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Creep behavior of boom clay

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ABSTRACT

Several creep tests (lasting more than one year) were performed to study the delayed mechanical behavior of Boom clay under the hydro-mechanical coupling effect. To prevent the soil from swelling as much as possible during re-saturation, the samples were submitted to a confining pressure close to the in situ effective mean stress (2.5 MPa) at a room temperature of 21 °C. However, certain swelling still exists at the beginning of the saturation. Creep tests further highlight the creep potential of Boom clay. Delayed behavior became more and more significant as the deviatoric stress increased. A deviatoric stress threshold (approximately 1.0 MPa), below which only primary creep occurred, was proved to exist from the development of secondary and tertiary creep phases during the creep tests. If we introduce a quasi-steady state creep rate, i.e., the average creep rate after the creep deformation becoming stable, it can be found that the quasi-steady state creep rate of Boom clay is on the order of 10^{-6} ε/h under low deviatoric stress (1.5 MPa) in the laboratory, which is on the same order as the average creep rate of the in situ measurements in the second year (1988). However, in situ measurements show that steady creep state of the host rock was not reached even after five years. The in situ quasi-steady state diameter reduction rate calculated from the average of 10 years (1996–2006) of stable deformation of the tunnel linings is on the order of 10^{-8} ε/h.

1. Introduction

In all nuclear power generating countries, the management of radioactive waste is currently a very important issue. Disposal of these wastes in deep geological formations is, at present, the most promising option. A tertiary formation located in northeastern Belgium has been selected as a potential host rock for conditioned radioactive wastes [1]. The very low permeability, high ion exchange capacity, self-sealing properties and relative thickness of this argillaceous formation provide an efficient natural barrier against the release of radionuclides contained in wastes.

A large investigation program has been running for more than thirty years to characterize Boom clay formation. In addition to the in situ measurements of Boom clay [2–6], as first drillings performed on the SCK-CEN site from 1975 onwards, analyses of core samples were made for determining lithological, chemical, mineralogical, ion exchange and geomechanical properties of Boom clay [7]. Geohydrological and geophysical studies were also undertaken [8].

Oedometer tests [9–14] were usually performed, as they allow for great measurements and load control of simple volume clays used for nuclear waste disposal. In addition to the oedometer tests, uniaxial compression tests, isotropic compression tests and axi-symmetric triaxial tests (compression and extension) were performed on Boom clay to characterize its mechanical behavior. Coll [15] found that the uniaxial compressive strength of Boom clay is 2.5 MPa through uniaxial compression tests. However, Bernier et al. [16] proposed a value of 2 MPa. The results of undrained triaxial tests performed by Giraud and Rousset [17] showed that the plasticity is very significant and that the ductility is a main feature of the mechanical behavior of Boom clay. Indeed, Bésuelle at al. [18] further confirmed that the longer the swelling before shear, the more the response under shear becomes ductile and the lower the initial stiffness. Under deviatoric loading, Coll et al. [15] found that the higher the initial water content, the lower is the initial shear strength of Boom clay, and he also found that softening-dilatant behavior and strain localization are induced by a higher strain rate. Moreover, tests of mercury intrusion [19,20], transmission electron microscopy (TEM) [21,22], scanning electron microscopy (SEM) [20,23,24] and X-ray CT [1,18,25] were performed to study the soil fabric of Boom clay.

However, the mechanical behavior of geomaterials shows not only elasticity and plasticity but also the nature of time-related

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Table 1
Physical information for the samples tested.

Samples	Diameter [mm]	Height [mm]	Density [g/cm^3]	Dry density [g/cm^3]	Water content [%]	Void ratio	Saturation degree	Fluid in contact
TCP1	38.10	74.00	2.04	1.65	24.0	0.66	0.98	SBCW
TCP2	37.83	76.53	2.02	1.63	23.9	0.68	0.96	SBCW
TCP3	37.50	75.77	2.02	1.63	24.0	0.68	0.96	SBCW

Note: SBCW is the abbreviation for synthetic Boom clay water.

