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Investigation on creep behavior of geo-materials with suction control technique

Tomoyoshi NISHIMURA[1]

[1]*Department of Civil Engineering, Ashikaga Institute of Technology, Tochigi, Japan*

Abstract. The compacted bentonite which has typical couple problem associated to thermal - hydration - mechanical – chemical (THMC) consist of one component of engineered barrier. Recently, the couple THMC formulation modelling suggested by some researchers can be predicted basically phenomena for engineered barrier that approach to correct evaluate satisfied facilities. The compacted bentonite is essentially unsaturated condition, some behaviors for bentonite has similar or close with generally expansive unsaturated soils. Therefore, hydrations have given significant influence on deformation of compacted bentonite such as swelling. There are many researches for swelling behavior of compacted bentonite within soaking. Extended theoretical or experimental investigations for unsaturated soil mechanics are possible to describe the strength-deformation behavior of compacted bentonite with suction controlling principle. A new method of determining the failure phase such as great axis deformation and destructions like strip of surface in the laboratory is described and the creep behavior of compacted bentonite is considered under maintain of high relative humidity environment. The creep deformation measured using improved cyclic relative humidity control apparatus in terms of specific suction control technique.

1 Introduction

Atomic power plant supply enough electrical power to industrial activity or human life that must be administrate under strict surveillance. Simultaneously, the radioactive waste disposal have been produced from atomic plant that the engineers should establish the radioactive waste management. The hydro-thermal-mechanical properties of bentonite have been investigated the past decades in the area such as geotechnical engineering and geo-environmental engineering. To understanding its properties is useful to evaluate safety and verification in high level radioactive waste disposal system for terms significant long-time period. Geotechnical engineers have required to deal with accurate performance assessment of high level radioactive waste disposal, is related to effect of deformation due to placement heavy waste on the compacted bentonite as barrier system. In drained condition or undrained condition, volume changes response of clayey rock is known to sensitive to temperature elevation or decreasing of effective stress soil particle together with respect to overconsolidation ratio. Recently, further factors such as gas migration, gas pressure, thermal heat and unsaturation-saturation couple properties have been focused on, and mathematical models imposed these parameters are processed.

Generation of hydration efforts give that the resulting decrement of effective stress in macro-micro structures lead to negative consequence in terms of mechanical stability around barrier systems. The even lower permeability of compacted bentonite, the increasing soil moisture occur under high relative humidity conditions. This study investigated the creep test of compacted bentonite consisted of barrier system of high level radioactive waste disposal. In essentially, the creep behaviour which soil occurrence deformation with long time consuming is applied at constant effective stress (L. Bjerrum (1967), A. Singh, JK. Mitchell (1968), J-H. Yin, J. Graham (1999)). The creep behaviour of soils that were confirmed by experimental works described much significant time-dependency (L. Bjerrum (1967), J. Graham, et al. (1983)). Their materials were classified as clay, practice problems of which was typical consolidation phenomena. A several constitute models were established based on oedometer tests (G. Mesri, PM. Godlewski (1977), J-H. Yin, J. Graham (1999)). The oedometer test results indicated time dependent stress- strain behaviour of clay which contributed to propose accurate constitutive model. The empirical simulation models had advantage to explain time-characteristic comparison to theoretical models. Almost of previous literatures considered saturated soils. There were quite a few attempt for unsaturated soils (G. Mesri, et al. (1981), V. De Gennaro et al. (2003), V. Schwarz, et al. (2006), LA. Oldecop, EE. Alonso (2007), Nawir, F. Tatsuoka (2011)). To understand, however, is interesting and useful into engineering practices. Recently, creep behaviour of unsaturated clay which was evaluated assessing suction control by X.L. Lai, et al. (2014) obtained from conventional unsaturated triaxial test.

tomo@ashitech.ac.jp

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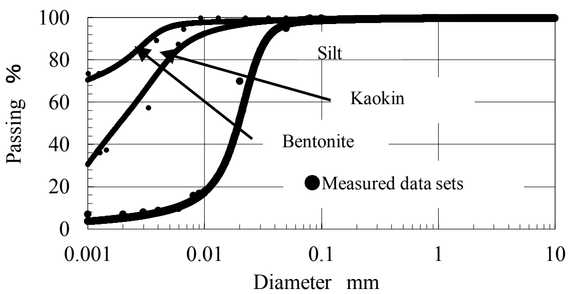

Figure 1. Grain size distribution for materials used in this test.

