Measurement of Swelling Pressure for Bentonite under Relative Humidity Control

Tomoyoshi Nishimura, Junich Koseki, and Masafumi Matsumoto

Abstract. Several experimental producers including using suction control to interpret swelling pressure for compacted bentonite have become generally accepted in geo-environmental engineering. This study focuses on both soil-water characteristic curve and swelling pressure of compacted bentonite. Soil-water characteristic curve was measured using vapour pressure technique. Compacted bentonite having two different soil suctions were prepared for swelling pressure tests. This new swelling pressure testing apparatus was developed in order to measure swelling pressure in a constant relative humidity environment. The apparatus was mainly consisted of the triaxial chamber and relative humidity control circulation system. The total volume of compacted bentonite was maintained constant during absorption process. This study demonstrates the influence of soil suction on swelling pressure under permitted adsorbed water into the compacted bentonite. Change of soil suction influenced the maximum swelling pressure of compacted bentonite.

Keywords: soil suction, bentonite, soil-water characteristic curve, swelling pressure, relative humidity.

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1 Introduction

Several experimental procedures to interpret shear strength, volume change and seepage hydraulic conductivity for unsaturated soils have become generally accepted in geotechnical and geo-environmental engineering. Soil suction or total suction corresponds to the free energy of the soil water and is comprised of two components identified as matric suction and osmotic suction (Krahn & Fredlund 1972). Delage et al. (1987) successfully used the osmotic technique to investigate unsaturated soil behaviour. The vapour pressure technique is used in the triaxial test apparatus for determining the unsaturated soil parameters. Several papers have reported modified shear testing devices to determine the shear strength of unsaturated soils over the last several decades (Blatz & Graham 2000, Nishimura & Fredlund 2001).

This study focuses on both soil-water characteristic curve and swelling pressure of compacted bentonite with high soil suctions. A new swelling pressure testing apparatus was developed to determine swelling pressure in a constant relative humidity environment. The apparatus consists of a triaxial chamber and relative humidity control circulation system. This study demonstrates the influence of soil suction on the swelling pressure under permitted absorbed water into the compacted bentonite. Soil suction used in this paper means total suction.

2 Test Procedure

2.1 Soil Material

Sodium bentonite was in for this test program. Silica sand was mixed with bentonite at a ratio of 30 % by dry weight. The specimen was statically compacted in rigid steel mold at an initial water content of 5.9 %. The compacted bentonite specimen had a dry density of 1.6 g/cm^3 as target value. The height of specimen was 25.5 mm. Also the diameter of specimen was 60.0 mm. Soil suctions of both compacted bentonite and salt solutions were measured directly using a chilled mirror dew point potentiometer (WP4-T of DECAGON DEVICES).

2.2 Modified Swelling Pressure Apparatus

The modified swelling pressure testing apparatus consisted mainly of a triaxial chamber, a pedestal, a steel mold, a double glass burette, a differential pressure transducer, a difference displacement sensor, load cell sensor and relative humidity control circulation system. The relative humidity control circulation system is established using a conventional pump, along with a small chamber with salt solution. The air flow maintained a constant relative humidity surrounding the compacted bentonite.

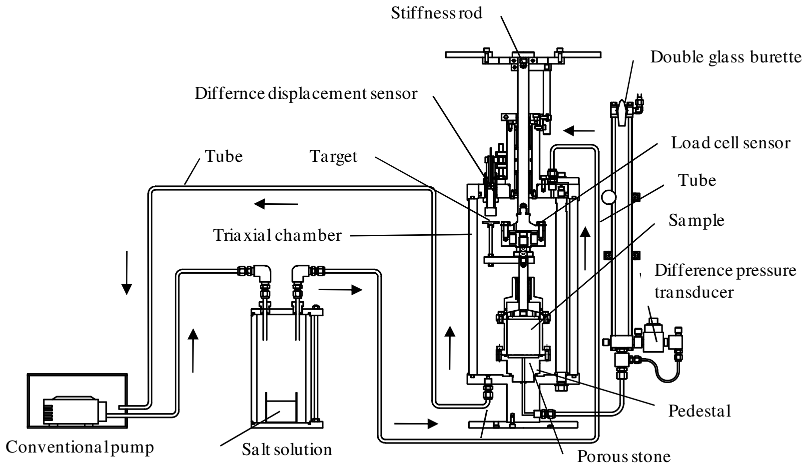

Fig. 1. Newly modified swelling pressure apparatus.

