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The role of topography on the volume of material eroded by debris flows

Tsukasa Kudo[a,*], Taro Uchida[b], Wataru Sakurai[b]

[a]*Sabo Engineering Corporation, Kawagoe, Japan*
[b] *National Institute for Land and Infrastructure Management, Sabo Planning Division, Tsukuba, Japan*

Abstract

Prediction of sediment volume of debris flows is the most important factor for designing debris-flow control structures or estimating debris-flow prone area. It has been considered that debris-flow volume may increase due to erosion at the steep channel. So, clarifying erosion volume (in this study, erosion volume is sediment volume in the channel eroded by debris flow) due to debris flow is a key information to mitigate debris-flow disasters. This study hypothesized that erosion volume might be controlled by topography, because it can be thought that the transport capacity of debris flow increased with the increase of stream bed gradient and contributing area. In Recent field observations by Schürch et al. (2011) supported to this hypothesis and showed a correlation, showing the correlation between flow depth and magnitude of erosion. However, detailed information about spatial pattern of erosion depth due to debris flow is still limited. In this study, spatial pattern measurements of erosion volume due to debris flows for 16 debris flows in Japan. LiDAR data taken before and after the debris flow was used for the comparison. Then, examination of stream bed gradient and drainage area derived from the LiDAR dataset was performed. The study found that erosion volume of debris flow increases as slope of stream bed gradient and drainage area increases. The study proposed methods to predict erosion volume due to debris flow using stream bed gradient and drainage area based on the probabilistic relationship between measured erosion volume and topography. That is, it is considered that the topography derived from LiDAR can be used as one of the indicators used in estimating volume of future debris flow.

Keywords: Debris flow, erosion volume, topography, LiDAR survey

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1. Introduction

Many debris flows increase in volume as they travel downstream, enhancing their mobility and hazard (Reid et al., 2016). It is recognized that an increase in debris-flow volume of debris flow can result from diverse physical processes (e.g., Reid et al., 2016). In general, it is recognized that the volume of debris flow should be controlled by sediment transport capacity or removable sediment volume. Removable sediment volume should be determined by both distribution of channel-bed sediment and the range where erosion is expected by debris flow.

This study reports on the relationship between topography and erosion volume of debris flow, using LiDAR data, and proposed methods to predict erosion volume due to debris flow using stream bed gradient and drainage area based on the probabilistic relationship between measured erosion volume and topography.

2. Method

2.1. The debris-flow data

This study focused on 16 debris-flow events that occurred from 2009 to 2014, in Japan (Table. 1). 16 debris flows are classified into 5 location. The data of Minamiuonuma City, Nagiso town and Hofu city is mainly Granite area.

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* Corresponding author e-mail address*: t_kudou@saboeng.co.jp*

The data of Inabe City is mainly limestone area. The data of Aso City is mainly pyroclastic flow deposits area.

2.2. Estimation of sediment volume of debris flow and calculation of topography

The runout path of debris flows was interpreted from aerial photos. Then a survey point was established every 10m in the longitudinal direction of the identified runout path of the debris flow (Fig.1). Additionally, discharged sediment volume due to debris flow was estimated and topography at each survey points was calculated at each survey points using LiDAR dataset (Fig.1). Discharged sediment volume due to debris flow is variation volume estimated every 10m in the longitudinal direction of the runout path using surface changes derived from DEM data. Topography calculated in this study is slope and catchment area. The slope was measured on the average 100m using DEM data before debris flow occurred to longitudinal gradient in the runout path. Similarly, the catchment area was measured upstream area from each survey points using DEM data.

