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Engineered barrier of bentonite pellets and compacted blocks: State after reaching saturation

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ABSTRACT

The EB experiment was a large-scale test performed in the Underground Research Laboratory of Mont Terri (Switzerland) for the demonstration of an engineered barrier concept for nuclear waste disposal consisting of the simultaneous use of high-density bentonite blocks and a lower-density bentonite pellets mixture (the granular buffer material, GBM). For that purpose, a gallery was excavated in the Opalinus clay and a dummy waste canister was placed on a bed made of bentonite blocks and surrounded by the GBM material. The bentonite barrier was artificially hydrated with Pearson water and after 10.5 years of operation at isothermal conditions it was considered that the bentonite was completely saturated and the dismantling of the barrier was undertaken. A sampling campaign was done to assess the final state of the bentonite barrier with regards to dry density and water content.

Upon dismantling, the GBM looked perfectly homogeneous, with every void and gap between the different elements (blocks/GBM, GBM/host rock, GBM/canister, etc.) having been sealed. Full saturation had been reached all through the barrier. Moreover, the dry density of the blocks had decreased to values similar to those of the GBM, and the average water contents for both kinds of materials were similar. Nevertheless, the initial conditions of the system did have a certain impact on the final distribution of dry density and water content: the bottom of the barrier had a chance to quicker and higher water uptake (due to the heterogeneities in the initial porosity and characteristics of the artificial hydration system), which gave place to immediate swelling that resulted irreversible, with permanent higher water contents and lower dry densities towards the floor and back of the gallery, particularly in the GBM. Despite these heterogeneities, the water contents and dry densities of the whole barrier (GBM and blocks) were much more homogeneous than at the beginning of the test and remained within a relatively narrow range. The bentonite degree of saturation was homogeneous and very close to 100% all through the barrier.

The feasibility and performance of this kind of initially heterogeneous barrier was proved in that it had an optimal sealing capacity and developed acceptable swelling pressures between 1.3 and 2.2 MPa.

1. Introduction

The backfilling and sealing of deposition galleries or holes and access galleries and shafts is an important part of nuclear waste underground repository design. Any opening created during the construction of the repository is a potential preferential pathway for water, gas and radionuclide migration, and has to be effectively sealed. Bentonite or bentonite-based mixtures have been proposed as backfill and sealing materials for their low permeability, high swelling capacity and high retention capacity. These materials have been widely characterised in the form of high-density pre-compacted blocks, and their performance under repository conditions has been also mainly assessed in large-scale experiments in which the barrier around the waste packages consisted of compacted blocks, such as the FEBEX mock-up and in situ tests (ENRESA, 2006; Villar et al., 2005, 2012) or the Prototype Repository (Börgesson et al., 2002).

The use of high-density bentonite pellets (combined or not with powdered bentonite) was also proposed long ago (Salo and Kukkola, 1989; Volckaert et al., 1996). A mixture of high-density bentonite pellets and bentonite powder was used in the large-scale demonstration experiment RESEAL, carried out in a vertical shaft under isothermal conditions at the Hades Underground Research Facility in Mol, Belgium (Volckaert et al., 2000; van Geet et al., 2009). Bentonite pellets were also proposed to backfill the slot between bentonite blocks and the host rock in deposition holes, such as in the Prototype Repository in situ experiment (Svensk Kärnbränslehantering AB, 2002). The advantage of this material is that it is easy to manufacture and instal: the bentonite pellets can be emplaced using auger discharge tubes or even

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pneumatic projection techniques. Thus, the backfilling operation becomes an easier and potentially robotised procedure. On the other hand, the problem of this emplacement technique is that the final values of the key parameters of the barrier (such as dry density and permeability), which depend on the initial characteristics of the backfill material, the emplacement technique used and the hydro-mechanical interaction between the backfill and the surrounding rock, have not been yet demonstrated (Mayor et al., 2005). Besides, in the case of horizontal placement a rigid support for the canister is needed, what can be achieved by a bentonite block bed on which the canister is laid, and this must be used in combination with the pellets' backfill. Although the hydro-mechanical characterisation of pellets performed in laboratories has shown that their saturated permeability and swelling pressure are mainly controlled by the overall dry density of the sample rather than the initial grain size distribution, and are thus similar to those of bentonite blocks of the same dry density (Imbert and Villar, 2006; Hoffmann, 2005; Alonso et al., 2010), the combined use of pellets and blocks in the same section of the barrier introduces difficulties in the understanding and modelling of the system performance that have to be addressed.

The Engineered Barrier Emplacement Experiment in Opalinus Clay, "EB" Experiment, aimed the demonstration of a new concept for the construction of nuclear waste repositories in competent clay formations using horizontal deposition drifts (Mayor et al., 2005). The principle of the new construction method was based on the combined use of a lower bed made of highly compacted bentonite blocks in which the waste canister rested and an upper buffer made of granular bentonite material, consisting of a mixture of different-sized bentonite pellets. To asses that this backfilling technique was feasible, it had to be first demonstrated that the final values of the key parameters of the clay buffer that may be achieved with this method, such as dry density, swelling pressure and permeability, were suitable within the limits considered in the Performance Assessment of the repository concept, and this was precisely the objective of the EB experiment. This paper presents a brief description of the configuration of the test and its operation, and focuses on the observations made and results obtained concerning the state of the bentonite barrier upon its dismantling after reaching full saturation.

