A laboratory testing procedure for the determination of coupled thermo-poromechanical properties of low permeable geomaterials

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Introduction

The determination of thermo-poro-elastic parameters of low permeable geomaterials in laboratory experiments is a difficult task due to some issues in drainage conditions. In elementary tests, the homogeneity of the pore pressure field within the sample should be ensured in order to measure drained parameters, resulting in long testing durations. Undrained tests can be generally carried out more rapidly, but require correct measurements with respect to the deformability of the drainage system (Wissa 1969; Bishop 1976; Ghabezloo and Sulem 2010).

In this work, we analyse the generation of pore pressure and the resulting deformations in various isotropic loading tests, using analytical functions described by Braun et al. (2018). We find that loading conditions can be improved by first loading the material under a high rate within a short period of time, and then keeping this load constant. This permits to determine two material parameters and back-calculate the permeability in one experiment. After this test, in contrary to a monotonic loading path, the material is in equilibrium. Further tests can then be immediately continued, increasing time efficiency. The proposed loading protocols are demonstrated on experiments on the Callovo-Oxfordian claystone (COx).

Materials and methods

The sample tested in this work was trimmed from the COx core EST53650, which was extracted from the underground laboratory in Bure, France. Before testing the sample, its wet density was determined to 2.40 g/cm^3. A water content w = 7.7 % and a saturation degree S_r = 94 % were measured on cuttings from the core. The specimen of 38 mm diameter and 10 mm height was mounted in the isotropic cell and saturated with synthetic pore water under an effective stress of 8 MPa, close to that in-situ in the Bure underground laboratory at a depth of 490 m. Pore pressure and confining pressure were then simultaneously brought to 4 MPa and 12 MPa, respectively.

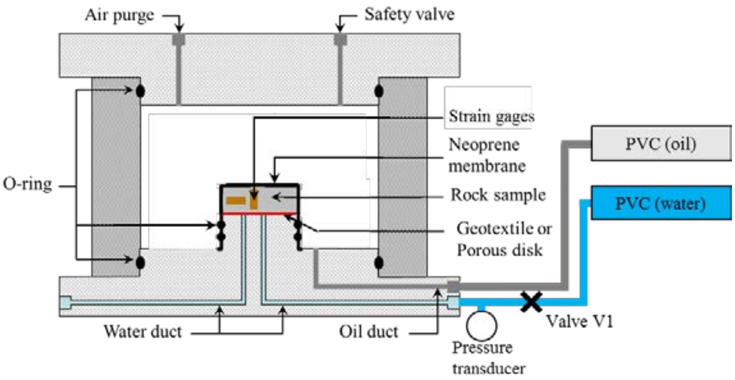

Fig. 1: Isotropic high pressure cell (adapted from Belmokhtar et al. 2017)

The high-pressure isotropic cell shown in Figure 1 allows to submit a rock specimen to controlled isotropic confining stress, pore pressure and temperature. A short sample height (10 mm) reduces the drainage length and allows faster saturation and a faster diffusion of the pore fluid. The device was adopted from the cell used by Mohajerani et al. (2012) and Belmokhtar et al. (2017), with some further improvements. The deformations of the specimen are measured locally by using an axial and a radial strain gage directly glued on the specimen surface. Disturbing effects of changes in cell temperature, room temperature or confining stress on the strain gages are eliminated by using a dummy gage glued to a reference steel piece inside the cell.

Testing protocol and results

Laboratory tests on low permeable geomaterials in isotropic or triaxial cells have two shortcomings, related to the shape of the sample and the drainage conditions in the testing device: i) in drained tests, the pore pressure generated through loading needs a certain time to equilibrate with the pore pressure controlled through the drainage system; ii) the measured parameters in undrained tests have to be corrected for the deformations of the drainage system (Wissa 1969; Bishop 1976; Ghabezloo and Sulem 2010); iii) after carrying out a monotonic loading, a certain period of time has to be waited for before the specimen comes back to equilibrium.

The sample in our isotropic cell can drain only in the axial direction towards the porous disk at the bottom. Assuming linear poro-thermo-elasticity, and pore fluid flow governed by Darcy’s law, we can calculate the transient deformations during mechanical or thermal consolidation, using some analytical expressions recently developed by Braun et al. (2018). By doing so, we can find and analytically describe an adapted loading protocol similar to that of Hart and Wang (2001), which avoids the previously mentioned shortcomings by applying first a rapid loading (true undrained deformation that does not need to be corrected for any dead volume of the drainage system). Pore pressures can afterwards progressively dissipate and ultimately generate a completely drained deformation.

Results

Drained and undrained modulus or thermal expansion coefficients can be read directly from recorded load-strain curves, as it is done in Figure 2a. Hereby the undrained properties are determined as a tangent during the loading phase and the drained properties as a secant through initial and final deformation. In the drained compression test in Fig. 2, we obtain the undrained and drained bulk modulus K_u = 16.3 GPa and K_d = 2.0 GPa, respectively. Analogously, we can measure the drained and undrained thermal expansion coefficients in a thermal step test under constant confining pressure. In addition, the change with time of the calculated deformations can be fitted by changing the permeability k, with a best fit of $k = 1.7\times10^{-21}$ m² (Figure 2b). This permits to measure three material properties in less than one day. Note that a monotonic loading test would only provide one parameter in about two days.

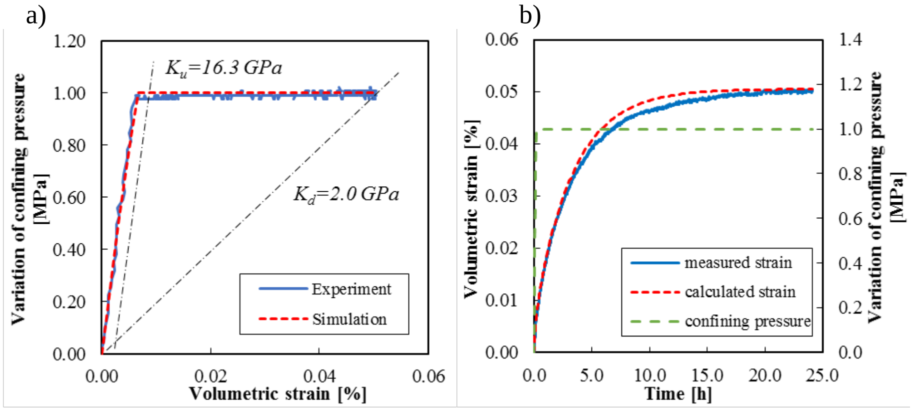

Fig. 2: Measured and calculated deformations during a step isotropic compression test

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