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Homogenization in clay barriers and seals: Two case studies

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ABSTRACT

The paper presents two case studies that provide information on the process of homogenization of initially heterogeneous clay barriers and seals. The first case is the canister retrieval test performed in the Aspö Hard Rock Laboratory (Sweden). The heterogeneity arises from the use of a combination of blocks and pellets to construct the engineered barrier. The degree of homogenization achieved by the end of the tests is evaluated from data obtained during the dismantling of the test. To assist in the interpretation of the test, a fully coupled thermo-hydro-mechanical (THM) analysis has been carried out. The second case involves the shaft sealing test performed in the HADES underground research laboratory (URL) in Mol (Belgium). Here the seal is made up of a heterogeneous mixture of bentonite pellets and bentonite powders. In addition to the full scale test, the process of homogenization of the mixture has also been observed in the laboratory using X-ray tomography. Both field test and laboratory tests are successfully modelled by a coupled hydro-mechanical (HM) analysis using a double structure constitutive law. The paper concludes with some considerations on the capability of highly expansive materials to provide a significant degree of homogenization upon hydration.

1. Introduction

In many designs of high level nuclear waste disposal schemes in deep geological repositories, the canister containing the waste is surrounded by a clay-based engineered barrier. The barrier is usually composed of compacted clay with high swelling characteristics, sometimes it is mixed with other materials such as sand or excavation products. In the initial transient period, the barrier is subjected to considerable thermo-hydro-mechanical (THM) actions that may bring about important changes to the final state of the barrier (Gens et al., 2002; Gens, 2010). Other important elements in deep geological repositories are the seals required for access shafts and drifts that are also constructed, in most cases, using clayey materials. Seals are also subjected to substantial hydro-mechanical (HM) effects in the initial transient period. In both barriers and seals, chemical actions are also significant but they are outside the scope of this paper (Guimarães et al., 2007).

The desired outcome is that, at the end of this THM-influenced transient phase, the engineered clay barrier or the seal is in a state as uniform as possible in order that there are no preferential paths for radionuclide migration. However, the initial state of the barrier after emplacement is often quite different from homogeneity. Some barriers are made up of compacted bentonite blocks that leave between them initially open joints (Gens et al., 2009). Heterogeneities also arise from the lack of perfect contact between blocks and the surface of the opening in which they are emplaced. In other cases, barriers or seals are made up of a combination of pellets and powder so the heterogeneity is intrinsic to the material used throughout (Volckaert et al., 2000). Significant initial heterogeneity is also a feature in the designs that use a combination of compacted clay blocks and pellets in order to take advantage of the favourable properties of each type of materials (Thorsager et al., 2002). In all these situations, it is important to try to ascertain, as accurately as possible, the final state of the barrier or seal with respect to the degree of homogeneity. This goal can best be achieved by a combination of experiments and numerical analyses conveniently validated against the observations of those same tests.

In this paper, two case studies are presented and discussed focusing on the issue of barrier/seal homogenization. The first one is a THM in situ test where the engineered barrier is made up of bentonite blocks with an annulus of pellets placed between blocks and borehole wall. The second one refers to in situ and laboratory seal experiments where the material is an initially heterogeneous

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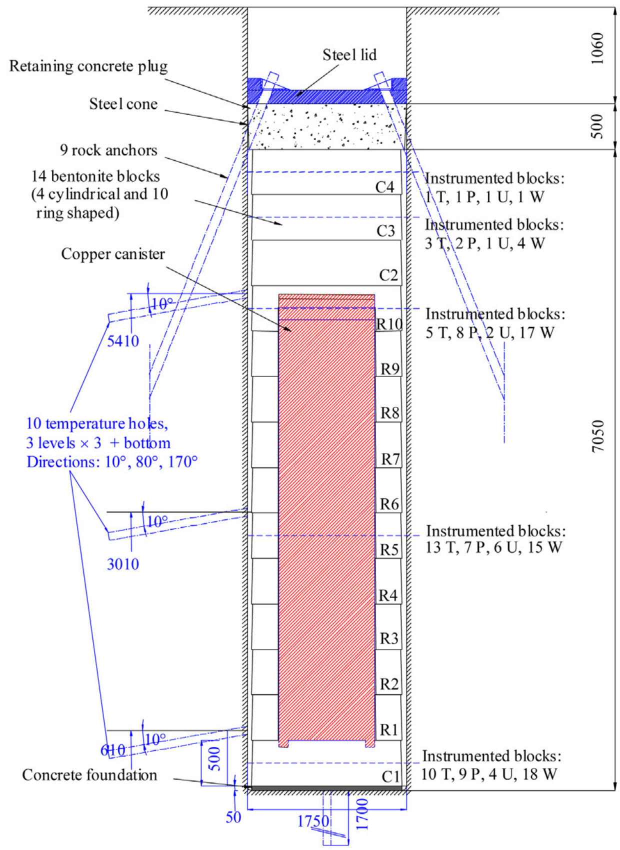

Fig. 1. Layout of the canister retrieval test (unit: mm).

mixture of bentonite pellets and bentonite powder. Some general concluding remarks, based on the cases described, close the paper.

