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Elastic Granular Flows

CHARLES CAMPBELL, University of Southern California

There is no fundamental understanding of the mechanics of granular solids. Partially this is because granular flows have historically been divided into two very distinct flow regimes, (1) the slow, quasistatic regime, in which the bulk friction coefficient is taken to be a material constant, and (2) the fast, rapid-flow regime, where the particles interact collisionally. But slow hopper flow simulations indicate that the bulk friction coefficient is not a constant. Rapidly moving large scale landslide simulations never entered the collisional regime and operate in a separate intermediate flow regime. In other words, most realistic granular flows are not described by either the quasistatic or rapid flow models and it is high time that the field look beyond those early models. This talk will discuss computer simulation studies that draw out the entire flowmap of shearing granular materials, spanning the quasistatic, rapid and the intermediate regimes. The key was to include the elastic properties of the solid material in the set of rheological parameters; in effect, this puts solid properties back into the rheology of granular solids. The solid properties were previously unnecessary in the plasticity and kinetic theory formalisms that respectively form the foundations of the quasistatic and rapid-flow theories. Granular flows can now be divided into two broad categories, the Elastic Regimes, in which the particles are locked in force chains and interact elastically over long duration contact with their neighbors and the Inertial regimes, where the particles have broken free of the force chains. The Elastic regimes can be further subdivided into the Elastic-Quasistatic regime (the old quasistatic regime) and the Elastic-Inertial regime. The Elastic-Inertial regime is the "new" regime observed in the landslide simulations, in which the inertially induced stresses are significant compared to the elastically induced stresses. The Inertial regime can also be sub-divided into an Inertial-Non-Collisional where the stresses scale inertially, but the particles interact in clusters through long duration contacts, and the Inertial-Collisional (or the old rapid-flow) regime. Finally, the simulations show that Stress-Controlled flows are rheologically different from Controlled-Volume flows. Physically, there is a range of dense concentrations ($0.5 < \nu < 0.6$) in which it is possible, but not necessary to form force chains and demonstrate elastic behavior. (In other words it is possible for the material to exhibit two different states at the same concentration.) By forcing the material to support an applied loads across force chains, Stress-Controlled flows may behave elastically through this range of concentrations while, at the same shear rates rate Controlled-Volume flows, fixed at the average concentration of the Stress-Controlled flow, behave inertially.