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Swelling pressure for bentonite-sand mixture subjected to drying and wetting application

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ABSTRACT

This study focuses on the effect of suction for bentonite-sand mixture through a series of testing programs, and consist of measurement variety of water content distribution, evaluation of the reduction of unconfined compressive strength under not uniformity distribution of suction in the soil, determination of soil-water characteristic curve on high suction ranges and providing for swelling pressure associated to chemical components. The summary of obtained results is relevant to for deep geological disposal with a multi-barrier system, and provide as hydration-mechanical-chemical phenomena. Materials used for this testing program are sodium bentonite, calcium bentonite and the different silica sands. Vapor pressure technique was used to control high suction which is recognized one of high suction control method, and salt solutions are prepared. Also, salinity water (i.e. salt water) was used to compare to measurement of swelling pressures for calcium bentonite subjected to suction increment and decrement due to distilled water absorption.

Keywords: Swelling pressure, bentonite, suction, relative humidity, drying-wetting

1 INTRODUCTION

Deep geological disposal with a multi-barrier system such as artificial barrier has been recognized as significant useful strategy for the safe disposal of radioactive waste. Compacted bentonite-sand mixture sample can occur some damages with/within continuously due to changing potential such as absorbed seepage, various relative humidity and thermal heating. On previous works, thermal-hydraulic-mechanical-chemical properties have been investigated for unsaturated-saturated bentonite or unsaturated-saturated bentonite-sand mixture, which is important material for artificial barrier. It is possible that unsaturated bentonite-sand mixture probably has suction change during a long period.

Pan et al. (2011) decided the effort of pH, ionic strength as chemical factor to Na-type bentonite on chemical properties opinion. Produced pressure according to seepage and accumulated swelling deformations on phenomena is not so difficult to estimate for limited dry density ranges. Ying et al (2021) attempted to understand the salinity effect on mechanical properties that mechanical properties developed by compaction application is obviously importance for management of safety. Many factors influence on thermal-hydraulic-mechanical-chemical properties for bentonite-sand mixture, and to study is required with selected significant key feature for interpretation. To investigate swelling pressure measurement for bentonite-sand mixture subjected to increment/decrement in suction often not consider in couple phenomena.

This study has aim to appear that swelling pressures of bentonite-sand mixture subjected suction changes in repeatable that drying-wetting application in suction apply using vapor pressure technique in order to determine soil-water characteristic curve using water content, dry density and degree of saturation such as volumetric parameters. Swelling pressure measured in overall volume constant with two different seepage waters, which was distilled water and salinity water (i.e. salt water). Comparing, increasing of swelling pressure associated to suction increment and dry density increment for bentonite-sand mixture. As one of serious of testing program, through a previous testing program, investigation to soil moisture distribution and alternation of stress-strain properties induced by suction controlling are provided, and consider the effort of suction.

2 TEST PROCEDURE

2.1 Soil materials and specimens

This study used two different bentonite and three different sands, and one bentonite is sodium bentonite that other one is calcium bentonite. Two bentonites have high content of montmorillonite component. Also, three different sands are classified as silica sand, and each sand named as Misawa sand, Silica No. 3 and Silica No. 5. All of silica sands have highly unique grain size distribution. Air-dried bentonites and sands were humidified by spraying deionized water to reach confirmed water contents on this testing program. In addition, non-plastic silty soil was prepared with water content of 10.0 %. This testing program compose soil-water characteristic curve test, swelling pressure test, distribution of water content measurement test and unconfined compression test. Each test program require to variety of testing such as difference specimen size and difference dry densities.

Swelling pressure test and SWCC test prepared calcium bentonite, Sand with water content of 20.0 % that a height and a diameter are 20 mm and 60 mm, respectively. Water content distribution measurement test used bentonite, non-plastic silty soil and silica sand with No. 3 and No. 5. Prepared water content is 18.0 % for sodium bentonite-sand mixture and 10.0 % for non-plastic silty soil, respectively. Each physical component has many test results in laboratory tests.

2.2 Testing program and apparatus

This study conducted out three testing programs, which are soil-water characteristic curve test, swelling pressure test, water content distribution measurement test and unconfined compression test. The water content distribution measurement test aims to investigate the effort of difference relative humidity using vapor pressure technique that two differences relative humidity apply to upper portion and bottom portion. After approach certainly equilibrium to each suction value in the specimen, water content distributions with axial direction were determined using a developed mold. The upper portion and bottom plates of mold connected air circulation system that air flow produced by conventional pump, the air able to control required relative humidity due to vapor pressure technique.