A series of creep test with high suction control by circulation relative humidity apparatus were performed, which used vapour pressure technique. All of creep tests remained at constant vertical stress under no lateral confining pressure. These test results presented in terms of vertical deformation-time in the constant relative humidity. Then, effect of initial water content, stress level and suction on deformation were described during long-time, and strain-rate was calculated. Not only compacted bentonite, creep behavior of kaolin and silt were measured to compare with compacted bentonite which were not expansive properties.

2 Materials and testing procedure

2.1 Materials

The bentonite, kaolin and silt were prepared as soil materials for this testing that the grain size distribution were shown in Fig.1. Fine contents of each material was were evaluated as following; 95.6%, 80.8% and 9.2%. It was clear that bentonite had most large content comparison to kaolin and silt. Also, the bentonite was made in Kunigeru Co. Ltd which was Sodium type. To obtain accurate measurement results that soil specimen maintained uniformity by static compaction.

2.2 Testing procedure

2.2.1 SWCC test

Three difference soil materials were prepared in powder condition without compaction performance. Initial water contents had a range from 5.7 % to 6.2 %, and the weight of sample was from 6 g to 14 g. Highly suctions more than 2.8 MPa that can be controlled using salt solutions. The conformed suction had a range from 2.8 MPa to 296 MPa that corresponded to a range from 98 % to 11 % in relative humidity. Seven difference salt solutions were used to control suction. The powder bentonite in air-dried condition and salt solutions were put into a glass container. For suction equilibrium, the change of soil moisture is quite slowly reason why hydration activity was performed as vapour migration. T. Nishimura (2015) described suction equilibrate of compacted bentonite which SWCC test required at least one month. Also, T. Nishimura (2015) investigated the influence of thermal effort on SWCCs for various soil materials. The changes of water

Table 1. Summary of creep test.

Specimen	Water content at compaction %	Dry density g/cm^3	Applied RH %	Vertical stress kPa
Silt	10.00	1.387	98	9.9
Kaolin	10.00	1.600	98	9.9
Bentonite	6.80	1.600	98	9.9
Bentonite	9.70	1.600	98	9.9
Bentonite	17.20	1.600	98	9.9
Bentonite	21.20	1.600	98	11.9, 20.9, 119.8, 474.4

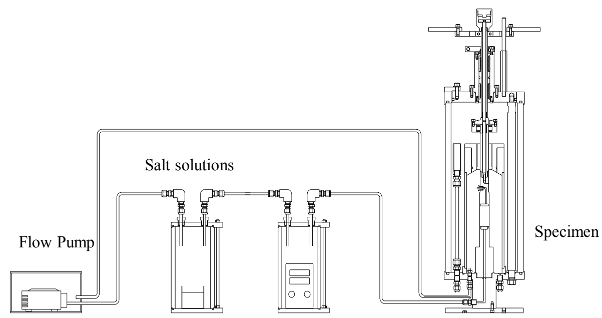

Figure 2. Modified creep test apparatus corresponding to RH control.

content with days was a likely hyperbolic curve, which was slightly a little. Therefore, employment of one confirmed suction was maintained a period of more one month. Measurement of weight of specimen realized the drainage or adsorption of soil moisture. Hyperbolic curve can useful to refer for decision of suction equilibrate in this SWCC test.

2.2.2 Unconfined compression test

All specimens with a dry density of 1.60 g/cm^3, which had a height of 10 cm, a diameter of 5 cm in size. Specimens were put on the pedestal, the cap was placed the top face of specimen. The triaxial cell was fixed to basement. The axial displacement was measured using a digital transfer sensor having a capacity of 50 mm. At once set up the specimen, axial displacement sensor and loading sensor were initialized, taking zero values. The axial strain ratio of 1.0 % per min was applied to specimen without confining pressure, which this test procedure applied correspondingly to the following JIS A 1216 code. The end of test was urged when the deviator stress described quite large reduction comparison with maximum deviator stress or occurred critical damage by shearing.

