Applied Clay Science 120 (2016) 81–90

Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: www.elsevier.com/locate/clay

Research paper

Role of different suction components on swelling behavior of compacted bentonites

Zemenu Geremew Yigzaw, Olivier Cuisinier *, Luc Massat, Farimah Masrouri

LEMTA, Laboratoire d'énergétique et de mécanique théorique appliquée, UMR 7563 Université de Lorraine/CNRS, TSA 70605, 54518 Vandœuvre-les-Nancy Cedex, France

A R T I C L E I N F O

Article history:
Received 17 July 2015
Received in revised form 25 November 2015
Accepted 27 November 2015
Available online 9 December 2015

Keywords:
Compacted bentonite
Topic:
Swelling pressure
Suction
Topic:
Osmotic technique
Laboratory tests

A B S T R A C T

The paper reports results of an experimental study focused on the investigation of the development of swelling pressure in compacted bentonites during wetting under confined conditions. The main swelling pressure testing program has been performed using a new constant-volume oedometer especially designed to apply suction using the osmotic method. The device allows to continue to determine swelling pressure under constant-volume conditions during wetting close to saturation (suction below 8.5 MPa). Constant-volume swelling pressure tests were performed by decreasing the suction (or increasing the humidity) of the specimens from almost 100 MPa to 8.5 MPa and then in stepwise manner toward a zero value. In addition, a series of swelling pressure tests were performed using different experimental devices to compare test results obtained using the new device and to investigate the effect of hydration mode on the swelling pressure of compacted bentonites.

Different wetting modes, water or vapor wetting, resulted different equilibrium swelling pressure values. Three stages of swelling pressure development are identified during suction reduction. In the first stage, following large suction reduction, swelling pressure increases up to a peak value; then, in second stage, in suction range comprised between 8.5 and 3.5 MPa, swelling pressure tends to decrease to a minimum value; and finally, upon further suction reduction to low values, swelling pressure increases again and eventually stabilizes. A possible interpretation of this pattern is given from micro-structural perspective.

1. Introduction

Geotechnical problems associated with expansive soils are well documented in the literature. Predicting volume changes and swelling pressures in expansive soils are required in many engineering situations concerned with stability problems of foundations, retaining walls, slope stability of embankments and excavations in expansive soils (Chen, 1975; Sridharan and Choudhury, 2002). Since the past decades, compacted bentonites and bentonite-aggregate mixtures have been proposed and widely studied as buffer and backfilling materials for underground nuclear waste disposal systems because these materials must have, besides low permeability and high water retention capacity, swelling characteristics in order to seal and separate the waste from the surrounding environment (Pusch, 1980a; Komine and Ogata, 1994; Marcial et al., 2002; Lloret et al., 2003; Villar and Lloret, 2008; Baille et al., 2010; Wang et al., 2012; Agus et al., 2013). Since the barrier and backfill materials are made from dry, highly compacted clay, the bentonite and bentonite-aggregate mixtures are initially unsaturated with high suction values, and consequently exhibit high swelling potential upon wetting. These materials are expected to swell due to the possible intrusion of pore water and salt solution from the host rock. Moreover, due to boundary conditions, it is expected that swelling will be restrained by the host rock; swelling pressure develops in the buffer materials under nearly constant volume conditions and in a gradual manner following suction reduction caused by the intrusion of water from the surrounding host rock. The swelling pressure should be high enough to ensure self-healing but it should not exceed the in situ minor stress to ensure the mechanical stability of the disposal system. Therefore, the study and understanding of the development of swelling-pressure in conditions similar to the field conditions would be important to enhance the understanding of the performance of radioactive waste disposal systems.

The development of swelling pressure in compacted bentonites and bentonite-aggregate mixtures upon water wetting in laboratory has been investigated by several researchers (Pusch, 1980b; Komine and Ogata, 1994; Marcial et al., 2002; Karnland et al., 2006; Imbert and Villar, 2006; Villar and Lloret, 2008; Schanz and Tripathy, 2009; Baille et al., 2010). Wetting has most often been performed by flooding the soil with water starting from the initial water content to full saturation, without suction control. The swelling pressure behavior has been generally studied in relation to the initial sample condition (water content and dry density) and the measured final swelling pressure. A monotonic or a non-monotonic swelling pressure development is observed depending on the density and initial water content of the tested soils. However, the transient swelling pressure behavior, which corresponds

* Corresponding author.
E-mail address: Olivier.Cuisinier@univ-lorraine.fr (O. Cuisinier).