Table 1. Debris flows used in this study

Name	Date of occurrence	Location
Ubasawa	July 29-30, 2011	Minamiuonuma City, Niigata Pref.
Futagosawakawa	July 29-30, 2011	Minamiuonuma City, Niigata Pref.
Garasawakawa	July 29-30, 2011	Minamiuonuma City, Niigata Pref.
Koudanakawa	July 29-30, 2011	Minamiuonuma City, Niigata Pref.
Tsuchisawa	July 29-30, 2011	Minamiuonuma City, Niigata Pref.
Nashisawa	July 8-11, 2014	Minamikido town, Nagano Pref
Nishinokaitogawa	September 16-19, 2012	Inabe City, Mie Pref.
Kotakigawa	September 16-19, 2012	Inabe City, Mie Pref.
Abetanbugawa	July 21, 2009	Hofu City, Yamaguchi Pref.
Yahatadanikeiryu	July 21, 2009	Hofu City, Yamaguchi Pref.
Matsugatanikawa	July 21, 2009	Hofu City, Yamaguchi Pref.
Kamisatogawa	July 21, 2009	Hofu City, Yamaguchi Pref.
Uedaminamigawa	July 21, 2009	Hofu City, Yamaguchi Pref.
Daimongawa	July 11-12, 2012	Aso City, Kumamoto Pref.
Sakanashi area	July 11-12, 2012	Aso City, Kumamoto Pref.
Shioigawa2	July 11-12, 2012	Aso City, Kumamoto Pref.
Shinsyogawa3	July 11-12, 2012	Aso City, Kumamoto Pref.
Doigawa	July 11-12, 2012	Aso City, Kumamoto Pref.

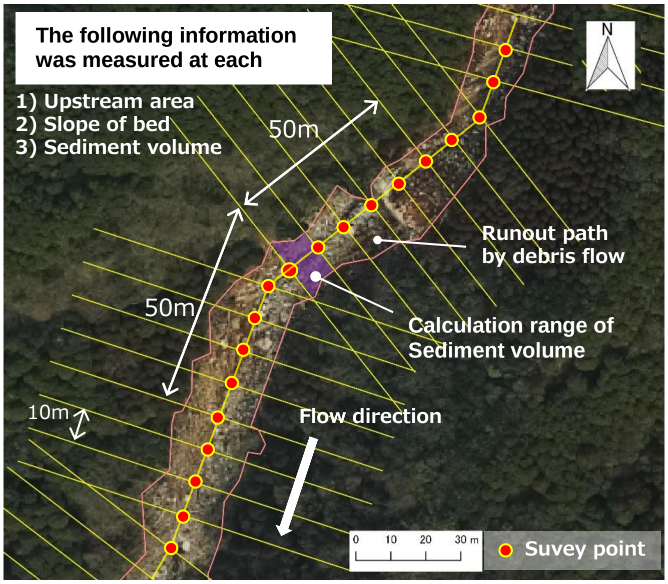

Fig. 1. Example of survey points

2.3. Relationship between topography and sediment volume of debris flow

Topography was classified at each survey points into categories. The slope and catchment area classes were classified based on Fig.2. The slope was classified into 9 every 5° classes and the catchment area was classified into 8 classes per order size. Additionally, the calculated variation volume at survey area was applied to each category. Then, the percentile (10%, 50％, 75％, 90％) of variation volume every 10m in the longitudinal direction of the runout path using surface changes was calculated in each category (Fig.3).

2.4. Estimation of erosion volume of debris flow based on relationship between topography and sediment volume

This study proposes methods to predict erosion volume due to debris flow using stream bed gradient and catchment area based on the probabilistic relationship between measured erosion volume and topography (that is, probabilistic method in this study). In this study, the 50th percentile (the median) of variation volume for each category obtained from 16 debris-flows data was assumed as standard erosion volume by debris flow occurring at the topographic condition corresponding to each category. Therefore, the 50th percentile calculated in this study is used as estimated erosion volume due to debris flow for each topographic condition. Then a comparison of actual erosion volume with topography was developed using pre-flow and post-flow LiDAR imagery.

3. Results

Fig 2 shows the relationship between catchment area and the slope of the stream bed with the plots classified by erosion or deposition calculated each survey area (Fig.1.purple area). Erosion or deposition were determined based on the variation volume. The plots where erosion dominates is widely distributed regardless catchment area size and stream bed gradient.

Fig 3 shows the relationship between topography and percentile (10%, 50％, 75％, 90％) of erosion volume due to debris flow. For each classified category, erosion and deposition were classified and color coded according to the scale. Place where the number of plots corresponding to the category is less than 1％ of the total number of plots is indicated by parenthesized numbers, and places where there is no corresponding plot are indicated by [－].

