Quasistatic response of loose cohesive granular materials. A numerical study.

Jean-Noël Roux
Laboratoire Navier, Université Gustave Eiffel, École des Ponts, CNRS, France
(jean-noel.roux@univ-eiffel.fr)

Motivated by the investigation of the micromechanics of powders and cohesive soils, we use discrete, grain-level numerical simulations (DEM) to study the quasistatic deformation of model cohesive granular materials, assembled in loose homogeneous and isotropic configurations, and then subjected to varying stresses.

We adopt assemblies of wet spherical beads, in which cohesive effects stem from capillary forces, as a model material for which favourable quantitative comparisons with some experimentally observed behaviours are possible, both in inertial shear flow and in oedometric compression.

For grains of diameter a, under pressure P, the adhesive force (or contact tensile strength) F_0 defines a force scale and a dimensionless reduced pressure, $P^* = a^2P/F_0$. Loose states may be obtained in the cohesion-dominated states at low P^*, exhibiting tenuous structures akin to colloidal gels, while dense, confinement-dominated large P^* states are similar to those of cohesionless granular materials. In our simulations, homogeneous solidlike loose states (solid fraction Φ as low as 20-30%) are first obtained by ballistic cluster aggregation. Then they are subjected to quasistatic isotropic and triaxial compressions.

Under growing isotropic pressure, as the large initial voids gradually collapse under compression, void ratio $e = -1 + 1/\Phi$ decreases irreversibly as in cohesive soils. The compression curve, e versus $\log P^*$, is sensitive to the initial characteristic velocity during aggregation, which determines network connectivity and microstructure, and to the initial density. It is strongly affected (as is the aggregate structure) by small resistance to rolling or pivoting in contacts. Despite the large heterogeneities, this curve is remarkably reproducible, independent of sample size and aspect ratio. Its slope, the compression index, varies with the initial density in the aggregation stage. Surprisingly, this compression index correlates with small scale microstructural features much better than with large scale ones.

Next we subject isotropic systems, prepared under different P^*, to triaxial compression tests: keeping constant lateral stresses $\sigma_2 = \sigma_3 = P$, as axial strain ϵ_1 is slowly increased. Deviator stress $q = \sigma_1 - P$, volumetric strain and internal state variables are monitored. Such tests are carried out for initial reduced pressure P^* ranging from 0.1 (cohesion-dominated case, for which systems typically equilibrate with solid fraction $\Phi \simeq 0.35$), to large values for which the cohesionless behavior is retrieved. We characterize the approach to the critical state – a stationary state with constant stresses, density and internal variables, achieved for large monotonically increasing strains, and independent of the initial state. It is observed for larger and larger strains as P^* decreases. Critical ratio q/P strongly increases for decreasing P^*, as roughly predicted in an "effective stress" scheme. While extensive geometric rearrangements take place, no shear banding is observed. Loose cohesive granular assemblies are thus capable of large quasistatic stable plastic strains and ductile rupture.