

UNIAXIAL COMPRESSION TEST WITH VARYING SILICA SAND CONTENT, PARTICLE SIZE AND TEMPERATURE

*Shinichi Kanazawa¹, Masaki Yanai¹, Nozomi Ichikawa¹, Naoki Muto¹, and Koji Ishiyama²

¹National Institute of Technology, Fukushima College, Japan;

²Nishimatsu Construction CO.LTD

*Corresponding Author, Received: 14 June 2019, Revised: 29 Nov. 2019, Accepted: 01 July 2020

ABSTRACT: At present, underground geological disposal at depths greater than 300 m is considered a viable disposal option for high-level radioactive waste generated from the reprocessing of spent fuel used in nuclear power plants. In geological disposal, bentonite is employed as the primary component of buffer material filling gaps between waste and geologic rock. Bentonite has remarkable water absorption swelling and low permeability characteristics. Bentonite buffers are generally mixed with silica sand to improve workability and economy. However, specification details have yet to be completely determined. It is anticipated that the buffer material will be exposed to high temperature due to the heat generated by the vitrified solid. This study aims to understand the mechanical properties of bentonite buffer material by employing uniaxial compression tests after applying temperatures between 30 °C to 90°C to bentonite specimens with different silica sand contents and particle sizes. Results of the experiment confirmed that uniaxial compressive strength tends to decrease with higher blending ratios of silica sand greater particle sizes and temperatures.

Keywords: Bentonite, Geological disposal, temperature, Uniaxial compression test

1. INTRODUCTION

At present, the use of bentonite as a buffer material for geological disposal is being examined. Bentonite fills gaps due to its water intake swelling properties and low permeability, thus preventing the leakage of groundwater contaminated with high levels of radiation. In Japan, various tests, such as swelling pressure tests and uniaxial compression tests, have helped to characterize swelling performance and mechanical properties of bentonite [1]. In addition, workers have examined the method for mixing silica sand with bentonite from the viewpoint of workability and economic efficiency. However, complete specifications for this method have yet to be determined. In this study, to understand the mechanical properties of bentonite buffer material, uniaxial compression tests were conducted by applying temperatures in the range of 30°C to 90°C to bentonite specimens with different silica sand contents and particle sizes.

2. TEST METHOD

The initial conditions were set at a dry density of 1.6 Mg/m³ and a saturation of 30%. Temperatures of 30 °C, 50 °C, 70 °C and 90 °C were applied to bentonite (Kunigel V1) with No. 3, 5 and 8 silica sand ratios of 20%, 30% and 40%. Table 1 summarizes the physical and chemical properties of Kunigel V1 and silica sand.

Table 1 Physical and chemical properties of Kunigel V1 and silica sand

soil particle density(Mg/m ³)	2.61
Montmorillonite content(%)	51
Silica sand No. 3 particle density(Mg/m ³)	2.691
Silica sand No. 5 particle density(Mg/m ³)	2.62
Silica sand No. 8 particle density(Mg/m ³)	2.701
Silica sand No. 3 particle size(mm)	1.2~2.4
Silica sand No. 5 particle size(mm)	0.3~0.8
Silica sand No. 8 particle size(mm)	0.08~0.2

2.1 Sample Preparation Method

A mixed sample of bentonite and silica sand was prepared at ratios of 6:4, 7:3, and 8:2 for Kunigel V1 and silica sand particle sizes, nos. 3, 5, and 8. The montmorillonite content of bentonite in Table 1 was measured with reference to the Methylene Blue adsorption measurement method of AIST [2]. The properties of each sample are shown

in Tables 2, 3, and 4. Eq. (1) was used for the effective clay density [3] of JAEA.

$$\rho_e = \frac{\rho_d(100 - R_s)}{(100 - \frac{\rho_d R_s}{\rho_s})} \quad (1)$$

(1) where, ρ_e : effective clay density, ρ_d : dry density, ρ_s : soil particle density of silica sand, R_s : silica sand mixing ratio

Table 2 Properties of each sample at the 6:4 mixing ratio

silica sand No.	No.3	No.5	No.8
Mixed soil particle density(Mg/m ³)	2.64	2.612	2.644
Void ratio	0.650	0.632	0.653
Effective clay density(Mg/m ³)	1.260	1.270	1.258

Table 3 Properties of each sample at the 7:3 mixing ratio

silica sand No.	No.3	No.5	No.8
Mixed soil particle density(Mg/m ³)	2.632	2.610	2.635
Void ratio	0.645	0.631	0.647
Effective clay density(Mg/m ³)	1.363	1.371	1.362

Table 4 Properties of each sample at the 8:2 mixing ratio

silica sand No.	No.3	No.5	No.8
Mixed soil particle density(Mg/m ³)	2.623	2.609	2.625
Void ratio	0.639	0.631	0.641
Effective clay density(Mg/m ³)	1.453	1.458	1.452

2.2 Water Content Adjustment

The water content of the mixed samples was adjusted to a saturation of 30%. The water content was measured using a microwave oven (500 W, 15 min) to shorten the time.