Looking at the overall trend, in areas where the slope is steep and the catchment area is large, the volume of the eroded sediment tends to be larger than in the area with a low gradient slope and a small catchment area (Fig.3).

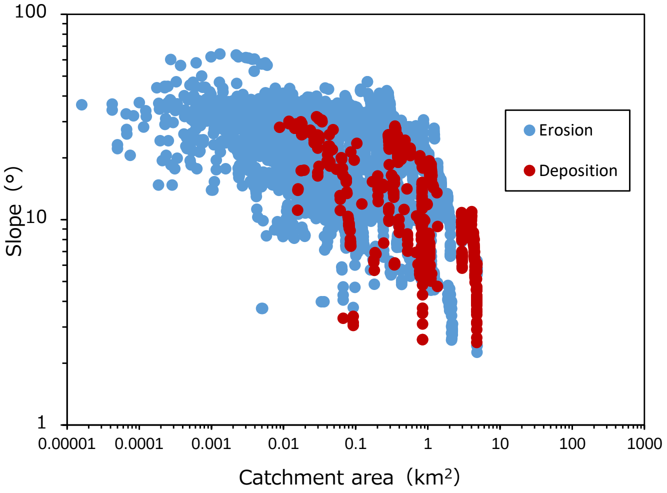

Fig. 2. Relationship between catchment area and slope of bed for each survey points