2.2.3 Creep test

For preparation of specimen on creep test, firstly bentonite and kaolin was no air-dried, and the silt was air-dried. Then, the dis-air water were sprayed to all soil materials and the required water contents had a range from 6.80 % to 21.2%. The soil regulated the water content was put into sealed plastic bag at least three days. Statically compaction with one layer which was performed in the

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stiffness steel mould had to avoid the influence of non-uniformity in the specimen. Finally, the specimens had a diameter of 50 mm, and a height of 100 mm which were unsaturated conditions in various suctions. Table 1 summarized basic properties of specimens.

At once specimen was mounted on the pedestal in the triaxial chamber of modified creep test apparatus (Fig. 2). The creep test apparatus was employed a conventional cyclic relative humidity control system, which can applied required RH using vapour pressure technique. This apparatus consist of triaxial chamber, air cyclic flow pump, the chamber including salt solution and dial gage sensor (maximum capacity was 100 mm). A dynamic activity of the conventional pump had at least 10kPa in pressure, which maintained steady air flow. The suctions corresponding to its relative humidity were imposed completely to the specimen in the triaxial chamber that the specimen occurred hydration pressurization following the vapour pressure technique. The air in the system remained circulation by performance of conventional pump. It was true that continue hydration pressurization diffusion from surface to inside.

An axial force up to 2 kg corresponding to axial stress up to 9.9 kPa, was applied in the axial direction using a cylinder. Axial displacement can be monitored on PC display using digital transducer equipment and RS232C electrical code. The critical programs were conducted out in this creep test, all test series were shown in Table 1. The laboratory room temperature was remained at 20 degrees.

3 Test results

3.1 Soil-water characteristic curves

High suctions were applied to three different materials which each fine component had a significant difference. It was clear that grain size distribution curve (Fig. 1) indicated difference of fine contents among them. Each soil-water characteristic curve was shown in Figs.3 to 5. Firstly, each water content of silt and kaolin was slightly a little at suction of 2.8 MPa (corresponding to RH 98 %), which was less than 10.0 %. Retention of water content for bentonite remained relatively much, it was 18 % at least. After suction of 2.8 MPa, water content indicated large reduction till suction was 9.8 MPa with exception of bentonite. Subsequently, ratio of water content reduction to suction was rather slight, and the incline was remained to maximum suction. In case of bentonite, water content leaved more than 10 % till suction 39 MPa, which retention activity was considerably difference comparison to other two materials. Three incline straight lines on logarithmic scale were determined on conventional diagram, which each inclination value was shown in figures. The inclination value was recognized as one of distinguishing feature parameters, and included into expression for prediction of soil-water characteristic curves with whole suction ranges (E.C. Leong, H. Rahardjo (1997)). The inclination for bentonite had more than ten times to other two materials.

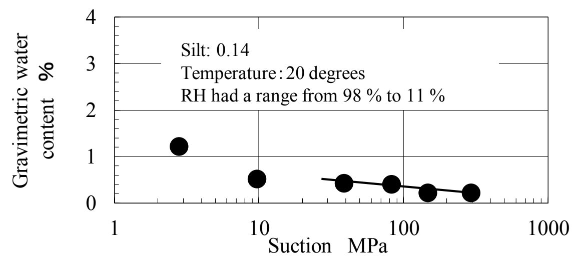

Figure 3. Soil-water characteristic curve for silt.

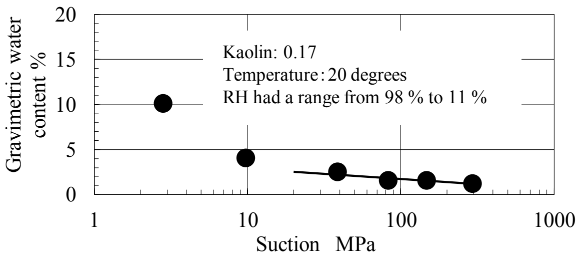

Figure 4. Soil-water characteristic curve for kaolin.

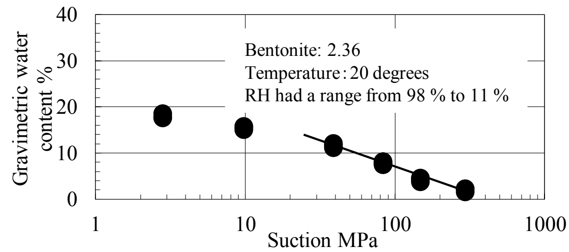

Figure 5. Soil-water characteristic curve for bentonite.

