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A New Elastoplastic Damage Model for Constitutive Modeling of Argillaceous Formations

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Abstract

This contribution introduces a new elastoplastic damage model dedicated to constitutive modeling of semi-brittle geomaterials like argillaceous formations showing two irreversible phenomena. The model deals with the plastic behavior of such medium by a new thermal variant of Barcelona Basic Model. In addition, micromechanical definition of damage and phenomenological concepts of damage propagation are combined in the framework of Continuum Damage Mechanics (CDM) for damage modeling. Damaged effective stress variables are employed for formulation of elastoplastic behavior laws. Plastic yield surface is a damage dependent one. The model has been implemented in Θ-STOCK Code and the mechanical aspects of the model have been validated by comparing the numerical results with reference experimental results of argillites and results of an elastodamage model.
Keywords: Elastoplastic, Argillaceous Formations, Semi-brittle, Continuum Damage Mechanics.

1. INTRODUCTION

Argillaceous formations are under widespread consideration as host rock for radioactive waste disposal because of their favorable properties including very low hydraulic conductivities, low diffusion coefficients, and a high retention capacity for radio-nuclides [1]. In this framework, constitutive modeling of clay formations as geological barrier is also an active scientific field for geotechnicians. As a result, several elastoplastic and elasto-damage models have been introduced by different researchers. Nevertheless the experimental results on clay stones show an important plastic flow being coupled with an induced anisotropic damage [2]. Accordingly, an elastoplastic damage model might be an appropriate choice for constitutive modeling of semi-brittle geomaterials like argillites. Although a number of plasto-damage models are also introduced in the literature, most of these models are based on the use of Bishop's like effective stress (e.g. [3]).

As pointed out by Sheng et al. [4], the complex stress variables (e.g. Bishop's effective stress) are dependent on material states and therefore are not straightforwardly controllable in conventional laboratory testing procedures. It is not feasible to develop an entirely new constitutive relationship in terms of these variables, unless an existing framework is used. In the models which make use of the Bishop's effective stress with the parameter $\chi=S_r$, the inherent hydro-mechanical coupling is greatly dependent on the water retention relation used in the model. This entails utilizing sophisticated water retention models. Consequently the water retention properties of unsaturated medium should be specifically determined and it may necessitate the use of hysteretic water retention models in addition to mechanical formulation. On the other hand the experimental results on the retention properties of damaged geomaterials are scarce in the literature. Therefore independent stress state variables including net stress and suction are adopted as stress variables of the proposed elastoplastic damage model.

The proposed model has been implemented in Θ-STOCK Code which is a finite element code for computation of coupled thermo-hydro-mechanical (THM) problems of multiphase media. The program is developed by Gatmiri and his co-workers and three independent modules are integrated for dry, saturated and unsaturated elements [5,6]. Linear and nonlinear elastic, elastoplastic and elasto-damage constitutive laws as well as soil–atmosphere interaction model have already been incorporated in the unsaturated module of the code and several validation tests have been performed and published by the second author [7-10].

This paper first presents the damage-related formulation of the model in the framework of Continuum Damage Mechanics (CDM). Afterwards, a new elastoplastic formulation is proposed based on Barcelona