COMPARATIVE MODELING OF SHEAR LOCALIZATION IN GRANULAR BODIES USING A DISCRETE AND CONTINUUM APPROACH

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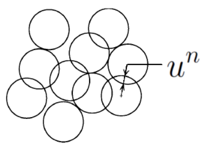
1. Introduction

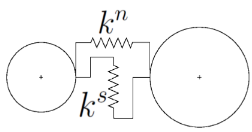
The intention of this paper is to compare the calculation of shear localization in granular material by a discrete (DEM [1, 2]) and a continuum approach on the basis of the FEM and a micro-polar hypoplastic law [3].

The discrete element method [1, 2] treats a granular material as a system of particles which may be (or not) in many contacts. In this study, we used a so-called soft sphere approach with particles virtually overlapping when a contact occurs (Fig.1a). The contact force between two particles is decomposed into its normal and tangential part. The normal part takes into account an expression for the repulsive force. The tangential force involves dissipation due to different mechanisms of friction, i.e. from static friction through sliding to rolling friction. If all forces acting on a selected particle are known, the problem is reduced to the integration of the Newton's equations of motion for both translational and rotational degrees of freedom. To simulate grain roughness, the model takes into account a contact moment [2].

The DEM-calculations were carried out in co-operation with University of Grenoble, where the first author took part in the implementation of the Yade-Open DEM software [2].



a)



b)

Figure 1: DEM: a) interaction between spherical discrete elements (u^n – overlap, shown bigger for clarity); b) elastic interaction between normal and shear springs (k_n, k_s - spring stiffness) [1]

In turn, the micro-polar constitutive law takes into account the effect of density, pressure, direction of deformation rate, mean grain size and grain roughness on the material behaviour [2]. Due to the presence of a characteristic length in the form of a mean grain diameter, the law can describe the formation of shear zones: their thickness and spacing, and the related size effect.

The comparative calculations of shear localization in granular bodies between DEM and FEM were performed for shearing in a direct shear tester [3], [4]. This tester is very popular in soil mechanics, used to determine important properties of granular and cohesive materials such as: drained strength envelope, angle of internal friction, wall friction angle and cohesion.

2. Discrete model DEM

The DEM method uses an explicit numerical scheme in which the interaction of particles is monitored 'contact by contact' with states of equilibrium. The resultant forces on any sphere are determined exclusively by its interaction with the spheres with which it is in contact. It is possible to follow a non-linear interaction of a large number of particles without excessive memory requirements or the need for an iterative procedure. The interaction force vector $\vec{F}$ between two spheres may be decomposed into a normal and a shear vector $\vec{F}_i^{\,n}$ and $\Delta\vec{F}^{\,s}$ respectively, which may be classically linked to relative displacements through normal and tangential stiffness, k^n and k^s (Fig.1b). The normal contact force between two particles is governed by the normal contact overlap (Fig.1a), and the tangential contact force is related to the tangential displacement:

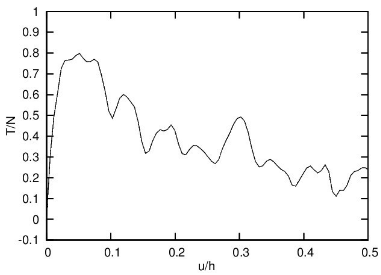
(1) $$\vec{F}_i^{\,n} = k^n u^n \vec{n}_i, \qquad \Delta\vec{F}^{\,s} = -k^s \Delta\vec{u}^{\,s},$$

where u^n is the relative normal displacement between two elements, $\vec{n}_i$ is the normal contact vector and $\Delta\vec{u}^{\,s}$ denotes the incremental tangential displacement. The shear force $\vec{F}^{\,s}$ is obtained by summing the $\Delta\vec{F}^{\,s}$ - increments. The elastic moment M^L is created by the rolling part in a local set of axes L as (k^r - rolling stiffness):

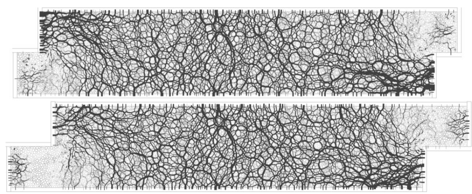
(2) $$\vec{M}^{\,L} = k^r \Theta_r^{\,L},$$

where $\Theta_r^{\,L}$ is the angular vector of the rolling part. The tangential contact displacement depends on both the translations and rotations of contacting particles. A Mohr-Coulomb friction law determines the maximum value of the tangential contact force and the maximum tensile strength that a cohesive link can sustain [1].

Fig.2 shows the force distribution between spherical elements during a direct shear test under vertical pressure of 100 kPa. The granular specimen 20×100 mm^2 included 10000 spherical elements with an average radius of 2 mm (the inter-particle friction coefficient was 0.5).



a)



b)

Fig. 2: DEM-results of direct shearing: a) ratio between shear and normal force versus normalized horizontal displacement, b) force distribution between spherical elements during shearing

3. References

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