediment volume of solid and liquid phase are estimated 1,781 $m^3$ and 139 $m^3$, respectively. Moreover, averaged near peak of debris-flow surge, is 0.279 during June in 2014 to June 2016 in Nojiri River (see Table 1).

Table 1 lists calculated sediment concentration near peak stage by the DFLP system at Arimura River. Disconnected wire, accumulated rainfall depth and rainfall depth during 10 minutes before debris-flow occurrences are also listed in the table. Table 2 lists calculated sediment concentration and so on at Noriji No. 1 sabo dam like Table 1. Sediment concentration seems to be independent on rainfall intensity in Arimura and Nojiri River.

Table 1. Sediment concentration of debris flow calculated by DFLP at Arimura No. 3 sabo dam

| Time (y/m/d) | Disconnected wire (1st, 2nd, 3rd) | Sediment concentration near peak stage | Rainfall depth (mm) (*) | Rainfall depth during 10 min. (mm) (**) |
|---|---|---|---|---|
| 2012/6/15 | 2 | 0.290 | 39.0 | 14.0 |
| 2012/6/21 | 1 | 0.371 | 122 | 10.0 |
| 2014/6/27 | 3 | 0.288 | 34.0 | 11.0 |
| 2014/8/1 | 2 | 0.295 | 21.0 | 15.0 |
| 2014/8/29 | 2 | 0.515 | 13.0 | 6.00 |
| 2015/6/3 | 2 | 0.491 | 52.0 | 7.00 |
| 2015/6/11 | 2 | 0.554 | 10.0 | 9.00 |
| 2015/6/14 | 2 | 0.551 | 23.0 | 7.00 |
| 2016/6/27 | 1 | 0.654 | 86.0 | 12.0 |
| 2016/9/20 | 2 | 0.402 | 74.0 | 16.0 |
| Average | - | 0.441 | 39.3 | 9.88 |

(*) Accumulated rainfall before debris-flow occurrences
(**) Maximum rainfall depth during 10 minutes before debris-flow occurrences (mm)

Table 2. Sediment concentration calculated by DFLP at Nojiri No. 1 sabo dam

| Time (y/m/d) | Disconnected wire (1st, 2nd, 3rd) | Sediment concentration near peak stage | Rainfall depth (mm) (*) | Rainfall depth during 10 min. (mm) (**) |
|---|---|---|---|---|
| 2014/6/21 | 2 | 0.156 | 12.0 | 5.0 |
| 2014/6/27 | 1 | 0.191 | 55.0 | 10.0 |
| 2015/3/19 | 3 | 0.435 | 16.0 | 6.0 |
| 2015/4/6 | 1 | 0.371 | 8.00 | 7.0 |
| 2015/6/6 | 2 | 0.187 | 24.0 | 7.0 |
| 2016/4/21 | 2 | 0.182 | 15.0 | 8.0 |
| 2016/6/19 | 2 | 0.270 | 42.0 | 19.0 |
| 2016/6/27 | 2 | 0.443 | 82.0 | 12.0 |
| Average | - | 0.279 | 23.0 | 7.00 |

(*) Accumulated rainfall before debris-flow occurrences
(**) Maximum rainfall depth during 10 minutes before debris-flow occurrences (mm)

Estimated sediment concentration counts solid and liquid (mud) phase, and the value does not seem to be equal to the equilibrium sediment concentration of solid phase, that is coarse component of sediment. The bed slope at the Nojiri No. 7 sabo dam is 1/7.6 (7.50 degrees) and the supposed equilibrium concentration for coarse component of sediment is 0.147 for the bed slope, and the values of 0.235 and 0.0721 are also supposed respectively for the bed slope at the Arimura No. 3 sabo dam is 1/5.3 (10.7 degrees) and recently 1/14 (4.1 degrees). Meanwhile, averaged value of calculated sediment concentration is 0.279 and 0.441, respectively, using the DFLP system. Those values are almost twice than those of estimation by the equilibrium concentration for coarse components, and we need evaluate whether those differences are caused by liquid phase (mud), other factors and so on.

## 4. Conclusions

Debris-flow measurement system with loadcell and pressure sensor (DFLP system) are developed by modification of the DFLP proposed firstly in Switzerland, to almost directly measure temporal changes of debris flows. In Nojiri and Arimura Rivers in Sakurajima Island, DFLP systems were installed in March of 2013 and June of 2012, respectively. Temporal changes of debris-flow quantities need to be evaluated through stable measurement method such as direct measurements using the DFLP system, because of evaluation for internal flow structures of debris-flow surges. Several typical debris flows were measured by present methods. Results obtained using the DFLP in present study are summarized as follows.

(1) Mass density and sediment concentration are calculated using data obtained by the DFLP system and data measured by ultrasonic level meter and surface velocity by of image analyses of CCTV camera. There are at least 10 data in Arimura River and 8 data in Nojiri River for calculations of temporal changes of mass density and sediment concentration since 2012 and 2014, respectively. Especially, coarse components (solid phase) and liquid phase of debris flows can be estimated by calculations using the DFLP system, and those mass density and sediment concentration are calculated.

(2) Estimations for sediment concentration for each event are compared to rainfall values such as the accumulated rainfall before debris-flow occurrences and maximum rainfall depth during 10 minutes before debris-flow occurrences. Averaged value of calculated sediment concentration is 0.279 and 0.441 based on measured data obtained from DFLP systems in Nojiri No. 1 sabo dam and Arimura No. 3 sabo dam, respectively.

(3) However, values of calculated concentration do not always take correlation with rainfall depth before debris-flow occurrences. Data analyses continuously need by more data collections of debris-flow events.

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