Vertical deformation of bentonite in high suction ranges

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ABSTRACT

This study focused on the creep behavior of compacted bentonite due to hydration effort induced by changing of relative humidity. This testing program used a relative humidity circulation system in developed conventional triaxial apparatus, and different relative humidity were applied to all specimens. The compacted bentonite produced deformation-induced by hydration, which related to increasing of relative humidity. Magnitude of vertical stress closely related to strain rate occurred in the axial direction. Vertical stresses were determined from unconfined compressive strength. It was obviously that the deformation of bentonite on creep tests was affected by both mechanical forces and hydration effort. Collapse or destruction were observed in short time period on the highly vertical stress.

Keywords: creep; bentonite; suction; relative humidity

1 INTRODUCTION

Radioactive waste disposals have been produced from atomic plant, and geo-environment agencies should establish extremely safe disposal management protocol. Barrier systems constructed for waste disposal under deep ground consider to strength, deformation, thermal action, hydraulic conductivity and chemistry in safety estimations (Cui and Delage 1993, Push and Karnland 1996, Gen et al. 2013). Highly dense compacted bentonite is one of significant component of barrier buffer that is extremely low seepage (Delage et al. 1998, Komine and Ogata 2003, Lloret et al. 2003, Nishimura and Koseki 2013, Nishimura and Koseki 2014).

This study focused on the creep deformation induced by hydration effort for compacted bentonite at long-term time period. Creep in saturated soils is generally moderated at constant effective stress over long duration. Measurement of the vertical strain of unsaturated, compacted bentonite was continued with various external vertical stresses. This testing program had an application using relative humidity circulation system in a conventional triaxial apparatus, and different relative humidity were created in the triaxial chamber. The compacted bentonite was subjected total suction (i.e. sum of matric suction and osmotic suction), and indicated the vertical deformation due to hydration effort. Applied vertical stress was closely related to produce the deformation strain in the axial direction. Vertical stresses were determined by results obtained from unconfined compression test. It was appeared that the deformation of bentonite on creep test was affected by both mechanical effort and hydration effort. Occurrence of collapse and destruction were observed, and high vertical stress obviously developed vertical strain. Also, many cracks sprayed at lateral surface in specimens.

2 SOIL MATERIAL AND TESTING PROCEDURE

2.1 Soil material

This testing program used Sodium bentonite, which was produced as Kunigel V1, and it was one of most investigated expansive materials in Japan, many reports of swelling pressures were represented. This study conducted out unconfined compression test and creep test for compacted bentonite. The unconfined compression tests were performed along five different compression strain rates, which had a range from 1.0 % per min to 0.007 % per min. Unconfined compression test assessing various strain speeds were relevance to consider creep behavior of bentonite.

The creep deformation measurement in this testing program was carried that vertical stress similar to deviator stress was loaded without lateral confining pressure, and its stress was less than unconfined compressive strength. The bentonite was adjusted to two difference water contents of 8.0 % and 17.2 %. The specimens had a diameter of 50 mm, and a height of 100 mm. A dry density was 1.600 g/cm^3 as target value, which was confirmed as a significant parameter for barrier buffer construction in high level radioactive disposal waste system.

2.2 Modified creep apparatus

The modified creep test apparatus was shown in Fig. 1. The apparatus employed a conventional cyclic relative humidity control system, which was possible to supply

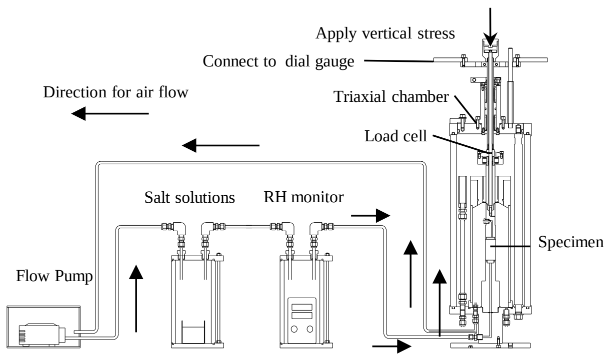

Fig. 1. Modified creep test apparatus.

