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A numerical study of THM effects on the near-field safety of a hypothetical nuclear waste repository—BMT1 of the DECOVALEX III project. Part 3: Effects of THM coupling in sparsely fractured rocks

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Abstract

As a part of the international DECOVALEX III project, and the European BENCHPAR project, the impact of thermal–hydrological–mechanical (THM) couplings on the performance of a bentonite-back-filled nuclear waste repository in near-field crystalline rocks is evaluated in a Bench-Mark Test problem (BMT1) and the results are presented in a series of three companion papers in this issue. This is the third paper with focuses on the effects of THM processes at a repository located in a sparsely fractured rock. Several independent coupled THM analyses presented in this paper show that THM couplings have the most significant impact on the mechanical stress evolution, which is important for repository design, construction and post-closure monitoring considerations. The results show that the stress evolution in the bentonite-back-filled excavations and the surrounding rock depends on the post-closure evolution of both fields of temperature and fluid pressure. It is further shown that the time required to full resaturation may play an important role for the mechanical integrity of the repository drifts. In this sense, the presence of hydraulically conducting fractures in the near-field rock might actually improve the mechanical performance of the repository. Hydraulically conducting fractures in the near-field rocks enhances the water supply to the buffers/back-fills, which promotes a more timely process of resaturation and development of swelling pressures in the back-fill, thus provides timely confining stress and support to the rock walls. In one particular case simulated in this study, it was shown that failure in the drift walls could be prevented if the compressive stresses in back-fill were fully developed within 50 yr, which is when thermally induced rock strain begins to create high differential (failure-prone) stresses in the near-field rocks.
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Keywords: Modelling; Coupled processes; Fractured rock bentonite; THM; Nuclear waste disposal

1. Introduction

This paper evaluates the impact of thermal–hydrological–mechanical (THM) couplings on the performance of a bentonite-back-filled nuclear waste repository in a

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sparsely fractured hard rock. The present paper is the third of three companion papers on Bench-Mark Test 1 (BMT1) of the DECOVALEX III and BENCHPAR projects [1]. The overall aims and definition of the BMT1, as well as the model conceptualisation and characterisation, were presented in the first companion paper [2]. The second companion paper [3] focused on the impact of THM coupling for a repository located in continuous and homogeneous (intact) rock without fractures. This is the third (and final) paper with focus on the impact of THM couplings in near-field of a repository located in sparsely fractured rock (Fig. 1b). The sparsely fractured rock in this case is envisioned as a fractured rock mass that contains a few connected hydraulically conducting fractures that carry the main part of the water flow. In this case, one vertical fracture is assumed to be located about 5 m from the deposition hole and this fracture is connected to another horizontal fracture that intersects the deposition hole (Fig. 1b). The results and conclusions are based on coupled THM analyses conducted by four research teams: Royal Institute of Technology (KTH), Canadian Nuclear Safety Commission (CNSC), Commissariat a l'Energie Atomique de Cadarache (CEA), and Japan Nuclear Fuel Cycle Development Institute (JNC). Computer codes used by each research team and their sources [4–7] are listed in Table 1.

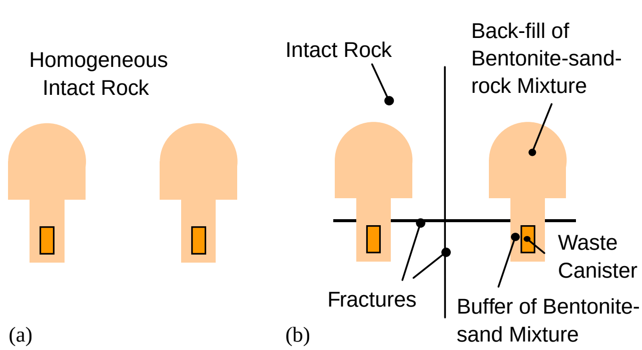

Fig. 1. (a) Homogeneous intact rock versus (b) sparsely fractured rock cases.

Table 1
Research teams, codes and their sources

Acronyme	Research team	Code
KTH	Royal Institute of Technology	ROCMAS [4]
CEA	Commissariat a l'Energie Atomique de Cadarache	Castem2000 [5]
CNSC	Canadian Nuclear Safety Commission	FRACON [6]
JNC	Japan Nuclear Fuel Cycle Development Institute	THAMES [7]

In this paper, we will first introduce briefly the simulation tasks and model conceptualisations. The THM model conceptualisations and simulation results are then presented, followed by discussions about the impacts of THM couplings and near-field rock fractures on repository performance. The impact of fractures is analysed by a comparison with results in the second accompanying paper on continuous homogeneous (intact) rock [3].

2. Simulation tasks

The basic task of BMT1 was to perform a scoping calculation of coupled THM processes around a hypothetical bentonite-back-filled nuclear waste repository in fractured rock. The repository geometry is based on the radioactive waste disposal concept from the Japanese H12 project [8]. Using this concept, the spent-fuel assemblies will be encapsulated in metal canisters, then placed in vertical deposition holes drilled from horizontal drifts deep in the bedrock. The waste canisters are embedded in a buffer of a highly compacted bentonite-based material and the drifts are back-filled with a mixture of bentonite, sand, and crushed rock (Fig. 1b). This is similar to prospective designs and engineering barrier systems for many countries [9], including the original Swedish KBS-III concept. Most of the material properties for buffer and rock were extracted from a comprehensive data set that was been developed at the Kamaishi Mine, Japan, during DECOVALEX II. Additional rock properties are taken from data sets of the sparsely fractured crystalline in the Canadian Shield.

The overall objective of BMT1 is to investigate the impact of coupled THM processes on the near-field performance of a typical bentonite-back-filled nuclear waste repository (Fig. 2). To investigate the influence of each coupling mechanism, the results of a fully coupled THM simulation is compared to partially coupled solutions. Four simulations are therefore conducted. First, a fully coupled THM simulation is conducted, including the most apparent couplings illustrated in Fig. 2. Thereafter, coupled TH/uncoupled M, coupled HM/uncoupled T, and coupled TM/uncoupled H simulations are conducted. In these simulations, one of the processes M, T or H was uncoupled, meaning that these processes are solved independently of the others. However, all simulations start with the same initial conditions (before excavation for the rock and after emplacement for the bentonite). For example, when running coupled TH/uncoupled M simulations, the hydraulic conductivity of the rock is determined by the initial effective stress and is kept constant throughout the simulation. In the case of coupled HM/uncoupled T simulations, the thermal conductivity of the bentonite is