To conduct out unconfined compression test for specimen subjected to different suction value is effectively to estimate the influence on changing of void structure and mechanical properties. For soil-water characteristic curve test the calcium bentonite-Misawa sand mixture was used, a dry density was 1.650 Mg/m^3 with water content of 20.0 %. Vapor pressure technique in glass desiccator is useful to determine water content and overall volume correspond to suction, which suctions have a range from 2.8 MPa to 296 MPa. Drying stage and wetting stage are applied repeatable application. Beyond decision of soil-water characteristic curve, swelling pressure measurement was performed using a swelling pressure apparatus. Overall volume of the specimens is remained constant that is same to initial volume through swelling pressure test. The influence of chemical component in seepage water investigated due to comparison between distilled water and salinity water with concentration of 0.8 %.

3 TEST RESULTS

3.1 Distribution of water content subjected to two different suctions

This study investigated that distribution of water content using sodium bentonite and calcium bentonite when vapor pressure applied to produce some suctions, and a series of suction control test supplied 98 %, 93 %, 54 % and 11 % in relative humidity for three different dry densities. Each relative humidity maintained at least one month that water content corresponding to distance from upper surface of the specimen was shown in Fig. 1. Relative humidity at upper portion of the specimen is larger than that at bottom portion, and the described three straight lines provides information on the distribution of water content in the specimen.

Water content is close to subjected to magnitude of various relative humidity, and amount of soil moisture in the specimen decrease according to approaching bottom portion. The effect of relative humidity is obviously to the changing of water content. It is possible to be assumption the relationship between distance from upper potion and water content. The relationship is defined as straight line, which have some inclines. In case of dry density of 1.600 Mg/m^3, the incline estimated as 0.08 % per mm, and the incline found that vapor pressure technique made equivalent uniformity water distribution, if soil sample is applied relative humidity control under surrounding.

