Small Flume Experiment on the Influence of Sediment Inflow Angle on Landslide Runout Length

○Hefryan Sukma KHARISMALATRI, Yoshiharu ISHIKAWA, Takashi GOMI,
Katsushige SHIRAKI, Taeko WAKAHARA, Hiroyasu OSHIMA,
Tokyo University of Agriculture and Technology

Introduction

Debris flow, flow movement of sediment and water mixture which behave as a continuous fluid to downstream under the influence of gravity, particularly dangerous to life and property since it moves rapidly, large in volume, destroy object without warning, and often occur without warning (Takahashi, 2007; Highland et. al, 1997). Takahashi (2007) classifies debris flow as stony-type debris flow, turbulent-muddy-type debris flow, and viscous debris flow, which is a. The classification is a function of flow pattern (Reynolds number as benchmark), rock type (Bagnold number as benchmark), and geomorphic aspect of stream (flow depth/median diameter of solid particle as benchmark) (Takahashi, 2009).

Assessment of runout distance, i.e. the length travelled by a debris flow from the initiation zone until their lowest point of deposition zone, has crucial role for determining affected areas to develop sediment disaster preparedness, prevention and mitigation (D'Agostino, 2010; Strimbu, 2011). Runout distance of debris flow is controlled by properties of the material and characteristics of the movement path (Fannin & Bowman, 1998). On our previous research, we found out that landslides which has large confluence/inflow angle (>60°) and gentle stream gradient (<10°) are likely to form landslide dam, whilst landslides which has small inflow angle (<60°) and steep stream gradient (>10°) are likely to move downstream as debris flow.

Debris flow occurred in Hiroshima City (Hiroshima Pref.) on August 2014 and in Izu Oshima (Tokyo Pref.) on October 2013, both were caused by accumulative of heavy rainfall and led to large casualties and property damages in downstream. Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) reported that in total, there were 36 deaths, 3 missing, 71 destroyed houses, and 132 severely damaged houses in Izu Oshima disaster (MLIT, 2013). Whilst in Hiroshima City, there were 73 deaths, 39 injuries, 123 destroyed houses, and 232 severely damaged houses in Hiroshima City (MLIT, 2014). The disaster in Izu Oshima classified into muddy-type debris flow, the sediment is mainly fine grain soil and sand of volcanic ash, the flow length approximately 2.5 km, and average stream gradient 10.7°. The sediment in Hiroshima City is dominated by granite and weathered sedimentary rock, and the soil movement classified into gravel-type debris flow which contains large amount of sand and gravel.

Based on our previous founding, we examine the behavior of soil from Izu Oshima and Hiroshima disasters in small flume experiment to analyze the influence of stream gradient and sediment inflow angle to the sediment delivery percentages, the characteristics difference of stony-type and muddy-type sediment movement, and the possibility of natural dam formation.

Methodology

The small flume used in this research has two segments, namely the main stream and sediment inflow segments, both segments were 10 cm width and 15 cm height. The stream segment's gradient was varied to 10° and 15°, whilst the inflow segment's gradient was fixed on 45°. Furthermore, the inflow angle (the angle between stream segment and inflow segment) was varied to 60° and 90°. Additionally, the sediment was situated 30 cm from the confluence section of the stream and inflow, the stream was 170 cm length, and a bucket was placed in the end of the stream. The sediment percentages remaining in the confluence section to upstream, from confluence section to 50 cm downstream, from 50 cm to the end of stream, and in the bucket were calculated. As well as the deposition height in confluence section, sediment collision height, and sediment backflow length. The sediments used for experiments were soil samples from the initiation zones (failure zones), consist of 8 samples of Izu Oshima volcanic ash, 9 samples of Hiroshima granite, and 3 samples of Hiroshima weathered sedimentary rocks, where all soil samples were conditioned at its saturated condition to represent the disaster moment.

Result and Discussion

The results show that stream gradient affect sediment movement effectively rather than sediment inflow angle. The sediment percentage in the bucket was significantly increased with the increasing of stream gradient, from median 31% to 55% for Izu-Oshima volcanic ash, 0% to 18% for Hiroshima granite, and 41% to 67% for Hiroshima sedimentary rocks (Fig. 1). This implies that the steeper stream gradient, the longer material runout length and the larger affected areas. However, the sediment movement was not significantly affected by inflow angle modification. The median for Izu-Oshima volcanic ash decreased from 31% to 12%, whilst the results did not change significantly for Hiroshima soil samples (0% for granite, 41% for sedimentary rocks).

Ministry of Construction (1987) examined 110 data of landslides in Japan, USA, Canada, Peru, New Zealand, and Pakistan, and found out that no natural dams occurred at stream with gradient more than 15°. The inflow angle influence was not analyzed in that research but it assumed that stream gradient is sufficient to examine the possibility of collapsed material to form natural dam or debris flow. Furthermore, Rickenmann (2005) resumed that Hungr et al. (1984) and Takahashi (1991) described theoretical equations on predicting the runout distance, by considering gradient of runout stream, gradient of inflow stream/slope, inflow velocity, inflow depth, and friction of slope, without considering the inflow angle.

