Study of debris flow peak discharge at Kamikamihorizawa Creek

Akihiko Ikeda[1*], *Takahiro* Itoh[2], and *Takahisa* Mizuyama[3]

[1]Sabo & Landslide Technical Center, Volcanic Disaster Prevention Department, 2-7-5 Hirakawacho, Chiyoda-ku, Tokyo, Japan
[2]Center for Advanced Research, R & D Center, Nippon Koei Co. Ltd., 2304 Inarihara, Tsukuba, Ibaraki, Japan
[3]Professor emeritus, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto, Japan

Abstract. Prediction of the peak discharge of debris flow is one of the most important factors in mitigating debris flow disasters. Currently, empirical methods based on the relationship between the peak discharge and total debris flow volume (magnitude) for many debris flow events are used to estimate peak discharge for planning or designing debris flow countermeasures in Japan. In order to estimate the peak discharge of debris flow with high accuracy, the debris flow monitoring sensors with load cell and pressure sensor (hereafter referred to as a DFLP system), was installed to evaluate various characteristics during floods involving debris flows at Kamikamihorizawa Creek. During the debris flow that occurred on August 29, 2019 at Kamikamihorizawa Creek, seven surges corresponding to debris flow events were monitored by the DFLP system for a 20-minute period. Based on the relationship between the peak discharge and magnitude, the observation data of Kamikamihorizawa Creek, Illgraben and Schipfenbach has been added to previous data from the literature and the relationship has been updated. The peak discharge and magnitude of debris flow on August 29, 2019 at Kamikamihorizawa Creek exhibited distributions similar to past observation data, which shows that the relationship between peak discharge and magnitude follows a similar trend.

1 Introduction

Prediction of peak discharge of debris flow is one of the most important factors in mitigating debris flow disasters. In general, the peak discharge of debris flow has been either measured at observation sites directly or estimated based on debris flow velocity and cross-sections (flow depth) derived via field investigations [1, 2]. Based on these data, the peak discharge of debris flow has been estimated from various aspects. Currently, empirical methods that are based on the relationship between the peak discharge and total debris flow volume (magnitude) of many debris flow events are used to estimate peak discharge for planning or designing debris flow countermeasures in Japan.

Significant sediment deposition and large numbers of debris flow events have been observed since the 1970s at Kamikamihorizawa Creek, which is located on the eastern side of Mt. Yakedake, an active volcano. The relationship between the peak discharge and magnitude at Kamikamihorizawa Creek is used to estimate peak discharge of debris flow as described above [2, 3]. In order to estimate the peak discharge of debris flow with high accuracy, it is necessary to acquire a large number of observation data with better accuracy than the currently available data. Therefore, the debris flow monitoring sensors with load cell and pressure sensor (hereafter referred to as a DFLP system), were installed to evaluate the characteristics of debris flows at Kamikamihorizawa Creek in November 2014 [4].

This study introduces the measured characteristics of the debris flow that occurred on August 29, 2019 observed by the DFLP system at Kamikamihorizawa Creek, and discusses the addition of this observation data to the past data to improve the accuracy of the peak discharge estimation based on the relationship between the peak discharge and magnitude.

2 Outline of Kamikamihorizawa Creek DFLP system

The Kamikamihorizawa Creek DFLP system was installed at the Kamikamihorizawa No.6 Weir, which is a site where a significant number of debris flow events and large amounts of sediment deposition have been reported previously. At the installation location, an 8° bed slope was fabricated with a gabion just upstream. In the DFLP system, a pin-type load cell was used to measure the weight while the vertical force component was measured by a force plate, thus allowing both the vertical and horizontal components of the force on the bed to be measured at the site.