3.2 Unconfined compression strength

Results of unconfined tests at different water contents are described as stress-strain curve. Here, saturated condition was prepared which unsaturated, compacted bentonite was swelled at constant volume for a long time before unconfined compression test. The different suctions were employed corresponding to water content as shown in SWCC (Fig. 5). Suction of bentonite having water content of 9.70 % can be evaluated around 75 MPa. When water content were 17.20 % and 21.20 %, suctions were determined as following; 8.0MPa and 2.8 MPa.

The stress-strain curves were shown in Fig. 6 that all curves clearly had the influence of suction or water content. Deviator stress increased rapidly at beginning of compression for water content 9.70 %, which typical stress-strain behavior was observed as like to rather stiffness material. At once, specimen approached to maximum deviator stress, which unconfined compression strength can be determined till axial strain was 2.0 %. Subsequently, deviator stress had large reduction. The behavior which specimen having water content of 17 % was almost similar to water content of 9.70 %. The unconfined compression strength, however, clearly decreased that its reduction corresponded to 743.2 kPa.

According to decrease suction such as increasing water content, shear resistance described further. As suction was zero, saturated bentonite evidenced lowest

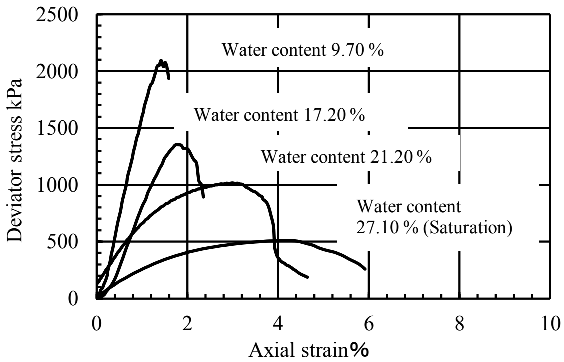

Figure 6. Stress-strain curve with various water contents for bentonite.

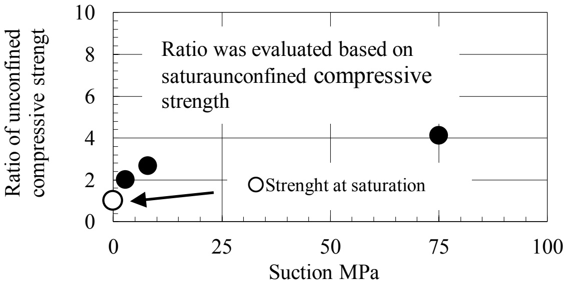

Figure 7. Influence of hydration effort on unconfined compressive strength.

strength. Also, stress-strain curve of saturated bentonite was quite difference with unsaturated bentonite. During axial strain processed in a range of 1.75 %, the deviator stresses of saturated bentonite were remained constant

Relationship between suction of bentonite and increment of unconfined compression strength was shown in Fig. 7. Hence, increment meant the difference of unconfined compression strength among each value of unsaturated bentonites and a saturated bentonite. The increment for the strength associated closely with suction, which the feature was seemed to be a hyperbolic curve. Increment of suction (i.e., contrast with decreasing of water content) induced a decreasing of shear resistance.

3.3 Creep phenomena

3.3.1 Silt and kaolin

Measured axial strain and elapsed time was presented for silt and kaolin in Fig. 8. There was a difference between silt and kaolin in axial strain and time relationship. At end of creep test, elapsed time approached to 110 days at least. Silt indicated shrinkage strain (i.e., compression) corresponding to deviator stress of 9.9 kPa at once, which the strain of 0.05 % was measured. The axial strain behavior seemed to be steady when elapsed time was over 10 days. After that, the axial strain was 0.08 % whole creep test. An axial strain of silt was measured without cracks and damages on lateral surface.

Kaolin occurred expansion in axial direction that was quite contrast creep behavior comparison to silt. The axial strain of 0.09 % was calculated at beginning of creep test

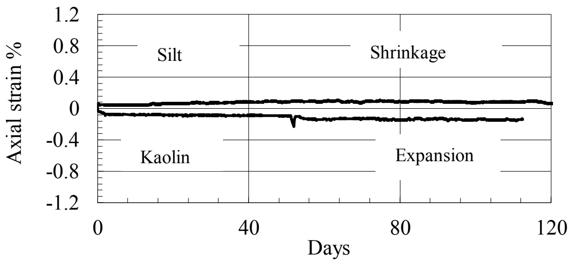

Figure 8. Change of axial strain with time for silt and kaolin.