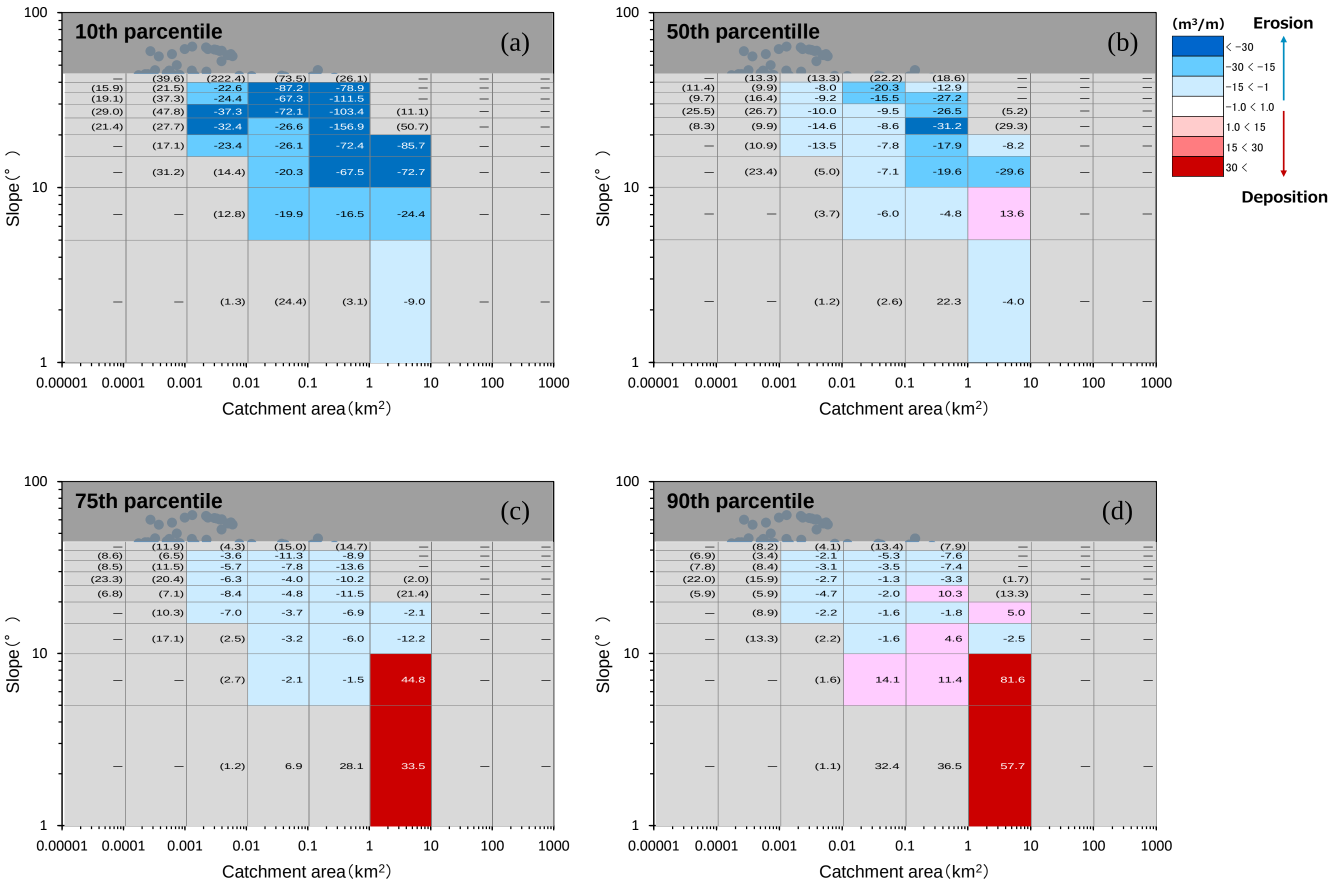

Fig. 3. Relationship between topography and variation volume due to debris flow, (a)10th percentile of variation volume, (b) 50th percentile of variation volume, (c) 75th percentile of variation volume, (d) 90 percentile of variation volume,

Fig 4 shows example of the result of the relationship between actual sediment volume and estimated sediment volume. There was a clear correlation between actual sediment volume and estimated sediment volume in Koudanakawa02 (Fig 4 (a), orange plots). Although, in Koudanakawa01 (Fig 4 (a), blue plots), the actual sediment volume was about 3 times the estimated value regardless of survey points. Also, in Matsugatanikawa05 (Fig 4 (b), blue plots), the actual sediment volume was about half of the estimated sediment volume.

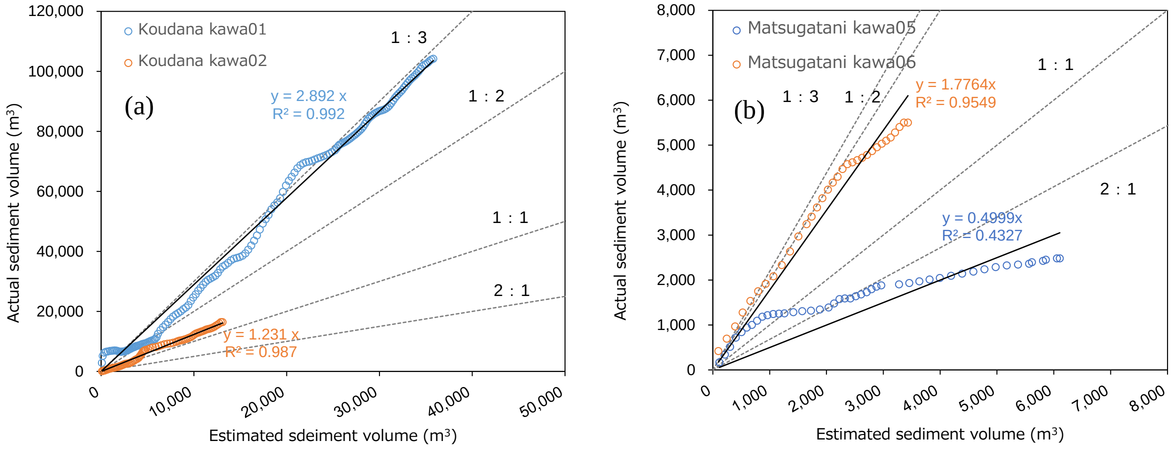

Fig. 4. Relationship between actual sediment volume and estimated sediment volume, (a) Example of Koudanakawa river, (b) Example of Matsugatanikawa river

4. Conclusion

By comparing pre-and post-flow LiDAR imagery, this study found that erosion volume of debris flow increases as slope of stream bed gradient and drainage area increases. Then, An erosion volume prediction was developed using a probilistic relationship between measured erosion volume and topography. As a result, it is considered that the topography derived from LiDAR can be used as one of the indicators used in estimating volume of future debris flow. On the other hand, there may be a large difference between the actual sediment volume and estimated sediment volume. In this case, it is thought that the debris-flow scale at the start point and distribution of channel-bed sediment are influenced, but detailed analysis is necessary.

References

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