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Investigating the pore-water chemistry effects on the volume change behaviour of Boom clay

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ABSTRACT

The Essen site has been chosen as an alternative site for nuclear waste disposal in Belgium. The soil formation involved at this site is the same as at Mol site: Boom clay. However, owing to its geographical situation closer to the sea, Boom clay at Essen presents a pore water salinity 4–5 times higher than Boom clay at Mol. This study aims at studying the effects of pore water salinity on the hydro-mechanical behaviour of Boom clay. Specific oedometer cells were used allowing "flushing" the pore water in soil specimen by synthetic pore water or distilled water. The synthetic pore water used was prepared with the chemistry as that for the site water: 5.037 g/L for core Ess83 and 5.578 g/L for core Ess96. Mechanical loading was then carried out on the soil specimen after flushing. The results show that water salinity effect on the liquid limit is negligible. The saturation or pore water replacement under the in situ effective stress of 2.4 MPa does not induce significant volume change. For Ess83, hydro-mechanical behaviour was found to be slightly influenced by the water salinity; on the contrary, no obvious effect was identified on the hydro-mechanical behaviour of Ess96. This can be attributed to the higher smectite content in Ess83 than in Ess96.

1. Introduction

In the Belgian program for nuclear waste disposal, the Essen site has been considered as an alternative site to the relatively well-known Mol site (Bernier et al., 2007; Cui et al., 2009). The Essen site is located in the north-east of Belgium, about 60 km far from Mol (Fig. 1, De Craen et al., 2006). As it is closer to the sea than the Mol site, the Boom clay involved presents a pore water salinity 4–5 times higher than that at Mol (De Craen et al., 2006). To the authors' knowledge, the effect of this high pore water salinity on the hydro-mechanical behaviour of Boom clay has not been investigated yet. Nevertheless, for other clays, numerous studies have been reported in the literature about the effect of pore-water chemistry on the hydromechanical behaviour (Bowders and Daniel, 1986; Waddah et al., 1997; Di Maio, 1996; Di Maio et al., 2004; Chen and Anadarajah, 1998; Sridharan and Prakash, 1999; Kaya and Fang, 2000; Sridharan et al., 2002; Ören and Kaya, 2003; Wakim, 2005; Gajo and Maines, 2007; Yukselen-Aksoy et al., 2008; Smiles, 2008). These studies showed that inorganic salt solutions have a strong impact on the hydro-mechanical behaviour of clays, especially on swelling clays. Examination of the test conditions applied in these studied shows that it is difficult to extend the results to Boom clay. Indeed, most tests were carried out on either soil slurries or remould soils. The salinity was applied to the soil either before the sample preparation by mixing soils powder with the studied solution or after the sample preparation by putting the sample in the salinity environment (Wakim, 2005). Obviously, when studying the pore-water chemistry effect on Boom clay, the salinity methods for slurries and remould clays are not applicable as it is not allowed to destroy the initial microstructure of the soil. On the other hand, the method used by Wakim (2005) is believed to not be efficient because the fully saturation of soil sample by the desired pore water of different salinity can be suspected when simply putting the sample in the pore water.

In the present work, to ensure the full replacement of pore water with the soil sample, a "flushing" method was applied that allows the desired water to percolate the soil sample. Synthetic pore water that has the same chemistry as the site water was used. Distilled water was also used to make a comparison. Note that the range of water chemistry considered was not large since the total salinity of pore water at Essen site is between 5.037 and 5.578 g/L. The liquid limit w_L of Boom clay at Essen was were first analysed

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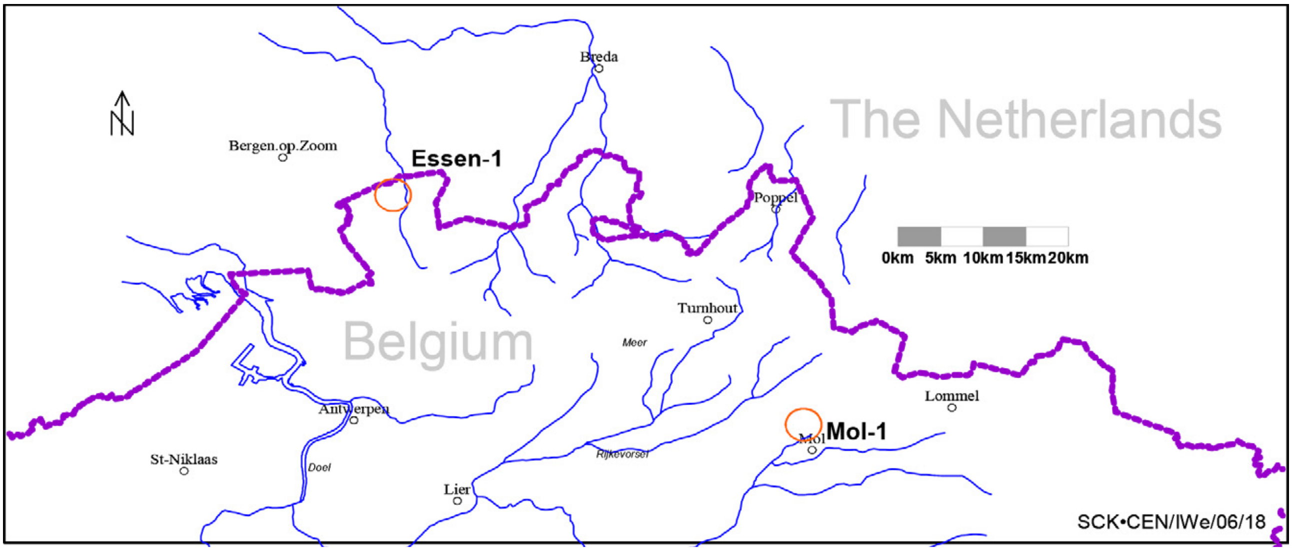

