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CAPILLARY EFFECTS MODELLING IN UNSATURATED GRANULAR MATERIALS

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ABSTRACT

Unsaturated soil behaviours are directly dependent of the water content level. More particularly, capillary cohesion is known to strongly influence the strength and flow properties of granular materials as basically observed in practice. The presence of combined air and water leads to the formation of menisci between the grains, introducing additional interparticle forces. Capillary theory, through the Laplace-Young equation, allows the force induced by a menisci to be linked to the local geometry of the contact and to the water volume at a given contact. We propose here a modelling of capillary effects in a granular material by using a micro-mechanical approach based on discrete element method (DEM) simulations and micro-mechanical calculations. Capillary effects are described on the local scale and superimposed to the standard dry particle interaction actually well described through an elasto-plastic relation, whereas the Laplace equation allows the water content inside the sample to be assesed for.

The calculations are based on a homegenization procedure that relates both macroscopic strain and stress tensors from a constitutive description on contact scale. As the DEM constitutes a powerful numerical tool to track the mechanical response of granular assemblies, this micro-mechanical approach finally gives rise to a constitutive relation, including microstructual considerations.

Simulations of triaxial compression tests at several water content levels are used to investigate both macroscopic and microscopic effects of partial saturation. The results provided by the two methods (the DEM and the micro-mechanical computations) are in rather good agreement, in particular they both reproduce the increase of the shear strength classicaly observed in laboratory experiments on unsaturated materials. Besides, through these computations, a capillary stress tensor can be exhibited from capillary forces using homogenization techniques :

$$\sigma_{ij}^{cap} = \frac{1}{V}\sum_{p=1}^{N}\sum_{q=1}^{N} F_{cap,i}^{q,p} l_j^{q,p} \tag{1}$$

where N is the number of particles within the volume V of the sample, $\vec{F}_{cap}^{q,p}$ is the capillary force exerted on particle p by the menisci linking particles q and p, and $\vec{l}^{q,p}$ is the branch vector pointing

from the particle q to the particle p ($\vec{l}^{q,p} = \vec{x}^p - \vec{x}^q$).

Moreover, this stress tensor appears to be directly linked to the macroscopic cohesion as defined by the Mohr-Coulomb criterion. As this capillary stress is a function of the water volume at contact, a non-linear evolution of the cohesion with the water content is obtained, resulting in shear strength saturation with increasing water content. Finally, a confrontation with the concept of generalized effective stress is proposed, comparing the capillary stress tensor contribution to the standard equivalent suction pressure ($\chi(S_r)(u_a - u_w)\delta_{ij}$) in the Bishop's relation:

$$\sigma'_{ij} = (\sigma_{ij} - u_a\delta_{ij}) + \chi(S_r)(u_a - u_w)\delta_{ij} \tag{2}$$

where $\chi(S_r)$ is called the efective stress parameter or Bishop's parameter, and is a function of the degree of saturation S_r of the medium ($\chi = 0$ for a dry material, $\chi = 1$ for a fully saturated material).

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