2.3 Specimen Molding

The sample was divided into five layers, placed in the mold, and compacted. Afterwards, static compaction (40 MPa, 10 min) was applied with a hydraulic jack to produce the test specimen. Eq. (2) and (3) were used for the mass of the specimen, assuming that the volume of the

specimen was constant.

$$e = \frac{\rho_s}{\rho_d} - 1 \quad (2)$$

$$S_r = \frac{w\rho_s}{e\rho_w} \quad (3)$$

(2) where, e: void ratio, ρ_s :soil particle density, ρ_d : dry density ; (3)and where, S_r : degree of saturation, w:water content , ρ_s : soil particle density e: void ratio, ρ_w : water density (1.00Mg/m³).

2.4 Temperature Change

Specimen temperature was achieved by curing the sample for 1 day in a constant-temperature water tank. A water interception sheet prevented the specimen from touching the water.

2.5 Uniaxial Compression Test

The compression test was carried out according to the test method of the JIS standard [4]. The fixed load speed was 0.4 (mm/min). An electric screw jack system of 10 kN capacity was employed as a testing machine. A schematic diagram of the tester is shown in Fig.1.

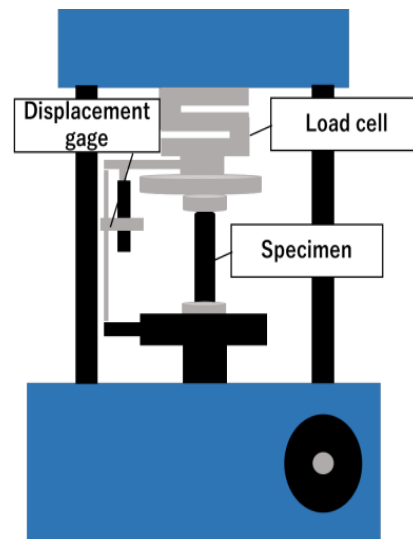


Fig.1 Schematic diagram of the test machine

3. TEST RESULTS AND DISCUSSION

Figs.2-4 show the results of the uniaxial compression tests in which the temperature and silica sand content were varied according to silica sand particle size. Figs.5-7 show the results of the uniaxial compression test in which the temperature and the type of silica sand particles were varied for each silica sand content.

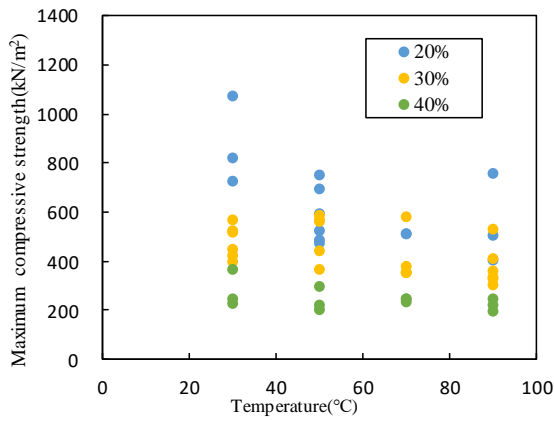


Fig.2 Relationship between temperature and maximum compressive strength (Silica sand No.3)

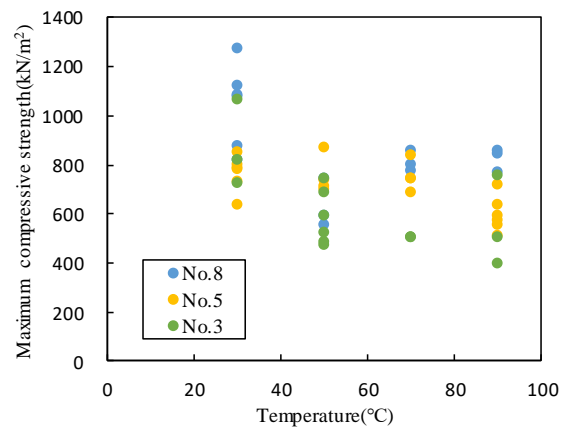


Fig.5 Relationship between temperature and maximum compressive strength (6:4)

