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Hydro-mechanical behaviour of Boom Clay investigated through high capacity oedometric and triaxial compression tests

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Summary

This study presents a first set of results related to the geomechanical behaviour of intact Boom Clay extracted at three different depths (at the surface level, at 223 m and 350 m depth) from consolidated drained triaxial compression tests and oedometric compression tests. Those tests have been performed on high capacity equipment to reproduce stress level as experienced at those depths. A special attention has been held on the saturation process, performed under in-situ stress conditions, to avoid detrimental swelling upon saturation that could affect the subsequent geomechanical response of the material.

1 Introduction

In Belgium, the national organization responsible for the management of radioactive waste, ONDRAF/NIRAS, considers the disposal for intermediate level and high level radioactive waste in deep geological layer. The Boom Clay Formation is one of the potential host formation under study for that purpose. Boom Clay was deposited 29 to 34 million years ago, this corresponds to the Rupelian Age in the first half of the Oligocene Epoch [1]. In Belgium, Boom Clay is present in the natural region called "Campine" which is situated in the North-Eastern part of the country [2].
The HADES Underground Research Laboratory (URL) built in the beginning of the eighties at a depth of 223 m in the Boom Clay Formation is in the Mol-Dessel area in the North-East of Belgium. Over these past 40 years, many geomechanical laboratory tests were performed and analyzed on specimen cored from the underground laboratory leading to well-known hydro-mechanical properties of Boom Clay at this depth [3]. Neither the depth nor the geological formation of a geological disposal facility (GDF) in Belgium has been defined yet. . However, today, the reference design is fixed at a depth 400 m in poorly indurated clays. In this case, the knowledge of Boom Clay hydro-mechanical properties at HADES level is not sufficient and need to be extended to greater depths. With that perspective, this study aims to analyze the variability of Boom Clay hydro-mechanical properties and behaviour with depth.

In this paper, the results of triaxial tests performed on sample taken at 223 m depth and at the surface level (Rumst Quarry) are analysed as well as the results from high capacity oedometer tests on samples taken at the surface level, 223 m and 350 m depth in the Boom Clay Formation.

2 Materials and Methods

2.1 Samples

All samples were prepared such that their bedding orientation was perpendicular to the loading direction. The samples were water-drilled from the core. For the tests conducted on samples from a depth of 223 m, material was obtained from two cores drilled in the HADES URL: CG_78-79w_core_35_section_35.1 and CG_78-79w_core_34_section_34.1. These cores were drilled with their cylinder axis parallel to the bedding. So, specimen where obtained by coring radially in the main core. Surface-level samples were cored from decimeter-sized blocks collected from the Rumst Quarry, specifically between Septarian carbonate concretion levels S50 and S60. For the tests at 350 m depth, a core from the MOL-2D drilling campaign (ON-MOL2D_Core_55) was used. This core was drilled with its cylinder axis perpendicular to the bedding. So, specimen where obtained by coring axially in the main core.

2.2 Triaxial tests

Triaxial tests are performed on cores of Boom Clay taken at a depth of 223 m from HADES URL and under conditions representative of this depth. A high capacity triaxial cell (HC) able to develop a confining pressure up to 40 MPa and axial load of 350 kN, with control of pore water pressure up to 35 MPa, is used. After reconsolidation up to 2.25 MPa followed by the saturation phase under a pore water pressure of 2 MPa (maintaining a constant effective confining stress of 2.25 MPa), consolidated drained triaxial compression tests are performed at effective confining pressure between 1 and 4 MPa. The rate of axial displacement during compression is fixed at a value of 0.25 μm/min, low enough to guarantee drained conditions during compression (Ref Coll 2005?). For the sake of comparison, additional tests are also performed on Boom Clay specimen (taken at a depth of 223m and at surface level) with lower capacity triaxial cell (LC), up to 1.5 MPa of total confining pressure. Saturation protocol is slightly different in the sense that it is performed under a pore water pressure of 0.5 MPa at a confining pressure of 0.7 MPa. At the end, the effective confining pressure is limited to 1 MPa. The sample dimensions were 7.5 cm in height and 3.5 cm in diameter.

