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Hydromechanical modelling of shaft excavation in Meuse/Haute-Marne laboratory

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ABSTRACT

This paper presents a numerical modeling of hydromechanical response of a vertical shaft subjected to excavation in hard clay called argillite. The excavation procedure of the shaft is first presented. Based on experimental data obtained in conventional laboratory tests, a unified plastic and viscoplastic model is used to describe poromechanical behavior of the argillite in saturated and unsaturated conditions. This model takes into account the main features of poromechanical behavior of the material such as non-linear yield surface, non-associated plastic flow, sensitivity to water saturation, instantaneous and time-dependent plastic deformations. The model's parameters are determined from experimental data obtained in triaxial compression tests and triaxial creep tests. The proposed model is implemented in a fully coupled finite element computer code in order to perform numerical modeling of boundary values problems. The numerical simulation of the shaft is then presented in the second part. Evolutions of displacement and pore pressure are evaluated during the excavation and compared with in situ measurement. It is shown that the hydromechanical responses of rock are affected by drying process inside the shaft. However, the influence of creep deformation seems to be negligible due to the relatively short duration of excavation.

1. Introduction

In the context of feasibility study for nuclear waste storage, extensive experimental investigations and numerical simulations have to be performed in order to evaluate thermal and hydromechanical disturbances in engineered and geological barriers. For this purpose, a series of research works have been conducted for many years now under the coordination of the French "Agence Nationale de gestion des Déchets RAdioactifs" (called Andra). In particular, an underground research Laboratory has been constructed in the Meuse/Haute-Marne region in France (URL-Bure) in the Callovo-Oxfordian argillite formation. One of tasks of this URL is to perform a series of in situ experiments to evaluate thermal and hydromechanical responses of rock formation due to excavation and heating. The present work concerns one of these experiments, the Modex-REP experiment, which is a part of EURATOM project in the 5th European framework program. This project aims to elaborate and validate hydromechanical models and numerical modelling tools in view of predicting hydromechanical behaviour of argillite during excavation of the main access shaft.

Extensive experimental investigations have been performed on the Callovo-Oxfordian argillite in laboratory scale (Chiarelli, 2000; Chanchole, 2004; ANDRA, 2005). These investigations include triaxial compression tests with different confining pressure on samples with different water saturation degrees. Triaxial creep tests have also been conducted. According to the experimental data obtained from the various investigations, the basic mechanical behaviour of this material is characterized by significant plastic deformation which is coupled with induced damage due to growth of microcracks. However, the plastic deformation is generally the dominant mechanism with respect to induced damage by microcracks. Moreover, some fundamental features have to be taken into account in the description of plastic deformation, for instance non-linear failure surface, strain hardening and softening, non-associated flow rule and transition from plastic compressibility to dilatancy, and sensitivity to water saturation. Further, depending on loading rate and time scale, the Callovo-Oxfordian argillite may also exhibit important time-dependent plastic deformation. Such creep deformation could be an important factor to be taken into account in long term feasibility analysis of storage. In the present work, in order to establish a general framework in view of modelling both short and long term responses of argillite, it is proposed to formulate a unified constitutive model, which is able to describe instantaneous and time-dependent plastic deformation.

Further, in the context of geological storage, rock deformation is strongly coupled with fluid flow process. A coupled hydromechanical problem has to be solved. Therefore, the mechanical constitutive model should be extended to include poromechanical coupling. In

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addition, due to possible ventilation processes during excavation, the argillite can be in partially saturated condition. And mechanical behaviours of most clay-based rocks are strongly sensitive to water saturation degree. A number of works have been performed during the last 30 years on unsaturated soils and clays (Alonso et al., 1990; Gens and Alonso, 1992; Fredlund and Rahardjo, 1993; Cui and Delage, 1996; Thomas et al., 1998; Matyas and Radhakrishna, 1996). From the theoretical point of view, the classic Biot's poroelastic theory has also been extended to partially saturated porous media in particular in cohesive geomaterials such as rocks and concrete (Coussy, 2005). In this framework, the proposed constitutive model is extended to partially saturated materials by using a generalized effective stress concept. The proposed model is then implemented into a finite element computer code in view of numerical modelling of coupled hydromechanical boundary values problems. The present paper is organized as follows:

The Modex-REP experiment is first briefly introduced. Then the formulation of the constitutive model is presented. After the determination of model's parameters, the proposed model is applied to the argillite studied and some representative laboratory tests are simulated. The last part of the paper is devoted to numerical modelling of Modex-REP experiment. Numerical predictions of displacement and pore pressure are compared with in situ measurements. Comparative studies are also presented in order to capture influences of some main parameters involved in hydromechanical coupling.

