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# Examining Landslide Materials Movement Using a Small Flume Experiment : A Case Study of the 2018 Eastern Iburi Earthquake, Hokkaido

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## 1. INTRODUCTION

More than 6000 landslides on over 20 × 20 km area near Atsuma Town occurred by Eastern Iburi earthquake ($M_w$: 6.7) on September 6th, 2018 (Konagai et al. 2018). The density of the landslide was approximately 20 times greater than that in earthquake occurred in Wenchuan, China. Some of the material on hillslope was transported as debris flow and damaged houses and agriculture lands (Takahashi and Kimura 2019). Total sediment production was approximately 30 million m$^3$ (MLIT 2018). The area affected by landslides has various layers of volcanic deposit that originated from the eruption of Tarumae volcano 9000 years ago (Konagai et al. 2018). In these landslides, Yamagishi and Yamazaki (2018) represented that mobility of sediment varied from materials moved without mixed in a short run-out distance and fluidized creating long run-out distance.

Several studies analyzed the mobility of landslide material by flume experiments. For instance, Kharismalatri et al. (2018) pointed out that the mobility of different landslide sediments was associated with the combined effect of soil characteristics such as porosity, particle size distribution, and density. They identified that soil with 1.1 g/cm$^3$ of density, 60% of porosity, and 2.2 mm of $D_{50}$ had the highest transport rate. Eu et al. (2017) remarked that different composition of sand, gravel, and clay showed the different behavior of sediment movement. Indeed, they showed that in a condition where gravel was more dominant than sand, soil with 19% sand had higher sediment transport than the other condition with 30% sand. Most of these experiments were conducted using a mixture of soil and weathered rock materials. However, no study investigated the mobility of volcanic materials.

Volcanic deposit generally has unique consistency, low bulk density, and high water-holding capacity (Nanzyo 1993). A volcanic area typically has tephra defined as volcanic ejecta that contains various silicates with different size of materials and andosol defined as volcanic ash soil formed due to mineral decomposition of tephra deposition (Nanzyo 2006). Among the tephra, pumice was defined as a vesicular-textured volcanic deposit formed by rapid cooling down process of ejected volcanic rock (Sparks and Whitham 1986). Pumice typically had lower density ($0.2 \le \rho_b \le 0.75$ g/cm$^3$) and higher porosity ($60 \le n \le 91\%$) compared to volcanic ash soil ($0.6 \le \rho_b \le 0.9$ g/cm$^3$; $51 \le n \le 72\%$) (e.g., Maeda et al., 1982). Because pumice was widely distributed with 3 to 5 m in depth, pumice was the major mobilized materials in the area with landslides by Eastern Iburi Earthquake. Consequently, the testing on the mobility of pumice layer is one of key factors for examing the mobility of sediment.

Therefore, the objectives of this study are to (1) examine the physical and engineering characteristics of soil with volcanic deposit and (2) examine the movement characteristics of pumice by a small flume experiment. Information resulted in this study might be useful for assessing the risk of sediment disaster by an earthquake-induced landslide.

## 2. METHODOLOGY

This study consisted of (1) soil sampling and analysis and (2) flume experiment for sediment movement. Soil samples were collected from landslides located in Atsuma town on November 3rd – 4th, 2019. Six undisturbed samples was collected using 100 cc stainless tubes (5.1 cm in diameter, 5 cm in length) for analyzing permeability ($k$), while 14 disturbed samples were collected using 400 cc stainless tubes (11.3 cm in diameter, 4 cm in length) for water content ($w$), dry density ($\rho_b$), particle distribution ($D_{50}$), specific gravity ($G_s$), porosity ($n$), and liquid limit ($LL$). Dry density and water content were respectively analyzed based on ASTM D7263 and ASTM D4643. Particle size was analyzed using sieves for particles larger than ≥ 75 μm and laser diffraction particle size analyzer SALD-2300 for particles < 75 μm. The liquid limit was estimated using fall-cone penetrometer based on JGS 0142-2009. Specific gravity for indicating particle density was estimated based on ASTM D854. Samples were visually classified as pumice, weathered pumice, andosol, clay, and surface soils. Pumice was light brown with light gravel-sized texture collected from 1.8 m from soil surface in the depositional zone. Weathered pumice had a finer texture than pumice with similar color was collected from 2 m from soil surface in the depositional zone. Andosol that was defined as black or dark brown soil with high organic material formed from decomposed volcanic deposit (Nanzyo 2006) was collected from 1 m from soil surface in the depositional zone. Surface soil with a mixture of organic matter and roots were collected from 60 cm from soil surface in landslide scarp. Clay was collected from the lower layer of landslide scarp which possibly was 3 m from the soil surface.

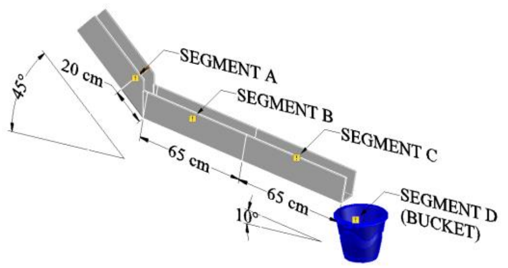


**Fig. 1** Schematic illustration of experimental flume

A small flume model is developed consisted of primary and secondary segments (**Fig. 1**). Each segment has 10 cm in width and 15 cm in height made of 1-cm thick acrylic board. The primary segment represents the valley while the secondary segment represents the slope for material supply. The primary segment is 130 cm length with placing a bucket at the end of the segment to collect transported materials. We classified four segments in the primary and secondary channel from segment A to D (**Fig. 1**). We used the 500 cc pumice which represented as 13500 m$^3$ of collapsed material by 1:300 scale. Because mean of landslide volume was 5000 m$^3$ based on MLIT (2018), our experiment focused on relatively larger size of landslides. Because water content of soil is one of key parameter for mobility (Iverson 2014), we applied different conditions of water contents with saturation 0, 0.3, 0.6, and 1, for which 0.58 (surface dry: $S_{SD}$) was assumed to be a threshold of saturation. The surface dry that represents inner-particle water holding capacity was estimated based on a condition when particle surfaces are dry but the inner-particle voids are saturated with water. We placed mixed soil and water at 20 cm upstream from the confluence and then released material. Then sediment deposited in the section from A to D was collected and the dry weight was measured. The experiment was conducted four times for each saturation.

