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A multi-scale approach for modeling the mechanical behavior of granular materials

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ABSTRACT

A constitutive modeling method for granular materials based on particle level interactions has been developed based on homogenization technique. The deformation of a representative volume of a granular material is generated by mobilizing particle contacts in all orientations. The stress-strain relationship can be derived as an average of the mobilization behavior of these local contact planes. In the model, a simple elastic-plastic behavior was assumed on each contact plane. The elastic part is based on the Hertz-Mindlin's contact formulation, while the plastic part is based on a Mohr-Coulomb friction law with an isotropic hardening assumption and a non-associated flow rule. For the whole packing, a critical state behavior is assumed at large deformations and the friction angle on each plane is related to the actual void ratio compared to the critical void ratio at the same state of stress. A strain softening behavior can therefore be obtained for dense materials. On the whole, the model requires a limited number of parameters, which can easily be determined from conventional triaxial testing.

The microstructural approach is attractive conceptually, because it dispenses in having to deal with relations between the stress and strain tensors. Rather, we need to describe only a simple relation between the vectors of forces and relative displacements on a contact plane, which thus requires fewer material parameters The stress and strain tensors are automatically obtained by integration over all spatial orientations. Aside from modeling simplicity, the microstructural approach is more realistic, especially for the stress-induced or inherent anisotropy. Furthermore it can capture the slip deformation on each plane, thus developing automatically the anisotropy induced from stress application.

The main advantage of the present model over conventional continuum constitutive models is its micro-scale consideration, which allows one to conveniently extend the model for new phenomenon at the particle level. Some examples will be presented such as the introduction of capillary forces for unsaturated granular assemblies or surface-energy forces such as Van der Waals forces.

(with the collaboration of Prof. Ching Chang, University of Massachusetts, Amherst, USA)