

Collapse of tall granular columns in fluid

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Abstract. Avalanches, landslides, and debris flows are geophysical hazards, involve rapid mass movement of granular solids, water, and air as a multi-phase system. In order to describe the mechanism of immersed granular flows, it is important to consider both the dynamics of the solid phase and the role of the ambient fluid [1]. In the present study, the collapse of a granular column in fluid is studied using 2D LBM - DEM. The flow kinematics are compared with the dry and buoyant granular collapse to understand the influence of hydrodynamic forces and lubrication on the run-out. In the case of tall columns, the amount of material destabilised above the failure plane is larger than that of short columns. Hence in tall columns, the surface area of the mobilised mass that interacts with the surrounding fluid is significantly higher than the short columns. This increase in the area of soil - fluid interaction results in an increase in the formation of turbulent vortices that alter the deposit morphology during the collapse. It is observed that the vortices result in the formation of heaps that significantly affect the distribution of mass in the flow. In order to understand the behaviour of tall columns, the run-out behaviour of a dense granular column with an initial aspect ratio of 6 is studied. The collapse of a tall granular column on slopes of 0, 2.5, 5 and 7.5 are studied.

1 Collapse of granular columns

The collapse of a granular column on a horizontal surface is a simple case of granular flow, however a proper model that describes the flow dynamics is still lacking. Experimental investigations have shown that the flow duration, the spreading velocity, the final extent of the deposit, and the energy dissipation can be scaled in a quantitative way independent of substrate properties, grain size, density, and shape of the granular material and released mass [3–5].

Granular collapse on a horizontal plane exhibit two distinct flow regimes: (a) for columns with aspect ratio ‘a’ < 1.7 a linear relation between the spread and aspect ratio can be observed, and (b) for ‘a’ > 1.7 a power-law relationship exists. [?] observed that a simple frictional dissipation model is able to capture the flow dynamics for columns with small aspect ratios. However, for tall columns the flow dynamics is controlled by the initial collisional regime, resulting in a power-law relationship with the aspect ratios. Simple mathematical models based on conservation of horizontal momentum capture the scaling laws of the final deposit, but fail to describe the initial transition regime [?]. Granular flow is modelled as a frictional dissipation process in continuum mechanics but the lack of influence of inter-particle collision and friction on

the energy dissipation and spreading dynamics is surprising.

2 Tall columns

In the case of tall columns, the amount of material destabilised above the failure plane is larger than that of short columns. Hence in tall columns, the surface area of the mobilised mass that interacts with the surrounding fluid is significantly higher than the short columns. This increase in the area of soil - fluid interaction results in an increase in the formation of turbulent vortices that alter the deposit morphology during the collapse. It is observed that the vortices result in formation of heaps that significantly affect the distribution of mass in the flow. (author?) [3] observed that the distribution of mass in a granular flow plays a crucial role in the flow kinematics. In order to understand the behaviour of tall columns, the run-out behaviour of a dense granular column with an initial aspect ratio of 6 is studied. The collapse of a tall granular column on slopes of 0°, 2.5°, 5° and 7.5° are studied. A hydrodynamic radius of $r = 0.85 R$ is adopted.

Snapshots of the collapse of an aspect ratio 6 column in fluid on a horizontal surface are shown in fig. 1. The initial stage of collapse is characterised by the free-fall of grains above the failure surface. Unlike the dry condition, as the grains undergo free-fall due to gravity, they interact with the surrounding fluid experiencing drag forces. This results in a significant drop in the kinetic energy available

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for the flow. As the grains reach the static region, they interact with the neighbouring grains and the kinetic energy gained during the free fall is converted into horizontal acceleration. Uniquely during this stage ($t = 3\tau_c$) the interactions between the soil grains on the surface with the surrounding fluid result in the formation of eddies. The number of eddies formed during the flow is proportional to the surface area of the granular mass interacting with the fluid. Hydroplaning can be observed at the flow front ($t = 3\tau_c$). Two large vortices with almost the same size can be observed at the final stage of collapse. The soil grains on the surface experience suction due to formation of eddies and this results in formation of heaps of granular mass in front of each vortex. The formation of heaps, although in evidence, doesn't significantly affect the distribution of mass in the case of collapse on a horizontal plane.

