Influence of shear speed on hydro-mechanical behavior for compacted bentonite

Tomoyoshi Nishimura

Professor, Department of Civil Engineering, Ashikaga Institute of Technology, 268, Omae, Ashikaga, Tochigi, 326-8558, Japan.

ABSTRACT

Safety of great deep repository design has been considered for high level radioactive waste disposal system in several countries such as Belgium, Canada, China, France, Germany, Japan, Sweden and Switzerland etc. The repository of the disposal is in most cases based on the aspect of multi-barrier system such as the natural barrier formation (i.e., host rock) and engineered barrier formation consisting of compacted bentonite. This study focuses on hydro-mechanical behavior of compacted sodium bentonite, and three different tests such as swelling test, one-dimensional compression test and constant vertical stress direct shear test were performed with suction control using vapor pressure technique. Also, a modified direct shear apparatus installed RH air circulation system was used in the direct shear test.

Keywords: bentonite, shear speed, suction, direct shear strength

1. INTRODUCTION

Safety of great deep repository design has been considered for high level radioactive waste disposal system in several countries such as Belgium, Canada, China, France, Japan, Sweden and Switzerland etc. The repository of the disposal is in most cases based on the aspect of multi-barrier system such as the natural barrier formation (i.e., host rock) and engineered barrier formation consisting of compacted bentonite. The mechanical behavior of compacted bentonite is strongly affected by some couple problems (Cui and Tang, 2013). In field, tests on long-term have been performed or investigated in different Underground Research Laboratory for identifying the key factors related to hydro-mechanical behaviour (Sanchez et al. 2012). A concept of unsaturated mechanics is well available to understand the properties of compacted bentonite subjected to complex couple problems, and then the aspect can provide rational engineering solutions (Alonso et al. 2013). This study focuses on hydro-mechanical behavior of compacted sodium bentonite, and three different tests such as swelling test, one-dimensional compression test and constant vertical stress direct shear test were performed with suction control using vapor pressure technique. Also, a modified direct shear apparatus installed RH air circulation system was used in the direct shear test.

Fig. 1. Change of swelling pressure.

2 SWELLING PROPERTIES

Sodium bentonite was used for this test program which SiO$_2$ occupied 62 % to all chemical components. All specimens were statically compacted for a dry density of 1.6 g/cm$^3$ as target value, and water content was regulated from 5.9 % to 6.0 %. Two different series were conducted out which consisted of standard swelling tests and suction control swelling tests. Standard swelling test was conducted for compacted bentonite with sand mixture, and swelling pressure was measured on long period. The initial sample was a height of 2.5 cm, and a diameter of 6 cm. During tests, vertical deformation remained stationary (i.e., remained an initial height of specimen). Figure 1 shows the change of swelling pressure for three specimens with days. At emplacement in de-air water, swelling pressure increased rapidly till eighteen days and the rate of increment of swelling pressure decreased with days. There was small reduction of swelling pressure behind each peak swelling pressures that all specimens had.
equilibrium over one month. It was found that different between maximum and minimum in swelling pressure at end of test was almost 0.7 MPa. In addition, swelling test imposed suction control was conducted, and then volume strain and change of adsorbed water were measured. All specimens were statically compacted without sand mixture which had an initial suction of 105 MPa (Nishimura et al. 2010).

Vapor pressure technique using Potassium Sulfate ($K_2SO_4$) induced RH 98% in a glass desiccator. The specimen was placed in RH 98%, which corresponded to suction of 2.8 MPa at 20 degrees. Figures from 2 to 4 show swelling behavior of bentonite subjected to hydration loading. At beginning of decrement of suction, bentonite provided rapidly expansion. According to days, expansion became to be steady state that remained constant in long term. Water content of bentonite increased due to absorbed effort as shown in Fig. 3. Change of measured water content was similar to that of volumetric strain mentioned in Fig. 2. Also, degree of saturation involving of change volume strain and water content described increment as shown in Fig. 4, and a steady state was observed after twenty days.

3 COMPRESSION PROPERTIES

This study performed one-dimensional compression tests on compacted bentonite with sand mixture. The initial specimen with water content of 5.9 % had a diameter of 6 cm and a height of 2.5 cm. Prescribed suctions were 105 MPa, 2.8 MPa and zero value (i.e. saturated condition). In case of suction of 2.8 MPa, suction was declined from suction of 105 MPa by means of RH 98 %. Also, suction of zero was produced due to swell in de-aired water. The saturated specimen in de-air water was maintained a constant initial height during soaking. The swelling period was at least over than one month. The specimen was loaded and unloaded in the ranged from 20 kPa to 1000 kPa.

