Effect of Finer Particle Content in Coarse Granular Flows on The Evolution of Bed Surface Morphology Under Different Flume Inclinations

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Abstract: This study presents the results of laboratory flume experiments conducted to evaluate how increasing finer particle content within coarse granular flows influences flow dynamics. Additionally, the evolution of bed surface morphology under varying flume inclinations was analyzed using a 3d laser scanner.

Keywords: ***Coarse granular flow, Flume experiment, Surface morphology evolution.***

Introduction

Debris flows are natural geomorphic processes occurring in mountainous terrains. However, they possess destructive potential and often lead to severe damage to the human lives and infrastructure. Broadly they are characterized as gravity-driven geophysical flows, typically consisting of a frontal part with 30-60% dense and coarse boulders and a rear part composed of a slurry mix of sand, silt, clay, and water (Hutter et al. 1996). The unanticipated long runout and the constituent materials of the flow body exert differential stress on the surface of the flow path and felicitates erosion and entrainment of the bed materials (Hungr et al., 2005; Iversion et al., 2012). Therefore, the characterization of erosion mechanism by debris flow and the integration of the magnitude of transported mass and bed failure are crucial components in evaluating mobility prediction for hazard assessment and designing protective structures based on flow characteristics.

Erosion by a debris flow takes place when the flow-induced shear stress exceeds the shear strength of the soil bed during its flow downstream. The natural mechanism of erosion by geophysical flows is governed by two important processes: collision-induced stress, mainly at the frontal part, and friction-induced stress, at the rear part of the flow (Haas & Woerkom, 2016; McCoy et al., 2013). Among these, the collisional stress by the granular masses is proven to be highly destructive and possesses greater erosive potential. The interaction between a granular flow and its substrate flow exerts strong discrete impacts and shearing forces on the slope sediment, leading to substantial erosion and entrainment. The complex dynamics of granular flows are intricately influenced by heterogeneity in material composition, energy dissipation, and boundary conditions. Furthermore, their erosion and transport processes are governed by the grain size and compositional characteristics of bed materials (Haas & Woerkom, 2016; Farin et al., 2019). Although significant advancement has been made to understand the effects of granular flows on erosion and entrainment mechanisms on the erodible substrate, the specific effects of finer particle content in dry granular flows on the change in surface morphology of the erodible bed and the associated flow dynamics have not been substantially explored. Accordingly, in this study, small-scale flume experiments were performed using glass beads of 5 mm, 25 mm, 40 mm, and 60 mm as granular material. The total mass of the mixture was fixed at 4.5 kg. For each primary particle size, initial tests were performed at flume inclinations of 25° and 30°. Subsequently, 5 mm particles were mixed with 25 mm, 40 mm, and 60 mm particles at a proportion of 22%, 44%, and 66% of the total mass in order to assess the role of finer particles on the debris flow erosion dynamics.

Material and Methods

The small-scale flume used in this study was constructed from 10-mm-thick acrylic plates, with a total length of 3,000 mm. The base width and side height of the flume were 300mm and 450mm, respectively. The flume consisted of three segments from top to bottom; viz: i) storage container (700 mm): to store the flow material; ii) a non-erodible section (1,300 mm): made of acrylic sheet, and iii) erodible section (1,000 mm): composed of Jumunjin standard sand of depth 100mm. To collect the eroded sand during the flow process, a plastic tub was placed at the toe of the flume. To capture the flow velocity and the flow interaction with the erodible bed, high-speed cameras (HAS-U2) were installed at the side of the flume. The resolution of the high-speed camera was 250 frames per second with 1920 × 1080 pixels (side view). Furthermore, a handheld 3D surface scanner (Creality CR Scan raptor) with a resolution of 0.01mm was used to measure the topographical changes and erosion depth due to the granular flow after the experiments.

Results and Discussion

The surface morphology of the erodible bed varied substantially with the proportion of finer particles in the granular flow mass (Figure 1). At flume inclination of 25°, the impact zones were widely distributed for 40 mm and 60 mm particles, thereby forming more discrete, localized and elongated grooves of flow erosion over the sand bed. In contrast, flows composed solely of 25 mm particles generated more spatially uniform erosion patterns. The addition of finer particles (5 mm beads) up to 44% of the total mass led to the development of narrow, well-defined scour zones at the impact and erosion substantially increases with gradually increasing deposition of finer particles (5 mm beads) due to their deceleration of the velocity and reduction in transport efficiency. However, further increase of fine particles up to 66% favours deposition over erosion with further deepening of scour zone. Broadly, it has been observed that the deposition dominates over erosion at flume inclination of 25° on addition of finer particles, resulting in decrease of transported mass of 41-93% in case of granular flow with 66% of finer (5 mm beads) as compared to their uniform size counterparts.

At the 30° flume inclination, erosion processes dominated across the bed for all particle-size combinations, yielding higher transported masses relative to the 25°. Experimental observations and surface scans inferred that flows composed entirely of coarse particles induced widespread erosion and elongated impact grooves, which could be attributed to the destabilization of the flow mass as the slope gradients approached the internal friction angle of the bed material. The addition of fine particles up to 44% to the total mass resulted in greater impacts on erodible bed, forming an elongated scour zone and overall enhance the transported mass. This case also caused a greater deposition of sand and finer beads at the end of the flume. However, with a further increase in fine particle content to 66%, deposition began to dominate over erosion, indicating a transition from an erosion-driven to a deposition-dominated regime. The transported mass increased nonlinearly—from approximately 12% in the 25 + 5 mm mixture to nearly 157% in the 60 + 5 mm mixture with 66% fine content, as compared to uniform coarse-particle flows.

The present study reveals a nonlinear influence of fine-particle content on flow dynamics and varying erosion potential under different slope conditions and the outcome of this investigation would be helpful in bridging laboratory-scale observations with field-scale processes and provide a controlled framework for an efficient assessment of debris-flow impacts and their role in long-term landscape evolution.

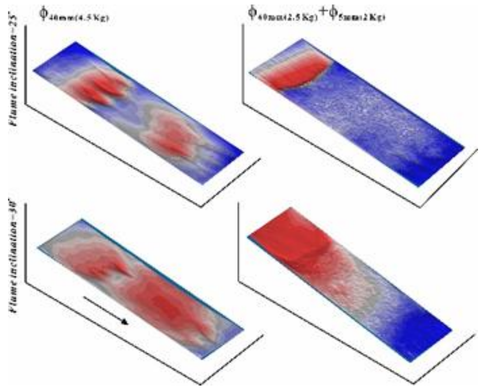

Figure 1, Representative erodible bed surface morphology after the granular flow

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