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Granular column collapse: the role of particle size polydispersity on the velocity and runout

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Abstract. Geophysical mass flows involve particles of different sizes, a property termed polydispersity. The granular column collapse is a simplified experiment for studying transitional granular flows. Our research focuses on the role that polydispersity has on the velocity and runout distance of dry and immersed granular columns, undergoing a numerical and experimental study. Our results highlight that polydispersity does not have a strong effect on the collapse of dry columns. On the contrary, the collapse sequence of immerse granular columns strongly depend on the polydispersity level.

1 Motivation

Granular flows are found in geophysical processes like landslides, debris flows or pyroclastic flows. Those flows are subaerial, but occasionally they are submerged in a viscous fluid environment. They could reach long runout distances and develop a fast-spreading velocity during flow, resulting in several damages. A characteristic among them is the presence of particles of different sizes, a property termed polydispersity. The flow of granular materials can be distinguished in three regimes according to the motion of the grains with the Stokes number St = $(\rho_p \Delta\rho g d^3)^{1/2}$ / $(18\mu_f\sqrt{2})$ and the density ratio $\chi = (\rho_p / \rho_f)^{½}$, where d is the particle diameter, g is Earth's gravity, μ_f is the fluid dynamic viscosity, $\Delta\rho$ is the density difference between the particles ρ_p and fluid ρ_f. The combination of these dimensionless numbers leads to three flow regimes, that are: the *inertial regime*, the *free-fall regime,* and the *viscous regime* [1]. Natural flows like debris flows and slides are commonly in the free-fall and inertial regime.

A benchmark study case for granular flows is the collapse of a granular column [2, 3, 4]. In this experiment, a column built up with particles with an initial length L_0, an initial height H_0, and an aspect ratio $A = H_0/L_0$ is let to collapse by self-weight in a horizontal plane, reaching a final runout L_f and a final height H_f (see Fig. 1.). During collapse, the column front has an initial acceleration phase followed by a steady propagation stage with constant velocity U, and then the collapse comes to a halt. The final runout of granular columns is found to be longer in dry systems than in immersed systems [5, 6], and for dry cases, polydispersity does not influence the column mobility [7]. Moreover, it has been found that the normalized runout $L^* = (L_f - L_0) / L_0$ increases with A and collapses on a power-law function with different exponent for short and tall columns [5, 6].

The collapse velocity during the steady propagation stage increases with A, but it is found that U normalized by the theorical free-fall velocity $U_{FF} = (2g^*H_0)^{0.5}$ has a characteristic value depending on the flow regime with U/U_{FF} = [0.55, 0.27, 0.196, 0.024] for free-fall, inertial, viscous inertial and viscous regime, respectively [5]. Previous studies have linked the column mobility with the collapse kinematics at the particle scale [3], considering the peak energy of a particle, and at the column scale [6], considering the collapse velocity U.

Although previous studies have done a great effort to understand the flow of granular columns, the influence that polydispersity has is still unclear. Understanding the role that polydispersity has on granular flows is important because it is intrinsic in many natural processes. Therefore, our research focuses on exploring the influence that polydispersity has on the collapse and runout of dry and immersed granular columns with two methodologies. We do 2D numerical simulations capable of managing high polydispersity levels, and we do experiments to study the three-dimensional nature of the process. We focus on processes that are in the free-fall and inertial regime, studying flows on the same regime as in natural flows.

2 Methodology

2.1 Numerical

We study the collapse of dry and immersed two-dimensional granular columns using a coupled Finite

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Element Method (FEM) with a Discrete Element Method (DEM). The fluid motion in immersed simulations is solved with a finite element spatial discretization combined with an implicit temporal discretization of the incompressible Navier-Stokes equations [9]. The solid phase is simulated with the Non-Smooth Contact Dynamics approach, a class of Non-Smooth DEM [10]. In Contact Dynamics, the particles are assumed to be perfectly rigid, interact by volume exclusion and Coulomb friction. This method requires no elastic repulsive potential and no smoothing of the Coulomb friction law for the determination of forces. For this reason, this method appears to be perfectly suited to the simulations of highly polydisperse systems without the need of tuningstiffness parameters as in the smooth DEM class.