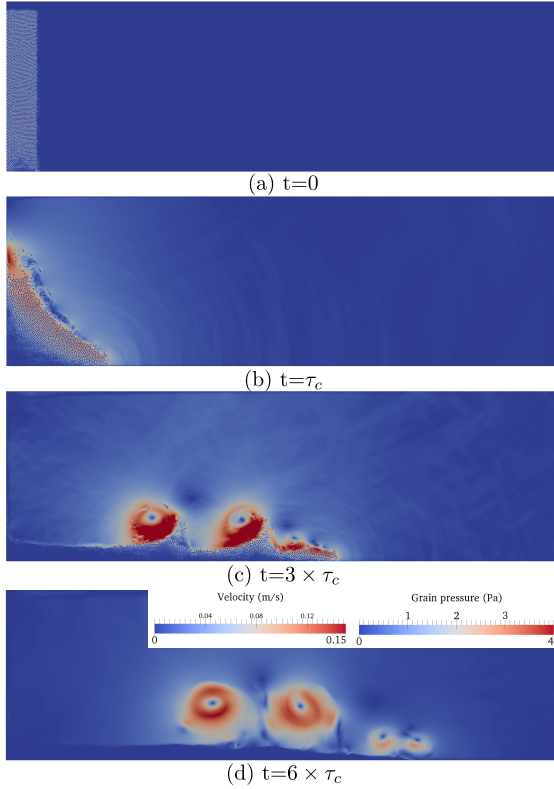


Figure 1: Flow evolution of a granular column collapse in fluid ($a = 6$) on a horizontal surface.

Snapshots of the collapse of a granular column ($a = 6$) on a inclined plane at angle of 5° are shown in fig. 2. The collapse on a slope of 5° show flow evolution behaviour similar to the case of collapse on a horizontal plane. The vortices are formed only during the horizontal spreading stage $t = 3\tau_c$, but the number of vortices formed during the collapse is higher than the collapse on a horizontal plane. However, as the flow progresses a single large vortex engulfs other smaller vortices, thus having a significant influence on the mass distribution. Figure 3 shows the distribution of mass and the packing density at $t = 6\tau_c$ and $t = 8\tau_c$. A heap can be observed in front of the large vortex almost at the middle of the flow. The height of the heap

