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INSTABILITY DURING THE EROSION OF A COHESIVE GRANULAR PILE

Pierre Jop*, Gautier Lefebvre, and Aymeric Merceron
*Surface du Verre et Interfaces, UMR 125 CNRS/Saint-Gobain,
 39 quai Lucien Lefranc 93303 Aubervilliers, France*

Summary The complex interplay between the topography and the erosion and deposition phenomena is a key feature to model granular flows such as landslides. Here, we investigated the instability that develops during the erosion of a wet granular pile by a dry dense granular flow. The morphology and the propagation of the generated steps are analyzed in relation to the specific erosion mechanism. The selected flowing angle of the confined flow on a dry heap appears to play an important role both in the final state of the experiment, and for the shape of the structures. We show that the development of the instability is governed by the inertia of the flow through the Froude number. We model this instability and predict growth rates that are in agreement with the experiment results.

INTRODUCTION

The situation where a cohesive granular media and a flowing granular layer interact encounters in the mixing processes of industrial applications or in some transport of sediment in nature. Erosion patterns are known to spontaneously develop at the bottom of the river bed depending on the coupling between the flow and the bed geometry through the erosion/transport laws [1, 2]. Granular flows such as landslides can also alter the underlying ground. However the erosion mechanisms are not clear when the granular material is dense. Thus recent studies have focused on the evolution of the interface between static and flowing dry granular layers, on the velocities and on the runout distances. Moreover the studies of instabilities in granular flows were generally focused on the flowing layer (roll waves, upward traveling waves). Finally, previous studies on the erosion rate of a cohesive media by a granular flow focused on the physical properties of the cohesive materials (e.g. [4]). Thus we explore here the coupling between a flow of dry granular material and a cohesive granular bed.

EXPERIMENTAL SET-UP

We performed experiments in a quasi-two-dimensional cell made of parallel vertical glass plates, whose gap width W was set at 6 and 12 mm. The same polydisperse glass beads of diameter 200-400 μm were used for both the cohesive granular bed and the flow. The cohesive material was obtained by mixing a small quantity of water with the beads to obtain a low water content of 1% wt, which corresponds to the formation of individual capillary bridges. This material was introduced and packed into the cell to form a heap with a planar free-surface of length ranging from 30 to 35 cm. We injected the dry granular material at the top left of the cell so a flowing layer would form above the wet heap [Fig. 1(a)]. The two remaining parameters are the initial inclination of the heap θ_i and the constant injected flow rate Q .

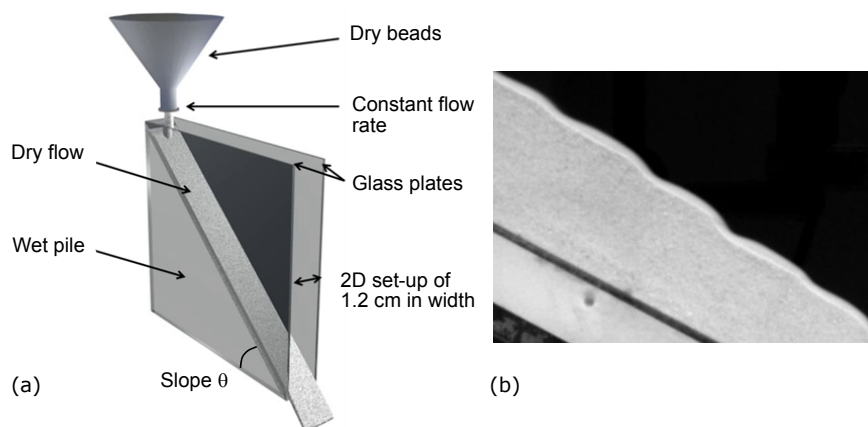


Figure 1: (a) Experimental set-up of the dry granular flowing on top of wet-cohesive granular pile. (b) Destabilization of the morphology of the pile during the erosion process, creating a succession of steps. The vertical scale is 12cm

