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Experimental and theoretical analysis of particle entrainment in dry, uniform-unsteady granular flows

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Experiments performed in steady-uniform flow conditions are often considered as a reference for investigating flow rheology and developing theoretical models of grain interaction for a wide range of geophysical flows, including sediment transport, debris flow, mudflow and snow avalanches. However in order to understand how this kind of flows evolve in time and space during their growing and deposition phase, alternative experimental conditions should be investigated, permitting to focus on the grain-scale mechanics of particle entrainment and disentrainment. This is a crucial aspect especially for the description of geophysical flows characterized by a very rapid evolution phase. As an example, snow avalanches, after being triggered, can increase their volume by orders of magnitude within a few seconds.

The interpretation of experiments in unsteady and non-uniform condition can be complicated, especially as far as the understanding of the functional relationship between the several involved variables. Therefore, we decided to design an experiment in which the particle entrainment could be measured in a flow evolving just in time, what we call here the uniform-unsteady condition. We used a 164 cm long and 5 cm wide flume, uniformly filled with a layer of particles arranged in order to obtain a homogeneous depth. Two different types of grains were used: plastic spheres with a diameter of 0.45 mm, a density of 0.98 kg/m^3 and a friction angle of 21° and PVC cylinders with an equivalent diameter (sphere having the same volume) of 3.50 mm, a density of 1.51 kg/m^3 and a friction angle of 31°. After carefully arranging the layer of particles in order to obtain a uniform depth (between 3 and 5 cm), the particles were pressed from above by a rigid plate in order to keep them at rest. The flume was then tilted to a slope larger than the friction angle and the plate was suddenly released, causing the particles to move. This particular experimental configuration induced a flow evolving in time, but without any variability in longitudinal direction, apart from some disturbances localized at the extremities of the flume. Using a high speed camera and particle tracking algorithms, we measured the time evolution of the flow depth, of the normal-to-bed velocity profile and of the granular concentration and compared them with the predictions of a simple theory. We solved for the time evolution of the momentum balance in the flow direction, assuming the self-similarity of the velocity profile, having the same shape than in a fully developed flow. This was obtained from the algebraic integration of an extended kinetic theory for a dense collisional flow of dissipative spheres. The concentration was assumed in first approximation to be constant throughout the flow depth. Despite the very simple theoretical approach, we found a good agreement between the predictions for the time evolution of the velocity profile and of the flow depth and the experimental measures. The proposed model relies only on measured physical properties of the particles, without any ad hoc calibrated parameter.