SWELLING CHARACTERISTICS OF BENTONITE AND BENTONITE-SAND MIXTURES FOR NUCLEAR WASTE DISPOSAL

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ABSTRACT

The density of bentonite and of bentonite-sand mixture is the prime criterion in the evaluation of the swelling pressure and deformation of buffer material which must be taken into consideration in the design of any type of waste disposal facilities. A series of laboratory swelling pressure and deformation tests using variable dry density of the specimens has been carried out to investigate the characteristics of buffer material for radioactive waste disposal. Initial dry density and loading pressure on the specimens has a noticeable influence on maximum swelling rate. Temperature is also an important factor in the control of the swelling rate of compacted bentonite. The void ratio increased in high initial dry density material and decreased for low level initial dry density when compared with the initial state at the end of swelling due to static load. The swelling pressure fluctuated with elapsed time in respect to temperature. The maximum swelling pressure is dependent on the initial dry density and the content of bentonite in bentonite-sand mixture.

1 INTRODUCTION

World-wide there are many initiatives to store or dispose of highly toxic chemical and radioactive waste in deep underground facilities. IAEA (2003) reported that more than one hundred radioactive waste disposal facilities have been operating and more that 42 repositories are in some stage of development in different countries.

Environmental requirements for all types of underground disposal will converge towards the approaches and standards being developed for long-lived radioactive waste disposal. Currently compacted bentonite and bentonite-sand mixture is an essential material for waste disposal. To ensure the long term safety of geological disposal a basic requirement for the buffer is to restrict radionuclide migration from breached waste packages to the surrounding host rock. The buffer material must restrict groundwater movement through it, sorbs dissolved nuclides and prevent migration of radionuclide bearing colloids.

A material in which 70% bentonite and 30% sand mixed with a dry density of 1.6 g/cm^3 has been selected as the base line for the buffer (JNC, 2000). Schematic diagram of bentonite-sand mixtures for nuclear waste disposal are shown in Figure 1. Initial dry density is the governing parameter which controls the swelling pressure, deformation and permeability of the bentonite and bentonite-sand mixture. Permeability of bentonite and bentonite-sand mixtures have been described by Shirazi and Kazama in previous research (2004a and 2004b). The present study describes a series of tests of swelling pressure and deformation of compacted bentonite using variable initial dry density. Effect of bentonite content on swelling characteristics of compacted bentonite-sand mixture has also been investigated.

2 TEST MATERIALS AND SPECIMEN MAKING

Powdered sodium bentonite (Kunigel VI), quartz sand No 3 and 5 was used in this experiment. Kunigel VI contains about 48% montmorillonite. Specific gravity, liquid limit, plastic limit, and plasticity index were 2.79 g/cm^3, 497%, 26% and 471, respectively. Kunigel VI was compacted by a compaction device (Model No. CLP-200 KNB) produced by Tokyo Sokki Kenkyuijo Co. Ltd., Japan. A schematic diagram of sample compaction apparatus is shown in Figure 2. The specimen height and desired density was maintained by the variation of specimen mass and compaction energy. The initial dry density of the bentonite only samples was about 1.33, 1.42, 1.52, 1.63, 1.70, 1.80 and 1.95 g/cm^3. Initial dry density of the bentonite-sand specimens was about 2.00 g/cm^3 and bentonite (B) was varied about 30%, 40%, 50%, 60%, 70%, 80% and 90%, respectively. The height of compacted bentonite and bentonite-sand mixtures was about 1 cm with a diameter of 6 cm in order to obtain the same density at every corner of that specimen. The initial status of every specimen was presented in Table 1. A total of 40 minutes was required to making a specimen with 20 minutes required to reaching its peak static load which was then kept for 20 minutes. The uniform shape and size of the specimens were confirmed before starting the swelling pressure and deformation test.