2. The EB experiment: configuration and operation

The full-scale Engineered Barrier Emplacement Experiment (EB) was carried out in a horizontal tunnel specially excavated with a road header in the Opalinus clay formation at the Mont Terri Underground Research Laboratory (URL) in Switzerland. The EB tunnel was 15 m long and had a geometry of a horseshoe section, 2.55 m high and 3 m wide (Fig. 1). A dummy canister, with the same dimensions and weight as the Spanish reference canister (ENRESA, 1995), was placed on top of a pedestal of highly compacted bentonite blocks which lay over a concrete bed. The remaining volume of the drift was backfilled with a granular material made of highly compacted bentonite pellets (GBM). Finally, the drift was sealed with a mass-type concrete plug, with a concrete retaining wall between the plug and the GBM. Due to the short amount of free water available in this formation, an artificial hydration system consisting of a series of porous tubes that crossed along the GBM and the bentonite blocks was installed to accelerate the hydration process in the bentonite (Fig. 2). The hydration tubes were connected in such a way that the water went into the material from the front to the back and from the floor to the roof of the gallery. To enhance the water homogeneous distribution, the concrete bed, the surface of the container and the three rings of the bentonite blocks bed were covered

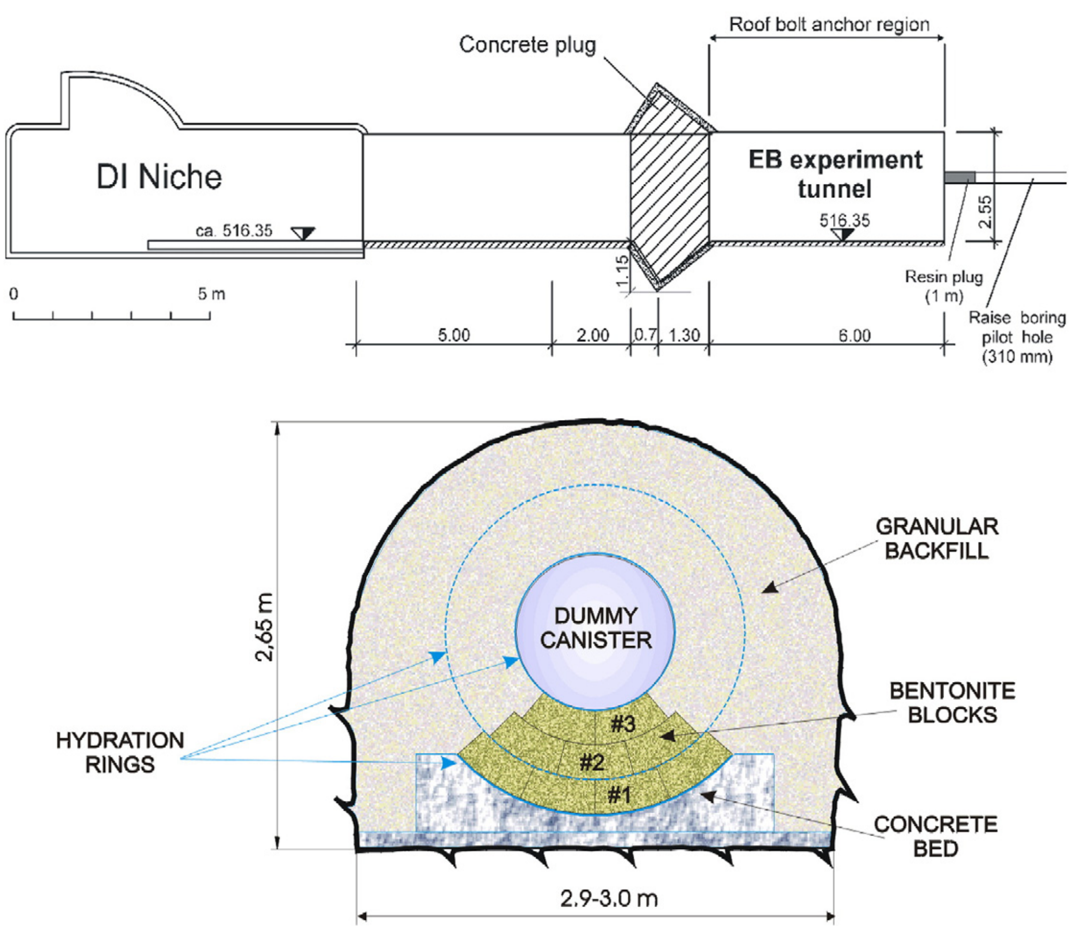

Fig. 1. EB drift at Mont Terri URL, longitudinal and cross sections (Mayor et al., 2005).