In addition to the DFLP system components, other sensors installed at the site include closed-circuit television (CCTV) video cameras, an ultrasonic level sensor, and a velocity meter. The CCTV video camera is used to evaluate the flow conditions and flow velocity on the DFLP plate, while the ultrasonic level and velocity meters measure the flow depth and surface velocity of debris flow surges, respectively. The ultrasonic sensors capture data at a resolution of 1.0 m/s and 0.01 m, and the measured data are recorded at the observation station at 1-minute intervals without time-

* Corresponding author: ikeda@stc.or.jp

averaged processing. The measurement areas on the bed surface are approximately 0.32 m^2 and 0.6 m^2 for flow depth and velocity, respectively. To calculate the surface velocity, CCTV-captured images are analyzed manually, primarily by visual inspection, because observers can more easily pick out objects in the debris flow and are uninfluenced by splashes near the free surface.

3 Debris flows on August 29, 2019

During the massive rainfall that took place from August 27 to 30, 2019, the Mt. Yakedake rainfall station recorded an accumulated rainfall depth of 217 mm and a maximum rainfall intensity of 35 mm/h at 06:00 on August 29. Rainfall intensity was based on radar measurements, and a heavy magnitude of rainfall was also observed at 04:00.

On August 29, 2019, the DFLP system observed and measured several debris flow surges resulting from a short period of rainfall. The rainfall intensity was 12 mm for a 10-minute period, resulting in an accumulated depth of 56 mm, and triggering seven debris flow events (surges) within a 20-minute period shortly thereafter.

Sediment concentration was calculated for the debris flow and the coarse phase by the DFLP system. A previous study showed that sediment concentrations could be divided into two components: coarse particle and mud phases, with the sediment concentration of mud phase calculated by pressure sensor [5]. Hence, using the DFLP system, the sediment concentration of time-averaged value of 0.458, can be divided by 0.201 for the coarse phase and by 0.257 for the mud phase. The sediment runoff volume of whole debris flow was calculated as 17,017m^3 without pore by the DFLP system analysis [4].

4 Relationship between debris flow peak discharge and magnitude of Kamikamihorizawa Creek

The observed debris flow on August 29, 2019 consisted of approximately seven surges, with the duration of the flow being about 17 minutes. The peak of this debris flow was estimated to have occurred during the second surge, because the ultrasonic level sensor and the bottom pressure sensor showed a maximum flow depth in the first surge, but the CCTV-captured images showed a maximum flow depth in the second surge.

The peak discharge of debris flow was estimated to be 96.1 m^3/s based on the flow depth and velocity of the second surge from the CCTV-captured images. The magnitude of the second surge corresponding to the maximum flow depth was estimated to be 5,228m^3.

Figure 1 shows the relationship between the peak discharge and magnitude of debris flow on August 29, 2019 at Kamikamihorizawa Creek alongside past data [5], including recent observed data from Illgraben and Schipfenbach, Switzerland [1, 7]. The line indicates the quasi-theoretical linear relationship represented by the following equation:

$$Q_p = \alpha \cdot Q_T^{\ 0.833} \quad (1)$$

where Q_p is the debris-flow peak discharge [m^3/s], Q_T is the magnitude [m^3], and α = 1.0–0.001. The data shown in Figure 1 vary widely over the range of α = 0.1–0.001, principally in the interval α = 0.1–0.01. The variation in peak discharge even for the same magnitude is estimated to be due to differences in sediment supply conditions and deformation of riverbed.

Monitoring data obtained near the initiation zone of debris flows from Kamikamihorizawa Creek are approximated by (1), where the α values tend to be approximately α = 0.01 if the debris flows are muddy (Nojiri River, Jiangjia creek and Hunshui gully) but approximately α = 0.1 if the flows are granular (Kamikamihorizawa Creek, Name River).

The distribution of the debris flow data for the event on August 29, 2019 at Kamikamihorizawa Creek is near (1) with α = 0.1, similar to the distributions of the past data. Hence, although there are differences in observation method depending on the observation period, a similar distribution trend was observed at Kamikamihorizawa Creek.