Fig. 1 shows the modified swelling pressure testing apparatus. All compacted bentonite specimens were placed into steel mold. Inflow from the double glass burette due to absorption was allowed from the low portion of specimen. Absorption water volume change in the double burette was measured using the differential pressure transducer. Initial total volume was maintained constant for all compacted bentonite specimens.

2.3 Testing Program

The soil-water characteristic curve is measured in this testing program. The small samples were put on glass contains that were placed in the glass desiccators with salt solutions for at least one month. The initial sample had a diameter of 2.0 cm and a height of 1.0 cm, respectively. The salt solution created the equilibrium relative humidity. After all samples have achieved equilibrium condition, both the gravimetric water content and volume deformation were measured.

Compacted bentonite specimens with two different soil suctions were prepared for swelling pressure tests. Initial compacted bentonite had a soil suction of 105 MPa. Soil suction of 2.8 MPa was imposed using vapour pressure technique. Soil suction of 2.8 MPa corresponds to relative humidity of 98 %. The gravimetric water content changed due to effect of relative humidity. The gravimetric water content of the compacted bentonite sample subjected to relative humidity of 98 % increased to 9.7 % from 5.9 %. Also, expansive deformation was induced when soil suction was decreased resulting in a vertical strain of 9.5 %. The dry density of the sample having soil suction of 2.8 MPa decreased to 1.427 g/cm^3.

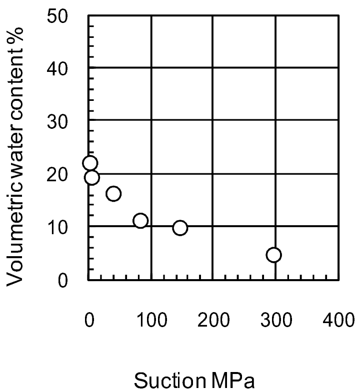

Fig. 2. Soil-water characteristic curve of compacted bentonite.

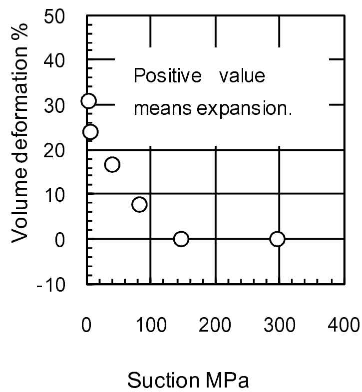

Fig. 3. Relationship between volume change and soil suction of compacted bentonite.

3 Test Results

3.1 Soil-Water Characteristic Curve

Relationship between gravimetric water content and suction of the compacted bentonite is shown in Fig. 2 as a soil-water characteristic curve. The bentonite had a gravimetric water content of 2 % at a suction value of 296 MPa. The soil suction at 105 MPa corresponds to initial gravimetric water content of 5.9%. Volume deformation with soil suctions are shown in Fig.3. The expansions increased with decreasing of soil suction.

3.2 Swelling Behaviour

Swelling pressure tests under constant volume were conducted on compacted bentonite specimens. Fig. 4 shows the swelling behaviour of compacted bentonite at initial water content of 5.9 % with an initial soil suction of 105 MPa. The swelling pressure increased rapidly at the beginning of the absorption phase. The swelling pressure remained increasing till elapsed time was 75 hours and reached swelling pressure of 353 kPa. Subsequently, the compacted bentonite decreased in swelling pressure. The swelling pressure indicated minimum value near elapsed time of 350 hours. The swelling pressure increased smoothly after the swelling pressure achieved a minimum value.

