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Numerical simulation of ATLAS in-situ test using a new two yield surface thermo-plastic constitutive model

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Abstract

In this research, an in-situ field experiment called ATLAS carried out by François et al. [1] is simulated by means of a Finite-Element program capable of conducting coupled Thermal-Hydro-Mechanical analysis. When a heat source is buried in the soil, the increase in the temperature causes excess pore water pressure. The behavior of the soil is also affected by the change in temperature. In this paper, using a new Thermoplastic constitutive model developed by Abuel-Naga et al. [2], the effects of a buried heat source in the soil is modeled, and the numerical results are compared with the experimental data obtained from ATLAS experiment. In addition, the effect of temperature on the volumetric thermal expansion coefficient and viscosity of water is considered, leading to more accurate results compared to the results of simulation with the original constitutive model assuming of temperature-independent volumetric thermal expansion coefficient and viscosity for water.

Keywords: Numerical simulation, ATLAS in-situ test, Two yield surface thermo-plastic constitutive model, Thermal expansion coefficient, Viscosity.

1. INTRODUCTION

In recent decades, the interest in the assessment of the Thermo-Mechanical behavior of soils and rocks has increased dramatically. The simulation of the effects of temperature changes in the ground has many applications such as environmental geotechnics, petroleum geomechanics, using soils for the storage of energy, and geothermal reservoirs. In this respect, a number of thermo-mechanical constitutive models have been developed, which are able to simulate the effects of temperature on the behavior of the material. Among the different types of soils, saturated clayey soils are more sensitive to the changes in temperature. In this case, due to presence of water in porous medium, coupled Thermo-Hydro-Mechanical behavior should be considered. Abuel-Naga et al. [2], François et al. [1], and Huckel & Borsetto [3] are among the scholars who developed thermo-plastic constitutive models for saturated clayey soils. Among these models, the thermo-plastic constitutive model developed by Abuel-Naga et al. [2] is chosen to be implemented in THM simulation.

Also, several large scale field heating tests have been carried out in several underground laboratories, measuring the evolution of temperature, pore pressure, and displacements around the buried heat source. In ATLAS in situ experiment, conducted in Boom Clay Formation, changes in temperature, and pore pressure around the heat source are measured for more than six years. In this research, this experiment is simulated with the mentioned thermo-plastic constitutive model, and the results of this experiment is used for verification of the developed numerical program.

2. CONSTITUTIVE MODEL

The thermo-plastic constitutive model developed by Abuel-Naga et al. [2] is used in this research. This model accommodate non-linear thermo-elasticity as well as thermo-plasticity. The model is developed on the basis of Modified Cam-Clay (MCC) model.

In this model, the elastic behavior of saturated clay can be described by the equations below:

$$d\varepsilon_v^e = -\frac{de^e}{1+e} = \frac{\kappa}{1+e}\frac{dp}{p} \quad (1)$$