Coupled THM analyses of nuclear waste barriers incorporating different model assumptions

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Introduction and background

Considerable progress has been made, in the past 25 years, in defining a scientific basis for the final disposition of radioactive waste. Notably, underground repository concepts under development in the EU put strong emphasis on the performance of the engineered barriers surrounding the hazardous materials, the so-called "near field", whose role in the overall disposal system is not only to fill the space between the waste canister and the host rock but also to delay the saturation of the surrounding rock, thus minimizing the possible release of radionuclides into groundwater.

The paper focuses on the long-term analysis of clay barriers studied in the context of the FEBEX (Full-scale Engineered Barriers Experiment) experiment at the Grimsel test site (Switzerland). The test aims at assessing the behaviour under natural conditions of the Engineered Barrier System (EBS) designed by the Spanish Agency for Radioactive Waste Disposal (ENRESA), which represents the Spanish concept for the isolation of high-level radioactive waste in crystalline rock. According to this idea, the canisters enclosing the waste are placed horizontally in drifts excavated into the granite and surrounded by a clay barrier made of highly-compacted bentonite blocks. In the experiment the nuclear waste is simulated by two cylindrical heaters so that the overall problem can be numerically handled in axial-symmetry. Heating is performed at a constant temperature of 100°C, while the bentonite buffer is slowly hydrated under natural conditions (Huertas et al., 2006; Sánchez et al., 2012a).

The study focuses, beyond the service life of the barrier, its state at two dismantling stages, a first one after 5 years and a final one after almost 18 years of prolonged heating and hydration.

Comprehensive laboratory tests carried out in the context of the project have already allowed the calibration of the finite element model CODE-BRIGHT (Olivella et al., 1994, 1996) adopted to describe the THM behavior of compacted expansive clays put in place as buffer material, and the good agreement obtained so far with the experimental results are a proof of a satisfactory understanding of the processes taking place in the EBS (Gens et al., 2009).

Numerical analyses

An Operational Base Case (OBC) was originally formulated (Huertas et al., 2006; Gens et al., 2009; Sánchez et al., 2012b) for the material parameters and for initial and boundary conditions, based on the experimental data collected at the beginning of the operational stage of the FEBEX experiment. Therefore the results obtained with this model correspond to actual predictions from the start of the test, when the experimental information was limited. In particular the performance of the model has shown to be quite satisfactory globally, in terms of evolution in time of the more relevant variables (temperature, liquid pressure, relative humidity, stress), however the model appears to overpredict the water saturation of the barrier in some sections of the experiment or underestimate the radial distribution of the degree of hydration (see Fig. 1a). In the OBC formulation the Barcelona Basic Model (BBM) is implemented (Alonso et al., 1990), as subsequently modified by Gens et al. (2009) to take into account the characteristic swelling. The retention curve follows a modified Van Genuchten model, for which the influence of the air entry pressure value P0 has been also considered in Fig. 1, as long as the overall retention curve is still consistent with the initial calibration.