Figure 5 shows compression curves for three different suctions namely, initial compacted bentonite, suction of 105 MPa, 2.8 MPa and 0 MPa (i.e., saturation). Both loading path and unloading path were performed to determine compression index and swelling index. Suction of both 105 MPa and 0 MPa showed a slight reduction of void ratio through loading path. For suction of 2.8 MPa, the specimen provided a distinct expansion due to suction hydration prior to compression test. It was predicted from perspective on soil structure that macro-micro pore distribution and soil moisture distribution were considerable different with initial structure of sample. After compression stress was over 40 kPa, reduction of void ratio was large, and the curve was seemed to be liner on a semi-logarithmic scale. Subsequently, expansive deformation was measured at unloading path. Measured compression index of suction of 2.8 MPa was largest among other two bentonite specimens which its value was 0.47.
4 SHEAR PROPERTIES WITH DIFFERENT SUCTIONS AND SHEAR SPEEDS

The specimen with sand mixture was statically compacted in the shear box under a compression stress of 3.5 MPa, and had an initial water content of 5.9 %. The specimen corresponding suction of 105 MPa had a dry density of 1.6 g/cm$^3$, a diameter of 6 cm and a height of 2.5 cm. The specimens were applied two different suctions of 2.8 MPa and zero value similar to compression test. All specimens controlled suction was installed in the modified direct shear apparatus (Nishimura and Koseki, 2013) as shown in Fig. 6 and a normal stress of 200 kPa was loaded. The modified direct shear apparatus was possible to maintain constant suction for specimen. Suction was imposed using a vapor pressure convection circuit connected to the cell and controlled by conventional air pump. Air circulation flowed through the chamber of direct shear apparatus, which was maintained at relative humidity of 98 % for remaining an ideal condition. In case of saturated specimen, the de-aired water was supplied in the chamber till the water level approached upper surface on specimen. This preparation is capable to maintain saturation condition during shear process. Direct shear tests were performed for different shear speeds (i.e., 0.004, 0.05, 0.25 and 0.5 mm/min) under constant normal stress of 200 kPa.

Shear properties involving dilations were shown in Figs. from 7 to 9 for four different shear speeds. These behaviors were capable of interpretation that increment of shear stress at initial shear stage was strongly effect of suction. Also, anomalous behavior was observed in results for both shear stresses and dilations. Particular, few results in shear behavior indicated to be extreme small increment. In case of suction of 105 MPa, both shrinkage and expansion in dilation phenomena were recorded that at suction of 2.8 MPa, shrinkage behavior was only observed for all shear speeds. Dilation of saturated bentonite was remarkable small compare with two different suctions, and described slightly shrinkage and expansion through shearing.

Figure 10 shows variation of shear strength with suction and shear speed. The shear strength of suction of 105 MPa was largest among three different suctions that it was provided a significant effect of suction on shear strength for compacted bentonite subjected
hydration. As unsaturated compacted bentonite such as suction of 105 and 2.8 MPa, shear strength decreased when shear speed increased from 0.004 mm/min to 0.5 mm/min. The bentonite with suction of 105 MPa exhibited a sensitivity of shear speed response. The saturated bentonite, however, indicated the different effort of shear speed on shear strength compare with unsaturated bentonite. The shear strength of saturated bentonite maintained almost constant regardless of shear speed. Eventually, relationship between shear strength and shear speed for compacted bentonite was difference between unsaturated condition and saturated condition.

5 CONCLUSIONS

This study focuses on hydro-mechanical behavior of compacted bentonite in order to assess rational engineering solutions. Three different tests such as swelling test, one-dimensional compression test and constant normal stress shear test were performed with imposing suction control. Summarized of test results were described as following:

1) Decreasing of suction induced a distinct volume expansion of compacted bentonite, and then water content increased simultaneously. Steady state of these behaviors was observed over twenty days.

2) The compacted bentonite equilibrated at lower suction exhibited remarkable increment of compression index in one-dimensional compression test.

3) Compacted bentonite at high suction showed a significant increment of shear stress at initial shear stage in direct shear test, and decreasing of suction described pronounced decrement of shear strength.

4) Dilation due to direct shearing was anomalous behavior in unsaturated condition, and also swelled saturated bentonite exhibited slightly dilation.

5) Shear resistance of unsaturated compacted bentonite depended on shear speed, and its value decreased smoothly at high shear speed. However, the influence of shear speed on swelled bentonite became to be slightly, and its influence was possible to neglect.

ACKNOWLEDGEMENTS

This research was supported by a research grant-in-aid of Ashikaga Institute of Technology, Japan.

REFERENCES

1) Alonso, E.E., Zandarin, M.T. and Olivella, S. (2013): Joints in unsaturated rocks: Thermo-hydro-mechanical formulation and constitutive behaviour, Journal of Rock Mechanics and Geotechnical Engineering, 5(3), 200-213.

2) Cui, Yu-Jun. and Anh Minh Tang. (2013): On the chemo-thermo-hydromechanical behaviour of geological and engineered barriers, Journal of Rock Mechanics and Geotechnical Engineering, 5(3), 169-178.

3) Nishimura, T., Rahardjo, H., Koseki, J. (2010): Direct shear strength of compacted bentonite under different suctions, Proceedings of the Fifth International Conference on Unsaturated Soils, 323-328.

4) Nishimura, T. and Koseki, J. (2013): Influence of shear speed on direct shear strength for compacted bentonite with different soil suctions, Third International Conference on Geotechnique, Construction Materials and Environment. Nagoya. Geo-Mate 2013, 598-603.

5) Sanchez, M., Gen, A. and Guimaraes, L. (2012): Thermal-hydraulic-mechanical (THM) behaviour of large-scale in situ heating experiment during cooling and dismantling, Canadian Geotechnical Journal, 49(10), 1169-1195.