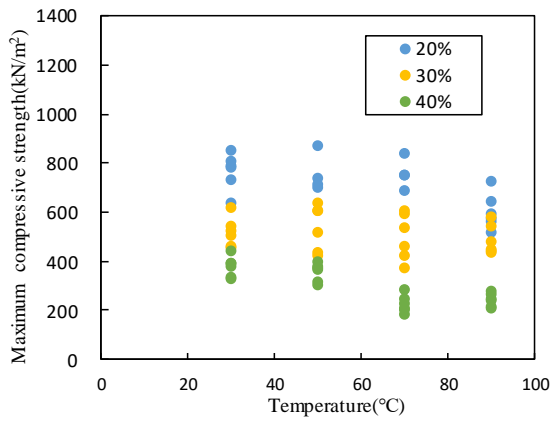


Fig.3 Relationship between temperature and maximum compressive strength (Silica sand No.5)

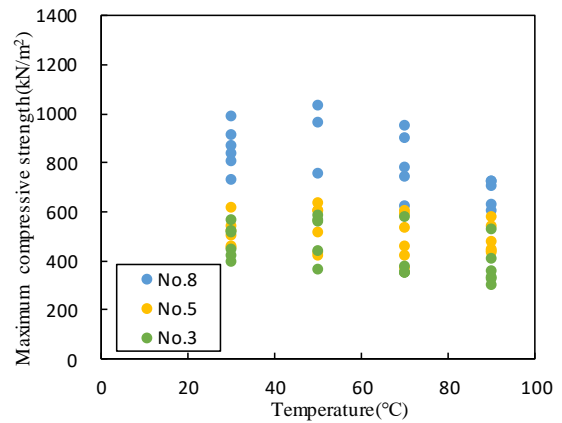


Fig.6 Relationship between temperature and maximum compressive strength (7:3)

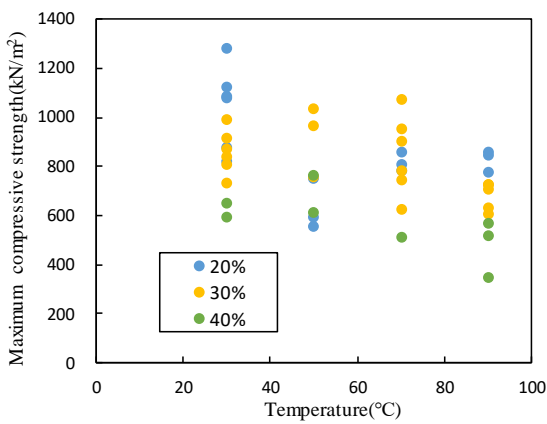


Fig.4 Relationship between temperature and maximum compressive strength (Silica sand No.8)

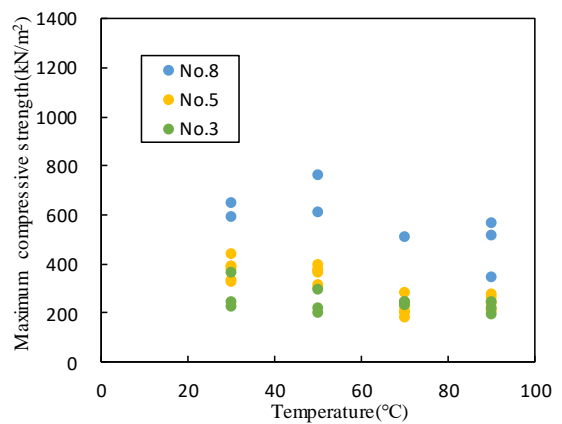


Fig.7 Relationship between temperature and maximum compressive strength (8:2)

