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An unsaturated hydro-mechanical modelling of two in-situ experiments in Callovo-Oxfordian argillite

Robert Charlier [a], Frédéric Collin [a,*], Benoît Pardoen [a], Jean Talandier [b], Jean-Pol Radu [a], Pierre Gerard [a]

[a] Université de Liège, Département ArGEnCo, Chemin des Chevreuils 1, 4000 Liège, Belgium
[b] Agence nationale pour la gestion des déchets radioactifs (ANDRA), France

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ABSTRACT

The unsaturated behaviour of Callovo-Oxfordian argillite is investigated through the modelling of 2 in-situ experiments. The first test studies the influence of ventilation in a gallery on the hydro-mechanical behaviour of the rock mass. The second test consists in a gas injection in the rock mass from an experimental borehole. A hydro-mechanical model is described and used in the modelling of the experiments. A review of the main hydro-mechanical parameters of argillite is presented. The numerical results highlight the need of a flow boundary condition reproducing the fluid transfers between the surroundings and the rock mass. The influence of dissolved gas on the compressibility of the liquid phase is also emphasised.

1. Introduction

The long term management of radioactive waste is nowadays a crucial issue in several countries. The most often proposed solution is storage in deep and weak permeable geological layers. Owing to their good confining properties, argillaceous rocks constitute an ideal barrier for the insulation of high-activity and long lived radioactive waste disposal. Some underground research laboratories (URL) have been drilled in Europe in order to study the feasibility of such solutions, for instance in France in a thick layer of Callovo-Oxfordian argillite (Félix et al., 1996), in Belgium in Boom clay (Neerdael and Boyazis, 1997) or in Switzerland in the Opalinus clay (Croisé et al., 2004).

The research programs in the different laboratories must allow the understanding and the characterisation of the confining properties of argillaceous rocks. Moreover it has to show that the construction of such repository site and the operation phases due to the storage of radioactive wastes will not introduce pathways for the migration of radionuclides through the host rock. For instance, the different thermo-hydro-mechanical solicitations occurring during the drilling and the operation phases affect the host rock, by the creation of a perturbed zone around the underground structure openings, where the geotechnical and hydro-geological properties are modified (Bossart et al., 2002; Blüming and Konietzky, 2003; Tsang et al., 2005). Such zones could alter the confining function of the host rock.

The understanding of the geomechanical behaviour of argillaceous rocks is thus a crucial issue to ensure the feasibility of such repository solutions. In order to well understand the geomechanical behaviour of argillaceous rocks and its coupling with the hydraulic and thermal conditions, several laboratory experiments are thus performed on small argillaceous rock samples. In parallel to these laboratory investigations, large scale in-situ tests are achieved in the underground laboratories in order to provide additional data on more complex loading paths.

In this paper, we focus especially on the modelling of the unsaturated behaviour of argillaceous rocks through the modelling of two in-situ experiments. These experiments deal with the understanding of fluid flows mechanisms under unsaturated conditions, and its potential coupling with the mechanical behaviour. Both in-situ experiments are performed by Andra in the underground research laboratory of Bure (France), drilled in Callovo-Oxfordian argillite. The first experiment investigates the unsaturated features of argillite through a ventilation test performed in an experimental gallery (SDZ). The second one analyzes the impact of gas migration on the rock mass behaviour through gas injection test performed from an injection chamber set up in a small borehole (PGZ1). After a description of the experiments and the main experimental observations that have been obtained in Section 2, a general framework for unsaturated porous media is proposed and described in Section 3. A review of the hydro-mechanical characteristics of Callovo-Oxfordian argillite is then presented in Section 4. This review is useful to determine the hydro-mechanical parameters used in the modelling of the two in-situ experiments. The Section 5 is devoted to the numerical results, with an emphasis on the main developments that allow a good reproduction of the experimental observations by the numerical results, as for instance the expressions of the boundary condition or the influence of some hydraulic parameters.

* Corresponding author.
E-mail address: f.collin@ulg.ac.be (F. Collin).

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2. Andra Underground Research Laboratory in Bure—in situ experiments

The building of an Underground Research Laboratory (URL) by Andra began in 1999 in Bure on the border of the Meuse and Haute-Marne departments in eastern France (Delay et al., 2007). The laboratory has been drilled in a geological layer of Callovo-Oxfordian argillite at 490 m depth. In this paper, we will focus on two experiments that are performed in this laboratory. The first one (SDZ experiment) investigates the unsaturated behaviour of argillite through a ventilation test achieved in a large scale gallery, whilst the second one (PGZ1 experiment) studies the host rock behaviour when gas is injected from an experimental borehole.

2.1. SDZ experiment

2.1.1. General description

The first in-situ experiment (SDZ) is devoted to the characterisation of the structure and the size of the excavated damaged zone (EDZ) according to the desaturation and possible resaturation induced by the evolution of the ventilation conditions imposed in an experimental gallery. The experimental zone is isolated to the GED experimental horizontal gallery through a 2 m long airlock. The test zone contains a first part without covering (with a length of 7.2 m) and, at the end, another 5 m long zone with a concrete covering with a thickness of 20 cm and a thin impervious geotextile (Figure 1).