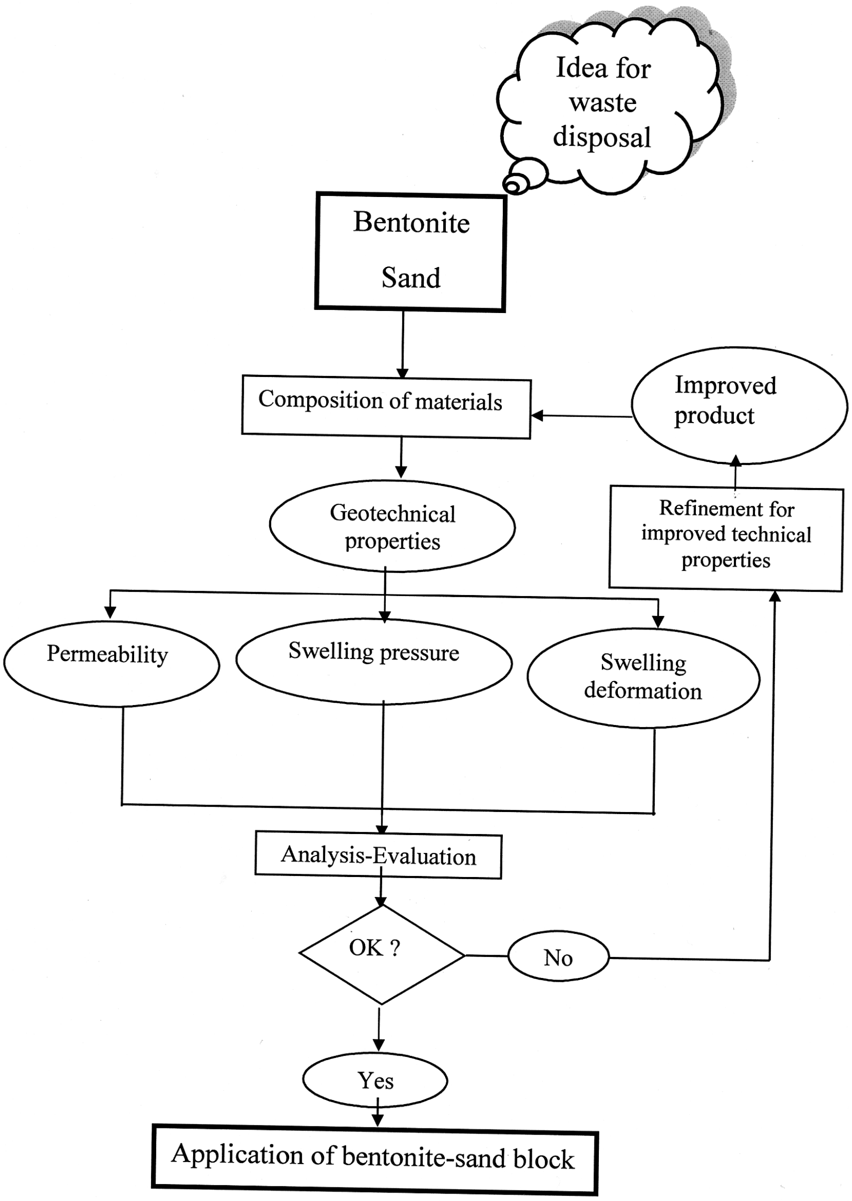

Figure 1: Schematic diagram of bentonite-sand mixture for waste disposal.

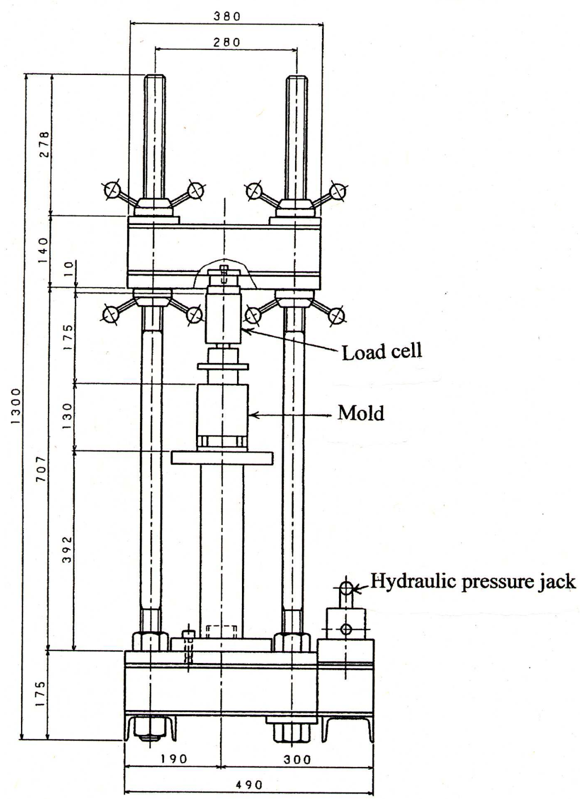

Figure 2: Schematic diagram of sample compaction apparatus (all dimensions are in mm).

Table 1: Initial status of test specimen for swelling pressure and deformation.

