



A new hollow cylinder triaxial cell to study the behavior of geo-materials with low permeability

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ABSTRACT

A new hollow cylinder triaxial cell (60 mm internal diameter and 100 mm external diameter) has been designed to study the behavior of low permeability saturated geo-materials such as stiff clays or argillites under controlled temperature and pore pressure conditions. The main advantage of this device is the short drainage path allowed by the hollow cylinder geometry that is reduced to half the thickness of the sample (10 mm)—four times less than that of standard full cylinder samples of 78 mm height. The reduced drainage path allows a significantly faster resaturation procedure of initially unsaturated samples compared to conventional full cylindrical samples. It also permits the achievement of drained conditions (i.e. negligible excess pore pressure during testing) with a higher loading rate. A numerical simulation of the saturation process demonstrates that the resaturation of the hollow cylinder clay sample can be achieved almost 30 times faster than in standard full samples that are drained at one end, and about seven times faster than in samples drained at both ends. Appropriate loading rates to be used in drained tests on stiff clays and argillites are also discussed based on a numerical simulation of the isotropic compression test. The effect of the deformability of the drainage system on the measured parameters during undrained tests is also analyzed. A correction method is proposed, based on the work of Bishop, by considering the deformability of the porous elements and of the drainage system.

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1. Introduction

Storage of high activity radioactive waste in deep geological formations is considered as a possible solution for long-term repository. The very low permeability of natural barriers is essential to ensure long term storage safety. In this regard, storage in low permeability argillite with favorable self-sealing properties [1] appears to be an appropriate option in various countries including Switzerland (Opalinus argillite [2]) and France (Callovo-Oxfordian argillite [3]).

Hydro-mechanical testing in argillites presents significant difficulties related to their very low permeability ($k < 10^{-19} \text{ m}^2$). In standard triaxial testing, a first delicate and time consuming procedure consists in resaturating standard argillite triaxial cylindrical samples (38 mm in diameter, 76 mm in height) that have inevitably been desaturated during the processes of coring, transport, conservation and trimming in the laboratory. Also, testing in fully drained conditions (i.e. with no induced change of pore pressure) requires extremely slow testing rates given the drainage length of the sample that is equal to the mid-height (38 mm). Obviously, the very long duration of tests makes it

difficult to obtain large data bases and fully drained tests in properly saturated samples of argillites appear to be scarce. A possible solution to overcome this problem is the reduction of the sample height as done by Coll [4] and Escoffier et al. [5] but then the standard slenderness ratio (height/diameter ≥ 2) is not satisfied and the influence of the friction between the platens and the sample may be significant. Lenoir et al. [6] kept a slenderness ratio of two by adopting small cylindrical samples of 20 mm in height and 10 mm in diameter, with a drainage length of 10 mm. Compared to a 38 mm drainage length and given the diffusive nature of the equation that governs the pore pressure change [7], a reduction by a factor of approximately 16 of the pore pressure diffusion rate can reasonably be expected with a drainage length of 10 mm that is approximately four times smaller than that of standard triaxial specimens (38 mm). It appears however impossible to monitor local strains in such small samples and only global volumetric changes and external axial strain can be monitored.

To cope with these difficulties, a new specific triaxial system was designed. In this device the length of drainage was reduced by adopting hollow cylindrical samples with enhanced drainage ensured along the inner and outer lateral faces. The external and internal diameters of the specimen have been taken equal to 100 and 60 mm, respectively, providing a sample thickness of 20 mm. The sample height is between 75 and 80 mm. With this sample

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the slenderness ratio, $H/(\varphi_{ext} - \varphi_{int})$, is thus equal to 3.75–4.0 which is about twice as large as the standard triaxial samples, thus optimizing end effects.

Standard triaxial stress conditions are ensured by applying the same confining pressure on both the inner and outer cylindrical faces of the sample. Shearing is carried out by applying axial loading by using a loading frame with a capacity of 25 tons. In this system, lateral drainage is also ensured by placing two geotextile bands along both the inner and outer lateral faces of the sample, reducing the drainage length to 10 mm, i.e. half the thickness of the hollow cylinder. A local strain measurement system is also installed around the external face of the specimen.

In this paper, the experimental device is first described in details and the procedure of preparing hollow cylinder specimens in argillites is presented. Various calibrations tests have been carried out to quantify the effect of the compressibility of the drainage system during undrained tests. Feasibility tests were also carried out on a sandstone (Rothbach sandstone). Finally, the cell is used to resaturate an Opalinus argillite ($k \approx 10^{-20} \text{ m}^2$) sample. A numerical analysis of the resaturation process of this argillite is performed and the time needed to resaturate the sample is predicted. The saturation of the sample is verified by performing an undrained isotropic compression test and by evaluating the Skempton coefficient. In order to investigate the appropriate range of loading rates that are necessary to ensure a drained condition, a numerical analysis of the pore pressure change inside the sample as a function of the loading rates on Opalinus argillite is proposed for various drainage conditions.