During the test, ventilation is performed in the gallery. After 230 days of ventilation, the airlock was closed and the ventilation thus stopped in the experimental zone. The relative humidity in the GED zone evolves freely. The moisture exchanges between this zone and the GED gallery could only occur through axial flows in the damaged zone developed around the cavity wall.

The air relative humidity and the temperature in the experimental gallery are monitored before and after the airlock closure thanks to several sensors set up at the gallery wall (Figure 2). From 160th day, measurements of the pore pressures inside the rock mass are performed through sensors (characterised by a range of measurements from 0 to 10 MPa) set up with different orientations and distances from the experimental zone (Figure 3). Moreover a geological survey of the zone without covering is performed after the excavation of the GED gallery in order to characterise the damaged zone. It highlights the cracking of the Callovo-Oxfordian argillite.

2.1.2. Experimental observations

In this paper, only the main experimental observations are presented. More complete results can be found in Cruchaudet et al.

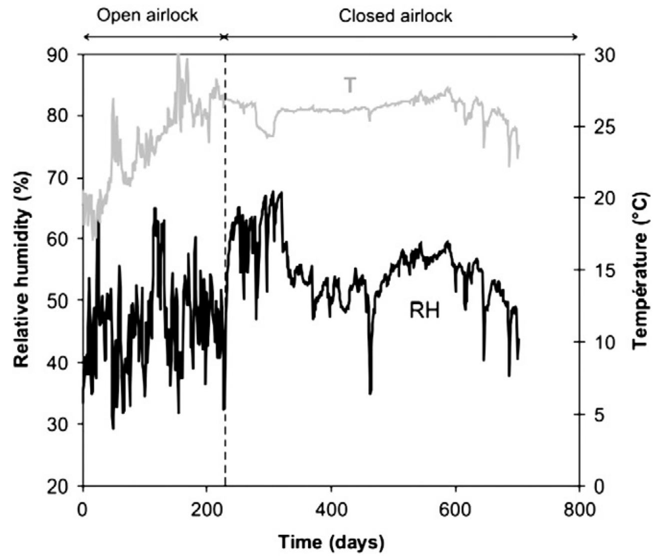

Fig. 2. Time evolution of relative humidity and temperature into the galleries.

(2010). The geological survey of the damaged zone in the non-covering part of the GED experiment is firstly performed thanks to 12 boreholes drilled in different directions from the gallery wall. The analysis of the fracturing in the damaged zone observed along different argillite cores shows that the vertical extent of the damaged zone (1.5 m) is higher than the horizontal one (0.3 m). The cracks density is also more important in the vertical direction. From a modelling point of view, an anisotropic mechanical behaviour (or at least an anisotropic initial stress state in the rock mass) is certainly needed to explain these observations.

Moreover the development of the excavated damaged zone alters probably the permeability near the GED gallery wall. Fig. 4(a) shows indeed that the pore pressures in a 3 m ring around the non covering gallery are very low and close to the atmospheric pressure, whilst the drainage has not a strong influence on the measurements of the sensors located from 4.5 m and 6 m to the cavity wall. Such distribution of the pore pressures around the gallery can be numerically reproduced if the permeability increases substantially in the damaged zone, in order to facilitate the drainage in this domain. Moreover the permeability seems to be not influenced in the far field (more than 4.5 m from the gallery), because the pore pressures are relative close to the initial water pressure in the rock mass. A hydro-mechanical coupling that provides an increase of the permeability

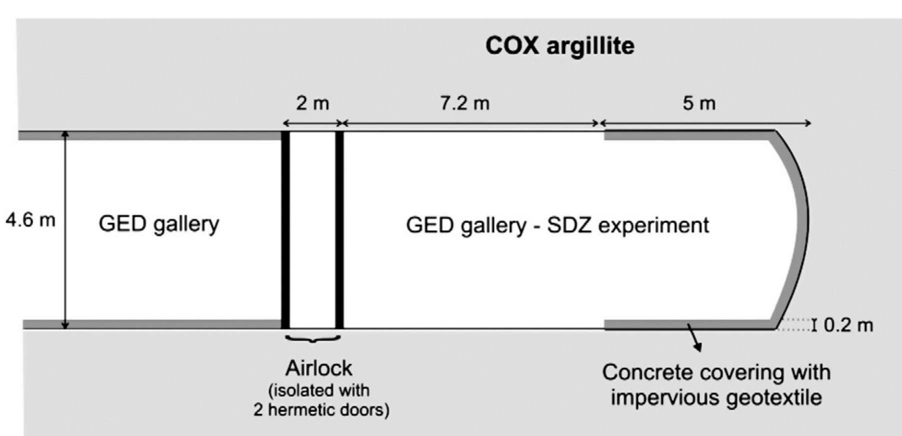

Fig. 1. Geometry of the SDZ experimental zone.