Geophysical Research Abstracts
Vol. 14, EGU2012-10942, 2012
EGU General Assembly 2012

Shearing fluid-filled granular media: A coupled discrete element – continuous approach

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Fluid-filled granular layers are abundant in the Earth's shallow crust as saturated soils and poorly consolidated hillslope material, and as fluid-filled fault gouge layers. When such grains-fluid systems are subjected to excitation by the passage of seismic waves, tectonic loading, or gravitational loading they exhibit a highly non-trivial dynamical behavior that may lead to instabilities in the form of soil liquefaction, debris flow mobilization, and earthquakes. In order to study the basic coupled mechanics of fluid-filled granular media and the dynamical processes that are responsible for the emergence of instabilities we develop a model that couples granular dynamics (DEM) algorithm with a continuous Eulerian grid-based solver. The two components of the model represent the two phases (grains and fluid) in two different scales. Each grain is represented by a single element in the granular dynamics component, where grains interact by elastic collisions and frictional sliding. The compressible pore fluid is represented on a coarser Darcy scale grid that is super-imposed over the grains layer.

The pore space geometry set by the evolving granular packing is used to define smooth porosity and permeability fields, and the individual grain velocities are interpolated to define a smooth field of a solid-fraction velocity. The porosity, permeability, and solid velocity fields are used in the continuous fluid grid-based solver to find pore fluid velocity and pressure. Pore fluid pressure gradients are interpolated back from the fluid grid to individual grains, where they enter the grains force balance equation as seepage forces. Boundary conditions are specified separately for the two phases. For the pore fluid we test two end-member drainage conditions: completely drained system (with infinite boundary permeability) and completely undrained system (with zero boundary permeability). For the grains, two-dimensional time dependent stress and velocity conditions are specified at the boundaries.

We perform simulations to study the dynamical response of fluid-filled granular layers to shear deformation. Our results show that the exact combination of fluid and grains boundary and initial conditions together with the mechanical, geometrical, and hydraulic properties of the layer are responsible for the emergence of a wide collection of instabilities: steady-state liquefaction, transient liquefaction and hardening, dilatant hardening, and stick-slip motion. We further perform parametric analysis and offer a non-dimensional measure of soils and fault gouge liquefaction potential.

Ref: Goren, L., E. Aharonov, D. Sparks and R. Toussaint, (2011) The mechanical coupling of fluid-filled granular material under shear, Pure Appl. Geophys. 168, (12), Doi: 10.1007/s00024-011-0320-4