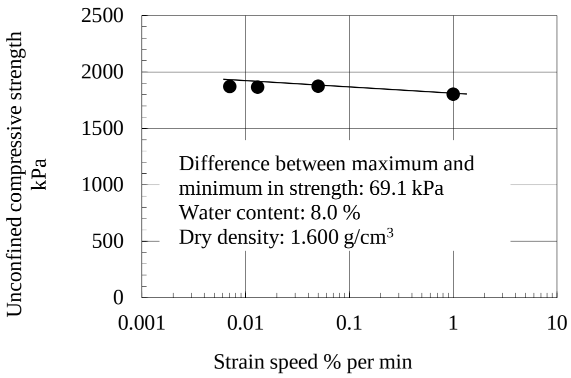

Fig. 2. Reduction of strength with strain speed on water content of 8.0 % at compaction.

stable realized relative humidity using vapor pressure technique. The vapor pressure technique is a conventional suction control method as well as pressure plate technique using ceramic disk plate. Meanwhile there is different suction controlling ranges between two methods. Vapor pressure technique can apply high suction value up to 296 MPa, and using various salt solutions produced different relative humidity (i.e. various suctions). Highly expansive soil such as bentonite is further water retention capacity that vapor pressure technique is possible to high suction more than be adequately stable. All creep stresses were determined based on the unconfined compressive strength measured in strain speed of 1.0 % per min.

3 TEST RESULTS

3.1 Unconfined compressive strength

The unsaturated, compacted bentonites were performed the unconfined compression test with various strain speeds. The obtained unconfined compressive strength was plotted against to strain speed as shown in Figs 2 and 3. The bentonite with water content of 8.0 % described more than 1800 kPa at least, and that of water content of 17.2 % was more than 1300 kPa in strength.

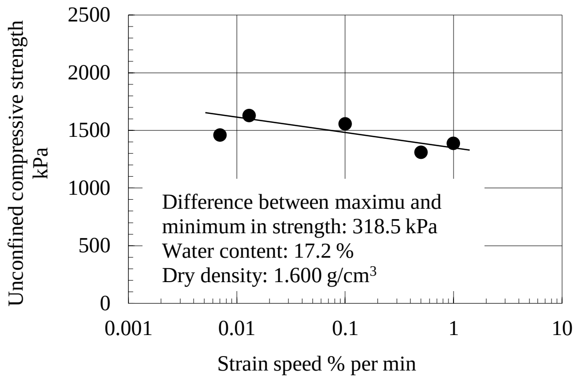

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Fig. 3. Reduction of strength with strain speed on water content of 17.2 % at compaction.

Table 1. Summary of creep test for bentonite.

No	Water content %	RH %	Hydration effort	Creep stress kPa	Ratio
1	8.0	98	Application	898.9	0.50
2	8.0	98	Application	799.0	0.40
3	8.0	98	Application	549.3	0.30
4	8.0	98	Application	364.5	0.20
5	8.0	98	Application	182.8	0.10
6	17.2	98	Application	694.1	0.50
7	17.2	98	Application	416.5	0.30
8	8.0	54	NO	182.8	0.10
9	8.0	54&98	Application	364.5	0.20
10	8.0	54&98	Application	549.3	0.30
11	8.0	54&98	Application	799.0	0.40

It was obviously that the strength of bentonite had strong influence of water content even if under constant dry density. Also, strength indicated the reduction according to increment of strain speed that was coincident regardless water content of 8.0 % or 17.2 %. The difference between maximum and minimum in strength was each 69.1 kPa and 318.5 kPa as mentioned in Figs. 2 and 3. The large different was measured in water content of 17.2 % comparison to water content of 8.0 %.

3.2 Vertical deformation due to hydration

The creep tests were conducted that creep stresses were prepared for specimens with two different water contents. Also, the vertical deformation was measured with times. The creep stresses were summarized in Table 1 that sum of cases were eleven. Ratio in term was defined as rate applied vertical stress to unconfined compressive strength obtained under compression speed of 1.0 % per min. Application was that specimens had a hydration effort induced by relative humidity changing. Limited few cases results of all tests were mentioned as following.

The vertical strains of bentonite with water content of 8.0 % were plotted with elapsed time in Figs. from 4 to 8. Some test contents were indicated in all of figures. Positive value expressed as shrinkage deformation of specimen, and negative value was expansive phenomena in notations. Controlled ratios had a range from 0.50 to

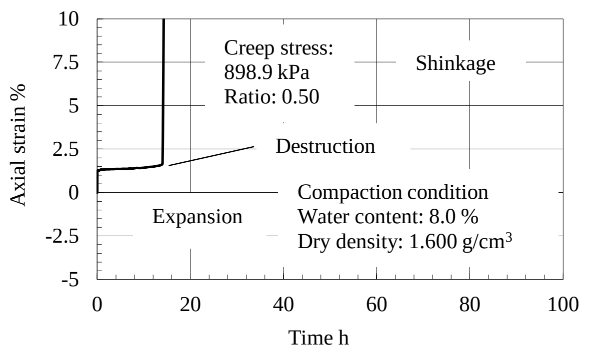

Fig. 4. Creep failure at ratio 0.50 under water content of 8.0 %.