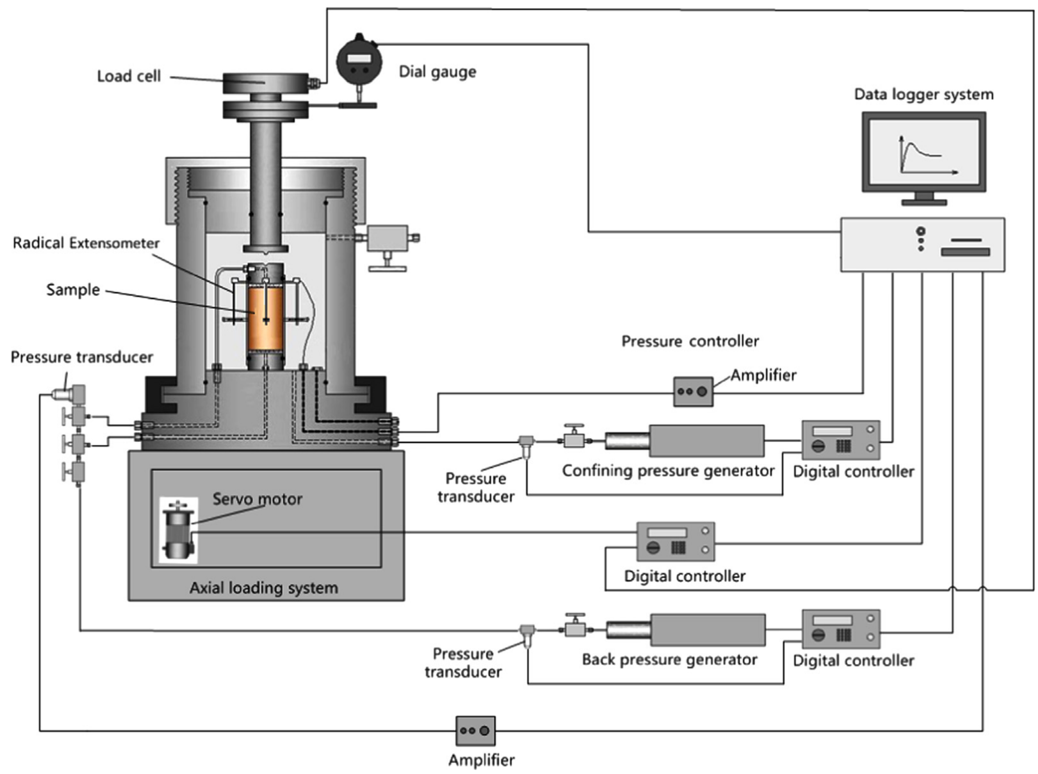

Fig. 1. Testing systems for triaxial creep tests.

Table 2
Test procedures during the creep phase after saturation.

Samples	Confining pressure σ_3 (MPa)	Water pressure p_l (MPa)	Deviatoric stress $(\sigma_1-\sigma_3)$ (MPa)	Drained conditions
TCP1	4.7	2.2	0.5, 1.0, 1.5,	Undrained
	4.7	0.0	2.0, 2.5, 3.0, 3.5, 4.0	Drained
TCP2	4.7	2.2	0.5	Undrained
TCP3	4.5	2.0	0.5, 1.0, 1.5, 2.0, 2.5	Drained

Note: In this paper, compression is positive and tension is negative.

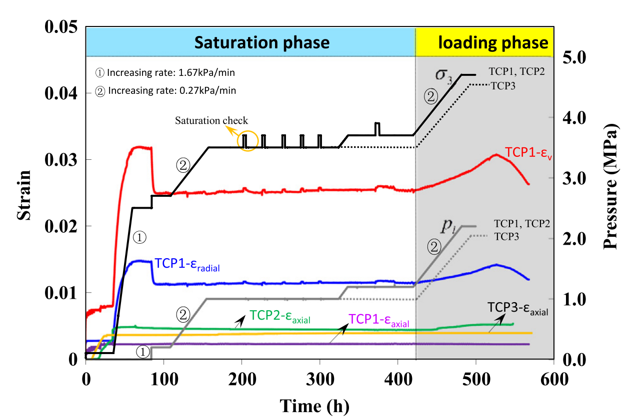

Fig. 2. Load procedures and deformation variation of the samples before the creep phase.

properties. A time-dependent deformation occurring in a material subject to load for a prolonged period of time is called creep [26]. In a narrower sense, creep means a time-dependent deformation caused by a constant load, which has a significant impact on the stability of underground structures, such as nuclear waste storage facilities, power plants and tunnels [27,28]. Although the delayed behavior of argillaceous rock has been widely investigated [29,30,31,32], there have been few experimental studies on the delayed behavior of Boom clay [33,34], especially on the delayed behavior under the hydro-mechanical coupling effect [17,35]. The previous experimental studies highlight the high creep potential of Boom clay. In order to reach a 'long-term failure', De Bruyn et al. [33] performed the creep tests using deviatoric stress range from 0.8 to 2.8 MPa, unfortunately, no tertiary creep were found even after several month. To investigate the time-dependent behavior of Boom clay under both thermal and mechanical loading, Cui et al. [34] performed high-pressure tests at controlled temperatures, he found that full consolidation of Boom clay requires a long period of time and it is difficult to distinguish consolidation and creep from the total volume change with time. Coll et al. [35] performed a series of creep tests on Boom clay, however, most of the creep tests were under 'open drainage' conditions, and no fluid was in contacted. The only hydro-mechanical creep tests show no significant influence on the