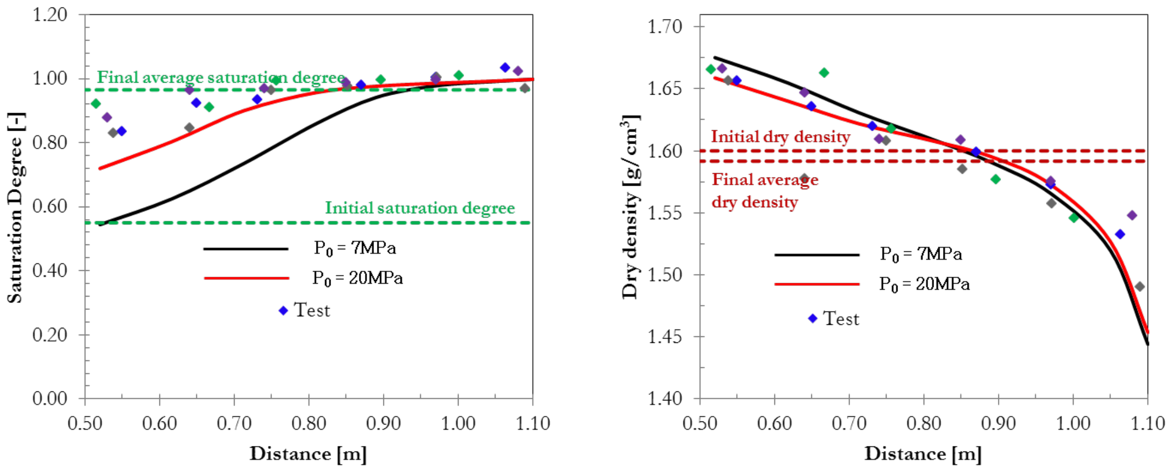

Fig. 1: Comparison between experimental and numerical results at final dismantling of FEBEX experiment at different air entry pressure values P0: a) degree of saturation; b) dry density

Future work

The behavior of the clay under FEBEX experiment conditions has been so far investigated in the OBC formulation. On the other hand, the possibility that the different scales of the porosity coexisting in the bentonite can affect its mechanical behavior, at the point that it most likely governs its swelling capabilities (Gens and Alonso, 1992; Lloret et al., 2003; Sánchez et al., 2005, 2008), is being analyzed in detail first on a mock-up test model, a reproduction of the in-situ test running at Grimsel, carried out at CIEMAT laboratories, Centre for Research on Energy, Environment and Technology in Madrid (Sánchez et al., 2012b) under controlled initial and boundary conditions, and secondary on the in-situ test model, possibly achieving an upgraded formulation with respect to the OBC model.

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References

Huertas F, Farina P, Farias J, Garcia-Sineriz JL, Villar MV, Fernandez AM, Martin PL, Elorza FJ, Gens A, Sánchez M, Lloret A, Samper J, Martınez MA (2006) Full-scale engineered barrier experiment, Updated Final Report, Technical Publication 05-0/2006. Madrid. ENRESA

Sánchez M, Gens A, Guinarães L (2012a) Thermal-hydraulic-mechanical (THM) behaviour of large-scale in situ heating experiment during cooling and dismantling. Canadian Geotechnical Journal 49:1169□1195

Olivella S, Carrera J, Gens A, Alonso EE (1994) Non-isothermal multiphase flow of brine and gas through saline media. Transport in porous media 15:271-293

Olivella S, Gens A, Carrera J, Alonso EE (1996) Numerical formulation for a simulator (CODE_BRIGHT) for the coupled analysis of saline media. Engineering Computations 13(7): 87-112

Gens A, Sánchez M, Guimarães L do N, Alonso EE, Lloret A, Olivella S, Villar MV, Huertas F (2009) A full-scale in situ heating test for high-level nuclear waste disposal: observations, analysis and interpretation. Géotechnique 59:377-399

Sánchez M, Gens A, Olivella S (2012b) THM Analysis of a large scale heating test incorporating material fabric changes. International Journal for Numerical and Analytical Methods in Geomechanics 36(4):391-421

Alonso EE, Gens A, Josa A (1990) A constitutive model for partially saturated soils. Géotechnique 40: 405-430

Gens A, Alonso E (1992) A framework for the behaviour of unsaturated expansive clays. Canadian Geotechnical Journal 29:1013-1032

Lloret A, Villar MV, Sánchez M, Gens A, Pintado X, Alonso EE (2003) Mechanical behaviour of heavily compacted bentonite under high suction changes. Géotechnique 53(1):27-40

Sánchez M, Gens A, Guimarães L, Olivella S (2005) A double structure generalized plasticity model for expansive materials. International Journal of Numerical and Analytical Methods in Geomechanics 29:751-787

Sánchez M, Gens A, Guimarães L, Olivella S (2008) Implementation algorithm of a generalised plasticity model for swelling clays. Computers and Geotechnics 35:860-871