3.1 Results of Tests Varying Silica Sand Content, Silica Sand Particle Size, and Temperature

Figs.2-7 illustrate that maximum compressive strength decreases linearly with increasing temperature under all conditions. Fig.9 shows the changes in the modulus of elasticity for silica sand No. 3 at different compositions, and Fig.11 shows the changes in the elastic modulus of silica sand for a silica sand composition of 40% with varying silica sand particle size (Nos. 3, 5, or 8). The elastic modulus demonstrated the same tendency as compressive strength with increasing temperature. The same tendency was also observed under other conditions. There are several possible reasons why the maximum compressive strength and elastic modulus decrease. The first is the expansion of the specimen volume. Fig.8 shows the rate of volume change of silica sand No.3 at different temperatures and silica sand contents. Fig.10 shows the volume change rate with temperature for a silica sand content of 40% and different silica sand particle sizes (Nos. 3, 5, or 8). Figs.8,10 confirm that the rate of volume change tends to increase with rising temperature during curing. Therefore, it is possible that at higher temperatures, with a lower dry density and smaller cracks, strength characteristics were lower [5-9]. Expansion of the specimen may be caused by the difficulty in discharging the pore water and air expanded by heat due to bentonite's low water and air permeability. The effects of cracks caused by drying shrinkage of the specimen surface could also be a factor. As temperature increased during curing, the amount of evaporation from the surface of the specimen increased, and the number of cracks due to drying shrinkage also increased, which may have decreased material strength. For this test, specific cracks inside of the specimen were not confirmed.

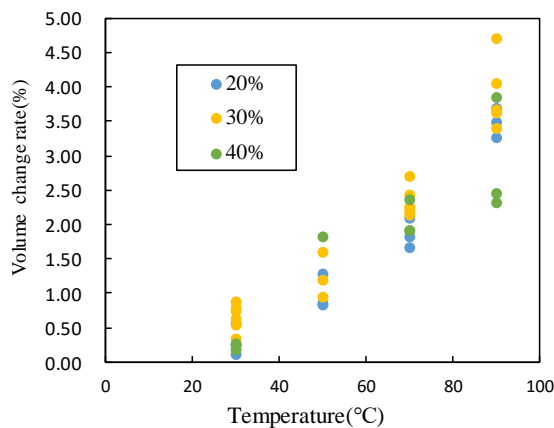


Fig.8 Relationship between temperature and volume change rate (Silica sand No.3)

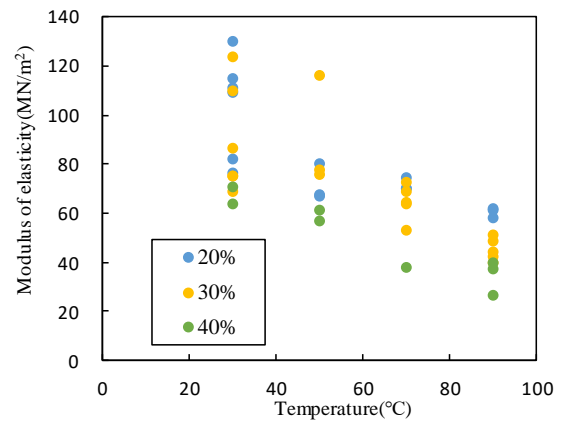


Fig.9 Relationship between temperature and the modulus of elasticity (Silica sand No.3)

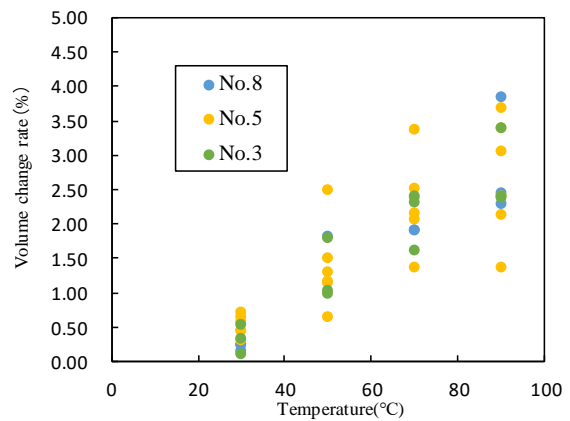


Fig.10 Relationship between temperature and volume change rate (6:4)

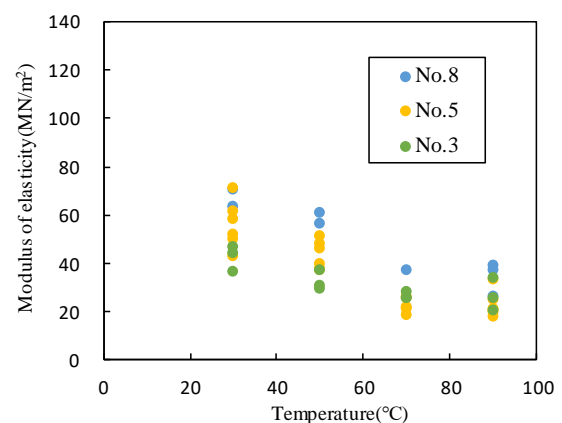


Fig.11 Relationship between temperature and the modulus of elasticity (6:4)

However, that interior cracks were generated was confirmed due to the remarkable shrinkage after curing, especially on the specimen surface. Since this effect increases with temperature,

compressive strength is also considered to decrease as the temperature increases.

