

## **Destabilization of immersed granular avalanches**

P. Mutabaruka<sup>1\*</sup>, J.-Y. Delenne<sup>2</sup>, K. Soga<sup>3</sup> and F. Radjai<sup>1</sup>

(1) LMGC, UMR 5508, Université de Montpellier 2, CNRS,  
Place E. Bataillon, 34095 Montpellier, France.

(2) IATE, UMR 1208, INRA, Université de Montpellier 2, Cirad, SupAgro,  
34060 Montpellier France.

(3) Cambridge University, Engineering Department,  
Cambridge CB2 1PZ, UK

\* Corresponding author: *patrick.mutabaruka@univ-montp2.fr*

By means of 3D coupled molecular dynamics/Lattice Boltzmann simulations, we analyze the destabilization process of a granular bed of spherical particles inclined above its angle of repose and immersed in a viscous fluid [1]. Extensive simulations were performed for different values of the packing fraction and slope angle. We study the evolution of macroscopic observables such as shear strain, packing fraction and excess pore pressure. We then analyze the contact network anisotropy. Two regimes are evidenced as in experiments [2,3]: 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. The two regimes belong to the packing fractions below and above 0.59, respectively. We focus in more detail on the creep-like deformation of the inclined bed in the dense regime. The time evolution of the packing fraction and shear strain scale with a characteristic time obtained from a model based on the balance of granular stresses in the presence of a pore excess pressure and the relation of the latter with dilatancy controlled by Darcian drag forces. The cumulative shear strain at failure is found to be around 0.2, close to the experimental value [2], irrespective of the initial packing fraction and inclination angle. In the same way, the time and packing fraction at failure are correctly predicted by the model. A noticeable finding is that the network deforms by distortion at nearly constant connectivity. The contact network anisotropy grows with shear strain, and slope failure is triggered when the anisotropy levels off. The anisotropy thus appears as an internal variable, reflecting the distortion of the contact network. The independence of the internal friction angle with respect to the initial packing fraction and its dependence on the slope angle were studied and shown to be a consequence of slope stabilization by the cohesive-like effect of negative excess pore pressure. It is also interesting to note that the transition from stable equilibrium to inertial flow in the presence of a fluid is accompanied by large fluctuations. As soon as the capacity of volume change by distortion is nearly exhausted, slope instability is triggered by the fluctuations and amplified by lubrication forces as the avalanches proceeds.

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[2] R. M. Iverson, Landslide triggering by rain infiltration, *Water Resources Research* **36**, 1897-1910 (2000).

[3] M. Pailha, M. Nicolas and O. Pouliquen, Initiation of underwater granular avalanches: Influence of initial volume fraction, *Physics of Fluids* **20**, 111701-111705 (2008).