We systematically vary H_0 = [0.015 – 0.25] m, studying short and tall columns with A = [0.3 – 5.0]. We also study different grain size distribution GSD, varying the ratio between the biggest and smallest grain $\lambda = d_{max} / d_{min}$ = [1 - 19]. All GSDs have 25 grain sizes linearly distributed between d_{min} and d_{max} sharing a common cumulative unitary mass 0.5 at d_{50} = 1.0 mm. Grains have density ρ_p = 1500 kg/m^3, with a friction coefficient of 0.3, and restitution coefficient of 0. For immersed simulations, the fluid has the physical properties ofwater with density ρ_f = 1000 kg/m^3 and viscosity μ_f = 0.001 Pa s. Those properties allow us to study granular flows in the free-fall regime for dry simulations, and granular flows in the inertial regime for immersed simulations, but near the transition towards the viscous regime.

2.2 Experimental

We study the three-dimensional nature of the process with granular column experiments in a rectangular channel of 100 cm long, 70 cm height, and 15 cm width. We study dry and immersed conditions and vary the polydispersity level between λ = [1 - 20], with d_{50} = 1.15 mm. We use glass beads particles with ρ_p = 2500 kg/m^3. The ambient fluid for immersed experiments is water with ρ_f = 1000 kg/m^3 and μ_f = 0.001 Pa s, studying flows in the inertial regime.

Besides the novelty of the use of different GSDs, our experimental setup is instrumented with a network of basal and side pore pressure sensors, allowing to evaluate pore pressure during collapse and its variation in the channel. Moreover, the experimental setup employs a novel release mechanism that diminishes the effects generated for the relative displacement of the releasing gate and the granular column. For this mechanism, we have covered the gate with a smooth PTFE film of 0.5 mm thick. One end of the PTFE film is fixed to a roller, and the other one has displacement constraints. A motor rotates the roller that pulls the PTFE film from one side, and removes vertically the gate. This mechanism diminishes the effects generated by the relative displacement of the gate and the granular column because they are not in contact. In consequence, the granular column is only in contact with the PTFE film that wraps on the roller.

The experimental setup is backlighted with a LED panel, and the column collapse sequence is recorded with a high-speed camera at a frame rate of 500 Hz. The same rate is used to register the pore pressure measurements. We do digital-image analysis to track the front position evolution and make a parallel analysis of the collapse with the pore pressure evolution (see Fig. 2.).

3 Results and ongoing work

We observed, numerically and experimentally, that dry column collapses are not affected by the increment of the polydispersity level, confirming previous results [7]. For dry columns, although polydispersity slightly increases the column front velocity, the ratio U/U_{FF} remains around a characteristic value of free-fall regime.

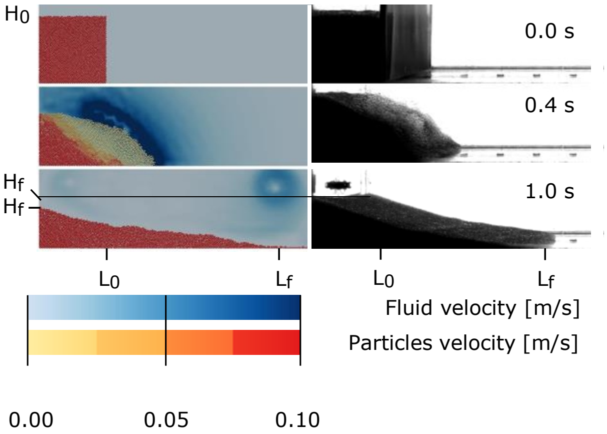

Fig. 1. Snapshots of an immersed granular column collapse with aspect ratio $A = H_0 / L_0$ = 1.0 and monodisperse particles with λ = 1. Collapse sequence from (left column) numerical simulations and (right column) experiments. Note that the color bars correspond to the velocity magnitude of fluid and particles obtained in the numerical simulations.

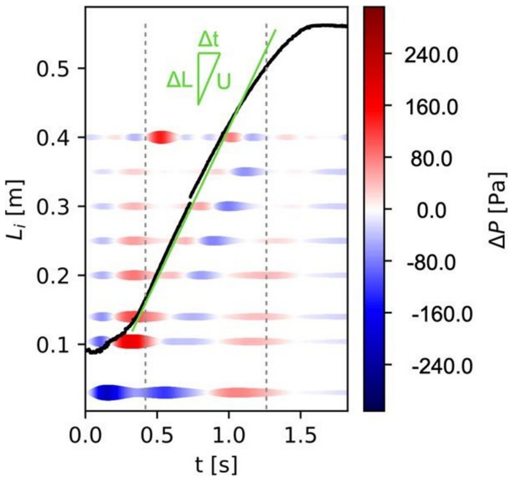

Fig. 2. Evolution of the front position of an experimental granular column with A = 2.8. The dashed grey lines delimit the collapse steady propagation stage interval. The side color bar shows the magnitude of the pore pressure change relative to the initial value for the sensors of the base.

