

## Numerical modeling of the onset of immersed granular avalanches

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A dense granular bed immersed in a viscous fluid and inclined above its angle of repose is stabilized by a tensile overpressure induced by the slow creep and expansion of the bed due to dilatancy. We analyze this transient creep flow and onset of slope failure as a function of the initial packing fraction and for different slope angles by means of 3D coupled molecular dynamics/Lattice Boltzmann simulations. Our data are in excellent agreement with the experimental results reported by Pailha et al. [1]. We find a parabolic increase of the overpressure with depth, as correctly predicted from the Darcy law and dilation rate, and show that the failure is triggered at the free surface and propagates consequently to the bottom of the bed. The mean triggering time scales with a characteristic time depending on the fluid viscosity and slope angle, and it increases nonlinearly with the initial packing fraction. We also derive the time evolution of the packing fraction that nicely fits the simulation data. Interestingly, the packing fraction at failure decreases only slightly as the initial packing fraction is reduced but remains always above the critical packing fraction, which is reached well after the failure during steady flow on the inclined plane. As in experiments, the cumulative shear strain at failure varies quite weakly with the initial packing fraction. A detailed analysis of the evolution of the granular texture during creep suggests that the pile expands for a nearly constant number of contacts. This leads to the rotation of the mean contact direction, accompanied by an increase of contact anisotropy and a decrease of force anisotropy. The rotation drives the system, increasingly fragilized by the increase of porosity, from a Mohr-Coulomb behavior to a fluid-like state. The difference between the principal stress directions with respect to the flow direction explains correctly the fact that the instability occurs for a nearly constant value of the cumulative shear strain with a weak dependence on the initial packing fraction and slope angle.

[1] M. Pailha, M. Nicolas, and O. Pouliquen. Initiation of underwater granular avalanches : Influence of the initial volume fraction. *Physics of Fluids*, 20(11):111701, 2008.