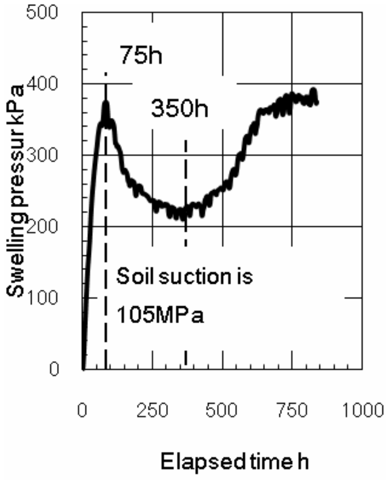

Fig. 4. Variation of swelling pressure for soil suction of 105 MPa.

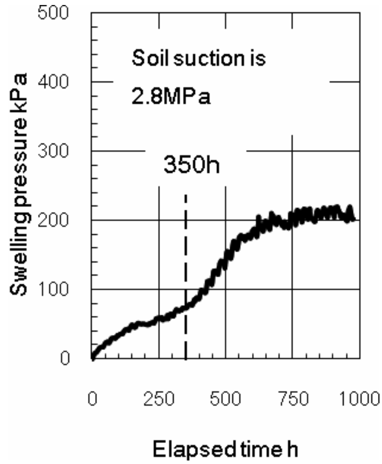

Fig. 5. Variation of swelling pressure for soil suction of 2.8 MPa.

Table 1. Summary of swelling pressure tests.

Sample	Initial	1
Soil suction before swelling test MPa	105	2.8
Maximum swelling pressure kPa	376.3	206.9
Total absorption water cc	31.4	35.6
Gravimetric water content after swelling test %	31.1	38.7

It is observed that swelling pressure become steady condition at 750 hours. Swelling pressure of 376.3 kPa was measured at end of test. The compacted bentonite with soil suction of 2.8 MPa shows smoothly increasing swelling pressure at beginning of test to the elapsed time of 350 hours. This behaviour is shown in Fig. 5. Subsequently, inclination of swelling pressure becomes to be large. The swelling pressure approached steady state similar to the characteristic observed in the compacted bentonite with soil suction of 105 MPa as previously mentioned. The variation of swelling pressure was influenced by soil suction of compacted bentonite before swelling. Particularly, the compacted bentonite having soil suction of 2.8 MPa showed smoothly increasing swelling pressure compare to initial soil suction.

Maximum swelling pressure and total absorption water obtained from swelling pressure tests are summarized in Table 1. In case of initial compacted bentonite specimen maximum swelling pressures are larger than bentonite with soil suction of 2.8 MPa. Due to decreasing soil suction maximum swelling pressure decreased. There is a reduction of 169.4 kPa between initial compacted bentonite and bentonite with soil suction of 2.8 MPa, and reduced to 45 % in maximum swelling pressure according to decreasing of soil suction. The gravimetric water contents at end of swelling tests were presented in Table 1. Measured gravimetric water contents ranged from 31.1 % to 38.7 %. All samples approached to saturation.

4 Conclusions

The soil-water characteristic curve of compacted bentonite was determined as relationship between volumetric water content and soil suction. Volume expansions increased with decreasing of soil suctions. Before swelling pressure test, dry density of compacted bentonite decreased with decreasing soil suction. The maximum swelling pressure is less than that of bentonite with initial soil suction. This shows the influence of soil suction on the swelling pressure. The compacted bentonite approached saturation regardless of soil suction before swelling.

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References

Blatz, J.A., Graham, J.: A system for controlled suction in triaxial tests. Geotechnique 50(4), 465–469 (2000)
Delage, P., Suraji De Silva, G.P.R., De Laure, E.: Un novel appareil triaxial por les sols non-satures. In: Proceedings of 9th ECMFE, Dublin, vol. 1, pp. 25–28 (1987)
Krahn, J., Fredlund, D.G.: On total matric suction and osmotic suction. Journal of Soil Science 114(5), 339–348 (1972)
Nishimura, T., Fredlund, D.G.: Failure envelope of a desiccated, unsaturated silty soil. In: Proceedings of the 15th International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, August 27-31, vol. 1, pp. 615–618 (2001)