Fracturation and Self-Healing Processes in Clays
-The SELFRAC Project-

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Summary

Radioactive waste must be managed and disposed off in ways that ensure the protection of people and the environment, now and in the future. In this sense, the long term prediction of disturbances in the surrounding rock mass induced by the construction and the operation of a waste repository is essential to assure a maximal protection of the environment and the people for both current and future generations against the soil contamination and a radionuclide release. Indeed, the evaluation of the evolution of the Excavated Damaged Zone (EDZ) with time is particularly important since its presence may result in changes to the transport characteristics of the rock mass adjacent to underground openings. The SELFRAC project aims to properly characterise the EDZ and its evolution with time. The main objective of the project is to understand and to quantify these processes and to assess their impact on the performance of radioactive waste geological repositories. Two different potential geological formations for deep radioactive waste repositories are studied: the Opalinus Clay of Mont Terri (Switzerland) and the Boom Clay (HADES, Belgium). First results are clearly demonstrating the sealing capacities of both clays leading to the decrease of the hydraulic transmissivity along the fractures.

1. Introduction

As in all nuclear power generating countries, high level and long lived radioactive waste management is an important environmental issue today. Disposal in a deep clay formation is one of the promising options to dispose these wastes. An essential item for the long-term safety of High Level Waste underground repositories is the proper evaluation of the Damaged Zone created in the walls of the openings during their excavation, the so-called Excavation Damaged Zone and of the evolution with time of both mechanical and transport properties in this zone. The perturbation of the excavation may lead to a significant increase of the permeability, which is related to diffuse and/or localised crack proliferation in the material. Fortunately, an opposite process, which involves the self-sealing properties of clays, can in turn reduce the permeability in time. The main objective of SELFRAC is to understand and to quantify these processes through a major theoretical and experimental research programme. Two types of clays are being studied: the Opalinus Clay of Mont Terri, Switzerland and the Boom Clay, Belgium. Another task of the project is to assess the potential impact of the Excavation Damaged Zone on the long-term performance of a nuclear waste repository.

This paper presents the preliminary results of the work performed within the European Commission project: SELFRAC, between December 2001 and November 2003. The SELFRAC project is coordinated by the EIG EURIDICE (European Underground Research Infrastructure for Disposal of

radioactive waste In a Clay Environment). The other partners are NAGRA (National Cooperative for the Disposal of Radioactive Waste), L3S (Laboratoire Sols, Solides, Structures), G3S (Groupement Structures Souterraines de Stockage), KUL (Katholieke Universiteit Leuven), EPFL (Ecole Polytechnique Fédérale de Lausanne) and SOLEXPERTS.

2. Methodology

A systematic approach is used for the development of the constitutive models on basis of laboratory tests. Once developed, the models should allow predicting the development of fractures around excavations and the possible sealing and healing processes. So the transport of radionuclide in the host rock will be better assessed. In-situ tests are also performed, in order to characterise the EDZ and its evolution in time and to compare the in-situ results with numerical simulations. The SELFRAC project studies also the long-term performance of the EDZ (Excavation Damaged Zone). This will lead to recommendations on excavation techniques and design of repositories. The SELFRAC project can therefore be considered as a key issue to improve constitutive models designed to carry out a safety assessment and to increase public confidence in long-term predictions of the behaviour of a deep nuclear waste repository.

3. Results

The first part of the project was devoted to an overview of the background information on the existing theoretical and experimental studies. The review has shown that up to now there is no established theory to describe the EDZ and its evolution with time. The SELFRAC consortium has therefore proposed new definitions for terms as [1]:
Excavation damaged zone is the zone experiencing a modification of the state and material parameters, which might have a negative effect in terms of safety assessment, due to the construction, the operation, the closure of a repository and the post-closure phase. The EDZ abbreviation is associated to this zone.
Excavation disturbed zone is the zone experiencing a modification of the state due to the construction, the operation, the closure of a repository and the post-closure phase. The damaged zone is a part of the disturbed zone. The disturbed zone without the damaged zone has no negative effect in terms of safety assessment..
Sealing is a process improving or restoring the hydraulic transmissivity of the host rock by closure of newly formed or re-activated discontinuities. The process can involve hydraulic and mechanical changes, but no structural change between both sides of the discontinuities.
Healing is a process improving or restoring the hydraulic and mechanical properties of the rock mass by a structural change between both sides of the newly formed or re-activated discontinuities. The process can involve hydraulic, mechanical, chemical and mineralogical changes.
The above definitions were given in the context of underground radioactive waste disposal and are site and model independant.

Triaxial and biaxial tests have been realised to understand and quantify the fracturing process and the increase of permeability related to crack proliferation around excavations. The results of these tests have allowed establishing the sets of parameters for the numerical simulation.

Other tests are currently conducted to characterise the sealing and healing processes by monitoring the evolution of the flow properties along a fracture created artificially. Results of these tests show that for Boom Clay sealing occurs very quickly after saturation of the fracture. During sealing the permeability decreases to a value close to that of intact Boom Clay (about 4.10-12 m/s). Microfocus X-ray computer tomography has been used to visualise the sealing of the fracture (see Fig. 1a and

Fig. 1b). This is a recent technique allowing non-destructive inspection of non-transparent objects [2]. Results on Opalinus Clay are not yet available.