## 3. RESULT AND DISCUSSION

### [1] Soil characteristics

Water contents of pumice and weathered pumice ranged from 108% to 172% (mean: 136%; *SD*: 24%), which was higher than that in the other soils (mean: 49%; *SD*: 23%). Because the presence of vesicles resulted in the high matric potential (suction) of dry pumice particles (Esposito and Guadagno 1998), pumice can hold more water than other soils. Pumice also had relatively large $D_{50}$ (mean: 5 mm; *SD*: 1.5 mm) compared to the other soil (mean: 0.7 mm; *SD*: 0.5 mm). The large $D_{50}$ resulted in high porosity of pumice, which ranged from 71% to 77% (mean: 74%; *SD*: 2%). The dry density of pumice was very low, ranging from 0.3 to 0.4 g/cm$^3$ (mean: 0.35 g/cm$^3$; *SD*: 0.05 g/cm$^3$). Our findings with low density agreed to the previous studies by Geoffrey et al. (2012) with 0.6 g/cm$^3$ and Whitham and Sparks (1986) with 0.27 g/cm$^3$. The specific gravity of pumice ranged from 1.3 to 1.5 (mean: 1.3; *SD*: 0.1) was not only lower than the other soil types (mean: 2.6; *SD*: 0.1), but also lower than that in the previous study by Bowles (1997) ($G_s$ = 2.6 to 2.8). The lower specific gravity signifies that pumice has numerous microscopic vesicles that make pumice floating in the water (Fauria et al. 2017) and having low shear strength (Roy and Bhalla 2017).

### [2] flume experiment

Movement of pumice differed depending on the water content of samples. Mean run-out distance from the confluence was 41.6 cm (*SD*: 4.6 cm) at zero saturation and became lower to 27.3 cm (*SD*: 2 cm) and 20.2 cm (*SD*: 5.1 cm) for 0.3 and 0.6 saturation. In general, lightweight materials with no cohesion between particles promoted much individual mobility for granular materials. Thus, condition with zero saturation had higher mobility than 0.3 and 0.6 saturation. When the saturation was nearly 0.6 (near $S_{SD}$), water applied to the samples were absorbed to the pumice materials. Indeed, total absorbed water in pumice was 230.5 g under 0.6 saturation, while the estimated amount of water under surface dry (0.58) was 222.8 g. Indeed, most of the pumice was contented water with 108% (162 g) to 172% (258 g) (about saturation 0.55 to 0.67) based on the soil analysis, which implied that field water content was near surface dry. Consequently, a few amounts of water retained between particles since the suction value is exceedingly high under 0.3 and 0.6. Therefore, our finding of pumice mobility under 0.6 saturation level was the lowest among other conditions.

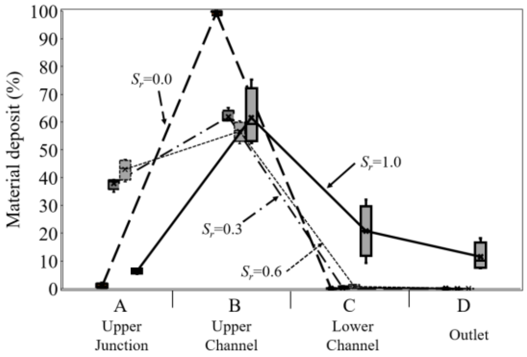


**Fig. 2** Material deposits with different water contents

When pumice was oversaturated ($S_r \geq 1$), we found that material was highly mobilized due to low shear resistance of materials (Al-Karni 2001). Indeed, percentages of pumice transported to the outlet became 7.2% to 18.2% (mean: 11.4%; *SD*: 5%) (**Fig. 2**). Kharismalatri et al. (2018) analyzed sediment mobility for four different soil types and remarked that sediment mobility is associated with the combined effect of the density and porosity. Our pumice has lower density and higher porosity than their soils, and consequently our pumice was highly mobilized than their sand and shale (outlet = 1%), pyroclastic sediment (outlet = 0%), and weathered granite (outlet = 13%). However, our pumice is less mobilized than their weathered sedimentary rock (outlet = 61.3%). Because pumice has high inner-particle water holding capacity ($S_{SD}$ = 58%), approximately only 42% of the total water in saturated condition retained in inter-particle voids. Even though pumice has high porosity, since their $S_{SD}$ is also high, the inter-particle water might be less than that in weathered sedimentary rock. This condition implied that the higher porosity does not always represent higher mobility. Our study agrees with Kharismalatri et al. (2018) that density and porosity affect sediment mobility. However, our experiment highlights that the inner-particle water holding capacity is also a key factor that controls sediment mobility.

## 4. CONCLUSION

Our findings showed that pumice had unique mobility by a high inner-particle water holding capacity. As Yamagishi and Yamazaki (2018) noted that mobility of landslides by east Iburi earthquake varied. Our findings implied that such mobility might associate with variability of water contents in pumice layers, which related to accumulation and storage of water by topography and soil conditions. We further investigate the mobility of different types of soil (pumice, weathered pumice, andosol, soil, and mixture) with different topographic conditions (e.g., junction angle).

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