2.3 Oedometer tests

Oedometer tests were conducted on Boom Clay samples taken from the surface (Rumst Quarry) and at depths of 223 m and 350 m. An automated oedometer equipped with a 50 kN load cell was used. Each sample was initially loaded to replicate in-situ stress conditions. After one hour, water was introduced to saturate the specimen under in-situ stress. Samples were then progressively loaded up to 32 MPa and subsequently unloaded along the same stress path. The sample dimensions were 2 cm in height and 3.5 cm in diameter.

3 Results and Discussions

3.1 Triaxial tests

Figure 1 presents the evolution of deviatoric stress versus axial strain, as well as volumetric strain versus axial strain. The test numbers correspond to those listed in Table 1. The results show that, across all confining pressures, the samples from 223 m depth exhibit a hardening behavior, even under low confining pressure. Under low confining pressure, these samples display a dilating behaviour, while at higher confining pressures they tend to show a contracting behaviour. Surface-level samples tested under low confining pressure demonstrate a softening dilating response. The observed trends in the q–ε_a plane align with findings from the literature [2][4]. However, in the ε_V–ε_a plane, the samples under low confining pressure deviate from established results, which generally indicate a contracting response. It is obvious that the samples from 223 m depth and the samples from the surface level exhibit a markedly different geomechanical behaviour. The results of all these tests are summarised in Figure 2 in the p' – q plane (p': effective mean stress, q: deviatoric stress). The failure points of specimen from 223 m depth compare relatively well with the failure lines deduced from literature review perfomed by [2][4].

Table 1: Results summary of the triaxial tests

	Depth	Confining effective stress p'_0 (MPa)	Effective mean stress at failure p'_{rupt} (MPa)	Deviatoric stress at failure q_{rupt} (MPa)	Cell	Saturation after test
1	223 m	4.0	5.00	3.01	HC	-
2	223 m	4.0	5.03	2.89	HC	98.8%
3	223 m	2.25	3.12	2.30	HC	99.5%
4	223 m	2.25	2.95	2.06	HC	100%
5	223 m	1.0	1.52	1.45	HC	100%
6	223 m	1.0	1.45	1.53	LC	100%
7	223 m	0.5	0.87	1.13	LC	100%
8	Surface	1.0	1.35	1.05	LC	99.3%
9	Surface	0.5	0.75	0.74	LC	99.0%
10	Surface	0.5	0.72	0.66	LC	100%

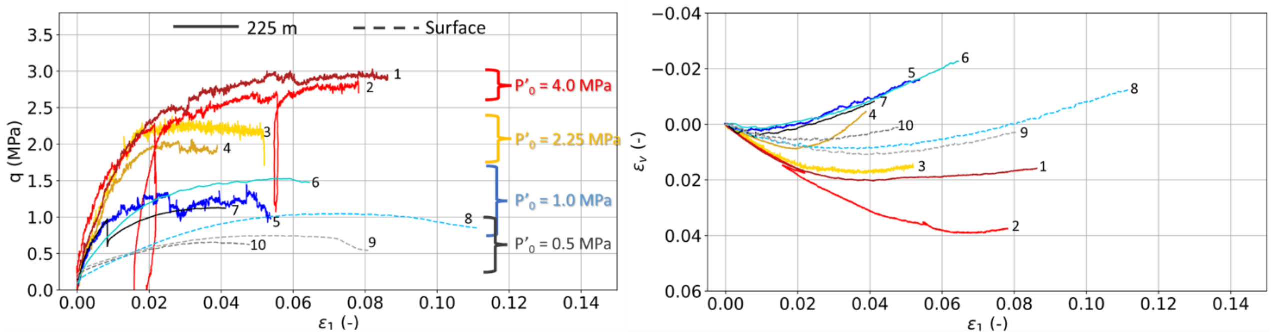

Figure 1: Results of triaxial test show as the axial strain function of the deviatoric stress and the axial strain as a function of the volumetric strain. The number corresponds to the ones in Table 1.

