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Hydro-mechanical analysis of SEALEX in-situ tests — Impact of technological gaps on long term performance of repository seals

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ABSTRACT

The paper describes the observations and numerical analysis of the first SEALEX performance test PT-N1 installed in Tournemire Underground Research Laboratory (URL). The aim of this large-scale in-situ test is to investigate the impact of technological gaps on the long term performance of bentonite based seals. The swelling core consists of pre-compacted blocks of MX80 bentonite/sand mixture (70/30 in dry mass). An annular technological gap with variable width exists between the bentonite-based core and the host rock. The test is extensively instrumented for monitoring the main Hydro-Mechanical (HM) variables. Material parameters are determined from an extensive laboratory program carried out in the context of SEALEX project. To ensure an adequate interpretation of the test, the annular technological gap has been appropriately represented. A coupled HM formulation that incorporates the relevant processes involved in the problem under consideration has been adopted to analyse the evolution of the test. The paper presents and discusses the hydraulic and mechanical observations in the bentonite based core. Special attention is paid to the effect of technological gap on bentonite homogenisation as hydration progresses. The model was able to predict correctly the global HM behaviour of the bentonite based core considering the uncertainties and heterogeneities associated to the fabrication and installation processes of the bentonite based blocks. Technological gap was demonstrated to have an impact on dry density distribution.

1. Introduction

Deep argillaceous rocks are considered in several industrial countries as potential repositories for high-level and intermediate-level long lived (HL-ILLL) radioactive waste. The confinement of the wastes is based on the multi-barrier concept consisting of the natural barrier (host rock) and engineered barriers which comprise the waste container, the buffer and the sealing elements.

Highly compacted bentonite is often considered as sealing materials due to their low permeability, high radionuclide retardation capacity and high swelling ability (Pusch, 1979; Yong et al., 1986; Villar, 2008). Under geological disposal conditions bentonite will progressively hydrate and swell filling up the existing technological gaps. Various laboratory and in-situ experiments were conducted in the past to characterise the Hydro-Mechanical (HM) behaviour of these materials (e.g. Delage et al., 1998; Volckaert et al., 2000; Börgesson et al., 2001; Lloret et al., 2003; Mayor et al., 2005; Romero et al., 2005; Imbert and Villar, 2006; Martino et al., 2006; Lloret et al., 2007; Barnichon and Deleruyelle, 2009; Van Geet et al., 2009; Gens et al., 2011; and Villar et al., 2012). However, little attention has been paid to the role and influence of technological gaps on the HM properties of the sealing materials during the saturation phase and especially on the degree of homogeneity of the bentonite based core at the end of the transient period. Still, the existence of technological gaps is generally neglected in numerical modelling and perfect contact is assumed between the different components of the sealing system.

Recently, the French Institute for Radiation Protection and Nuclear Safety (IRSN) has defined a R&D programme to allow IRSN to give an expert advice on the overall questions related to the safety of a geological disposal. Part of this programme focuses on the efficiency of engineered barriers made up of compacted swelling clays (cell seals, gallery seals, shaft seals) for which two main questions arise:

(1) Will sealing systems effectively limit potential water fluxes?
(2) What are the key mechanisms and parameters that govern the performance of sealing systems at an industrial scale under normal conditions, and what is the effect of some altered conditions on these performances?

To answer these questions, a series of large-scale in-situ SEALing EXperiments (SEALEX) was designed and implemented by IRSN to assess the performance of sealing systems under long-term representative conditions (isothermal and water-saturated). The in-situ experiments