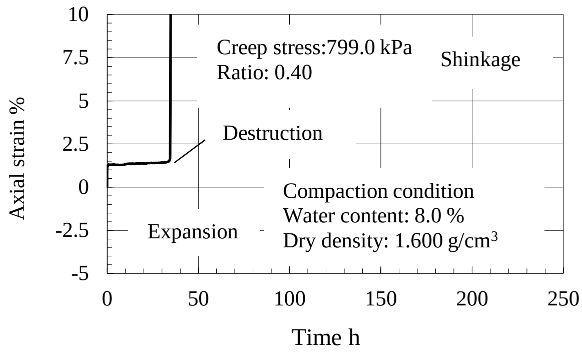

Fig. 5. Creep failure at ratio 0.40 under water content of 8.0 %.

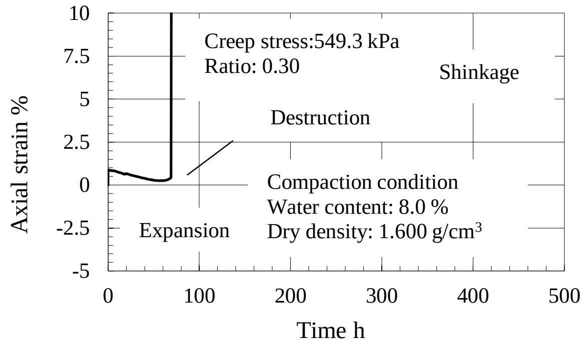

Fig. 6. Creep failure at ratio 0.30 under water content of 8.0 %.

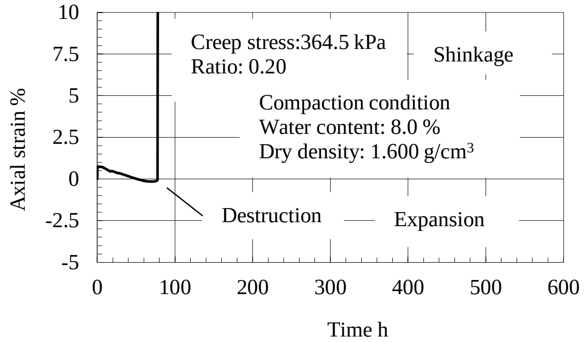

Fig. 7. Creep failure at ratio 0.20 under water content of 8.0 %.

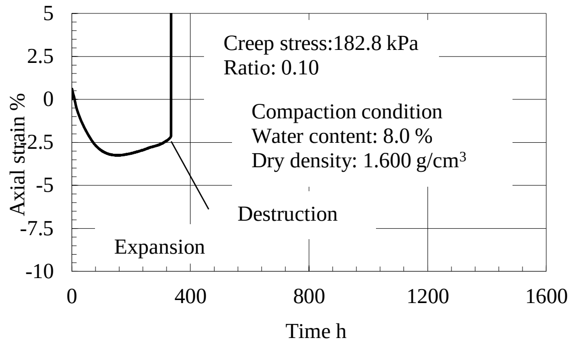

Fig. 8. Creep failure at ratio 0.10 under water content of 8.0 %.

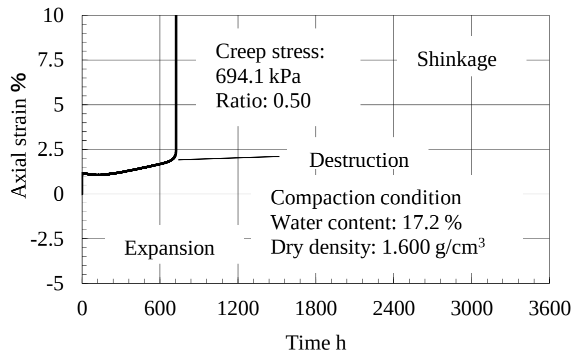

Fig. 9. Creep failure at ratio 0.50 under water content of 17.2 %.

0.10 in which was explained in previous. All of creep stresses were applied to specimens, and the shrinkage strain experienced in phenomena at once. The shrinkage vertical strains increased according to increment of external loading. On processing of hydration application, various deformations were produced, observed that was occupied by the magnitude of creep stress.