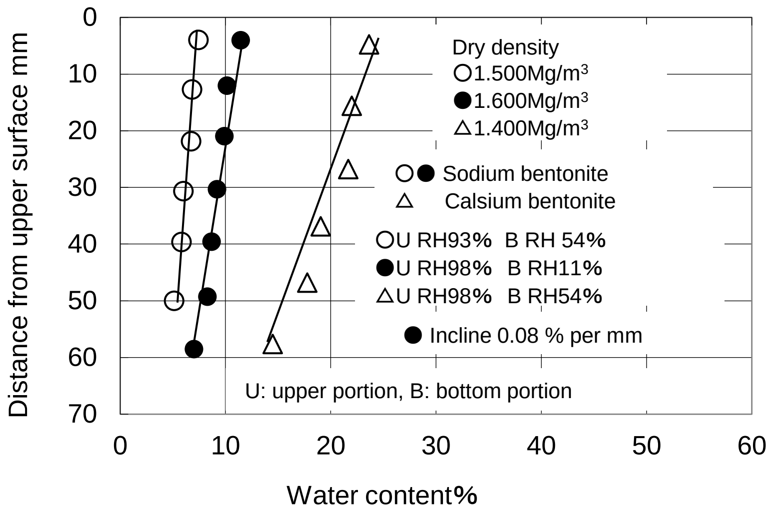

Figure 1. *Distribution for water content*

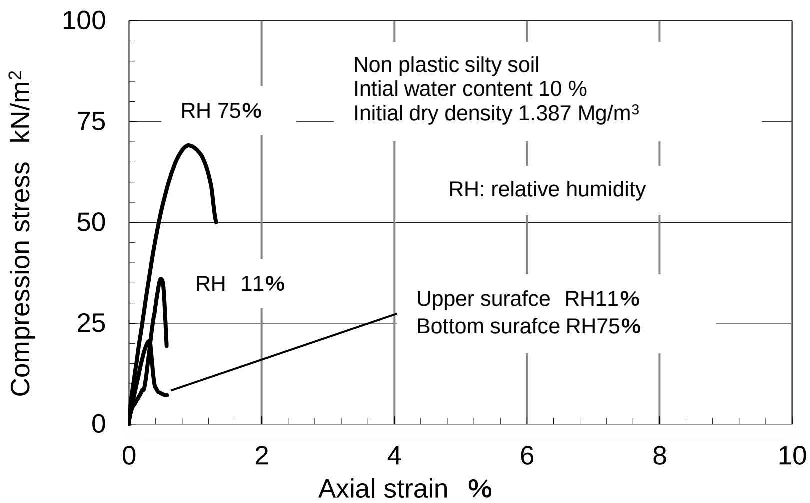

Figure 2. *Stress-strain curve for RH 75 % and RH 11 %*

The unconfined compression test for non-plastic silty soil, which had a not uniformity water content distribution by different relative humidity control technique in similar with above suction controlling. Before unconfined compression test, deterring a water content distribution line to 75 % and 11 % in relative humidity. SWCC describes that 11 % produce the further dry condition. Stress strain curves obtained from unconfined compression test are shown in Fig. 2. Controlling period is approximately one month at 20 degrees Celsius. Comparison of stress stain curves indicated reduction of strength. When difference relative humidity is used at upper portion and bottom portion to specimen, the stress strain behaviour provides small compression stress and small strain at failure, comparison with other two samples. Whole relative humidity is 75 %, unconfined compressive strength is 66.6 kPa and the strength decease to 18.5 kPa. As result, further reduction undergoes according to be no uniformity associated to suction distribution. It is able to consider that no uniformity of suction and water content in the void structures respond the decreasing of shear resistance.

3.2 Soil water characteristic curve under drying-wetting path

Understanding the changes in water content, dry density and degree of saturation due to suction that is the interpretation of the SWCC test data. It is clear that the soil-water characteristic curve data without drying-wetting cyclic performance (Ng et al., 2023) is not accurate for representation for the soil material in situ condition. Rather, the laboratory test measured SWCC data corresponds to a particular test procedure. It is, however, the SWCC including drying -wetting cyclic performance has proven to be of

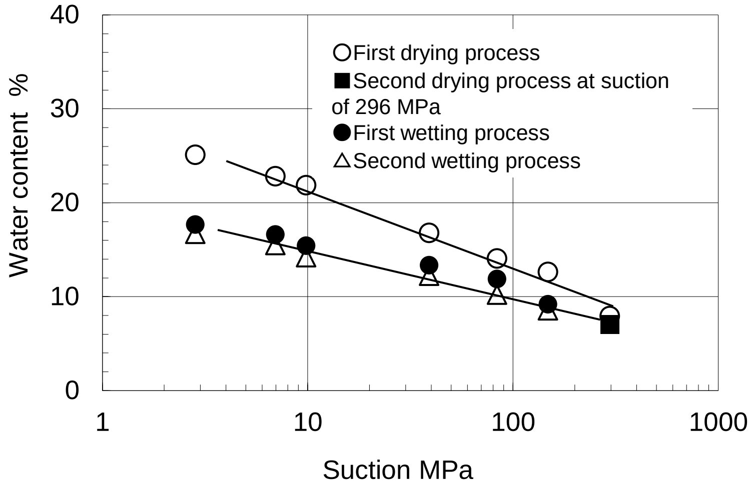

Figure 3. *SWCC verified by water content*

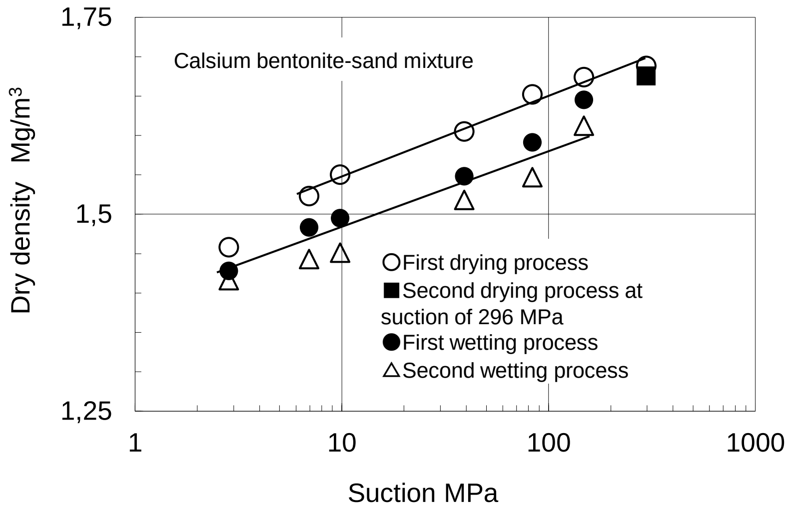

Figure 4. *Variation in dry density with suction*

significant data sets as an accurate guide for the prediction of compacted, unsaturated bentonite-sand mixture properties functions.

