

# **CHAPTER 1**

## **INTRODUCTION**

### 1.1 MOTIVATION AND OBJECTIVES

It is well known the big and complex problem that waste, coming from industrial activity, is generating in our society. Within the different types of waste, nuclear waste is, probably, the most difficult to deal with due to the large time of activity and its extremely hazardous consequences on life and environment. In the last decades, interest in handling, recycling, storing, etc., nuclear waste is arising and therefore, national agencies, universities and private companies from all over the World are involved in this difficult task.

The Department of Geotechnical Engineering and Geosciences of the Technical University of Catalonia (UPC throughout the thesis) closely collaborates with ENRESA (Spanish Radioactive Waste Agency) in a number of projects dealing with the safe storage of nuclear waste in engineered barriers. ENRESA also cooperates with other national waste management agencies (ANDRA, NAGRA or SKB, for instance). Within one of these cooperation projects between ENRESA and SKB (Swedish Radioactive Waste Agency), the Department of Geotechnical Engineering and Geosciences is involved in the Project named *Backfill and Plug Test*. This project is being carried out at the full-scale laboratory of Äspö Hard Rock Laboratory placed at the Swedish Island of Äspö. This project pretends to characterise technology and procedures for backfilling tunnels, to characterise different materials to seal the accessing galleries in a future deep repository for nuclear waste and to investigate the interaction between the host rock and backfill used to seal the galleries. In order to study all these aspects, a gallery (ZEDEX gallery) was excavated by careful blasting and backfilled with two different soils.

An artificial soil, obtained by mixing MX-80 sodium bentonite and crushed granite, was used to seal part of the gallery and determine its in situ hydraulic behaviour. After an experimental campaign varying the bentonite content of the mixture (0, 10, 20 and 30%), it was determined that 30% of bentonite content fulfilled all the requirements for the sealing mixture (Börgesson et al. 1996 and Johannesson et al. 1999). Therefore, 30% of bentonite content assures low permeability and diffusion, medium swelling capacity and high content of crushed granite with the aim of recycling the material coming from the excavation of the galleries. The thesis mainly deals with the study of the hydraulic behaviour of this bentonite – crushed granite rock mixture. The other material used to seal the gallery was crushed granite rock without bentonite. Free-bentonite backfill is very permeable and it is called *drainage material*.

Collaboration of the Department of Geotechnical Engineering and Geosciences on the Backfill and Plug Test Project through this thesis and the additional work to be performed in the future, focuses on the three main following aspects:

- Development and calibration of a new mini-piezometer in collaboration with AITEMIN (AITEMIN, 1999). Constant and variable head tests (injection or withdrawal) can be performed with this new mini-piezometer in compacted clayey soils. Local saturated backfill hydraulic conductivity can be determined with this equipment after the mathematical study of the dissipation processes.

- To carry out an experimental characterisation of backfill hydro-mechanical behaviour by means of oedometer tests, compaction tests, water uptake tests and determination of osmotic suction. Influence of pore water salinity on the hydro-mechanical backfill behaviour was also investigated.
- Numerical simulations with a finite element simulator of the saturation process of backfill compacted in situ in the ZEDEX gallery and simulation of global flow tests in the gallery after full saturation. A conceptual model, which takes into account the effect of salinity on backfill hydraulic conductivity and ion exchange reaction between  $\text{Na}^+$  and  $\text{Ca}^{2+}$ , was presented.

## 1.2 LAYOUT OF THE THESIS

The organization of this thesis has been strongly dependent on the evolution of the Backfill and Plug Test Project carried out at the Äspö Hard Rock Laboratory. This can be easily noticed throughout the document. Some difficulties appeared when compiling in a document all the work performed within the Project. It is clear that the threads of this thesis are the Backfill and Plug Test Project (BPTP) and backfill hydraulic conductivity. However, this thesis is neither an experimental thesis nor a numerical thesis but experimental work and numerical simulations by means of the finite element method were performed. As a result of the different work carried out at several stages of the Project, the chapters of this thesis are self-contained, clearly defined and independent.

Chapter 2 starts describing briefly the current SKB's concept for nuclear waste storage. Immediately, the Backfill and Plug Test Project is described in detail. A brief summary of the different stages of the project, installation process, objectives, instrumentation, evolution of some variables as injected water pressure or measured suction at psychrometers, etc., are provided. This chapter points out the difficulties and complications related to such an in situ test. As Backfill and Plug Test is mainly a full-scale flow test, hydraulic conductivity of the compacted material is the most studied property in the Project and the thesis.

Chapter 3 details the hydro-mechanical characterisation of the mixture considered for the Project after an experimental campaign carried out in the Laboratory of Soil Mechanics of the Department of Geotechnical Engineering and Geosciences. A summary of the tests performed in this backfill by Clay Technology AB (Sweden) and CIEMAT (Spain) is also provided. Mechanical strength of this mixture has not been studied because it is not relevant for the aims of the Project. Only change of volume was analysed by means of oedometer tests. Salt water effects on compaction, swelling pressure, compressibility and hydraulic conductivity of this mixture were extensively studied. Salt water effects on retention properties were investigated as well. Backfill osmotic suction had an important role in the Project as salt water is injected and the range of total suction is low in this problem ( $< 3$  MPa). In such conditions, osmotic suction becomes significant when compared with total suction and it cannot be assumed constant as usual in geotechnical engineering. Osmotic suction was computed from the concentration of salts in liquid phase by using the Van't Hoff law. It is important to find out the influence of salt water on backfill hydro-mechanical behaviour as aquifers at the Äspö area are connected to the Baltic Sea and average salt concentration in groundwater is 12 g/L.