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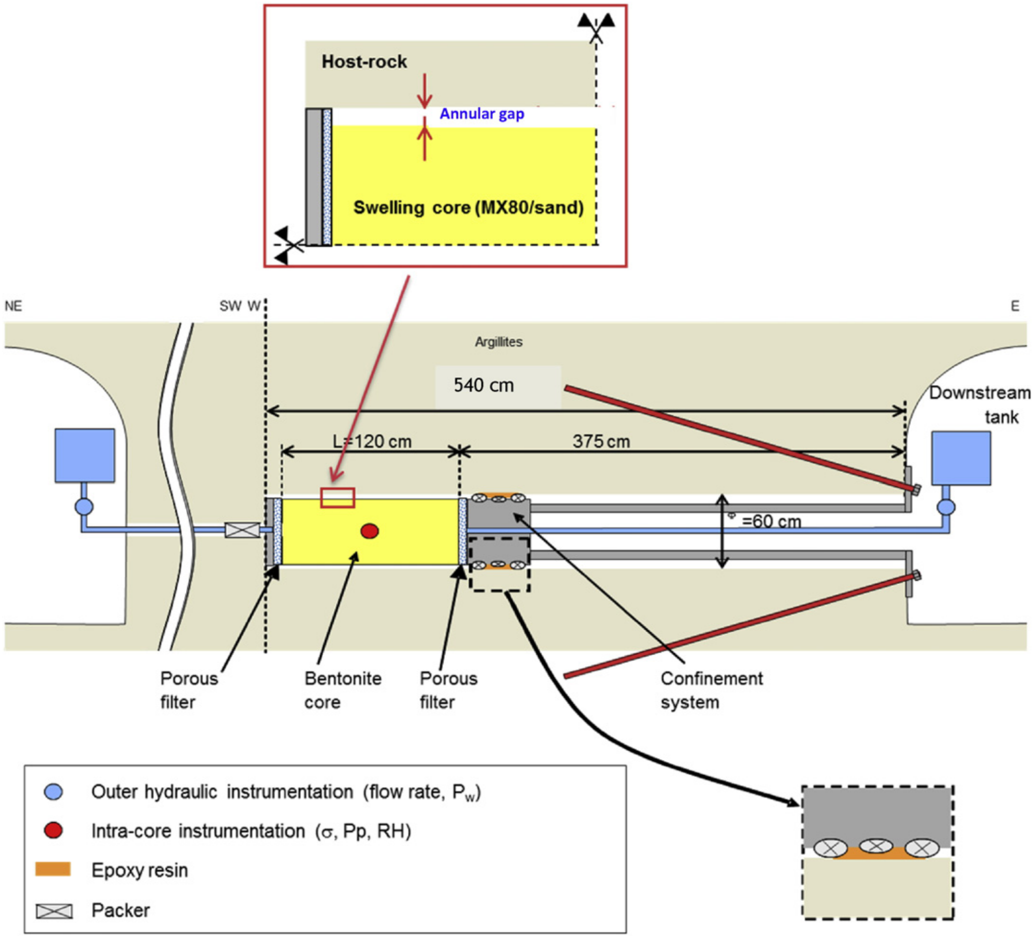

Fig. 1. Layout of SEALEX in-situ tests.

aim to (i) quantify the impact of intra core geometry (technological gaps) on the hydraulic properties of sealing systems, (ii) test the long-term hydraulic performance of sealing systems in normal conditions for different clay core compositions (pure bentonite or bentonite/sand mixtures) and conditionings (pre-compacted blocks or in-situ compacted), and (iii) investigate the concept of robustness by considering altered scenarios, such as an incidental decrease of the swelling pressure (for instance originating from the failure of the confining plugs). Six SEALEX in-situ tests were installed at Tournemire Underground Research Laboratory (URL). Each test allows exploring conditions that may impact the long-term performance of the seal by changing a single parameter at a time (core composition, conditioning, geometry…). The installation phase was undertaken from December 2010 to October 2013 and all tests are still currently ongoing. Each experiment consists of three operational phases: flooding, hydration and hydraulic testing phases. When saturation and equilibration of the core are reached a first hydraulic testing phase will be carried out to quantify the overall system permeability (e.g. pulse tests, steady-state test). For two SEALEX in-situ tests, an additional phase will be performed to simulate an incidental decrease of the swelling pressure. After the steady state is reached, a second hydraulic testing phase will be carried out. During the operational phases of the tests, the injected volume of water, total pressure at radial and axial directions, pore water pressure and relative humidity changes have been monitored at several positions within the seal.

The present paper describes the installation, performance, analysis and interpretation of SEALEX in-situ test, PT-N1 considered as a base case test itself, with a core composed of compacted mixture with 70% bentonite and 30% sand in dry mass. In such layout, an annular technological gap exists between the bentonite based core and the surrounding host-rock. This gap with variable thickness is explicitly taken into account in the numerical modelling.

A coupled numerical analysis based on a formulation that incorporates the relevant HM phenomena has been used to interpret and describe the behaviour of the bentonite based seal. A key feature in the simulation lies in the appropriate modelling of the bentonite–sand mixture hydro-mechanical behaviour. The determination of the model parameters used in the analysis has been based on an extensive campaign of laboratory tests carried out in the framework of SEALEX project (Wang et al., 2013a,b,c). A fundamental issue in modelling lies in properly representing the air-filled gap. Yet, the necessity to incorporate the effect of the gap with variable thickness forces the development of a model in 3-D.

In the first part of the paper, the construction and the main features of this test are presented. After that, the coupled HM formulation used in the analysis is briefly outlined. Material parameters are then described. The final part of the paper is devoted to the comparison and interpretation of predictions and experimental data obtained during the hydration stages. The analysis particularly focuses on the impact of the technological gap on bentonite-based core homogenization, thus, on the bentonite dry density distribution over the cross section of the test.

2. Description of SEALEX in-situ test, PT-N1

2.1. Testing geometry and operations

PT-N1 is the first of three SEALEX in-situ performance tests that have been designed to investigate the impact of intra core geometry