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Advances in modelling mechanics of flow and stress in unsaturated soil

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Soils are complex materials as they consist of three different phases, namely, solid grains, water and air, as well as three different interfaces. Current models of flow and deformation in soil are either based on *ad-hoc* generalizations of saturated soil equations or a simple combination of available formulas for flow and deformation. As a result, many phenomena observed in the experiments cannot be well captured using current models of soil deformation and fluid flow. Examples are hydromechanical coupling effects, hysteresis in hydraulic as well as mechanical behaviour of unsaturated soils, and the difference between equilibrium and transient behaviour of unsaturated soils.

In the recent years, various approaches for obtaining new models and advanced theories have been developed. One of these approaches has been the application of rational thermodynamics along with balanced laws which are upscaled from micro-scale to macro-scale. An important feature of this approach as well as some of other recent thermodynamic studies has been the introduction of interfaces into the theory [1-4]. In particular, the role of the interfaces in the modelling of hysteresis in capillary phenomena and deformation effects has been demonstrated [5-7].

Hassanizadeh and Gray (1993) claimed that the hysteresis in capillary pressure-saturation curves can be modelled through the inclusion of air-water interfaces as a new independent variable. In other words, the hydraulics of fluids distribution in soil under static conditions should be characterized by a unique three-dimensional surface formed by capillary pressure-saturation-interfacial area data points. They stated that hysteretic curves of capillary pressure-saturation are nothing but 2D projections of that surface [8]. Recently, Nikooee et al. (2013) stated that the same conjecture can be made for suction stress. That is, suction stress data points from drying and wetting cycles actually lie on a three-dimensional suction stress characteristic surface, which is a function of saturation and matric suction [6]. The conjecture made by Hassanizadeh and Gray (1993) has already been verified using micro-model studies, pore network models and sophisticated imaging techniques. But there is a long path ahead to verify and well understand the role of interfaces in the mechanics of unsaturated soils. It seems that the first steps have been taken and researches have become interested to dig into the subject not only by means of theoretical studies but also with the aid of numerical models and novel experimental techniques [9].

One the main challenges of unsaturated soil mechanics has been the formulation of the effective stress parameter and suction stress in unsaturated soils. Results of micro-mechanical studies point to the tensorial nature of the effective stress parameter and suction contribution to the effective stress, at least at low degrees of saturation [10, 11]. There is an open question on how interfaces contribute to such anisotropic effects. Such anisotropic effects have not been well studied from a thermodynamic standpoint. In addition, capillary pressure-saturation relationship under transient conditions can be different from the one under steady state and equilibrium conditions. Thus, we may expect to have additional terms in the effective stress formula under transient conditions [12]. Needless to say formulation of effective stress under transient conditions is essential for modelling natural hazards such as rainfall induced landslides and thus further researches in this direction are crucial. Therefore, there are many challenges which have to be coped with, many open questions to be highlighted and answered, and interesting findings to be discussed.

This presentation aims at demonstrating the role of interfaces in modelling flow and stress in unsaturated soil mechanics in light of advanced theoretical studies as well as numerical models. For this purpose, first, the reasoning behind the need for incorporating interfaces in an extended theory for unsaturated soils is demonstrated. Next, recent advances in experimental and numerical modelling of interfaces are explained. Finally, open questions are described and possible directions for future researches are set forth.

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