2. Summary of Modex-REP experiment

The Modex-REP experiment is one of a series of in situ experiments conducted in the underground research laboratory at Bure by ANDRA. There are double objectives in these experiments; to evaluate thermal, thermo-mechanical and hydromechanical responses of engineered and geological barriers subjected to various loading conditions such as excavation, desaturation and heating and to verify the predicting capacity of numerical models in reproducing observed responses. The Modex-REP experiment focuses on the hydromechanical response of the Callovo-Oxfordian argillite during the excavation of the main access shaft of the underground research laboratory. This experiment is properly conducted in the section between the depths −445 m and −476 m, as shown in Fig. 1. The chronological sequences of the experimental procedure are as follows:

- The main shaft is first excavated until the depth of −445 m and then the excavation is stopped.
- At this depth, a horizontal niche is constructed for experimental purpose (see Fig. 1). All necessary devices and instruments are placed in this niche for measuring and monitoring during the experiment. Further, from this experimental niche, a series of small boreholes are drilled in various orientations to reach the zone between the depths from −460 m to −475 m. Different kinds of sensors are then placed in the instrument boreholes and will record rock displacements and pore water pressure changes at various points, both during and after the sinking operation.
- The sinking procedure of shaft restarts from the depth of −445 m up to −490 m. The excavation was done by blasting with a velocity about 2 m/times in average. After each blast a debris removal period and a waiting period is necessary in order to prepare the next blast.
- With the help of the various sensors inside the boreholes, rock deformation (relative displacements) and pore pressure are continuously monitored during the progress of blast, inside the experimental zone between the depths from −460 m to −476 m.

Only some selected experimental data at some representative measuring points will be presented in Section 4 of this paper, together with numerical predictions.

3. Properties of Callovo-Oxfordian argillite

In Europe, there are three clay formations that are currently studied in detail as potential geological barriers for the implementation of a repository for high-level and long-lived radioactive waste: Boom clay in Belgium, Opalinus clay in Switzerland and Callovo-Oxfordian clay in France. The Callovo-Oxfordian argillite studied in this work is marine sediment of the Jurassic Age (about 150 million years old).

Mineralogy studies showed a rather homogeneous composition of quartz (23%), calcite (27%) and clay minerals (45%) together with subordinate feldspars, pyrite and iron oxides (5%). The clay minerals composition is relatively constant at 65% I/S (illite-smectite interstratified minerals), 30% illite and 5% kaolinite and chlorite. At the microscopic level, quartz and large calcite grains are scattered in a fine matrix of clay minerals and calcite which acts to cement the larger grains. Clay minerals are grouped in clusters of some

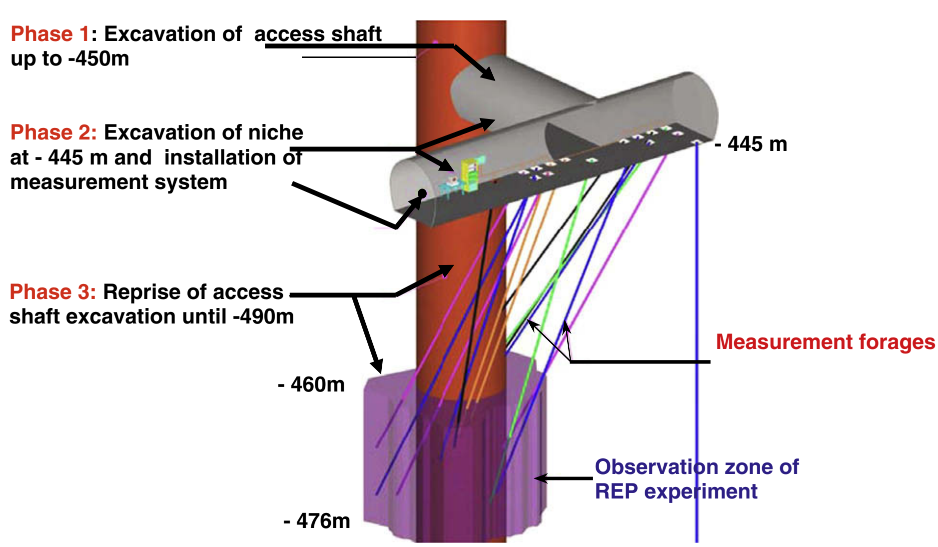

Fig. 1. Schematic presentation of geometric situation of REP experiment.