Illgraben is located in the Southern Alps near Sierre in Canton Wallis, and Schipfenbach is located in the Northern Alps near Silenen in Canton Uri, Switzerland. Additional observation data on debris flow collected at Illgraben and Schipfenbach are also shown in Figure 1. At Illgraben, on average 3 to 5 debris flows and additional debris floods are observed every year. The characteristics of debris flow in Illgraben generally include coarse granular fronts, although muddy debris flows also occurs [7]. The distribution of observation data for 2000, 2008 and 2009 are near power function (1) with α = 0.01, although debris flows in the interval α = 0.1–0.01 are classified as the muddy type. At Schipfenbach, a magnitude of 5,000-5,500m^3 debris flow occurred on 6 August 2000, analyses of the data suggest the event occurred in two surges separated by about 1-2 minutes [7]. The distribution of observation data is near power function (1) with α = 0.1 is classified as the granular type similar to Kamikamihorizawa Creek.

5 Conclusions

Characteristics of debris flow that occurred on August 29, 2019 at Kamikamihorizawa Creek has been carried out by the DFLP system that was installed in 2014, and seven surges corresponding to debris flow events were monitored during a 20-minute period.

To improve the accuracy of the empirical method to estimate peak discharge of debris flow based on the relationship between the peak discharge and magnitude, the observation data of Kamikamihorizawa Creek, Illgraben and Schipfenbach have been added to data from the literature and the relationship has been updated.

The peak discharge and magnitude of debris flow on August 29, 2019 at Kamikamihorizawa Creek indicates a similar distribution to past observation data, and the relationship between peak discharge and magnitude also follows a similar trend as in past data.