Specimen	Bentonite content (%)	Compaction pressure (kN)	ρ_d (g/cm^3)	Sample height H_0 (cm)	void ratio e_0	Water content W_0 (%)	Degree of saturation S_r (%)
Kunigel VI	100	16	1.33	1.00	1.10	6.39	16.25
Kunigel VI	100	24	1.42	0.99	0.96	6.39	18.62
Kunigel VI	100	42	1.52	1.00	0.84	6.40	21.30
Kunigel VI	100	70	1.63	1.00	0.72	6.4	24.86
Kunigel VI	100	72	1.70	1.06	0.64	6.9	30.16
Kunigel VI	100	115	1.80	1.08	0.55	6.95	35.34
Kunigel VI	100	200	1.95	1.09	0.44	8.10	51.49
Kunigel VI - Sand	30	200	2.00	1.03	0.33	1.87	15.15
Kunigel VI - Sand	40	200	2.00	1.02	0.34	2.59	20.51
Kunigel VI - Sand	50	200	2.01	1.03	0.35	3.02	23.38
Kunigel VI - Sand	60	200	2.00	1.06	0.36	4.81	36.44
Kunigel VI - Sand	70	200	2.01	1.03	0.37	4.98	36.94
Kunigel VI - Sand	80	200	2.00	1.04	0.38	5.66	41.14
Kunigel VI - Sand	90	200	2.00	1.03	0.39	5.89	42.24

3 SWELLING PRESSURE TEST

The vertical swelling pressure of compacted bentonite and bentonite-sand mixture was measured using a digital strain meter (TC-31K, Tokyo Sokki Kenkyuijo Co. Ltd., Japan) in the swelling pressure test assuming that the volume of the specimen remained constant. Distilled water was supplied from the bottom of the confined specimen. Vaseline was added to the inner cell of the swelling pressure box to reduce the frictional force. During water uptake the volume change of the specimen was considered to be negligible as the stiffness of the pressure box was sufficient to confine the specimen. From the beginning of the water supply the relation between elapsed time and swelling pressure (MPa) was observed. Temperature (^{o}C) was recorded after peak swelling pressure had been reached for every specimen to observe the relationship between temperature and swelling pressure. The water content of the specimen was measured at the end of the experiment and the degree of saturation of the specimens was about 98% to 100%. The specimens were considered to be completely saturated after the experiment.

4 SWELLING DEFORMATION TEST

The free swelling deformation test was performed on the compacted specimens by adsorbing distilled water under approximately zero vertical pressure i.e. loading the plate only. The swelling deformation test apparatus is shown in Figure 3. The inner diameter and height of the free swelling deformation test apparatus was about 6 cm. The free swelling deformation was observed in constant temperature at 5, 20 and 45^{o}C by an incubator. The vertical swelling deformation of compacted specimens under static load of 0.16, 0.32, 0.64 and 1.28 MPa was measured by an oedometer test apparatus. Distilled water was supplied and simultaneously prescribed vertical pressure was applied to the specimen. Vaseline was used on the inner wall of the swelling deformation cell to reduce frictional force. From the beginning of the water supply the relation between elapsed time and axial swelling deformation was measured. The swelling rate of the compacted specimen was calculated by the following equation.

$$S_R = \frac{\Delta h}{h_0} 100 \quad (1)$$

where S_R is the swelling rate, Δh is the swelling deformation and h_0 is the initial specimen height. At the end of experiment every specimen was cut by 5 mm interval and degree of saturation was about 98% to 100%.

