Micro- and Macro-Mechanics of polydisperse, anisotropic granular materials

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ABSTRACT

Granular materials are widely used as raw materials in various industries [1]. They behave differently from usual solids and fluids and show interesting properties like dilatancy, ratcheting and anisotropy. Most standard constitutive models have been applied to describe the local behavior of granular flows - sometimes with success, but typically only in a limited range of parameters and flow conditions. A very few models take explicitly into account the structure of the contact network, that has been shown to play a key role. The model proposed in [2, 3] includes the microstructural anisotropy as a state variable. Here we use DEM simulations to analyze the behavior of dense polydisperse frictionless granular assemblies sheared at constant volume. The goal is to relate the elastic stiffness with the state variables of the anisotropic material [3], and predict the constitutive behavior along a generic deformation paths, by means of the micro-mechanically based constitutive models [3].
Granular system composed of spheres of uniformly size (radius) distribution are first isotropically compressed, relaxed and later quasi-statically sheared under constant volume (undrained conditions). At stopping at different shear strains, from various static, relaxed configurations, now infinitesimal strain steps are applied to "measure" the effective elastic response; we quantify the strain needed so that plasticity in the sample develops as soon as contact and structure rearrangements happen. We can characterize the stiffness matrix by applying incremental pure volumetric or deviatoric (either plane-strain or axial) strain and measuring the incremental volumetric or shear stress response. Because of the anisotropy induced by shear, volumetric and deviatoric stresses and strains are cross-coupled via three anisotropy moduli, which are proportional to the product of deviatoric fabric components and bulk modulus (i.e. the isotropic fabric). Interestingly, the shear modulus of the material depends also on the actual stress state, along with the contact configuration anisotropy.
Finally we show that, by knowing the dependence between elastic stiffness and microstructure, the theory as proposed in Ref. [3] is able to predict quantitatively the evolution of pressure, shear stress and deviatoric fabric in the granular packing subjected to an independent test.
Further, we extend this approach to bi-disperse granular systems with high number and size ratios and show that the effective (bulk) stiffness of an ideal monodisperse assembly can be enhanced (or decreased) up to 20% by substituting as little as 5% of its volume with smaller particles of suitable size, while other properties are subject of present research.

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