http://dx.doi.org/10.1016/j.clay.2015.11.022

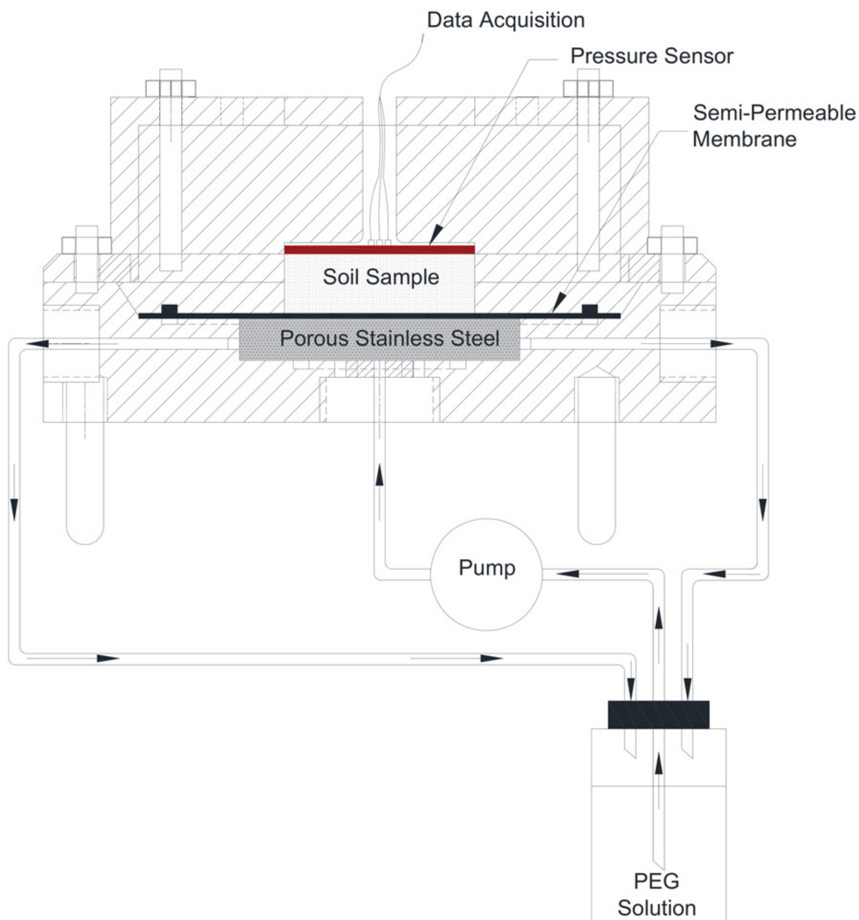

Fig. 1. Schematic layout of the new constant-volume osmotic oedometer.

to the moisture range between the initial water content and the full saturation state, is not often investigated. This can be achieved by running controlled suction tests. For example, Lloret et al. (2003) identified three distinct zones during suction controlled swelling pressure tests on compacted Ca-Mg-Na bentonite samples: in the first zone, or high suction zone, a large suction reduction caused progressive swelling pressure development to first maximum. In zone II, which corresponds to the region where suction-induced macro-structure collapse dominates, the swelling pressure decreases and in zone III, or the region of low suction, the swelling pressure increases again. They indicated that the latter swelling pressure development is due to the predominance of micro-structural swelling of clays close to saturation. Romero et al. (2003) also identified the first two zones for a moderately expansive low density compacted Boom clay. Agus et al. (2013), however, did not observe swelling pressure decrease during suction controlled wetting on highly compacted 50/50 bentonite-sand mixture.

Several researchers (Saiyouri et al., 2004; Devineau et al., 2006; Delage, 2007; Warr and Berger, 2007; Perdrial and Warr, 2011; Villar et al., 2012) have shown that the hydration of compacted bentonites occurs in an organized manner with the progressive insertion of one, two, three and four-layer water hydrates along the clay layers, accompanied by subdivision of the particles within the aggregate. The first process is manifested by increasing the interlayer spacing and the second by gradual increase of the inter-particle pores inside the aggregates. When the hydration occurs in free space, an appreciable macroscopic swelling occurs at high relative humidity. However in confined conditions, as macroscopic swelling cannot take place, a swelling pressure develops in the material. The results of Devineau et al. (2006) have shown that the hydration of compacted bentonites in confined conditions does not differ from free conditions for low relative humidity (or high suction). However, at high relative humidity (low suction), confinement appears to modify the repartition of water molecules between inter-aggregate pores and interlayer spaces favoring adsorption in the interlayer domain (early formation of a three-layer hydrate) accompanied by changes of porosity of the material.

In this context, the objectives of the research presented in this paper were focused, first, on the development of a constant-volume swelling pressure measuring device which allows the control of suction from 10 MPa to zero suction using osmotic technique and then, with the combined use of salt solution (vapor equilibrium) oedometer, to study the swelling pressure evolution of compacted bentonites under controlled suction close to saturation. The improved osmotic controlled constant-volume swelling pressure measuring device and experimental data obtained using the new and existing experimental devices are presented and discussed.

2. Experimental equipment and procedure

The main objectives of performing the series of tests reported here have been to study the swelling pressure behavior of compacted bentonites with and without moisture control. Different methods and experimental devices were used to determine swelling pressure and monitor the development of swelling pressure with saturation time.

2.1. Suction controlled swelling pressure tests

2.1.1. Osmotic technique

In this technique, drainage/wetting of the sample is caused by the process of osmosis (Kassiff and Shalom, 1971). The sample and an osmotic solution containing large size soluble polyethylene glycol