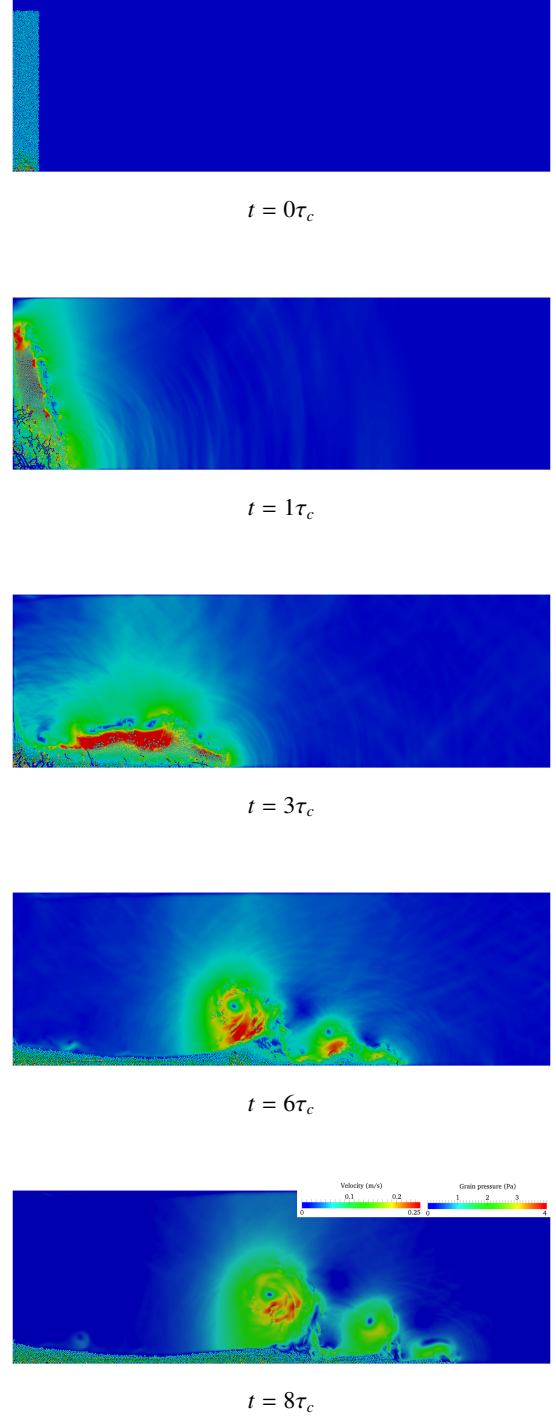


Figure 2: Flow evolution of a granular column collapse in fluid ($a = 6$) on a slope of 5° . Shows the velocity profile of fluid due to interaction with the grains (red - higher velocity).

formed in the middle of the granular flow is higher than the collapse height next to the wall. However, when the flow comes to rest and the vortex moves away from the flowing surface, the mass present in the heap gets redistributed (as seen at $t = 8\tau_c$). This behaviour is significantly different from that observed in the case of short columns.

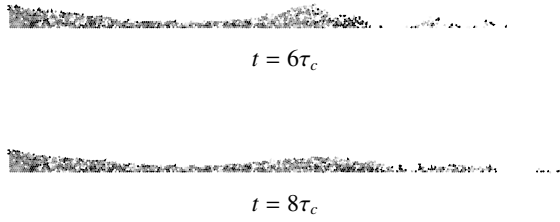


Figure 3: Packing density of a granular column collapse in fluid ($a = 6$) on a slope of 5° .

In order to understand the influence of slope angles on the run-out behaviour, the collapse of a granular column with an initial aspect ratio of 6 is performed on slopes of 0° , 2.5° , 5° and 7.5° . The run-out evolution with time for different slope angles are presented in fig. 4a. The run-out distance increases with increase in the slope angle, however the run-out distance in the fluid is significantly shorter than the dry condition. The slow evolution of run-out in the submerged condition is due to the delay in the dissipation of large negative pore-pressures developed during the initial stage of the collapse. The formation of eddies during the flow indicates that most of the potential energy gained during the free-fall is dissipated through viscous drag and turbulence. This effect predominates over the hydroplaning that is observed during the flow resulting in a shorter run-out distance in the case of fluid. The evolution of the normalised height with time (fig. 4b) for collapse on different slope angles indicates that the amount of material destabilised in fluid is less than the dry conditions due to the drag forces experienced by the grains, which retards the quantity and the rate of collapse.

Figure 5a shows the evolution of the normalised kinetic energy for a granular column ($a = 6$) collapse in fluid

on different slope angles. The amount of kinetic energy available for the flow in the submerged condition is almost half that of the dry condition. It can be seen from the figure that the vertical kinetic energy in the fluid condition dissipates a longer duration, in contrast to the free-fall release observed in the dry condition. The slower dissipation is attributed to the viscous drag force experienced by the grains.

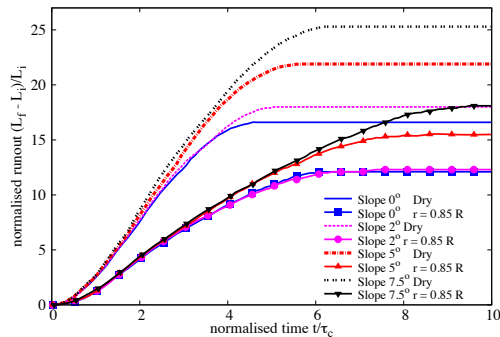
The behaviour of tall columns is significantly different from that observed in the case of short columns. The slope angle has a strong influence on the number and size of eddies during the flow. The eddies interact with the surface of the granular flow and forms heaps in front of each vortex. This significantly affects the mass distribution and in turn the run-out evolution. Although tall cliffs are quite rare in submarine condition in comparison to short cliffs or slopes, further research is required to understand the influence of permeability and packing density on the run-out evolution of tall columns.