The SWCC laboratory test procedure using vapor pressure technique with seven difference salt solutions commences with the unsaturated calcium bentonite-sand mixture, which is a diameter of 60 mm and a height of 20 mm at initial condition. The specimen then begins to desaturate and absorbed according to subjection of drying-wetting in repetitions. The desaturation stage and wetting stage along the drying branch and wetting branch of the SWCC is shown in Fig. 3. Two stages (i.e. drying stage and wetting stage) can be clearly defined on a plot of water content versus logarithmic of suction. The entire picture of calcium bentonite-sand mixture behaviour is clearly understood when the SWCC data sets are indicated from 1.0 MPa to 296 MPa in suction value.

Firstly, when suction is 2.8 MPa in drying stage, water content is 25.2 %, and when suction is 296 MPa, water content is 7.9 %. After drying-wetting cyclic performance, decreasing of water content is refereed and water content of 16.7 % at suction of 2.8 MPa and water content of 7.0 % at suction of 296 MPa. It is estimated that broken line is established in logarithmic scale. The interpretation of SWCC is often based on the assumption that the overall volume change for soil specimen is negligible during drying-wetting stage. On department of agriculture, soil moisture correspond suction is of further importance and the volume change of the soil is of little opinions. Other hands, for geo environment engineering solutions, the amount of volume change and variety of void structure can be of significance while interpreting experimental laboratory test. Dry density corresponding to suction is verified as identified factor to SWCC, and change of dry density is provided as shown in Fig. 4 for initial dry density of 1.600 Mg/m^3.

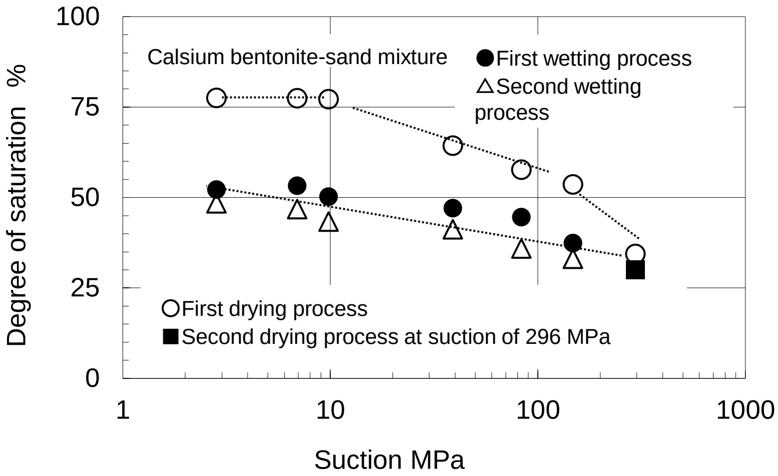

Figure 5. *SWCC verified by degree of saturation*

The distinctive feature that increment of dry density due to suction increment and decrement of dry density on wetting branch is provided. The specimen in wetting stage at suction was 2.8 MPa that remove from 1.600 Mg/m^3 as initial condition to 1.418 Mg/m^3. Decreasing of dry density subjected to drying-wetting cyclic performance that variations of void structure for bentonite-sand mixture is clearly designated.

Degree of saturation is prepared as factor including both soil moisture changes and overall volume change that is plotted on suction as shown in Fig. 5. It is similar in shape to a plot of water content versus suction as shown in Fig. 3 with same suction ranges. The wetting stage remains small incline comparison with drying stage and addition, the degree of saturation decreases drying-wetting cyclic application. Also, degree of saturation versus logarithmic of suction indicated certainly slope with distinct break for suction 10 MPa. The results show that all bentonite-sand mixture specimen seems essentially to produce one unique line for suction cyclic application.

3.3 Swelling pressure with suction changes

The laboratory measurement of swelling pressure has been focussed several research studies, which variety of test conditions have proposed as following; dry density, either sodium or calcium type for bentonite, influence of salinity components and magnitude of external loading pressure. In addition to measuring the swelling pressure using the constant volume, free-swell testing procedure and permit swelling deformation with external loading pressure.

Swelling pressure measurement conducted out using calcium bentonite-sand mixture under constant volume condition, which were specimens subjected to drying-wetting cyclic as shown in Figs. 3 to 5. These specimens have variety of water content that is range from 7.0 % to 16.7 % and dry density is a range from 1.418 Mg/m^3 to 1.675 Mg/m^3. Then, limitation of two suction (i.e. 6.9 MPa and 296.0 MPa), the salinity water was used for seepage water in hydration phenomena and the concentration is 0.8 %. Seepage water is distilled water with exception of suction 6.9 MPa. The results that swelling pressure measurement using distilled water increased with suction as shown in Fig. 6 and the swelling pressure resulted in straight line corresponding to logarithmic suction over suction of 9.8 MPa. When suction was

