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Effect of Collisional Granular Flow on The Erosion and Transport of An Erodible Bed Under Varying Particle Sizes and Mixing Ratios

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Abstract: In this study, a small-scale flume was constructed to simulate collisional granular flow over an erodible bed, and experiments were conducted by varying the particle size and mixing ratio of glass beads. High-speed cameras were positioned on the side and top of the flume to capture the interaction dynamics between the granular flow and the erodible bed. The experimental results were analyzed to compare the effects of particle size and mixing ratio on the bed erosion and transport characteristics.

Keywords: ***Granular flow, Small-scale experiment, Particle size, Mixing ratio, Erosion and transport.***

Introduction

Recently, slope hazards have occurred in urban areas due to localized heavy rainfall and typhoons. Among these, debris flows cause significant loss of life and property as the flows originating from slope collapse mix with rainfall and rapidly move downstream. Debris flows occurring at the top of a mountain can increase in volume by entraining sediments along the valley and eroding the basal bed. In particular, the debris flow was characterized by the presence of numerous boulders and coarse particles, and it has been reported that the front part of debris flows containing such materials causes substantial erosion.

Figure 1 shows the typical structure of debris flow. In this process, the volume increase caused by the erosion can lead to increased travel distance and kinetic energy, which can deposit a large amount of sediment in the downstream area and increase the damage magnitude (Hungr et al., 2014; Song and Choi, 2021). However, the growth mechanism through gradual erosion and entrainment caused by debris flow entrained with boulders is not yet clearly understood, and it remains very difficult to estimate the downstream deposition range from the effect of erosion. Consequently, erosion remains one of the most complex momentum exchange processes to predict (Hungr et al., 2005; Iverson, 2012).

In this study, a small-scale flume was made to simulate collisional granular flow and erodible bed, and then the experiments were performed by varying particle size and mixing ratio of glass beads. High-speed cameras were installed on the sides and top of the flume to record the erosion and transport behavior of the granular flow and eroded bed. After the experiment, the effects of particle size and mixing ratio on the erosion and transport of the eroded bed were compared and analyzed.

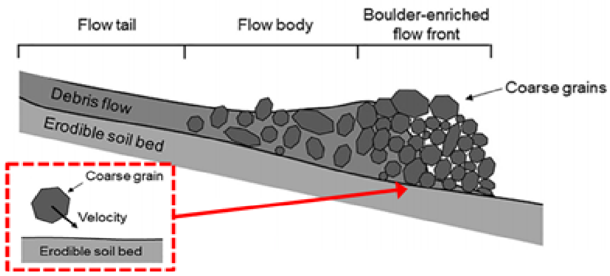

Figure 1, Structure of debris flow (Song and Choi, 2021).

Material and methods

The small-scale flume used in this study was fabricated from 10 mm-thick transparent acrylic plates, with a total length of 3,000 mm. The flume had a base width of 300 mm and a sidewall height of 450 mm. It was divided into three sections along its longitudinal profile: (i) a storage container (700 mm) to store the material of granular flow; (ii) a non-erodible section (1,300 mm) made for a stable path of flow; and (iii) an erodible section (1,000 mm) filled with a 100 mm-thick layer of Jumunjin standard sand. A plastic collection tub was placed at the toe of the flume to collect the sediment during the experiment. The experiments were carried out at an inclination of 30°. The initial density of the basal bed was 1,300 kg/m^3. To capture the interaction between the flow and the erodible bed, high-speed cameras (HAS-U2) were positioned laterally along the flume. These cameras operated at a resolution of 1,920 × 1,080 pixels and a frame rate of 250 fps. Additionally, a handheld 3D surface scanner (Creality CR Scan Raptor; resolution = 0.01 mm) was used to measure the topographic changes before and after the experiments. The experiment was conducted by varying diameter and ratios of particles for the cases without boulders (5D4.5) and with boulders (5D3.0/25D1.5, 5D2.0/25D2.5, 5D3.0/40D1.5, 5D2.0/40D2.5, 5D3.0/60D1.5, 5D2.0/60D2.5) as summarized in Table 1.

Results

Figure 2 shows the erosion and transport behavior of the basal bed due to collisional granular flow, captured by a high-speed camera installed on the side of the channel. As shown in Figure 1, the granular flow approaching from the upstream continuously eroded and transported the basal bed as it passed over the erodible bed. In particular, the concentrated boulders in the front flow resulted in greater erosion and transport of the basal bed. This erosion and transport process was observed throughout the entire erodible bed.

Figure 3 shows the transported mass of debris entrained by granular flows passed over the erodible bed. When boulders were included in the flows the amount of transported mass increased. Also, the transported mass of the basal bed further increased as the proportion of boulders increased from 1.5 to 2.5 kg. However, by increasing the particle size of boulders, the transported mass did not increase but rather exhibited a decreasing trend. A comparison of transported mass for each test revealed that it increased by an average of 30% in the granular flows, including larger boulders, compared to the flow including small boulders. However, as the particle size increased, the transported mass decreased by an average of 12%, indicating that the particle size did not have a significant effect on the overall flow of transport. This is because, as the particle size decreases, the number of particles per unit weight increases, which strengthens the interaction between the particles and the basal bed during transport.

Conclusions

This study investigated the influence of the size and mixing ratio of boulders on the erosion of an erodible bed by granular flows. The results indicated that the presence of boulders intensified the interaction between the particles and the basal bed, leading to an increase in sediment transport. Moreover, as the proportion of boulder increased, the amount of sediment transport increased. However, the particle sizes of the boulders did not significantly affect the overall sediment transport. These findings suggest that, according to boulder proportions in granular flows, basal erosion could be affected significantly. Also, the proportion of boulders appears to be a more dominant factor of erosion and transport than their individual size in these experimental conditions.

Table 1, Test conditions.

Test condition	Designation
Granular flow	5D4.5
	5D3.0/25D1.5
	5D2.0/25D2.5
	5D3.0/40D1.5
	5D2.0/40D2.5
	5D3.0/60D1.5
	5D2.0/60D2.5

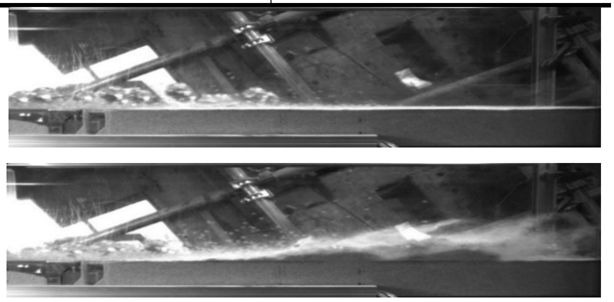

Figure 2, Observed kinematics of collisional granular flow impacting erodible bed (5D2.0/60D2.5).

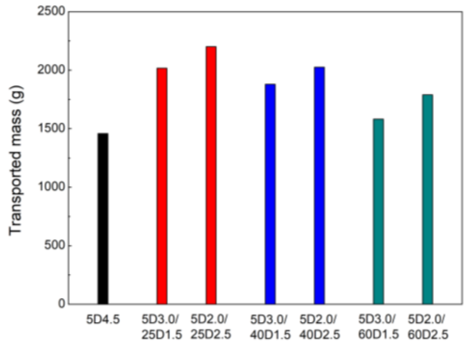

Figure 3, Transported mass.

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