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Slope failure mechanisms of an immersed granular bed

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Immersed granular avalanches have been investigated by several authors. In experiments where a granular bed is tilted above its angle of repose, two regimes can be distinguished: a loose regime where the slope fails spontaneously, and a dense regime where the failure is delayed as a result of negative excess pore pressure built up in reaction to the dilation of the bed. This difference reflects thus the value of the initial packing fraction, which can be below or above the critical packing friction. In order to better understand the initiation of avalanches, we investigate in detail the creep-like deformation which precedes failure (in the dense regime) by means of simulations using molecular dynamics for granular phase coupled with the Lattice Boltzmann method for fluid dynamics. Our granular bed is composed of spherical particles fully immersed in a viscous fluid and inclined above its angle of repose. Simulations were performed for several different values of the tilt angle and packing fraction. From the detailed numerical data, we explore the time evolution of shear strain, packing fraction, excess pore pressures, and granular microstructure in this creep-like regime. We show that they scale excellently with a characteristic time extracted from a model based on the balance of granular stress in the presence of a negative excess pressure and its interplay with dilatancy. Irrespective of the tilt angle and initial packing fraction, the shear strain at failure is found to be 0.2, and remarkably, the avalanche is triggered when dilatancy vanishes instantly as a result of fluctuations while the average dilatancy is still positive (expanding bed) with a packing fraction that declines with the initial packing fraction. Another nontrivial feature of this creep-like regime is that, in contrast to dry granular materials, the internal friction angle of the bed at failure is independent of dilatancy but depends on the inclination angle, leading therefore to a nonlinear dependence of the excess pore pressure on the inclination angle. We show that this behavior may be described in terms of the contact network anisotropy, which increases with a nearly constant connectivity and levels off at a value (critical state) that increases with the inclination angle. These features suggest that the behavior of immersed granular materials is controlled not only directly by hydrodynamic forces acting on the particles but also by the influence of the fluid on the granular microstructure.

Auteurs principaux: Dr MUTABARUKA, Patrick (LMGC, CNRS-Université de Montpellier); RADJAI, Farhang; Dr DELENNE, Jean-Yves (IATE)

Orateur: Dr MUTABARUKA, Patrick (LMGC, CNRS-Université de Montpellier)

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