*Corresponding author. Email: pierre.jop@saint-gobain.com

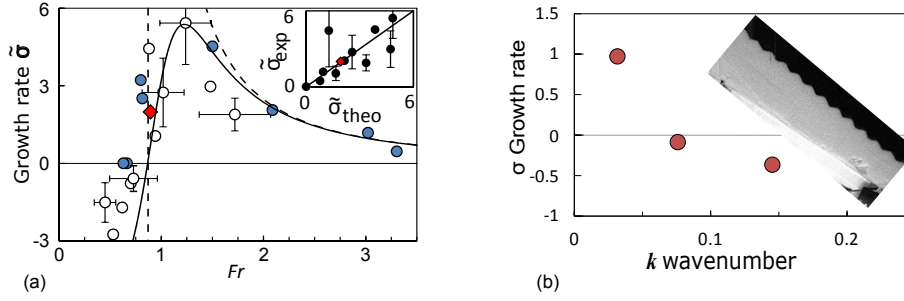


Figure 2: (a) Dimensionless growth rates of the steps as a function of the Froude number in experiments for glass beads in the 6 mm channels (●) and 12 mm channel (○) and steel beads in 12 mm channel (◇). The curves correspond to a prediction of the theoretical model for a wavenumber in agreement with the experiment $h_0 k = 0.1$ at an inclination of $\theta_i = 30^\circ$. Inset: Direct comparison of growth rates using the measured wave numbers \tilde{k} as a parameter. (b) Experimental growth rates for different imposed initial wavelengths. An example is shown on the inset.

RESULTS

With this low water content, we observe that erosion occurs at the interface between the cohesive pile and the granular flow, without deposition. Wet beads are slowly extracted by the action of the dry flow. Thus, the volume of the cohesive heap is gradually reduced during the experiment until it reaches a steady state in which the interface is flat and the dry granular material flows without eroding the wet bed. During this erosion process, two different behaviors can be observed. Either the eroded interface remains initially flat and parallel to the initial slope, or we observe the creation of step-shaped structures for rather high inclinations and high flow rates [Fig. 1(b)]. These steps grow and propagate upstream then disappear one after the other at the top of the channel. In both cases, the final interface is flat and forms an angle θ_f with the horizontal with $\theta_f < \theta_i$.

Due to the analogy with the shape and the propagation of the structures led by the pool and step instabilities in riverbeds [1], we expect to observe an inertial destabilization. The underlying mechanism would be the phase lag between the topography and the local erosion rate due to inertia. Such phase lag exists for step-pool formations between the erosion and the shape of the interface [1]. We expect therefore a stability criterion based on the Froude number $Fr = u/\sqrt{gh \cos \theta_i}$, which compares the inertia with the gravity effects, where $g \cos \theta_i$ is the projection of the gravity perpendicular to the slope.

We compute the initial growth rates of the instability scaled by the measured erosion time scale. The figure 2(a) show the existence of a critical Froude number, around 0.8, above which the instability develops with positive growth rates. The negative values are obtained by following a step coming from the downstream boundary conditions that disappears.

We model the flow using a depth-averaged method with the now well-established rheology of dense granular flows [5]. We make the assumption, as in the fluid case, that the erosion rate is linked to the inertia of the grains. We then carry a linear stability analysis. We show that the previous assumptions are required to predict an instability of the interface above a critical Froude number. Moreover we are able to compare the theoretical growth rates for the observed wavelengths [Fig. 2(a)]. Finally we measure the growth rate for three initial wavy interfaces as shown on figure 2(b). These results show that a mechanism for the wavelength selection need now to be modeled.

CONCLUSIONS

We study a new erosion instability occurring with granular flows over a cohesive granular bed. Above a critical Froude number, the interface is unstable and the shape of the steps is governed by the properties of the granular flows. We model the mechanisms in the framework of a Saint-Venant approach. We finally identify that the inertia of grains governs the erosion mechanisms in dense granular flows. We believe that our results could lead to a better understanding of geophysical flows. On the other hand, for applications of mixing of grains and liquids such as building materials, our work represents a mechanism of homogenization of wet aggregates with dry grains in slow mixers.

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