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An Elasto-Viscoplastic Constitutive Model for Unsaturated Soils: Numerical Implementation and Validation

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Abstract : Mechanics of unsaturated soils has been an active field of research in the last decades. Efficient constitutive models that take into account the partial saturation of soil are necessary to solve a number of engineering problems e.g. instability of slopes and cuts due to heavy rainfalls. A large number of constitutive models can now be found in the literature that considers fundamental issues associated with the unsaturated soil behaviour, like the volume change and shear strength behaviour with suction or saturation changes. Partially saturated soils may either expand or collapse upon wetting depending on the stress level, and it is also possible that a soil might experience a reversal in the volumetric behaviour during wetting. Shear strength of soils also changes dramatically with changes in the degree of saturation, and a related engineering problem is slope failures caused by rainfall. There are several states of the art reviews over the last years for studying the topic, usually providing a thorough discussion of the stress state, the advantages, and disadvantages of specific constitutive models as well as the latest developments in the area of unsaturated soil modelling. However, only a few studies focused on the coupling between partial saturation states and time effects on the behaviour of geomaterials. Rate dependency is experimentally observed in the mechanical response of granular materials, and a viscoplastic constitutive model is capable of reproducing creep and relaxation processes. Therefore, in this work an elasto-viscoplastic constitutive model for unsaturated soils is proposed and validated on the basis of experimental data. The model constitutes an extension of an existing elastoplastic strain-hardening constitutive model capable of capturing the behaviour of variably saturated soils, based on energy conjugated stress variables in the framework of superposed continua. The purpose was to develop a model able to deal with possible mechanical instabilities within a consistent energy framework. The model shares the same conceptual structure of the elastoplastic laws proposed to deal with bonded geomaterials subject to weathering or diagenesis and is capable of modelling several kinds of instabilities induced by the loss of hydraulic bonding contributions. The novelty of the proposed formulation is enhanced with the incorporation of density dependent stiffness and hardening coefficients in order to allow the modeling of the pycnotropy behaviour of granular materials with a single set of material constants. The model has been implemented in the commercial FE platform PLAXIS, widely used in Europe for advanced geotechnical design. The algorithmic strategies adopted for the stress-point algorithm had to be revised to take into account the different approach adopted by PLAXIS developers in the solution of the discrete non-linear equilibrium equations. An extensive comparison between models with a series of experimental data reported by different authors is presented to validate the model and illustrate the capability of the newly developed model. After the validation, the effectiveness of the viscoplastic model is displayed by numerical simulations of a partially saturated slope failure of the laboratory scale and the effect of viscosity and degree of saturation on slope's stability is discussed.

Keywords : PLAXIS software, slope, unsaturated soils, Viscoplasticity
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