2. The canister retrieval test

2.1. Description and experimental protocol

The canister retrieval test, CRT (Thorsager et al., 2002), is a full-scale in situ heating test that involves the placement of a full-scale canister in a vertical borehole surrounded by an engineered barrier. The layout of the test is depicted in Fig. 1 and a picture of the installation is presented in Fig. 2. The test is located in the 420 m level of the Aspö Hard Rock Laboratory (Sweden) excavated in granite. The borehole was bored with a full-face tunnel boring machine modified for vertical. The deposition borehole is 8.55 m deep and has a diameter of 1.76 m. The surrounding rock at the upper part of the borehole consists mainly of greenstone and at the lower part of Äspö diorite. For the purpose of applying artificial hydration to the barrier, 16 filter mats with a width of 10 cm were installed adjacent to the rock wall with uniform spacing, starting 0.15 m from the borehole bottom up to a 6.25 m height.

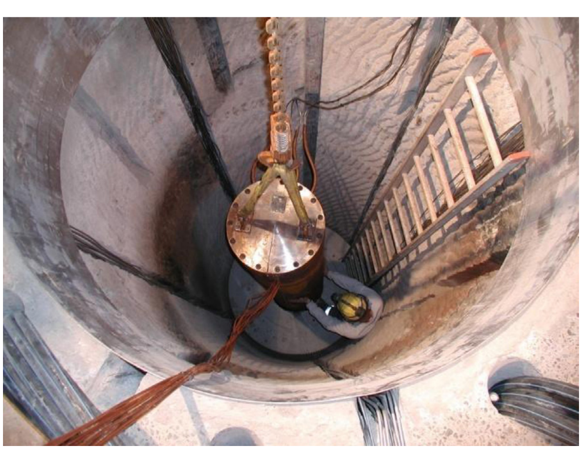

Fig. 2. Installation of the canister retrieval test.

MX-80 bentonite was used to construct the engineered barrier. The barrier consists of highly compacted bentonite blocks with an initial dry density of 1710–1790 kg/m^3. The initial water content of the bentonite was 17.3–16.7% with a mean value of 17%. The bentonite buffer was installed in the form of cylindrical or ring blocks, depending on elevation. The blocks have a diameter of 1.65 m and a height of 0.5 m. When the stack of blocks was 6 m high, the canister, equipped with electrical heaters, was lowered down in the centre of the borehole and the cables to the heaters and instruments were connected. A canister obtained from SKB's encapsulation project was used in this test. The outside diameter of the canister is 1.05 m. The height of the canister is 4.83 m and the weight is 21.4 tonnes.

At the top of the canister, MX-80 bentonite bricks fill up the volume between the canister top surface and the top surface of the upper ring (R10). The height difference between the two surfaces was 220–230 mm. More importantly for our purposes, the space between bentonite blocks and the borehole wall was filled with bentonite pellets and water. Additional blocks were emplaced until the borehole was filled to a distance of 1 m from the tunnel floor.

The top of the borehole was sealed with a retaining structure formed by a plug made of concrete, a steel lid and rock anchors. The aim of the structure was to prevent the blocks of bentonite from swelling uncontrollably. An impermeable rubber mat was installed between the top bentonite block C4 and the concrete plug. On top of the plug, a steel lid was installed. The plug and lid can move vertically and are attached to the rock by 9 rock anchors made up of 19 steel wires having 5 m fixed length and 5 m free length. The inclination of the anchors is 2.5:1.

A large number of instruments were installed to measure the following variables:

(1) Canister: temperature and strain;
(2) Rock mass: temperature and stress;
(3) Retaining system: force and displacement;
(4) Buffer: temperature, relative humidity, pore pressure and total pressure.

The protocol can be readily summarized in the following points:

(1) The starting date of the test was October 26, 2000 when the buffer-rock interface was filled with pellets. Afterwards, water was pumped into the gap occupied by the pellets and the filter mats.
(2) Once pellets were hydrated, the concrete plug was cast and heating started. Heating began with an initially applied constant power of 700 W at day 1.
(3) When the concrete plug rose 13 mm due to bentonite swelling, three rock anchors were locked on day 5. The initial force in each anchor was 20 kN.
(4) The canister heating power was raised twice, at day 18 to 1700 W and at day 110 to 2600 W, respectively.
(5) When the total force exceeded 1500 kN, the remaining 6 anchors were fixed. This procedure took place at days 46–48. The total force, distributed equally among all anchors, is about 170 kN per anchor.
(6) The water pressure at filter mats was increased gradually up to 0.8 MPa from day 679 to day 714 (September 5, 2002 to October