Abstract: Direct simulation of three phase problems in granular materials is an attractive mean to gain insight into their mechanical behavior. A discrete element model (DEM) of spherical particles with capillary bridges acting between them is introduced and used to perform numerical experiments. The model represents sphere packings in the pendular regime. The distribution of water in the void space is governed solely by Laplace law and a thermodynamic equilibrium condition.

It is shown that such model can predict the shear strength measured in experiments, and reproduces the complex phenomena associated to unsaturated materials, such as wetting collapse.

A micromechanical interpretation of the results is proposed. The total stress $\sigma_T$ is decomposed in two stress tensors defined on the basis of the Love-Weber homogenization formula. The first tensor, $\sigma_c$, reflects the contact forces, resulting from the deformation of the solid phase near the contact points. The second tensor $\sigma_w$ reflects the contribution of the capillary forces to the total stress, and is named the capillary stress tensor. The relation $\sigma_T = \sigma_c + \sigma_w$ is exact at static equilibrium, and can be verified in the DEM simulations [2].

The results of simulated triaxial shear tests, analyzed in terms of the contact stress, indicate that a unique failure criterion independent of succion may be defined (although no exact relation is inferred from the numerical experiments). Hence, $\sigma_c$ can be considered as the effective stress with respect to a Mohr-Coulomb type of failure criterion with null cohesion. Unfortunately, this stress tensor cannot be used in constitutive relations to produce the wetting collapse phenomenon. More surprising, it is only an approximation of the stress governing the elastic deformation. This can be understood by considering microscale phenomena [3].

The properties of the $\sigma_w$ tensor and its evolution during deformation are examined. An induced anisotropy of the capillary effects is revealed, leading to a deviatoric part in $\sigma_w$. This feature is not reflected in the usual definitions of effective stress, where the term linking the effective stress to succion is proportional to the identity tensor.

The modeling used in this study is only able to simulate a narrow range of mechanisms in unsaturated materials. Namely, the range of saturation is limited to the pendular regime, and the rate of deformation must be sufficiently low to keep the material near thermodynamic equilibrium. The possible extensions of this type of model and their great potential for investigating the effective stress concept are discussed and bottlenecks are identified.

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