Fig. 1. Locations of Mol site and Essen site (De Craen et al., 2006).

with both synthetic pore water and distilled water. Afterwards, a special oedometer was set up to replace soil pore water with either synthetic pore water or distilled water. Loading and unloading paths were then applied to study the hydro-mechanical behaviour under different salinity conditions.

2. Materials and methods

The soil cores studied were taken from the borehole drilled in Essen at the depth of 226.65–227.65 m (Ess83) within the Putte member, and at the depth of 239.62–240.62 m (Ess96) within the Terhagen member. The cores have a dimension of 1.0 m in length and 100 mm in diameter. They were sealed in plastic tubes with ends closed for water loss prevention, and transported to the laboratory for testing.

Table 1 shows the chemical composition of pore-water of cores Ess83 and Ess96 (De Craen et al., 2006) and that of Boom clay at Mol (Cui et al., 2009). The results show that the pore-water at Essen contains $NaHCO_3$, Na_2SO_4, KCl, $CaCl_2{\cdot}2H_2O$, $MgCl_2{\cdot}H_2O$ and NaCl, and NaCl being the main salt. The pore-water taken from Mol contains $NaHCO_3$, Na_2SO_4, KCl, $MgCl_2{\cdot}2H_2O$, NaCl, H_3BO_3, NaF and $CaCO_3$, and $NaHCO_3$ being the main salt. Comparison between the values for Ess83 and Ess96 shows that there is few difference between the two cores. The total salinity of the pore-water at Essen site is 5.037–5.578 g/L, while that at Mol site is only 1.286 g/L. The results also showed that the main cation at both sites is Na^+, with a concentration of 0.072–0.080 mol/L at Essen and 0.014 mol/L at Mol, i.e., 5–6 times lower. Note that the salinity of seawater usually ranges from 3.3% to 3.7% in weight; indicating that the salinity of pore water at Essen is about 1.5 times higher as that of seawater, while that at Mol is about 2 times lower than that of seawater.

Table 1
Pore water salinity of Boom clay.

Salt	Ess83	Ess96	Mol
	10^{-3} (mol/L)		
$NaHCO_3$	7.16	7.16	13.93
Na_2SO_4	5.23	5.81	0.002
KCl	0.61	0.61	0.34
$CaCl_2{\cdot}2H_2O$	0.52	0.57	
$MgCl_2{\cdot}6H_2O$	1.44	1.60	0.11
NaCl	54.7	61.6	0.17
H_3BO_3			0.70
NaF			0.26
$CaCO_3$			0.05
Na^+	72.32	80.38	14.104
Total salinity (g/L)	5.037	5.578	1.286

The geotechnical properties of these two cores that were determined using distilled water are shown in Table 2. It can be observed that Ess83 and Ess96 present similar properties: a specific gravity G_s = 2.64 against 2.68; a liquid limit w_L = 67.2 against 67.1%; a plastic limit w_P = 33% for both; a plastic index I_P = 37 against 36; a soil water content w = 27.2 against 26.5%; a void ratio e = 0.730 against 0.715; a blue methylene value VBS = 6.67 against 6.20; a carbonate content of 7.6 against 2.4 g/kg. The liquid limit values were also determined using Essen synthetic water (prepared with the same chemistry as for the site water) and slightly higher values were obtained: w_L = 69.6 for Ess83 and w_L = 68.9 for Ess96. The difference in w_L between the case of distilled water and the case of synthetic water is rather related to the test accuracy, and can be neglected. Yukselen-Aksoy et al. (2008) analysed the results from the literature on several clays and observed also a neglected effect of high salinity water (seawater) when w_L is lower than 110%. For high plasticity clay, lower w_L values have been obtained with high salinity water (Gajo and Maines, 2007; Yukselen-Aksoy et al., 2008).

The particle size distribution curves of the two cores are shown in Fig. 2. It is observed that the two curves are quite close, especially in the coarse particles part (>10 μm) where they overlap. The clay content (<2 μm) of Ess96 is about 61%, slightly higher than that of Ess83: 57%.

Table 3 shows the mineralogical composition of the whole soils and the composition of the clay fractions (<2 μm), obtained by X-ray diffraction analysis. It is observed that the main minerals of Ess83 are quartz (60%), illite/mica (10%) and kaolinite (30%). Ess96 has a higher quartz content (70%) and a lower kaolinite content (20%). For the clay fractions, the contents of chlorite, kaolinite and illite are similar for the two soils, but the smectite content of Ess83 is higher than that of Ess96: 20% against 10%.

In order to investigate the salinity effect on the hydro-mechanical behaviour of Boom clay, in this study, oedometer tests were conducted on soil samples (50 mm in diameter and 20 mm high) prepared by trimming with both synthetic water and distilled water.