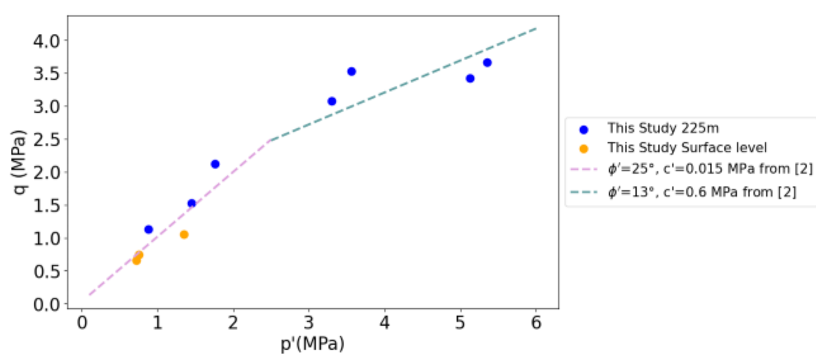

Figure 2: Shear strength data from this study for sample of Boom Clay collected at 225 m depth and at the surface level with the derived failure envelope from [2].

3.2 Oedometric tests

Figure 3 presents the results of oedometric tests conducted on Boom Clay samples extracted from three different depths: surface level, 223 m, and 350 m. The samples from 223 m and 350 m exhibit similar oedometric behavior. As shown in Table 2, both depths have comparable compression and swelling coefficients. As expected, the preconsolidation stress is slightly higher. In contrast, the surface sample displays a similar swelling coefficient but a lower compression coefficient.

Table 2: Results summary of the oedometric tests

Depth	Cc	Cs	σ'_p (MPa)
0 m	0.196	0.111	0.7
223 m	0.360	0.121	4.9
350 m	0.315	0.117	6.1

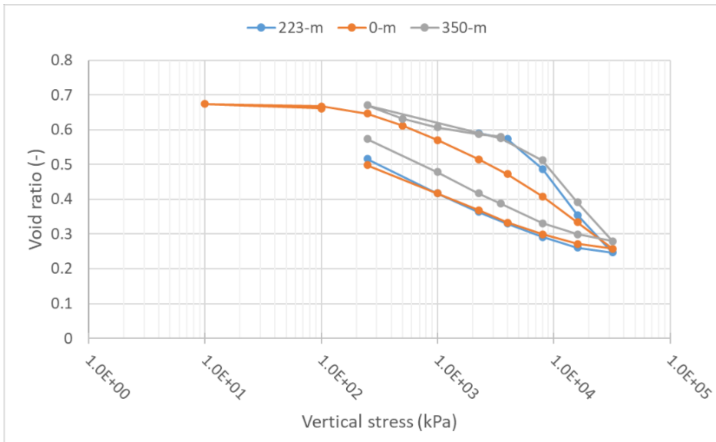

Figure 3 : Oedometric curve for a sample of Boom Clay taken at the surface level, 223 m depth and 350 m depth

4 Conclusion

Based on consolidated drained triaxial compression tests and oedometric compressions tests on intact Boom Clay extracted at three different depths (surface level, 223 m and 350 m depth) and loaded perpendicularly to the bedding plane, it is observed that the depth plays a role in term of strength and compressibility parameters. Clearly, oedometric curve of specimen extracted at the surface level exhibits a totally different trends than specimen extracted at 223m and 350m. Triaxial tests on specimen extracted from the core at 350m depth should still be performed to confirm this observed trend. Also, in a near future, the microstructure of Boom Clay at those various depths will be analysed to correlate it with their mechanical behaviour.

References

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