Acknowledgements

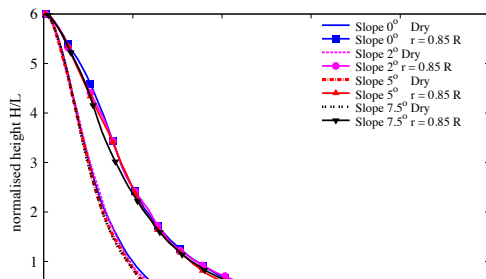
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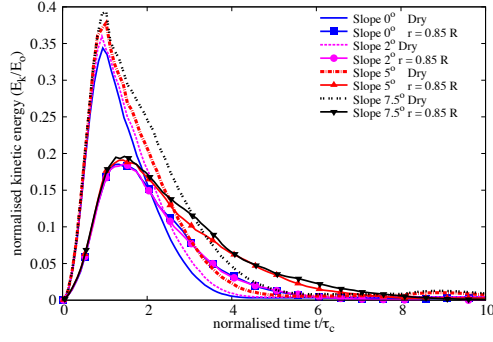
References

- [1] R. Denlinger, R. Iverson, J. Geophys. Res **106**, 553 (2001)
- [2] C. Meruane, A. Tamburrino, O. Roche, Journal of Fluid Mechanics **648**, 381 (2010)
- [3] L. Staron, E.J. Hinch, Granular Matter **9**, 205 (2007)
- [4] E. Lajeunesse, J.B. Monnier, G.M. Homsy, Physics of Fluids **17** (2005)
- [5] G. Lube, H.E. Huppert, R.S.J. Sparks, A. Freundt, Physical Review E - Statistical, Nonlinear, and Soft Matter Physics **72**, 1 (2005)

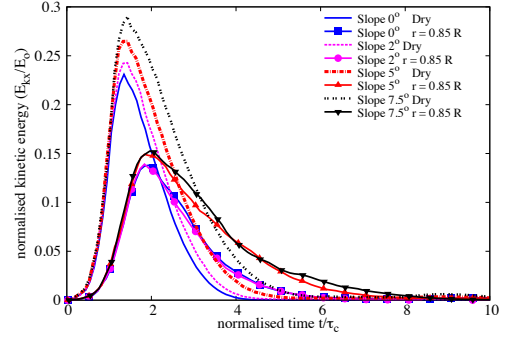


(a) Evolution of run-out for a column collapse in fluid ($a = 6$).

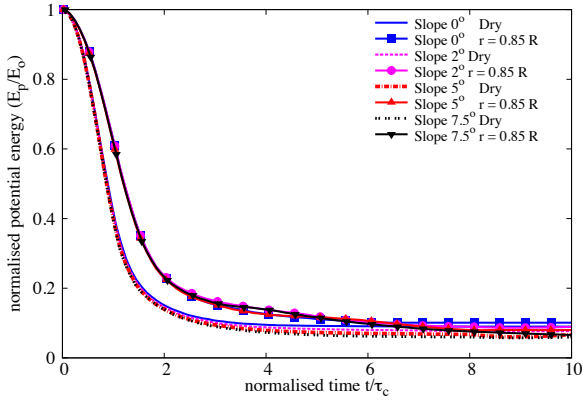




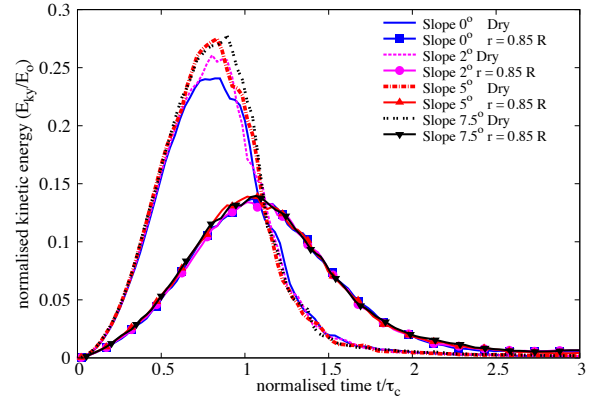
(a) Evolution of the total kinetic energy.



(a) Evolution of the horizontal kinetic energy.



(b) Evolution of the total potential energy.



(b) Evolution of the vertical kinetic energy.

Figure 5: Evolution of the kinetic and the potential energy with time for a granular column collapse in fluid ($a = 6$).

Figure 6: Evolution of the kinetic energies with time for a granular column collapse in fluid ($a = 6$).