Key parameters controlling thermo-hydro-mechanical pressurization in Callovo-Oxfordian claystone

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Introduction

The Callovo-Oxfordian claystone (COx) is considered as the potential host formation for the disposal of high activity radioactive waste (HWL) at great depth in France. The heat emitted from the waste provokes a pore pressure increase essentially due to the difference between the thermal expansion coefficient of the pore water and the solid skeleton and the low permeability of the COx, which prevents pore water diffusion. The main goal of the present paper is to investigate the role of different parameters on the induced pressure build-up.

The current concept of the HLW repository in France is based on the emplacement of waste packages in long parallel micro-tunnels. Regarding the periodic distribution of micro-tunnels and their lengths, the THM boundary conditions affect the response of the repository in a significant manner. Indeed, this architecture prevents lateral displacement, as well as heat and water flow between two parallel micro-tunnels. In contrary, the whole medium can expand quasi-freely in the vertical direction.

Thermo-hydromechanical pressurization

Pressure build-up due to a temperature increase is observed in many fine-grained geomaterials. Experimental investigations show that the amplitude of the induced overpressure can be related to that of the temperature change through a thermal pressurization coefficient Λ, when a constant mechanical load is applied on the sample. Λ is defined as the pore pressure increase due to a unit temperature increase in undrained condition. In undrained condition, the pore pressure (p) change due to a thermo-mechanical loading reads (Ghabezloo and Sulem, 2009):

$$\Delta p = B\Delta\sigma_m + \Lambda\Delta T$$

where B is the Skempton's coefficient and Λ the thermal pressurization coefficient, which read

$$B = \frac{\frac{1}{K}-\frac{1}{K_s}}{\phi_0\left(\frac{1}{K_f}-\frac{1}{K_s}\right)+\frac{1}{K}-\frac{1}{K_s}}, \text{ and } \Lambda = \frac{\phi_0(\alpha_f-\alpha)}{\phi_0\left(\frac{1}{K_f}-\frac{1}{K_s}\right)+\frac{1}{K}-\frac{1}{K_s}}$$

where K, K_s, K_f are respectively the bulk moduli of drained porous media, solid skeleton and fluid; α_f and α the thermal expansion coefficients of fluid and porous media; ϕ_0 the initial porosity; and σ_m the mean total stress.

When a rock mass is heated, the pore water increases in one hand due to the temperature increase, and in the other hand due to the total stress change. Thus, the mechanical boundary conditions may affect in a significant manner the amplitude of the induced overpressure through their effects on the amplitude of the induced thermo-mechanical stresses.

Sensitivity analysis

In the context of the French HLW repository, regarding the important number of similar parallel cells, the model geometry can be simplified thanks to the vertical symmetry. In what follows, a plane strain model is used to evaluate the THM response of the rock mass to temperature increase between two parallel HLW cells (Fig. 1). The considered model consists in a vertical cut that includes the half of a cell. The cut is perpendicular to the cell's axis at its middle length. The left side of the model passes at the cell centre, while the right side goes over the mean distance between two cells. The considered thermal loading consists in a thermal flux in time applied on the cell's wall. The model symmetry constrains the displacement, thermal flow and fluid flow to be nil on its left and right sides. These boundary conditions are also applied on the bottom of the model.

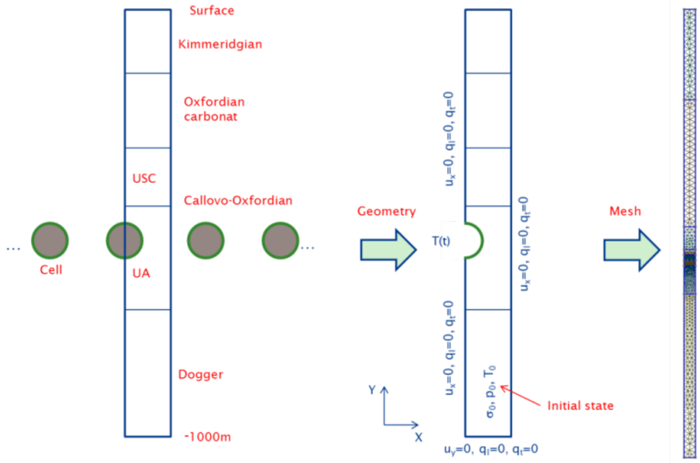

Fig. 1: Schematic representation of a series HLW cells and deduced plan strain model and mesh

Different parameters can affect the THM response of the rock to thermal loads. A "one factor at a time" sensitivity analysis (e.g., Rohmer and Seyedi, 2010) is conducted to evaluate the weight of each parameter on the THM response of the COx claystone when a thermo-poroelastic behaviour is considered. It consists of varying each input parameter separately while, other parameters are fixed and to measure its effect on the output. The threshold values are defined based on the observed variability in the experimental results as a possible range of variation. The tested parameters are COx's Young modulus [3 to 9 GPa], permeability [10^{-21} to 2.0 10^{-20} m^2], thermal conductivity [0,95 to 1,25 W/m/K], Poisson's ratio [0.2 to 0.4], Biot coefficient [0.6 to 1.0], thermal expansion coefficient of the solid skeleton [10^{-5} to 2.5 10^{-5} K^{-1}], and heat capacity [910 to 978 J.kg^{-1}.K^{-1}]. The obtained values of the vertical Terzaghi effective stress at the mid-distance between two parallel cells are reported on Fig. 2. The performed analysis shows that the Young modulus and the water permeability are the two parameters that affect more the THM response of the rock. Thermal conductivity, Poisson's ratio and Biot coefficient seem to constitute the second set of influencing parameters. It is worth to note that the obtained weight of each parameter depends, among other factors, on the range of its variability and the considered boundary conditions. Moreover, the present approach cannot account for the interactions between different parameters.

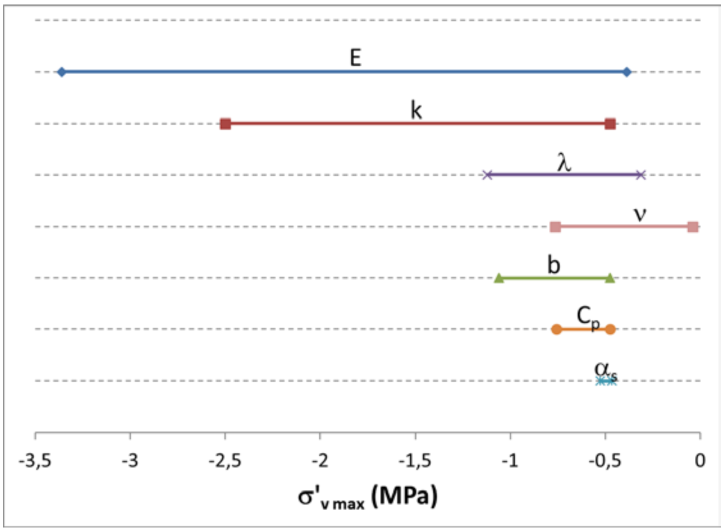

Fig. 2: Effect of different parameters on the vertical effective stress at mid-distance between two parallel cells; E stands for Young modulus, k permeability, λ thermal conductivity, ν for Poisson's ratio, b Biot coefficient, α_s thermal expansion coefficient of the rock skeleton and C_p its heat capacity (the negative values correspond to compressive effective stresses)

References

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