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Numerical gas flow simulation performed to analyze advective gas flow in a compacted clay material

Babak S. Noghretab[1,*], Ivan P. Damians[1], Sebastia Olivella[1] and Antonio Gens[1]

[1] BarcelonaTech and International Centre for Numerical Methods in Engineering (CIMNE), UPC, Barcelona, Spain
* Corresponding author: babak.sayad.noghretab@upc.edu

Burial of nuclear waste in a clay formation can result in the generation of significant amount of hydrogen and other gases due to corrosion of metallic materials under anoxic conditions, radioactive decay of waste, and radiolysis of water. If the rate of gas production exceeds the rate of gas diffusion within the clay porewater, formation and accumulations of a discrete gas phase will occur until the gas pressure becomes large enough to surpass the surrounding material gas-entry pressure; at that critical point occurrence of dilating and advective gas flow is expected [1]. Precompacted bentonite is suggested as a sealing material for the isolation of boreholes, disposal galleries, and deposition holes in a deep geological disposal facility for radioactive waste. Both formation of new porosity and the spread of dilatant pathways have been related to the advective flow of gas in bentonite [2]. Understanding of the processes and mechanisms involved is a key aspect when evaluating the impact of gas flow on repository design and construction of any future facility. A series of gas injection tests on compacted bentonite were carried out at the British Geological Survey within DECOVALEX-2023 (D-23) Task B: MAGIC and LASGIT. The project focuses on the development of new numerical techniques for the quantitative prediction of gas flow in repository systems.

DECOVALEX-2023 Task B started with Modelling Advection of Gas In Clays (MAGIC). The planned approach of the task includes different stages, with an initial conceptual model development phase. In this work, the D-23 MAGIC has been studied based on the same methodology as previously applied in the work for DECOVALEX-2019 Task A - stage 1A (ENGINEER) using the same material properties and modelling strategy [3, 4]. Based on the actual dimensions of the sample, the 3D finite element model includes the geometry of the sample, the injection rod, the shape of the injection tip, the back pressure and the two filters associated to the location of the sensors. Hexahedral elements have been generated utilizing the CODE_BRIGHT software [5], and the random heterogeneity have been defined considering 3 different materials (M1-M2-M3). Layer-by-layer random permeability distribution was assumed (see Figure 1) applying 2/3–1/6–1/6 weighting for intrinsic permeabilities (k_i) equal to 1×10^{-21}, 1×10^{-20} and 1×10^{-19} m^2, for materials M1, M2 and M3, respectively, as well as incorporating different embedded fracture parameters.

LASGIT (LArge Scale Gas Injection Tests modelling) is a full-scale demonstration experiment operated by SKB at the Äspö Hard Rock Laboratory Hard Rock Laboratory at a depth of 420 m [6]. The 3D finite element model geometry is generated according to the real dimension of the test. Tests measurements included pressure and rate of gas inflow, gas outflow volume and pore pressure observed at various points of the sample. The gas test 1 of the LASGIT experiment is modeled in this study using a multiphase flow in porous media approach with the aim of facilitating the creation of favorable gas migration routes assuming permeability heterogeneity (Figure 1(b)), the same strategy as the MAGIC random permeability distribution outlined above. In this case, a coupled hydro-gas 3D FEM numerical model has been developed by the UPC/Andra research team to simulate the gas flow tests using the computer software CODE_BRIGHT, including initial permeability heterogeneity throughout the model. The numerical formulation also includes embedded fractures. The proposed model has been able to reproduce satisfactorily the observed behavior of the test measurements.

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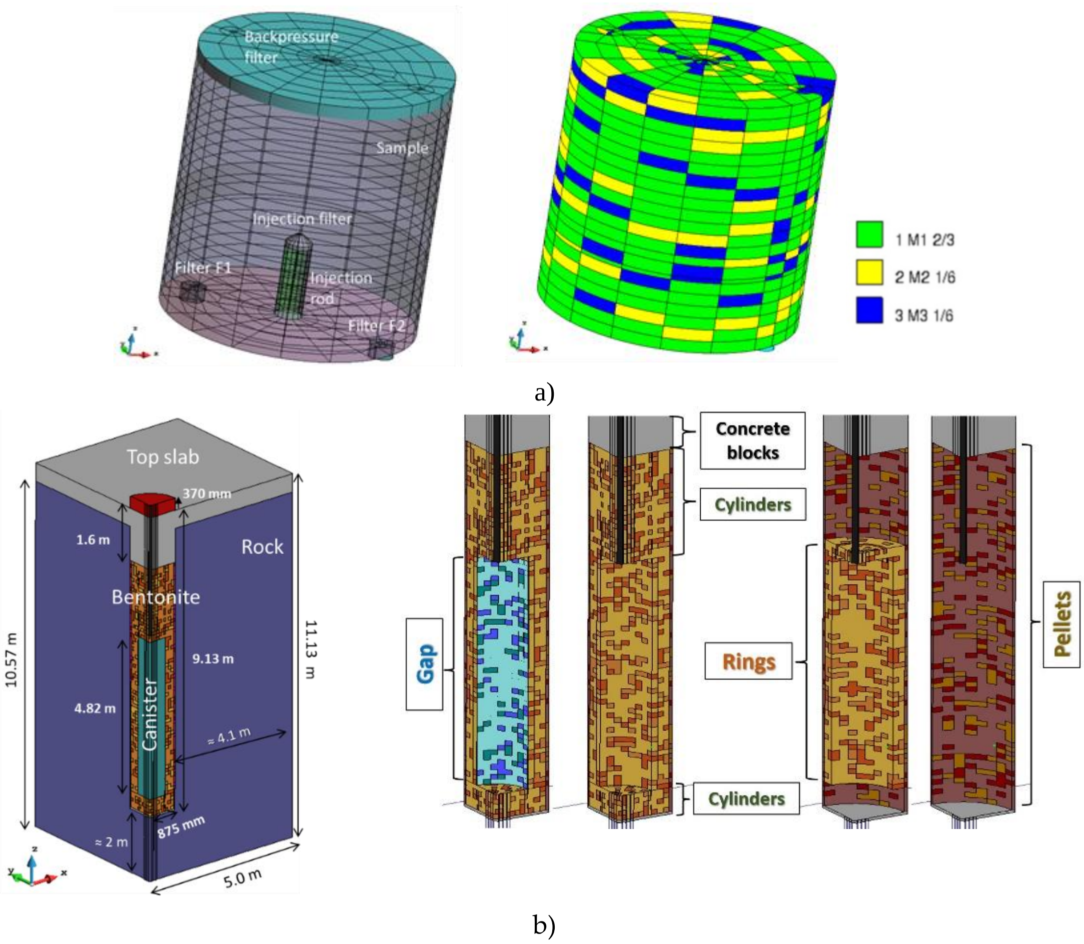

Figure 1: 3D FE model generated by CODE_BRIGHT according to the real geometry of the tests to be modelled: (a) MAGIC including the layer-by-layer random permeability distribution assuming 3 different materials (M1, M2 and M3), and (b) LASGIT showing the randomly-distributed permeabiliy heterogeneity assumed in different zones of the bentonite (cylinders and rings), pellets and gap.

Contributor statement

Conceptualisation, investigation, data curation and analysis, writing original draft, review, supervision and editing: all authors.

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