3.2 Results of Tests in which the Silica Sand Content and Silica Sand Particle Size (Nos. 3, 5, or 8) at each Temperature was Varied

Figs.12 and 13 show the relationship between silica sand particle size (Nos. 3, 5, or 8) and maximum compressive strength at temperatures of 30 °C, 90 °C and silica sand contents of 20%, 30% and 40%. Both figures confirm that maximum compressive strength increased as the particle size of silica sand decreased. The increase of maximum compressive strength with the decrease of silica sand particle size may result from a smaller particle size. The increase of the maximum compressive strength with the decrease of the silica sand particle size considered to be the increase of the forming pressure by the decrease of the silica sand particle size. These results also confirmed that the smaller the silica sand particle size, the higher the strength, under constant silica sand content. This is due to suction. Suction is the attractive force of pore water to soil particles in dry unsaturated soil and is calculated as the difference between pore air and water pressures. Generally, the greater the suction, the more the apparent adhesive force, and the better the strength and deformation characteristics. In other words, the smaller the particle size of silica sand, the larger the area of contact between silica sand and water. Therefore, it is considered that the smaller the particle size of silica sand, the greater the strength. Figs.14 and 15 show the relationship between silica sand content and maximum compressive strength at temperatures of 30 °C and 90 °C and silica sand numbers of 3, 5 and 8. In both figures, the maximum compressive strength decreases with increasing silica sand content. With this result, compaction is considered the cause.

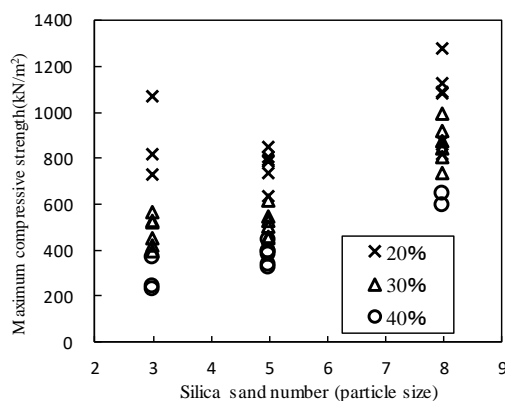


Fig.12 Relationship between silica sand number and maximum compressive strength (30°C)

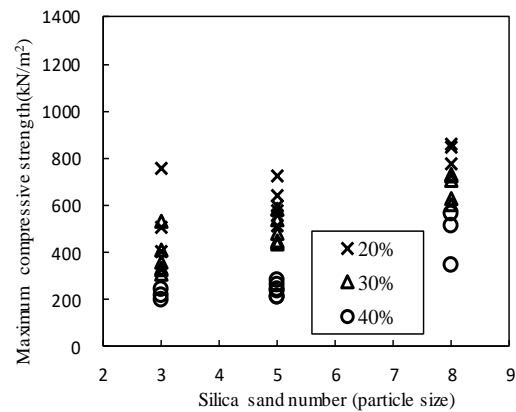


Fig.13 Relationship between silica sand number and maximum compressive strength (90°C)

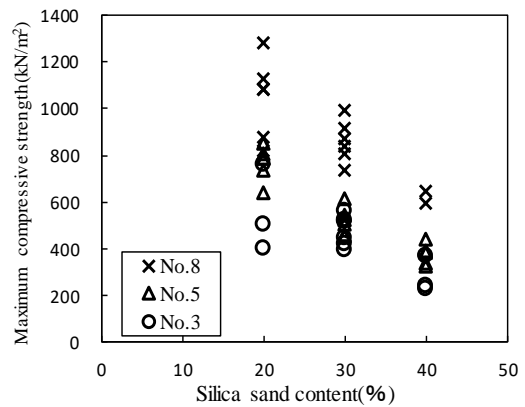


Fig.14 Relationship between silica sand content and maximum compressive strength (30°C)

