A Multi-Scale Model to Investigate Gas Migrations in Clay Materials

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Abstract

In the field of radioactive waste confinement, the question of gas transfers in clay formations is a crucial issue. A certain amount of gas, such as Hydrogen may indeed be generated during the exploitation phase in the nearfield of the repository by the deterioration of the metal components of the system. Since the host medium is characterised by a very low permeability, the mechanisms of gas transport by advection and diffusion within the groundwater remain insufficient to evacuate the gas generated in the nearfield and a free gas phase is formed. If the gas pressure keeps increasing and reaches the minimum principal stress acting on the rock, it seems plausible that micro-fractures, known as preferential gas pathways develop through the rock mass [1], which could affect the clay barrier integrity.

Since the gas transfers in an undisturbed confined medium appear to be governed by the rock structure at a micro-level, capturing the related transport mechanisms requires to go from macroscopic to microscopic scale. To avoid giant computation induced by the modelling of sizeable problems entirely at the microscale, a multi-scale approach is envisaged in the present work, and consists in inserting the microscopic constitutive laws at the macroscopic level (Figure 1a). This way, the model takes into account the complexity of the microstructure, i.e. pore network morphology and bedding planes, and the hydro-mechanical effect on the macroscopic gas flow. Practically, the physical and geometrical properties of the microstructure are embedded on a Representative Element Volume (REV), which allows to elude a complex description of the pore network on the entire domain. Based on the periodicity assumption of the microstructure and numerical homogenisation techniques [2], the response to loading can be derived at the macroscopic scale.

The multi-scale model proposed here is subsequently applied to the Boom Clay formation, a potential host rock for a deep geological disposal in Belgium. The size of the REV comes from experimental data acquired from tomography images, which give an estimation of the interdistance between the bedding planes. From these scans, it is then possible to extrapolate a conceptual scheme of the microstructure, built with one fracture corresponding to one bedding plane and the pore network substituted by an assembly of tubes. These microscopic constituents are defined in such a way as to satisfy the conditions of pore size distribution, macroporosity and intrinsic permeability. Each tube is treated as a linear elastic material and the fracture is described as an interface having a normal stiffness function of the aperture. Concerning the hydraulic aspects, a cubic law is used to compute the permeability from the hydraulic aperture of a single fracture or tube. To date, modelling efforts have focussed on purely hydraulic simulations of a soil column on the one hand and of a first gas injection experiment [3] on the other hand (Figure 1b).

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Figures

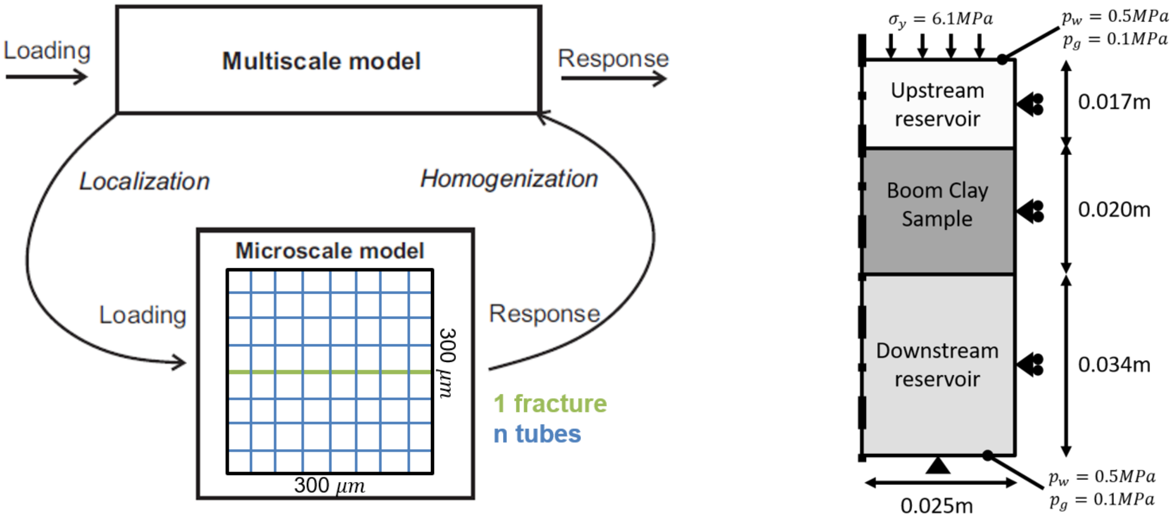

Figure 1: Multi-scale approach and geometry for numerical simulation.

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