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Introduction

In the context of radioactive waste management, one of the options currently being considered is to store it in deep geological formations. Clay formations, in particular, show very favorable confining conditions as repositories for long-term safety of nuclear waste due to their low hydraulic conductivity and significant retention capacity for radionuclides. In France, the National Radioactive Waste Management Agency (Andra) began to build the Meuse/Haute-Marne underground research laboratory (MHM-URL) in the Callovo-Oxfordian (COx) claystone formation, lying between depths of 420 m and 550 m. With regards to the main objectives of feasibility and safety assessment of a potential deep geological repository (Cigéo), a comprehensive scientific research programme of specific in situ experiments, laboratory tests and numerical modelling have been carried out to characterize and understand the behavior of the COx claystone formation in the framework of hydro-mechanical (HM) processes (Armand *et al.* 2017). In addition to the HM couplings and the associated parameters, it appears necessary to consider at least the inherent anisotropies (mechanical and hydraulic) of such rock, but also its time-dependent behavior (Armand *et al.* 2017). In this paper, we consider the transient creep mechanism determined from laboratory tests in order to study its effect on anisotropy and hydromechanical behavior of COx clay. The hydromechanical couplings are then evaluated around the GCS drift of MHM-URL (drift excavated following the major principal stress and without rigid lining) under satured conditions using Comsol Multiphysics code.

The long-term behavior of the COx claystone has been studied through laboratory creep tests on samples and in-situ experiments in MHM-URL (Armand *et al.* 2017). The laboratory tests did not demonstrate the existence of a viscoplastic threshold from which the creep mechanism occurs. Moreover, the measurements campaigns of the natural stress state performed at the MHM-URL show an anisotropic natural stress state. The absence of a measurable creep threshold stress at the laboratory scale means that the creep deformation of COx claystone starts even before excavation, which is unlikely from a physical point of view (Armand *et al.* 2017). Based on these observations, the viscoplastic strain rate that consider a threshold stress is assumed and expressed according to the power law:

$$\dot{\varepsilon}_{ij}^{vp} = A_c\left(\frac{q-q_o}{\sigma_{ref}}\right)^{n_c}\frac{3}{2}\frac{\partial q}{\partial \sigma'_{ij}} \tag{1}$$

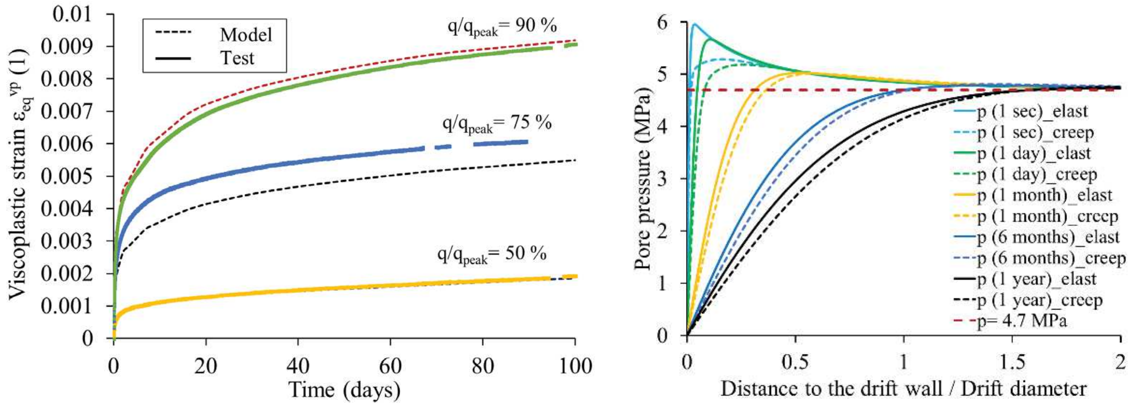
where A_c and n_c are coefficients of the power law, σ_{ref} is the reference stress, $q=\sqrt{3J_2}$ is the deviatoric stress, q_o is the initial deviatoric stress prior to any disturbance and J_2 is the second deviatoric stress invariant. The original implementation of power law in Comsol Multyphisics® does not assume a creep threshold (q_0 = 0).

The expression (1) reflects the stationary creep, i.e. that observed in the long term on in situ convergence measurements. In order to take account for the transient creep observed both on samples and in situ scales, the transient curve is then adjusted in pieces by using (1). Parameters relating to the long-term behavior of COx claystone are identified under the following assumptions: (a) the creep threshold is considered as null (q_o = 0), which is in agreement with most of laboratory tests, even under low stresses, (b) the parameters A_c and n_c of the power law are constants for $t \in [t_i\ ;\ t_e]$, where t_i is the initial time and t_e is the end time in the time interval considered and (c) the reference stress σ_{ref} = 1.0 MPa.

The equivalent viscoplastic strain for triaxial creep tests at a confining pressure of 12 MPa and three levels of stress at 50, 75 and 90% of the peak strength (36.5 MPa) were used to identify the parameters A_c and n_c. For the creep test (q_0 = 0), the deformation is expressed as:

$$\varepsilon_{eq}^{vp} = A_c \left(\frac{q}{\sigma_{ref}} \right)^{n_c} t \qquad (2)$$

In order to verify and validate the model implemented in Comsol Multiphysics®, three creep tests were simulated. A comparison between the tests and simulations (E= 4000 MPa and v=0.3) is shown in Fig. 1.a, with good agreement for 50 and 90% of peak strength, while for 75% it has a good trend.



(a) (b)

Fig. 1. (a) Tests and simulations of triaxial creep tests at stress levels of 50, 75 and 90% of peak strength. (b) Pore pressure profiles in horizontal direction (continue = poroelastic, dashed = poroviscoplastic).

The proposed model was then used to model the excavation of the GCS drift. The model parameters are found in Coarita-Tintaya *et al.* (2018). Comparison between poro-elasticity and poro-visco-plasticity modeling was made. Pore pressure evolution in the horizontal direction is particularly considered. As shown in Fig. 1.b, the creep behavior reduces the pore pressure due to the stress relaxation. The consideration of instantaneous plastic behavior is an ongoing work.

References:

Armand G., Conil N., Talandier J.,Seyedi D.M. (2017) Fundamental aspects of the hydromechanical behavior of Callovo-Oxfordian claystone: From experimental studies to model calibration and validation. Comput. Geotech., 85, 277–286.

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