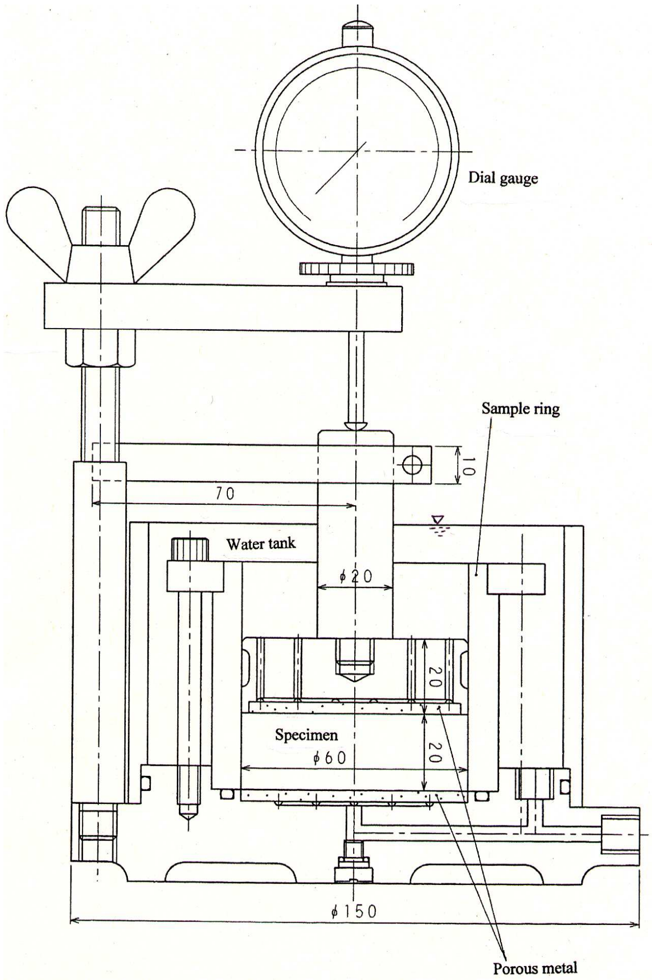

Figure 3: Swelling deformation test apparatus.

5 TEST RESULTS AND DISCUSSION

The free swelling of compacted bentonite using different initial dry densities at 20^{0}C are presented in Figure 4. Free swelling of compacted bentonite is strongly dependent on initial dry density. The swelling rate is markedly increased with the increasing rate of initial dry density of bentonite. At initial state swelling rate of lower initial dry density specimens were higher compared to higher dry density specimens due to initial void ratio. After some time higher density specimens exhibited higher swelling rate. Without loading the relationship between swelling rate and elapsed time did not followed exactly parabolic curve which is dissimilar with the findings of Komine and Ogata (1994 and 1999) and Sivapullaiah (1996). Final swelling rate noticeably varied due to initial dry density and temperature.

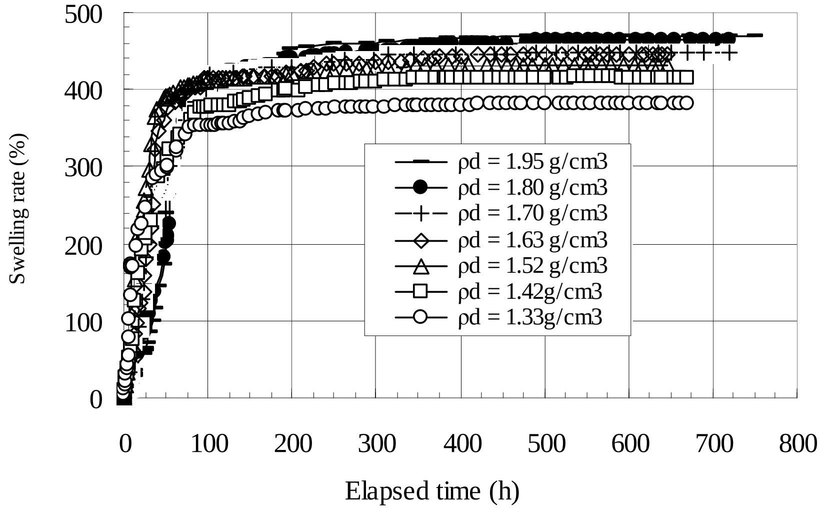

Figure 4 Free swelling rate of compacted bentonite at 20^0C

Temperature effects on free swelling rate of compacted bentonite are presented in Figure 5. This shows that with the same initial dry density the maximum swelling rate varied about 10~15 % due to the effect of temperature. At the lower temperature swelling rate was lower compare to higher temperature. It might be due to changes of water density and reaction of clay mineral by variable temperature. Generally at 4^oC water density is higher compared to another temperature.