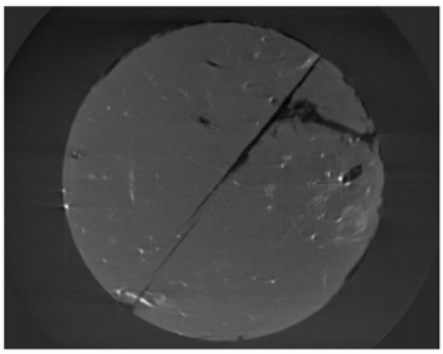

Figure 1a: Initial fracture within the sample

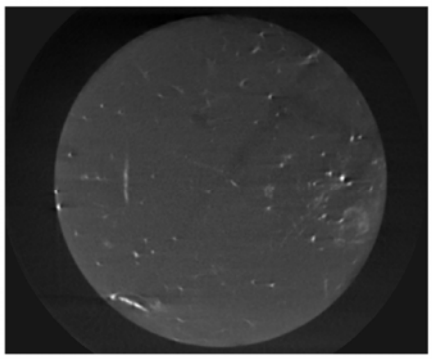

Figure 1b: Sealing after saturation of the fracture

Healing of clay is also investigated by means of the acoustic emission signals generated when loading a rock sample. A hypothesis on the relation between the healing of micro-cracks and the acoustic emission detected is investigated. In laboratory conditions, micro-cracks are induced during a first loading and the effect of short time intervals on possible healing is studied by loading the sample again –after different periods of time- and looking at the threshold load for acoustic emission events. First tests indicate that micro-cracks start growing at a lower load than that of the first loading cycle, which might be an indication for healing. Further fundamental research is needed to better understand the fracturing and healing mechanisms in clay. This study shows that acoustic emission gives additional information to the better understanding of the mechanisms involved, next to porosity and permeability measurements [3].

The first in-situ test conducted at Mt Terri in Opalinus Clay is now achieved. The main objective of this test is to study the influence of bentonite swelling pressure on the transmissivity in the EDZ. During various steps of a long term load plate test permeability measurements were performed in order to investigate mechanical-hydraulic effects (see photo 1). The assumed sealing effect/process combined with a significant reduction in transmissivity (nearly two order of magnitude with respect to the original within the EDZ) has been proved with the performed pressure load test [4, 5].

Photo 1: Complete test setup of the load plate experiment [4, 5]

One of the in-situ tests conducted at Mol in Boom Clay consists of the study of the long term evolution of the damaged zone along a gallery excavated in Boom Clay. The tests consisted in two vertical piezometers installed in vertical configuration equipped with large filters in order to detect possible preferential pathway along the gallery. No preferential pathway between the piezometers have been observed.

From other piezometer measurements around the gallery, we have observed a reduction of the extent of the EDZ with time. It has been shown that the open fractures close progressively. One and a half year after the excavation of the gallery the extent of open fractures do not extend beyond a zone of about 0.6 m around the gallery.

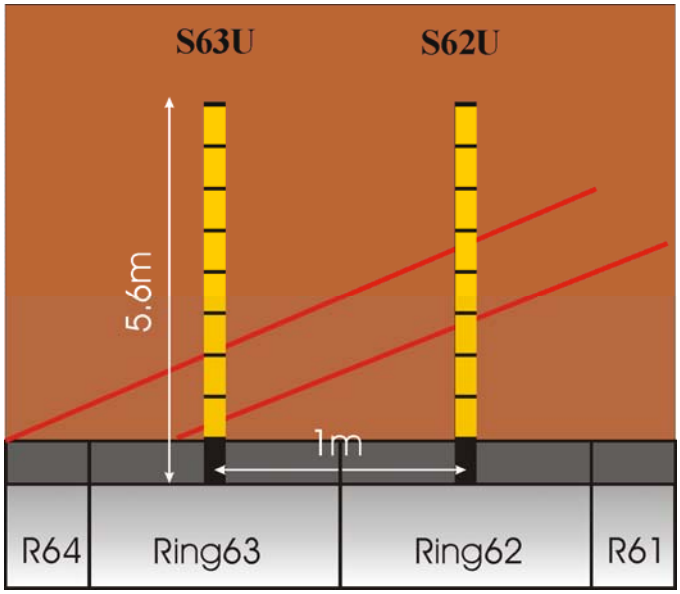

Fig. 2: Test set-up (two parallel multi-piezometers) to investigate the evolution of the EDZ around the connecting gallery in the HADES underground laboratory

An important issue of the SELFRAC project was also the organisation together with the EC of the International Conference held in Luxembourg on 3-5 November 2003 on “Impact of the Excavation Disturbed or Damaged Zone (EDZ) on the Performance of Radioactive Waste Geological Repositories”. The discussions during the Working Group Sessions have allowed to give a clear state of the art of the topic and answers to the impact of EDZ on performance/safety of a repository. The input of the SELFRAC project for the conference was very helpful. The proceedings will be published by the EC in 2004.

4. Discussions

The preliminary results are clearly showing the sealing capacities of both Boom Clay and Opalinus Clay. Fractures induced by the excavation close up during consolidation. Swelling and creep can be contributory factors. A load applied to the tunnel wall can favour and accelerate this process. The fractures remain present but the hydraulic conductivity in the near field is reduced along the fracture. In case of Boom Clay, healing is sometimes observed through a partial recovering of the cohesion along the fracture.

5. Conclusions and future work

The impact of the EDZ on the performance of radioactive waste geological repositories is an important issue. The first experimental results of the SELFRAC project clearly show the sealing capacities of both Boom Clay and Opalinus Clay. Consolidation, swelling and creep are the main mechanisms leading to the sealing of the fractures. It has been shown that the sealing process of the fractures present in the EDZ, lead to a decrease of the hydraulic conductivity in the near field.

The last year of the project will be mainly devoted to in-situ tests and modelling. Numerical models are developed to simulate fracturing, healing and sealing processes both for plastic and indurated clay. For this purpose a set of constitutive models are developed in the framework of hypoplasticity, which are especially well adapted to predict strain localisation. Shear band analysis allows predicting the onset of strain localisation as a bifurcation phenomenon, and the orientation of the shear band that develops at this time.

6. Acknowledgements

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