It is fundamental to point out that experimental characterisation of this mixture is quite complicated because of the big size of the crushed granite particles (up to 20 mm). Usually, the experimental equipment available in a laboratory of soil mechanics is not suitable for such a big size of particles. This means that big samples are necessary to characterise the mixture

and to obtain representative results of its macroscopic behaviour. Moreover, bentonite content is high enough to assure low permeability and diffusion. Both facts, linked together, made long and complex any experimental flow test performed in this mixture.

Chapter 4 details the study of backfill local saturated hydraulic conductivity by means of constant head tests at different hydraulic gradients and injecting pulse tests with different boundary conditions performed with a new mini-piezometer. The aim of this chapter is to describe the calibration of the new mini-piezometer in laboratory. This new mini-piezometer was developed in close collaboration with AITEMIN and it is suitable to perform such tests in compacted clayey soils. The pulse tests performed in laboratory were mathematically analysed with three different approaches: by using an analytical solution provided by Gibson (1963), a semi-analytical method provided by Brand & Premchitt (1982) and finally, by means of a numerical finite element code assuming that Biot's theory was valid. Differences obtained by the three different approaches, when studying the results of the pulse tests, were discussed and pointed out. In this way, some numerical tools were developed in order to analyse the in situ pulse tests in the ZEDEX gallery.

AITEMIN installed thirteen mini-piezometers in the ZEDEX gallery in 1999. The objective was to create a map of local saturated hydraulic conductivity in different areas of the backfill. Some pulse tests were performed in late March 2003 in different devices. The pulse tests carried out in situ were analysed with the previously designed tools and a range of in situ local backfill permeability was provided. After the very first pulse tests performed at the Äspö HRL, some improvements to the original set up were introduced to increase the efficiency of the test. Moreover, the procedure of the injection pulse test in situ was defined. It is expected to perform more pulse tests after full backfill saturation throughout 2003 and 2004.

Chapter 5 is focused on the study of backfill saturation process at the ZEDEX gallery after compaction. Water uptake tests performed by Clay Technology AB from 1997 to 1999 are simulated and calibrated with a finite element simulator able to solve the reactive transport equations fully coupled with a thermo-hydro-mechanical formulation (Guimarães, 2002). The parameters used in such calculations are used to reproduce the backfill hydration process in the gallery. Backfill is actually being saturated with salt water containing 16 g/L of salts. Salt water effects on intrinsic permeability were taken into account by means of a phenomenological law obtained after oedometer tests. This model was implemented into the THMC finite element code, and it was used to compute intrinsic permeability when salt concentration in pore fluid changed by assuming a geochemical model of the mixture. The results of the simulations performed were successful and encouraging after assuming an intrinsic permeability law depending on concentration and variable osmotic suction.

A very simple geochemical model (ion exchange reaction between sodium and calcium) was used to study the reactive transport. As sodium bentonite is being hydrated with water containing calcium chloride, it is expected a transformation of sodium bentonite into a calcium bentonite. Importance of backfill molecular diffusion on the saturation process and reactive transport problem was also discussed after these calculations. It was clear the importance of determining the backfill molecular diffusion when studying the saturation phase and the post-saturated phase in an engineered barrier. Owing to the low backfill hydraulic conductivity, diffusion becomes an important transport mechanism.

Finally, chapter 6 contains the main conclusions drawn from the work carried out in this thesis as well as some proposals for future research.

### 1.3 REFERENCES

- AITEMIN, (1999). Äspö “Backfill and Plug Test Project”. Sistema de medida local de permeabilidad mediante ensayos de pulso. Desarrollo, puesta a punto e instalación. COD. ADJ. 703267. Technical Report. (In Spanish), Madrid, Spain.
- Börgesson, L., Johannesson, L.E. & Sandén, T. (1996). Backfill materials based on crushed rock. Geotechnical properties determined in laboratory. SKB Progress Report. **HRL-96-15**. Sweden.
- Brand, E.W. & Premchitt, J. (1982). Response characteristics of cylindrical piezometers. *Géotechnique*, **32** (3), p. 203-216.
- Gibson, R.E. (1963). An analysis of system flexibility and its effect on time lag in pore-water pressure measurements. *Géotechnique*, **13** (1), p. 1-9.
- Guimarães, L. (2002). *Análisis multi-componente no isoterma en medio poroso deformable no saturado*. PhD thesis, Universidad Politécnica de Cataluña, Barcelona, Spain. (In Spanish).
- Johannesson, L.E., Börgesson, L. & Sandén, T. (1999). Backfill materials based on crushed rock (part 2). Geotechnical properties determined in laboratory. ÄHRL International Progress Report **IPR-99-23**, SKB, Sweden.