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Hydromechanical modelling and numerical simulation of self-sealing phenomena in the Callovo-Oxfordian claystone

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Extensive preliminary studies have led the National RadioactiveWaste Management Agency (ANDRA) to the choice of the Callovo-Oxfordian (COx) claystone of the Meuse/Haute-Marne as a host rock for a radioactive waste repository because of its very low permeability and adequate mechanical properties, which allow for the geological layer to act as a natural barrier against the spreading of radionuclides in the biosphere. However, the concept of underground storage relies on the excavation of a network of wells and drifts, which damages the surrounding rock, leading to the creation of a so-called excavation damaged zone (EDZ) along the gallery walls. As a consequence, the overall water permeability is increased by several orders of magnitude. This EDZ is important in the context of performance assessment because it might represent a preferential pathway for dissolved radionuclides which could reach prematurely the surrounding more permeable geological layers. Thankfully, existing fractures tend to close when this rock is wetted, mainly because of swelling phenomena and delayed deformations, which is referred to as self-sealing.

We propose here to model the hydromechanical couplings that take place during self-sealing so that the progressive resaturation of a drift may be studied from a theoretical standpoint. The swelling phenomena are first studied in a simplified linear elastic context to analyse the influence of geometry and boundary conditions on self-sealing, first at the scale of the sample using the finite element code Cast3M (CEA) to simulate the progressive resaturation around a set of periodic elliptical cracks. Non trivial effects are brought to light, and lead to the conclusion that self-sealing needs to be investigated at the level of the structure and not only at the level of the material. Thus, further investigations are performed at the scale of the underground drift. Using micromechanics, the EDZ is represented as a medium composed of a homogeneous matrix in which microcracks are distributed with preferential orientations. It should be noted that since the operation phase and the resaturation process take place over a hundred years and a few thousands of years respectively, delayed deformations are bound to develop, leading to convergence of the drift walls. This first model provides insights that may be useful for understanding the response of the EDZ, but also when developing a more elaborate model taking into account the viscoplastic behaviour of the rock in relation with the water content. Both aspects indeed appear to have a significant impact on the macroscopic response of the COx claystone subject to swelling phenomena. We then propose to develop a model based on micromechanics to describe the long-term response of the claystone. In this model, viscoplasticity is introduced at the interface between the clay particles, and a homogenisation scheme is used to determine the behaviour of the clay matrix. A second homogenisation step is then required to introduce the quartz and calcite inclusions, and their damageable interfaces with the matrix. The material response is then analysed and discussed as well as its implications with regards to self-sealing.