2. Experimental setting and sample preparation

A global overview of the cell is presented in Fig. 1a that schematically shows the hollow cylinder specimen (φ_{ext} : 100 mm, φ_{int} : 60 mm, H : 75–80 mm) inside the specially designed triaxial cell. One can observe the inner and outer lateral geotextiles that are placed along the sample with no contact with the upper and lower sample drainages (the geotextile height can vary between $H/2$ and $H/3$). The upper and lower bases were specially designed to be adapted to the hollow cylinder geometry and to ensure water tightness of the external and internal membrane fixations. An immersed force sensor able to withstand fluid pressures up to 10 MPa and temperature up to 100 °C directly measures the axial

force. The upper base includes an internal duct so as to apply the same confining pressure in the inner and outer volumes.

Given the large external diameter of the sample, a large stainless steel cell able to withstand confining pressures up to 30 MPa has been designed. As seen in Fig. 2, in which a schematic view of the lower cell base is presented, internal ducts have been machined so as to allow for fluid connections (confining pressure, pore fluid drainage from upper and lower porous disks and from the inner and outer lateral geotextiles), internal temperature measurement and local strain measurement system using LVDTs. The cell cylinder is 250 mm thick and 420 mm high so as to accommodate the immersed force sensor. Given the weight of the cell components (close to 80 kg each), an elevator has to be used to move and assemble the various parts.

Fig. 1b shows a schematic view of the hydraulic connections between the sample, the pressure–volume controllers (PVC) and the pressure transducers (PT). The system includes a high pressure (10 MPa) pressure–volume controller (PVC1) to apply the confining pressure in the inner and outer cell volumes. Three PVCs are used to apply and control the pore fluid pressure: PVC2 is connected to the upper and lower ends of the sample, PVC3 to the inner boundary and PVC4 to the outer boundary. Fig. 3 presents a scheme of the system used to monitor local strains, allowing for the fixation of four radial and two axial LVDTs (precision $\pm 1 \mu\text{m}$). This figure also shows the inner and outer radial connections to the geotextiles. Particular care had to be taken in the design of these connections so as to avoid any membrane punching at high pressure. Special hollow porous disks were also machined to ensure drainage on the upper and lower ends of the hollow cylinder sample.

The device is equipped with a heating system that consists of a heating belt placed around the cell and of a temperature regulator that controls the temperature with a precision of $\pm 0.1 \text{ }^\circ\text{C}$. The temperature is measured inside the cell close to the sample by a thermocouple. The cell is covered by an insulating layer in order to limit heat exchanges with the environment. In this paper, only isothermal tests performed at 25 °C are presented. The heating system was thus used to maintain a constant 25 °C temperature during the tests. Silicon oil is used as confining fluid because of appropriate low viscosity and electrical insulation properties

An important challenge is the preparation of the hollow cylinder sample. The marked anisotropic nature of Opalinus argillite makes it quite difficult to trim samples along the bedding

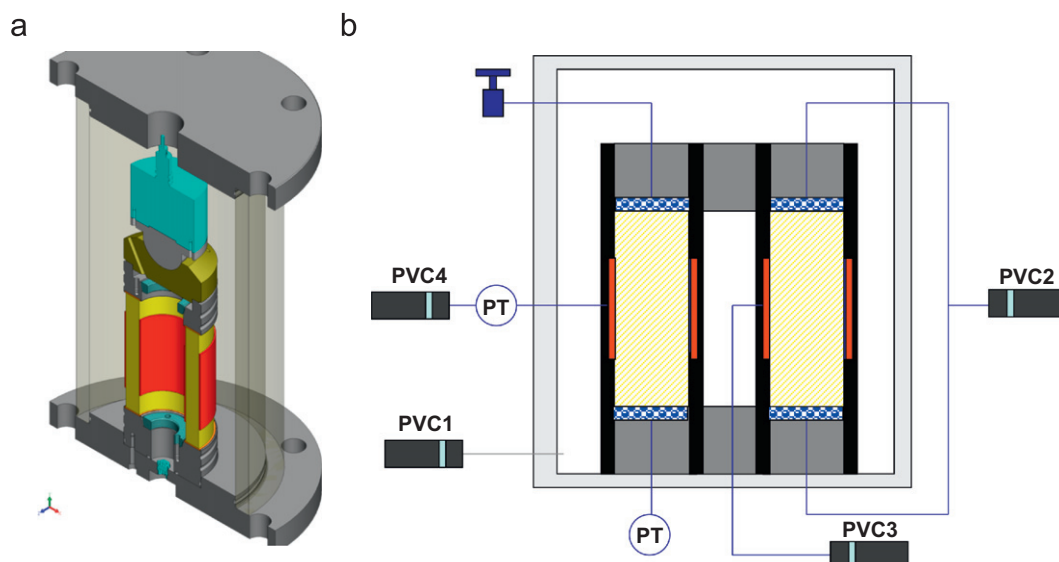


Fig. 1. (a) Hollow cylinder triaxial cell and (b) general setting of the hydraulic connections.

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