The entire collapse process of dry columns shows independent of the polydispersity, having granular flows with similar time-stages, front velocity, and runout. This result, considered in a large-scale scenario as alandslide, suggest that the GSD does not control/affect the granular flow.

Contrary to dry granular flows, immersed columns are affected by polydispersity. We have observed that the collapse sequence changes with the increase of the polydispersity, delaying the column collapse. Then, during the stage of nearly constant velocity, the increase of the polydispersity makes that the collapse remains longer in this stage and changes the column mobility. A similar behavior could be expected in submarine-landslides where GSD plays an important role.

Moreover, the previous observations addressed us to link the kinematics of the column collapse with its mobility and based on a simple model of a sliding bloc, we found that the column mobility scales with the kinetic energy, considered as the $E_K^U = UM/2,$ where M is the column mass. This simplified model works for flows in the free-fall and inertial regime [11] (see Fig. 3.).

We are aware that the methodology employed in the numerical simulations is a simplification of a complex process; however, preliminary experimental results validate the simplified model that links the final runout and the column kinematics, evidencing its relevance in a three-dimensional process.

Our study provides evidence that the collapse of immersed granular columns strongly depends on the polydispersity level. On the contrary, polydispersity does not have a strong effect on the collapse of dry columns. Our results could be of great use in understanding ancient geophysical flows but also for improving hazard evaluation methods that could benefit from accounting extreme grain size variations. Moreover, our ongoing experimental work counts with the observations from the collapse sequence and the internal pore pressure variations, providing a novel insight on the collapse kinematics of immersed flows.

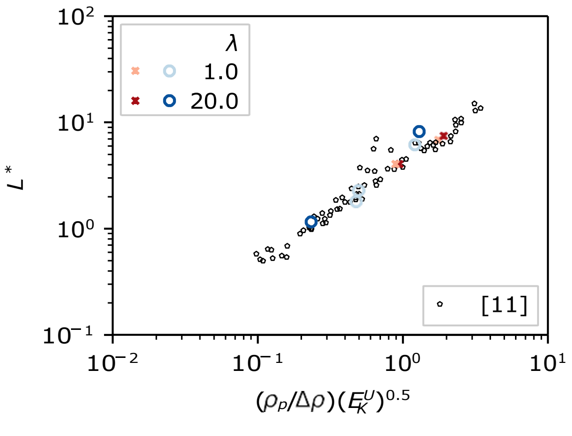

Fig. 3. Scaling of the column runout with the kinetic energy during the stage of constant propagation. The exes (x) and circle markers (o) are experiments. For these experiments, the darker the marker the greater the polydispersity level. Black pentagons are the data of the reference [11] obtained with numerical simulations with the methodology described in section 2.1.

References

1. S. Courrech du Pont, P. Gondret, B. Perrin, M. Rabaud, Phys. Rev. Lett., **90**, 044301 (2003)
2. E. Lajeunesse, J. Monnier, G. Homsy, Phys. Fluids, **17**, 103302 (2005)
3. E. Thompson, H. Huppert, J. Fluid Mech., 575, 177-186 (2007)
4. L. Rondon, O. Pouliquen, P. Aussillous, Phys. Fluids, **23**, 073301 (2011)
5. A. Bougouin, L. Lacaze, Phys. Rev. Fluids, **6**, 23, (2018).
6. V. Topin, Y. Monerie, F. Perales, and F. Radjai, Phys. Rev. Lett. **109**, 188001 (2012).
7. M. Cabrera, N. Estrada, J. Geophys. Res. Solid Earth, 126 (9), e2021JB022589 (2021)
8. G. Yang, L. Jing, C. Kwok, Y. Sobral, J. Geophys. Res. Earth Surface, **125**, e2019JF005044 (2020)
9. M. Constant, F. Dubois, J. Lambrechts, V. Legat, Comp. Part. Mech., **6**, 213 (2019).
10. F. Dubois, V. Acary, M. Jean, C. R. – Mec., 346, 247 (2018).
11. O. Polanía, M. Cabrera, M. Renouf, E. Azéma, Phys. Rev. Fluids. (2022).