296 MPa, swelling pressure is 2849.5 kPa. Other hands, swelling pressure is 429.5 kPa when suction is 2.8 MPa. It is approximately over six times comparison between 296 MPa and 2.8 MPa in suction value. Swelling pressure measurement performed a similar procedure using the salinity water for suction of 6.9 MPa and 296 MPa that the results plotted to logarithmic suction. It is verified that the influence of salinity component induced reduction of swelling pressure without effort of magnitude of suction. Regard to suction of 296 MPa, producing a reduction is from 2849.5 kPa to 1630.3 kPa (i.e. 1219.2 kPa in difference). Assumption that suction of 6.9 MPa predict as 583 kPa in distilled water seepage, and the decreasing allow to 261.7 kPa due to the salinity effect.

Several identical factors have been mentioned for interpretation of swelling pressure and dry density are considered in this study as shown in Fig. 6. Eight definitions of swelling pressure can be found that dry density vary from 1.416 Mg/m^3 to 1.675Mg/m^3. The relationship between dry density and swelling

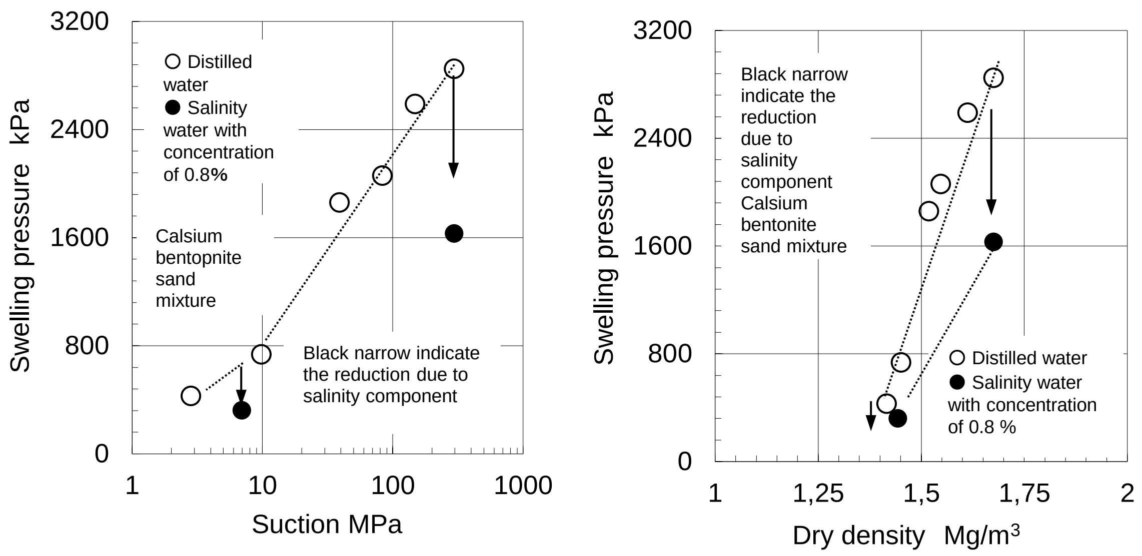

Figure 6 (a) and (b). *Swelling pressure with suction or dry density*

pressure is defined that swelling pressure increase according to dry density increment, and it find both distilled water and salinity water for seepage water. It is possible to define two swelling pressure curves in Fig. 6, which are seem to see broken line on logarithmic suction. Two slopes are compared that swelled specimens due to distilled water have large swelling pressures than that in case of salinity water seepage performance. Suction, dry density and salinity are need to measure or estimate for the swelling pressure of bentonite-sand mixture subjected to drying-wetting cyclic performance.

4 CONCLUSIONS

This study verified hydraulic-mechanical-chemical phenomena for bentonite-sand mixture that a series of testing program consisted of suction controlling test, water retention test, unconfined compression test and swelling pressure associated drying-wetting process in suction. The controlling suction range has from 2.8 MPa to 296 MPa. The obtained results are summarized as following;

(1) Unique water content distributions are produced in the specimen, when two difference suction are applied using vapor pressure technique. The specimen established water content distribution indicated that the unconfined compressive strength provided further reduction.
(2) Drying-wetting process in high suction produced the reduction of soil moisture volume, and then volume shrinkage indicated the increment of dry density in observation of soil-water characteristic curve. It is common that hysteresis phenomena have obviously at all of suction ranges.
(3) Swelling pressure for bentonite-sand mixture subjected to drying-wetting performance described certainly that increased with dry density and suction increment. The influence of chemical components is determined that swelling pressures decrese further due to salinity water, and it is regardless of dry density.

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