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SELFRAC: Experiments and conclusions on fracturing, self-healing and self-sealing processes in clays

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Abstract

In assessing the performance of a deep HLW repository, the evolution of the excavated damaged zone with time is a key issue. In the framework of SELFRAC fracturing, self-sealing and self-healing processes of Opalinus and Boom clay were studied in laboratory and in situ experiments. Definitions for the terms excavation damaged zone (EDZ), excavation disturbed zone (EdZ), sealing and healing are presented. It is shown that sealing and partial healing occur and the consequences of the results for performance assessment of HLW disposal in argillaceous rocks are discussed.

The results of several in situ experiments and observations at the HADES underground research facility are detailed. The origin and extent of excavation induced fractures are discussed and sealing and (partial) healing of these fractures is demonstrated. In the description of the hydraulic features of the EdZ, the anisotropic pore pressure distribution around HADES and its evolution with time are discussed. Pore pressure is influenced several tens of metres into the host rock and its evolution is influenced by the anisotropic in situ stress state and the anisotropic hydraulic conductivity of Boom clay. Around the connecting gallery, an increase of hydraulic conductivity is measured up to about 6–8 m into the host rock, outside this influenced zone values between 4×10^{-12} m/s and 6×10^{-12} m/s were obtained. The highest value measured (close to the gallery) was of the order of magnitude of 10^{-11} m/s. The observed increase is caused by lower effective stress levels close to the gallery rather than by excavation induced fractures.

Self-boring pressuremeter tests show that total stress is influenced up to 6–8 m into the host rock and material parameters such as undrained shear strength and shear modulus are influenced up to 2–3 m into the host rock. In situ seismic transmission measurements showed that the closure of a borehole influences the seismic parameters of the surrounding host rock: a decrease in seismic velocity is measured and higher frequencies disappear from the transmitted signals. After closure of the borehole, sealing of the damaged zone around it occurs, this is observed by the recovery of seismic velocity and the reappearance of higher frequencies. Fracture sealing is also demonstrated by seismic and hydraulic measurements on a reinstalled fractured clay core.

Keywords: EDZ (excavation damaged zone); Self-healing; Self-sealing; Clays; Hydraulic conductivity; In situ experiments

1. Introduction

Radioactive waste must be managed and disposed of in ways that ensure the protection of people and environment, now and in the future. In assessing the performance of a deep HLW repository, the evaluation of long-term disturbances in the surrounding rock mass induced by the construction and the operation of a waste repository is essential. A key issue in this field is the evolution of the excavated damaged zone (EDZ) with time, since its presence could result in altered transport characteristics of the host rock adjacent to the galleries. This was precisely the goal of the SELFRAC project: characterising the EDZ and assessing its influence and its evolution with time.

The present paper primarily deals with the in situ experiments conducted at the underground research facility

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HADES (Mol, Belgium) in the framework of the SELFRAC project. First, Section 2 describes the overall framework and work program of the SELFRAC project and gives some definitions. Observations and measurements performed in HADES are described and discussed in Sections 3–7. Besides the detailed conclusions of the work in the HADES URF, Section 8 also describes the general conclusions of the SELFRAC project as a whole, including the link with performance assessment. Further, some examples of experimental results obtained by other institutes are presented. For more information about the totality of SELFRAC experiments, the reader is referred to the final project report (Bernier et al., in press). Moreover, several publications give more information about experiments performed within the SELFRAC project, e.g. Coll (2005) and Blümling et al. (in press).

2. The SELFRAC project

2.1. Framework

The SELFRAC project was co-funded by the EC within the fifth framework programme, key action Nuclear Fission and ran from December 2001 until November 2004. SELFRAC covered two topics: the origin of fractures on the one hand and the occurrence of self-healing and self-sealing processes on the other. The main objective was to better understand and quantify these processes and to assess their impact on the performance of radioactive waste disposal sites. Two argillaceous rocks were investigated: the Opalinus clay of Mont Terri (Switzerland) and the Boom clay of HADES (Belgium). The SELFRAC project was coordinated by the EIG EURIDICE (European Underground Research Infrastructure for Disposal of radioactive waste In a Clay Environment, BE). The other partners were NAGRA (National Cooperative for the Disposal of Radioactive Waste, CH), L3S (Laboratoire Sols, Solides, Structures, FR), G3S (Groupement Structures Souterraines de Stockage, FR), KUL (Katholieke Universiteit Leuven, BE), EPFL (Ecole Polytechnique Fédérale de Lausanne, CH) and SOLEXPERTS (CH).

2.2. Terminology

Early in the project it became clear that one of the tasks to be performed was defining a clear terminology since no international consensus existed. A distinction was made between the excavation damaged zone (EDZ) and the excavation disturbed zone (EdZ):

- *EDZ*: the zone with hydro-mechanical and geochemical modifications inducing significant changes in flow and transport properties. These changes can, for example, include one or more orders of magnitude increase in flow permeability.
- *EdZ*: the zone with hydro-mechanical and geochemical modifications, without major changes in flow and transport properties.

The proposed definitions are site and host rock independent and should be detailed for each type of rock and each site. For instance, it should be quantified what the terms "significant" and "major" mean for each particular site (Davies and Bernier, 2005). For the Belgian reference case (Boom clay), we consider that a hydraulic conductivity increase by less than a factor ten is not significant or major.

The terms EDZ and EdZ remain very general; many types of damage or disturbance can occur which do not necessarily have the same extent. In fact, the extent of the EDZ and EdZ depend largely on the parameter under consideration.

The definitions of healing and sealing are clearer and are probably less controversial. Thus, we may define them as follows:

- Sealing is the reduction of fracture permeability by any hydromechanical, hydrochemical, or hydrobiochemical processes.
- Healing is sealing with loss of memory of the pre-healing state. Thus, for example, a healed fracture will not be a preferred site for new fracturing just because of its history.

2.3. Work program

At the start of the SELFRAC project, a report on the state of the art on fracturing and self-healing processes and the characterisation of these processes was drawn up (Coll et al., 2004). It gives an overview of the background information on the existing theoretical and experimental studies (laboratory and in situ) in this field.

The experimental research performed in SELFRAC comprised both laboratory and in situ experiments, as well as numerical modelling. Fracturing, self-healing and self-sealing processes were studied on both clays by means of hydromechanical tests, flow properties, acoustic measurements and constitutive modelling. In situ experiments were performed both at Mont Terri (Switzerland) and at HADES (Belgium).

3. HADES underground research facility (URF)

Studies of the disposal of HLW in Belgium focus on the Boom clay, a tertiary clay formation which is present under the Mol–Dessel nuclear site between 190 m and 290 m depth. Some characteristic properties are given in Table 1 (Mertens et al., 2004). The underground research facility HADES (high-activity disposal experimental site) was constructed at a depth of 223 m. The first construction phase started in 1980 and since then HADES has been expanded several times; Fig. 1 shows the construction history