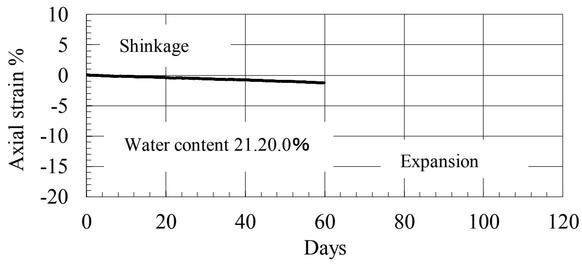

Figure 9. Creep behaviour for bentonite with water content of 21.20 %.

with a deviator stress of 9.9 kPa. With time, accumulation of expansion strain due to hydration was slightly. Measured creep strain was less than 0.15 % at end of test. There were no disturbance damages or cracks on lateral surface of specimen that was similar to phenomena for silt.

3.3.2 Bentonite at vertical stress of 9.9 kPa

Results of creep tests of bentonite compacted with various water content, all of which were presented Figs. 9 to 12. Here, water content mentioned in figures meant that initial specimen had before creep test. All of desired bentonite specimens described expansion behavior obviously in vertical direction. Hydration due to vapour pressure activity induced to encourage expansion to unsaturated compacted bentonite, in which was defined the influence of water content on magnitude of expansion.

In case of water content of 21.20 % (Fig. 9), considerable small expansive strain was measured at constant vertical stress of 9.9 kPa. The expansive strain was accumulated with slightly increment till end of test, and indicated the 1.24 %. The relationship between strain and elapsed days was assumed as straight line. More days was required to determine the equilibrium strain. In case of 17.20 %, expansive strain behavior was similar to the water content of 21.20 %, which the growing of strain increased slowly. Beyond elapsed times of 100 days, axial strain seemed to be equilibrium. Measured axial strain was large comparison with water content of 21.20 %. Both water content of 9.70% and 6.80 % described expansion-time curves which were quite difference comparison with above mentioned in Figs. 9 and 10. At beginning of hydration performance, the expansion strain had full growth, and approached to 5 % until elapsed time was five days. The strain rates obtained from Figs. 11 and 12 as shown in Figs. 13 and 14. The strain rates increased rapidly at beginning of hydration, which

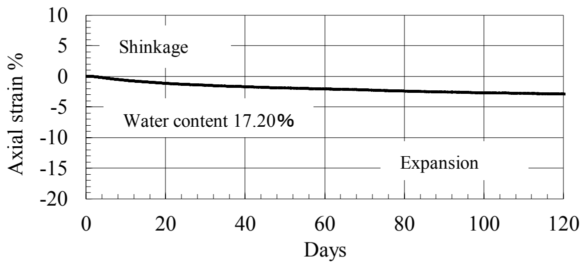

Figure 10. Creep behaviour for bentonite with water content of 17.20 %.

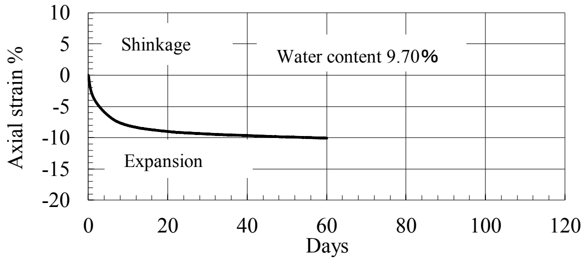

Figure 11. Creep behaviour for bentonite with water content of 9.70 %.

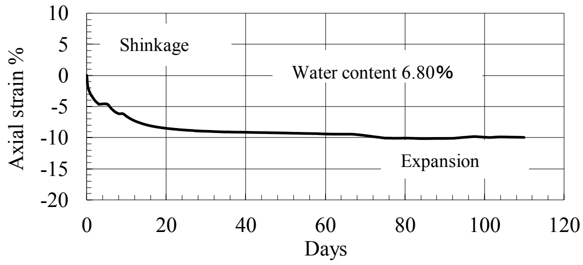

Figure 12. Creep behaviour for bentonite with water content of 6.80 %.

