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Hydromechanical behaviour of a compacted swelling soil over a wide suction range

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Abstract

A study of the hydromechanical behaviour of a compacted swelling material in the range of suctions comprised between 0 and 40 MPa was performed. This study has required the development of two kinds of suction controlled oedometer devices based on two different suction control techniques. In the range of suctions higher than 8.5 MPa, the saturated salt solutions method was used and a new oedometer using this suction control technique was developed. For suctions lower than 8.5 MPa an osmotic oedometer was used. Despite the differences between the applied suction components (matric and total), the correlation between the two methods was verified for the tested material. The second part of the paper presents a set of oedometer tests conducted under various suctions. The effect of the applied suction on the hydromechanical parameters was studied. First, two swelling phases were highlighted: a low swelling phase above a suction of 4 MPa and a high swelling one below this value. These phases were considered as being related to the microstructure of compacted swelling clays. Secondly, it was shown that the slopes of the elastic part and of the plastic part of the consolidation curves were not influenced significantly by the applied suctions. In opposition, the preconsolidation pressure is affected by the decrease of the applied suctions even in the low swelling phase. Such a behaviour could be explained by the effects of wetting on the microstructure.

Keywords: Expansive soil; Suction; Compacted soil; Hydromechanical behaviour; Compressibility; Laboratory tests

1. Introduction

Because of their very low permeability, compacted swelling soils are used for the construction of engineered barriers in waste disposal facilities. During their lifetime, these materials undergo wetting/drying cycles, i.e. suction variations. These soils exhibit large volume variations in response to suction changes. However, the relationship between suction variations and compressibility is not well known as far as compacted swelling materials are concerned. The experimental investigation of the hydromechanical behaviour of unsaturated swelling soils requires the use of suction controlled devices in a comprehensive range of suction, from low to very high suctions. However

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there are very few suction controlled studies performed over an extensive range of suction in the literature (Bernier et al., 1997; Al-Mukhtar et al., 1999; Villar, 1999; Alonso et al., 2001; Cui et al., 2002). This is mainly related to the fact that the methods commonly used in experimental testing, such as the air overpressure method (Richards, 1935) and the osmotic method (Kassif and Ben Shalom, 1971) investigate only a small suction range, from saturation up to a few MPa (Fig. 1). Some developments of these methods have been used, but the maximum suction they are able to reach is about 14 MPa (Villar, 1995; Delage et al., 1998). The only available method to reach several hundred MPa is the control of relative humidity by means of salt solutions. However, this is a complex method to implement because of some uncertainties on the imposed suction due to temperature and pressure variations, and the measurement of the exact value of the relative humidity inside the testing device (Delage et al., 1998; Cuisinier, 2002).

This paper presents a study of the hydromechanical behaviour of a compacted swelling soil carried out on a range of suction comprised between 0 and 40 MPa. In the first part, oedometers using the osmotic method and others based on the saturated salt solutions technique are introduced. The feasibility of these devices and the correlation between the two suction control methods is also discussed. In the second part, a set of suction controlled oedometer tests is presented. From these results, the influence of suction on the swelling potential ΔH/H, the preconsolidation pressure $p_0(s)$, the slopes of the elastic part κ, and of the plastic part $\lambda(s)$, of the consolidation curves is discussed.

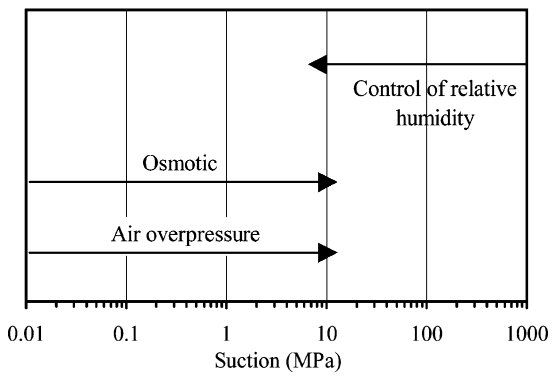

Fig. 1. Range of suction of the main suction control techniques.

The results are considered with two independent variables: the net vertical stress σ_v*, defined as the difference between the total vertical stress and the pore-air pressure, and the suction s, which corresponds to the difference between the pore-air pressure and the pore-water pressure (Coleman, 1962; Matyas and Radhakrishna, 1968).

2. Description of the suction controlled oedometer devices

Fig. 1 shows that at least two complementary suction control techniques are required to perform a study over an extensive suction range. The salt solutions technique for suctions higher than 8.5 MPa and the osmotic method for suctions lower than this value were selected.

2.1. Salt solutions method

The basic principle of the saturated salt solutions technique is to introduce a sample inside a hermetic chamber where the relative humidity is maintained constant with a salt solution. The water exchange occurs by vapour transfer. The relative humidity Hr (%) is linked to the suction, through Kelvin's law:

$$s = \gamma_w \frac{RT}{Mg} 1n(Hr) \quad (1)$$

with R = universal gas constant (8.31 J mol^{-1} K^{-1}); γ_w = unit weight of water (9.81 kN m^{-3}); g = gravitational constant (9.81 m s^{-2}); M = molecular weight of water (18 10^{-3} kg mol^{-1}); T = absolute temperature (K). It was possible to apply different suctions with this method, depending on the kind of salt solution used and its concentration. In this study, totally saturated salt solutions were selected.

The value of the relative humidity imposed by a given salt is highly dependent on temperature (AFNOR, 1999). In our tests, the room temperature was maintained at 20 ± 0.15 °C. The relative humidity imposed by a given saturated salt solution is known with an uncertainty comprised between 1% and 2% (AFNOR, 1999). Delage et al. (1998) and Cuisinier and Masrouri (2001) have demonstrated that these uncertainties limit the use of saturated salt solutions