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Cyclic Water Retention Behaviour of Compacted Granular Bentonite

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SUMMARY

The paper presents the analysis of the water retention behaviour of compacted MX80 granular bentonite when subjected to cyclic wetting and drying episodes. Bentonites are highly swelling materials and they experience strong modifications of their fabric when subjected to changes in their water content. Interestingly, the link between the evolution of the retention behaviour and the structural modifications during wetting and drying episodes has not been deeply investigated. To this regard, a new protocol has been designed to analyse the retention behaviour of swelling materials. The protocol allows to collect representative samples for microstructural investigations at different stages of the imposed hydraulic stress path. Microstructural analyses were run by combining mercury intrusion porosimetry tests and SEM observations. An irreversible modification of the retention behaviour was observed once the material approached the fully saturated state during the first wetting. The water retention capacity of the material was increased as a result of such modification. The microstructural analysis allowed relating this change in the retention properties to a strong modification of the fabric.

Introduction

Compacted granular bentonite is considered as a suitable buffer and backfilling solution in deep repositories for the high-level radioactive waste storage. Granular bentonite is usually manufactured and emplaced at its hygroscopic water content ($w = 5\text{--}6\%$) and at a target dry density. The progressive wetting of the bentonite upon water uptake from the host rock will be followed by the expansion of the bentonite and the consequent filling of technological gaps in the systems. Drying of the buffer may arise from the temperature increase within the repository. In this sense, the cyclic water retention behaviour of the compacted bentonite is a fundamental aspect to be considered in order to make analyses of the long-term behaviour of the repository. This paper discusses a new methodology that was developed to obtain water retention curves with high resolution and reproducibility (Seiphoori *et al.* 2014). The method provides measurements of the total suction of the swelling bentonite under constant volume condition. The method also provides representative samples for microstructural investigations by mercury intrusion porosimetry (MIP) analysis and scanning electron microscopy (SEM) observations during the different hydraulic paths. These combined features allow to establish a link between the cyclic water retention behaviour and the evolution of the microstructural characteristic of the bentonite.

Materials and methods

The bentonite used in this study is the MX-80 (Wyoming) granular bentonite (smectite content $> 85\%$). The bentonite is statically compacted at a target dry density of 1.8 Mg/m^3 . A rigid cell made of brass holds specimens with a height of 7 mm and a diameter of 30 mm. The cell consists of two parts that are connected by a thread lid to provide constant volume conditions during the hydration process. The top and bottom of the cell are perforated to provide for the possibility of water exchange in vapour or liquid form with the surrounding environment. After each equalization stage, the total suction is measured with a WP4C (Decagon Device, Inc.) dew point chilled-mirror potentiometer. The cell has been designed to be placed directly into the psychrometer. Specimens are prepared by compacting the material at the target dry density and water content directly into the cell. The initial total suction is read with the psychrometer. A wetting path is then performed by placing the cell in a controlled temperature chamber with an imposed relative humidity of 100% and by monitoring the water content with a precision balance. For each equalization stage, the cell is then sealed and cured for three days at a controlled temperature to ensure the homogenization of the water in the specimen. Total suction is then measured with the psychrometer. For the drying paths, the specimen in the cell is air-dried under laboratory conditions ($T = 22^\circ\text{C}$, $\text{RH} = 34\%$) or it is placed in a desiccator with a saturated salt solution. MIP tests and SEM observations were performed on specimens at different steps of the retention analysis.

Results

Figure 1 presents the cyclic water retention behaviour of the MX-80 granular bentonite along wetting and drying paths. The compacted specimen ($\rho_d = 1.80 \text{ Mg/m}^3$) was wetted in steps until full saturation was reached (path A–D). The main drying was then initiated until a suction value of 95 MPa was achieved (path D–E). A new wetting path (E–F) was then carried out. A second drying was then initiated until a suction of 174.5 MPa was reached (point G), and a final wetting was performed until a degree of saturation of 0.95 was obtained (point H). The first (D–E) and second drying paths (F–G) are aligned, whereas after the first wetting (A–D), the material does not follow the initial wetting curve, and a new main wetting curve is created (G'–H). Figure 1 shows that the material undergoes a significant and irreversible change in its water retention behaviour during the first wetting. After the first saturation (point D), the water retention capacity of the material increases in the sense that more water can be stored in the bentonite for a given suction in a wetting path. In order to understand the change in the water retention behaviour, MIP tests were carried out at different stages of the hydraulic paths. Figure 2 shows the pore size density (PSD) functions revealed by the MIP tests at different points of the water retention curves. The material in the as compacted state (A) exhibits a bimodal pore size distribution with the inter-bentonite assemblage pores (macropores) and the intra-grain

along with the intra-aggregate pores that constitute the micropores. This bimodal distribution is typical of granular bentonite, independently from the compaction method (Ferrari *et al.* 2014). During the first wetting, the PSD functions show a decrease in the macropore volume. At the fully saturated condition (D) a significant reduction of the macropores is observed due to the further hydration of the bentonite assemblages. As to the drying path, the PSD functions exhibit a single porosity distribution similar to the one obtained at full saturation (D). These observations show a significant and permanent modification of the bentonite fabric with respect to the as compacted state. This structural alteration is also perceptible in the SEM analyses (Seiphoori *et al.* 2014).

Figure 1 Cyclic water retention behaviour of compacted MX-80 granular bentonite ($\rho_d = 1.8 \text{ Mg/m}^3$).

Figure 2 Evolution of the microstructural features of the compacted bentonite during the wetting and drying paths.

Conclusions

An improved methodology was presented to analyse the water retention behaviour of compacted MX80 bentonite in cyclic wetting and drying paths. The water retention behaviour of the compacted MX80 revealed an irreversible modification of the water retention domain through the creation of a second main wetting path after the material approached full saturation. The new hydraulic domain was observed to be permanent for the following wetting and drying cycles and directly associated to the irreversible changes of the MX80 microfabric.

References

- Ferrari, A., Seiphoori, A., Rüedi, J. and Laloui, L. [2014] Shot-clay MX-80 bentonite: an assessment of the hydro-mechanical behaviour. *Engineering Geology*, **173**, 10-18.
- Seiphoori, A., Ferrari, A. and Laloui, L. [2014] Water retention behaviour and microstructural evolution of MX-80 granular bentonite during wetting and drying episodes. *Geotechnique*, **64**(9), 721-734.