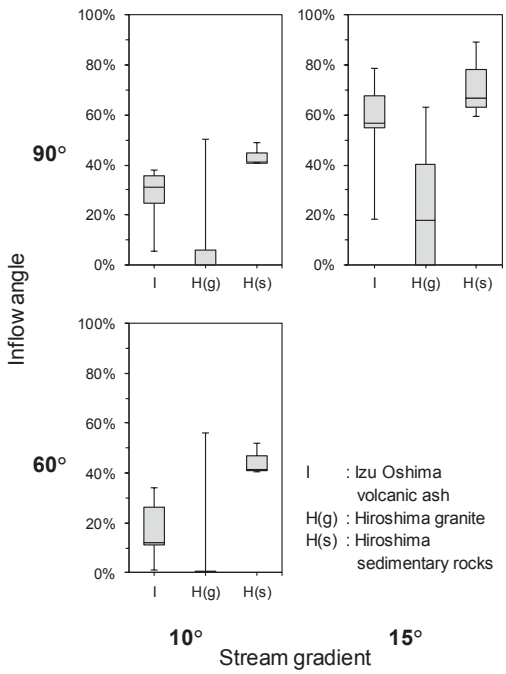

Fig. 1 Percentage of sediment delivery in the bucket

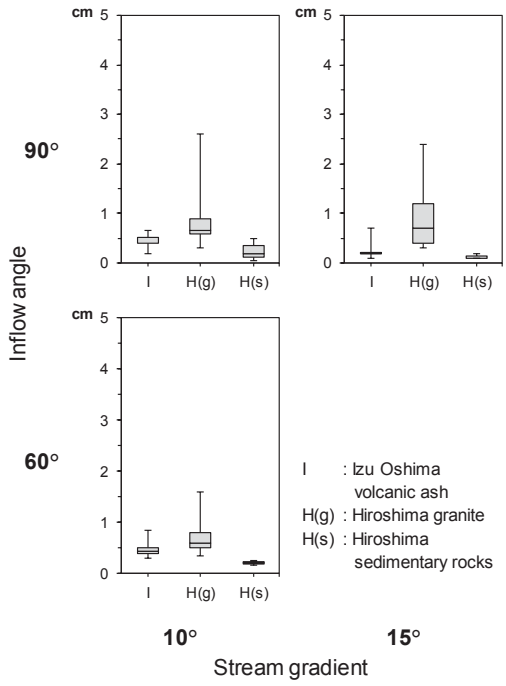

Fig. 2 Sediment deposition height at confluence section

Movement of sediment from Izu Oshima (muddy-type debris flow) and Hiroshima (stony-type debris flow) has several distinct characteristics. The muddy-type is very turbulent, the collision heights on the opposite of inflow segment are very high and sometimes overflowed, and all soil samples were transported up to the bucket. Therefore, muddy-type debris flow might have longer runout distance and larger affected areas. While the stony-type is not as turbulent as muddy-type, about 40% of soil samples could not reach the end of stream segment, and sometimes formed deposition along the stream segment.

Deposition of sediment in confluence section was formed in several experiments and the median value was not significantly changed with modification of stream gradient and inflow angle (Fig. 2). However, the maximum value was decreased when the stream gradient decreased and when the inflow angle decreased. Since the soil samples used in the experiments were from debris flow disaster initiation zones, the formation of big deposition (natural dam) cannot clearly be examined. Soil samples from initiation zones of natural dam are necessary in order to analyze the possibility of natural dam formation accurately.

Conclusion

Stream gradient significantly influence the percentage of sediment delivery to downstream rather than inflow angle, and it is sufficient to examine the possibility of collapsed material to form natural dam or debris flow. Sediment percentage in the downstream was significantly increased with the increasing of stream gradient, but was not significantly affected by inflow angle modification. Muddy-type sediment movements are very turbulent, might flows longer and have larger affected areas rather than stony-type sediment movements. Deposition of sediment in confluence section was formed in several experiments and the median value was not significantly changed with modification of stream gradient and inflow angle. Sediment deposition height in the experiments could not represent the possibility of natural dam formation, and soil samples of natural dam initiation zones are necessary to analyze accurately the possibility of natural dam formation.

Keywords: debris flow, natural dam, stream gradient, inflow angle, small flume.

References

D'Agostino, V., Cesca, M., Marchi, L. 2010. Field and laboratory investigations of runout distances of debris flows in the Dolomites (Eastern Italian Alps). Geomorphology. 115: 294–304.

Fannin, J., Bowman, E.T. 2008. Debris flows - Entrainment, Deposition and Travel Distance. Geotechnical News. 25(4): 3-6.

Petrascheck, A., Kienholz, H. 2003. Hazard assessment and mapping of mountain risks in Switzerland. In: Debris-Flow Hazards Mitigation: Mechanics, Prediction and Assessment. Rickenmann & Chen (Ed.). Milipress, Rotterdam, 25-38.

Ministry of Construction, Chubu Regional Construction Bereau, River Section. 1987. Collection of Landslide Dams 1987.

Rickenmann, D. 2005. Runout prediction methods. In: Debris-flow hazards and related phenomena. Eds M. Jakob & O. Hungr. Praxis. Springer Berlin Heidelberg.

Takahashi T. 2007. Debris Flow: Mechanics, Prediction and Countermeasures. London: Taylor & Francis Group.