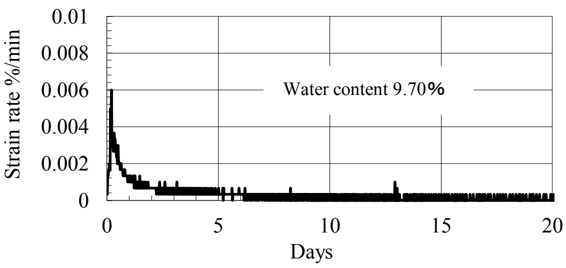

Figure 13. Strain rate in creep behaviour for bentonite with water content of 9.70 %.

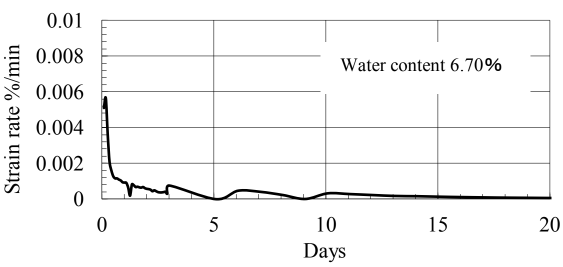

Figure 14 Strain rate in creep behaviour for bentonite with water content of 6.70 %.

Figure 15. Creep failure of bentonite with water content of 6.80 % at vertical stress of 9.9 kPa.

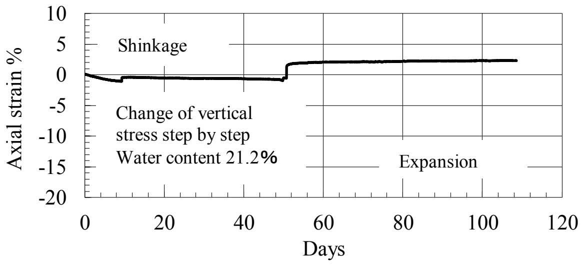

Figure 16. Creep behaviour for bentonite with water content of 21.20 % under different vertical stresses.

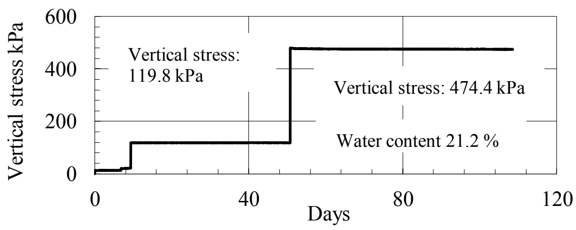

Figure 17. Different vertical stresses with elapsed time.

approach to 0.006 % per minute. At once, their strain rates were decreased that strain rate-time curves had a sharp point (i.e. maximum value). Beyond one day, the strain rates were less than 0.002 % per minute, which quite slow reduction was maintained till up to end of test. In addition, specimen with water content of 6.80 % produced so many cracks at lateral surface (Fig. 15).

3.3.3 Bentonite under various vertical stress

Fig. 16 showed changing of strain with increasing of vertical stress. The given vertical stresses which had a range of 11.9 kPa to 474.4 kPa remained at least 100 days (Fig. 17). The largest vertical stress was 474.4 kPa, which correspond to approximately 47 % to measured unconfined compression strength above mentioned in Fig. 6 (unconfined compression test). Firstly, the specimen indicated slightly little value at vertical stress of 11.9 kPa. After elapsed time was over 10 days, the vertical stress was up to 119.8 kPa. The expansion strain was accumulated slightly increment that described 0.94 %. Significant increment of vertical stress caused shrinkage deformation, which loaded from 119.8 kPa to 474.4 kPa. At once, the specimen occurred axial strain of 0.8 % in shrinkage, which maintained to reduce its height. Measured axial strain was equilibrium to 2.3 % in shrinkage at end of creep test.

4 Conclusions

This study conducted out three difference testing (i.e., SWCC test, unconfined compression test and creep test). Particularly, the creep testing apparatus was modified, which applying of hydration was maintained at constant RH environment with air circulation. The creep behaviour of compacted bentonite was summarized which provided the influence of initial water content at compaction.

(1) The inclination at high suction ranges was defined as ratio of water content reduction to suction. The inclination value of bentonite was more than ten times to silt or kaolin.

(2) The increasing of unconfined compressive strength closely associated with suction (or water content). Also, the stress-strain behaviour was influenced by similar effort.
(3) The bentonite described interesting phenomena regard to creep behaviour, which large axial strain in expansion was proved at relatively low water content. After long equilibrium time, so many cracks were occurred at lateral surface.

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