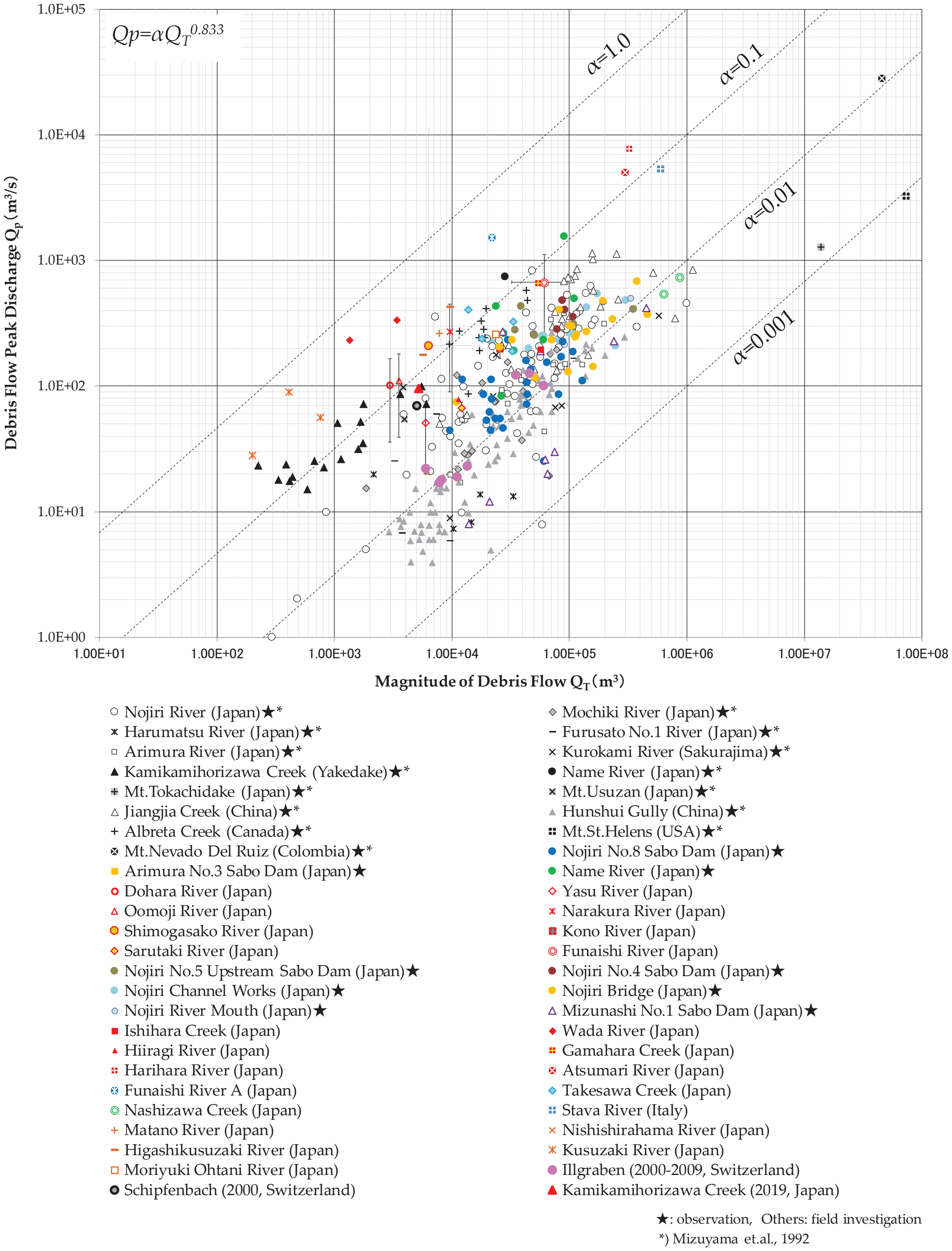

Fig. 1. Relation between peak discharge and magnitude of debris flow.

The distribution of observation data of 2000, 2008 and 2009 of Illgraben is near power function (1) with α = 0.01 but falls in the interval α = 0.1–0.01, which are classified as muddy type, while the observation data of 2000 of Schipfenbach is near power function (1) with α = 0.1 is classified as granular type debris flow.

Authors are thankful to the Matsumoto Sabo Office, Hokuriku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism in Japan (MLIT) and Dr. Dieter Rickenmann for monitoring data and for useful advice. Respectful condolences are extended to the family of Dr. Hiroshi Suwa, who has passed away on Jan. 14th, 2022, to whom providing us valuable figures and pictures of his field observations at Kamikamihorizawa Creek and for giving us permission for usage of valuable information.

References

1. D. Rickenmann, *Methods for the Quantitative Assessment of Channel Processes in Torrents (Steep Streams)*: IAHR MONOGRAPH, 138 p (2016).
2. T. Mizuyama, S. Kobashi and G. Ou, *Prediction of Debris Flow Peak Discharge*, Proc. Int. Symp. INTERPRAEVENT, Bern, Switzerland, Bd. 4, p. 99-108 (1992).
3. H. Suwa and K. Okunishi, *Motion, Debris Size and Scale of Debris Flows in a valley on Mount Yakedake Japan*, Annuals. Disaster Prevention Res. Inst., Kyoto Univ., No.33B-1, p. 191-203 (In Japanese with English abstract) (1990).
4. T. Itoh, T. Nagayama, S. Matsuda and T. Mizuyama, *Direct Debris fFlow Measurements using DFLP system at Kamikamihorizawa Creek*, International Journal of Erosion Control Engineering, **14**, **2**, pp. 12-19 (2021).
5. T. Osaka, R. Utsunomiya, S. Tagata, T. Itoh and T. Mizuyama, *Debris Flow Monitoring using Load Cells in Sakurajima Island*, in Proceedings of the INTERPRAEVENT Pacific Rim (edited by M. Fujita et al.), November 25-28, Nara, Japan, 2014, O-14.pdf in DVD (2014)
6. A. Ikeda, T. Itoh and T. Mizuyama, *Study of prediction methods of debris-flow peak discharge*, in Proceedings of 7th International Conference on Debris-Flow Hazard Mitigation, 10-13 June 2019, Golden, USA (2019)
7. M. Swartz, B. Mc Ardell, P. Bartelt and M. Christen, *Evaluation of a two-phase debris flow model using field data from the Swiss Alps*, Proc. Int. Symp. INTERPRAEVENT, Riva/Trient, Italy, Bd. 3, p. 319-329 (2004).