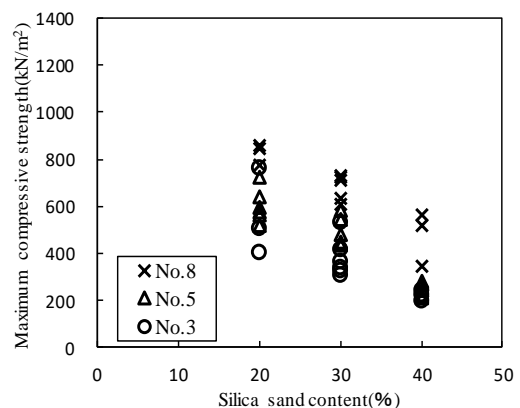


Fig.15 Relationship between silica sand content and maximum compressive strength (90°C)

According to Masuda et al [10], at higher montmorillonite contents, the compaction property worsens, and the molding pressure can be reduced by increasing the silica sand mixing ratio. In this case, montmorillonite content decreases with

increasing silica sand content, and the strength is considered to decrease because the energy of compaction is reduced.

4. CONCLUSION

In this study, uniaxial compression tests investigated the mechanical properties of bentonite mixed with silica sand, considering the effects of temperature. The findings obtained in this study are as follows.

(1) As temperature rises, the dry density of the bentonite mixed with silica sand decreases due to volume expansion caused by expanded pore water and air exiting the specimen. In addition, cracks occur on the surface and inside of the specimen due to drying shrinkage. Based on the above, maximum compressive strength is also considered to decrease.

(2) As the silica sand number increases, suction between silica sand particles increases. Maximum compressive strength is considered to further increase with this increase.

(3) Montmorillonite content decreases with increasing silica sand content. It is conceivable that the compressive strength of the specimen is decreased by reducing the energy used on the compression molding for higher sand specimens, compared to when the sand ratio is low.

The above results experimentally demonstrate the temperature dependence of bentonite mixed with silica sand and that suction and montmorillonite content affect strength characteristics. In future work, it is desirable to improve the accuracy of the data by continuously carrying out tests. Furthermore, when considering re-submergence of a geological disposal facility after construction, it is likely that not only the mixing ratio of silica sand and silica sand particle size, but also change in the degree of saturation affect the strength characteristics. Therefore, change in the degree of saturation of bentonite specimens with different silica sand contents and particle sizes should be tested. In addition, by considering the effect of heat generated from high-level radioactive waste, we hope that the uniaxial compression test with temperature change applied to the silica-sand mixed bentonite specimen will contribute to the performance design of bentonite buffer material from the viewpoints of workability, economy, and thermal conductivity.

5. REFERENCES

- [1] Japan Nuclear Cycle Development Institute (1999): Technical confidence on the disposal facilities for high level radioactive wastes 2nd Report.
- [2] Horiuchi Y., Takagi T., Method of the methylene blue adsorption test for bentonite at AIST., Research Materials of the Geological Survey of Japan., No.555(2012).
- [3] Japan Nuclear Cycle Development Institute (1999): Engineering technology for geological disposal
- [4] JIS A 1216:2009, Method for uniaxial compression test.
- [5] Ichikawa N., Kanazawa S., Hayashi H., and Ishiyama K., Study on the mechanical behavior of bentonite buffer considering temperature and saturation changes in geological disposal facilities., Journal of JGS (CD-ROM)., 2017.
- [6] Muto N., Kanazawa S., Hayashi H., Ishiyama K., and Iizuka A., Dynamic Characteristics of Bentonite Buffer Material Considering Temperature, Density and Saturation in Stratum Disposal Facility, Environmental Ground Engineering Symposium., Journal of JGS, Vol.12, 2017, pp.567-570.
- [7] Muto N., Kanazawa S., Hayashi H., Hoshi T., and Ishiyama K., Experimental study on mechanical properties of bentonite buffer considering various conditions., Journal of JSCE(CD-ROM)., 2018.
- [8] Yanai M., Kanazawa S., Ichikawa N., Muto N., Kobayashi S., and Ishiyama K., Uniaxial compression test of bentonite buffer material with varying silica sand content and temperature., Journal of JSCE., (CD-ROM), VII-133, 2019.
- [9] Yanai M., Kanazawa S., Ichikawa N., Muto N., Kobayashi S., and Ishiyama K., Experimental study on mechanical properties of bentonite mixed with silica sand considering temperature change., Environmental Ground Engineering Symposium, Journal of JGS., Vol.14., 2019., pp.467-470.
- [10] Masuda R., Amemiya K., Chijimatsu M., Adachi K., Komine H., Study on the influence of a specification of buffer material on the compaction characteristics., Journal of JSCE., No.772/III-68., 2004., pp.157-171.

Copyright © Int. J. of GEOMATE. All rights reserved, including the making of copies unless permission is obtained from the copyright proprietors.