At ratio of 0.10, the growing of expansive strain was most strong comparison to another ratios (i.e. ratios of 0.50, 0.40, 0.30 and 0.20). After elapsed time was 150 h, the deformation phenomena changed smoothly that expansive strains slightly decreased with time, because of developed void structures due to hydration effort. All of bentonite subjected to hydration effort occurred large shrinkage that the plotted straight line had jump up. It expressed that the bentonite was broken brightly. Thus, hydration effort induced the creep break for compacted bentonite.

In case of water content of 17.2 %, two different creep stresses such as ratios of 0.50 and 0.30 were applied to the bentonite under relative humidity of 98 %. The deformations with time were shown in Figs. 9 and 10. The shrinkage employed by applying of vertical stress at once. The bentonite with ratio of 0.50 accumulated strain into shrinkage slightly and reached to creep failure in cooperation with hydration effort. Other hands, the ratio of 0.30 had the expansion after applying of creep stress, and total expansive strain was relatively small. While creep test was through about 1100 hours, the bentonite remained small shrinkage strain to initial

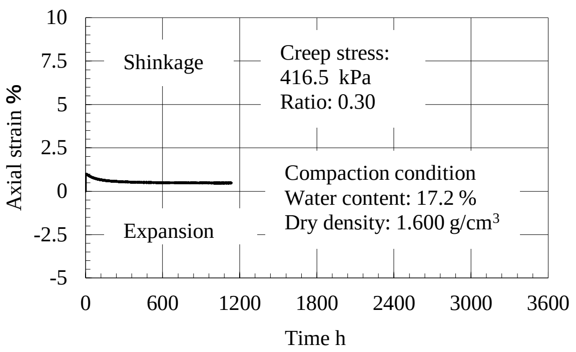

Fig. 10. Deformation at ratio 0.30 under water content of 17.2 %.

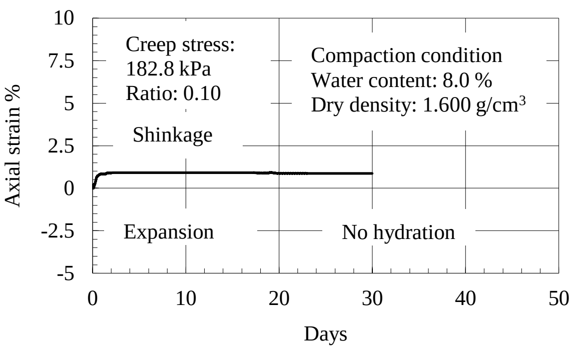

Fig. 11. Deformation at ratio 0.10 under no hydration effort.

height of specimen. Thus, the bentonite had not creep failure as shown in Fig. 10. In comparison both between water content of 8.0 % and 17.2 %, even if the ratio was coincident, creep failure occurred at lower water content.

The creep behavior clearly emphasized significant destructions or large deformation included two effective different causes such as mechanical and hydration. Moreover, this testing program attempted to consider influence of both with and without hydration effort. Here, “no hydration” in term was that applied suction was coincident to the suction of bentonite at initial condition. As the bentonite with water content 8.0 % had the suction of 105 MPa, the relative humidity of 54 % was controlled to specimen. RH of 54 % corresponding to suction of 83.4 MPa was induced by Magnesium Nitrate in salt solutions. Employed suction of 83.4 MPa was similar to an initial suction of specimen.

Firstly, a ratio of 0.10 (i.e. creep stress of 182.8 kPa) was supplied to the bentonite under RH of 54 %. The axial strain was measured a period of thirty days that the result was shown in Fig. 11. The axial strain in shrinkage was approximately 0.7 % at beginning which was produced in mechanical reflects due to loading. The axial strain of 0.7 % remained till end of test. It was evaluated that the influence of no hydration on deformation of bentonite according with time was possible to negligible.

4 CONCLUSIONS

This study conducted out creep test using modified creep apparatus for compacted bentonite, which was able to control relative humidity. Vertical strain was measured thought the creep test. The creep stresses were defined by unconfined compressive strength. In addition, changing relative humidity lead to substantiate hydration effort that compacted bentonite experienced the destruction through creep test. The obtained results were summarized as follow:

Unconfined compressive strength of compacted bentonite with water content of 8.0 % was larger than that of water content of 17.2 %, and each unconfined compressive strength decreased with strain speed regardless of water content at compaction process.

The bentonite subjected to both mechanical loading and hydration effort experienced either shrinkage or expansion in axial. If the bentonite subjected to small creep stress remained under process in hydration effort similar to initial suction (i.e. no hydration) that bentonite had not up to destruction or failure. Consequently, hydration effort such as decrement of suction evidenced instability or uncertain damages to unsaturated compacted bentonite.

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