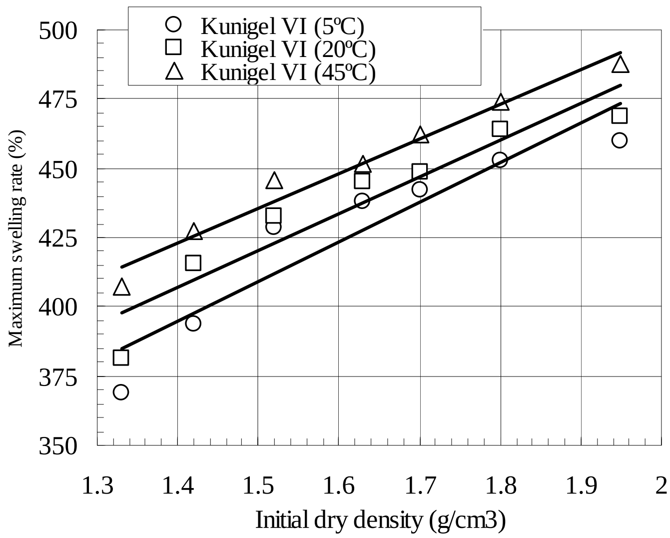

Figure 5 Temperature effect on swelling rate

Free swelling rate of compacted bentonite-sand mixture at 20^oC is presented in Figure 6. It shows the effect of bentonite (B) content in bentonite-sand mixture on swelling phenomenon. It has been clearly seen that content of bentonite in bentonite-sand mixture is the prime factor in swelling deformation.

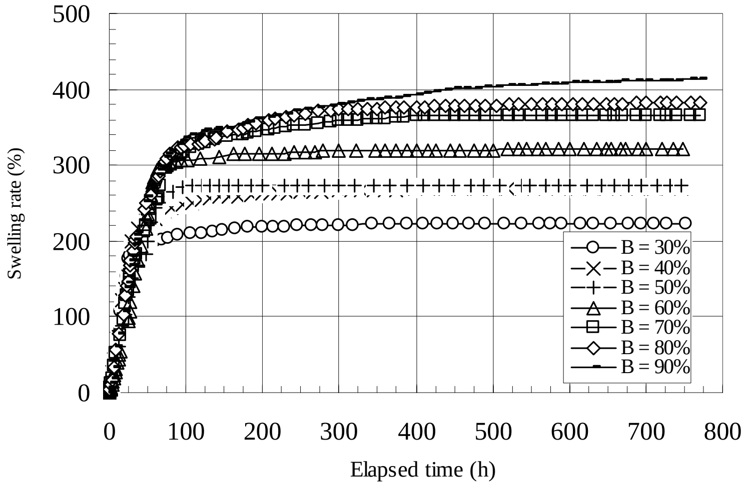

Figure 6 Free swelling rate of bentonite-sand mixture at 20^0C

Loading effects of compacted bentonite on swelling rate are presented in Figure 7. Static load (p_c) and initial dry density are the important factors in the control of the swelling rate of compacted bentonite. Maximum swelling rate rapidly decreased using a static load of 0.16 ~ 0.64 MPa and after that the swelling rate slowly decreased with static load up to 1.28 MPa. At a lower density of compacted bentonite the swelling rate was negative under a higher static load. The swelling rate gradually increased and comes to zero i.e. original height of the specimen and then positive at 1.28 MPa using variable initial dry density of compacted bentonite. The results indicate that bentonite has self sealing ability for toxic or radioactive waste disposal. The swelling characteristics of bentonite serve as a measure of the self sealing capabilities of the backfill with respect to filling cracks or gaps between the compacted bentonite and host rock.

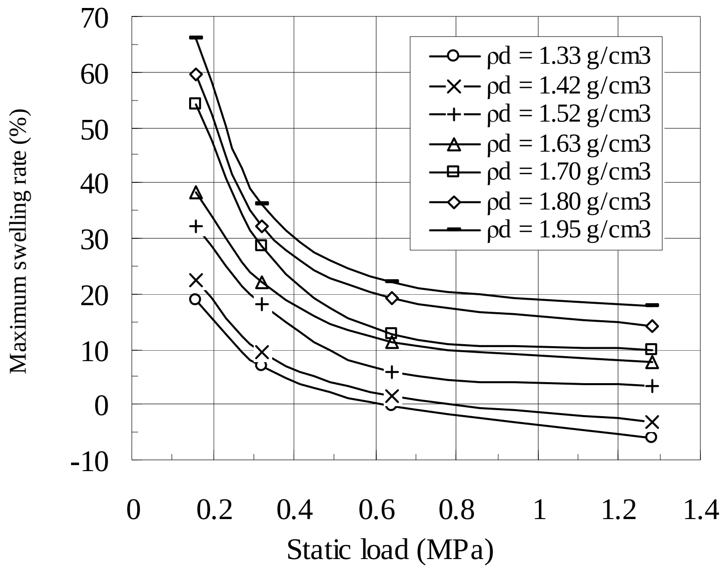

Figure 7 Loading effect on swelling rate

The loading effect on void ratio of compacted bentonite in a swelling deformation test is presented in Figure 8. Void ratio noticeably increased at the end of the swelling test compared with the initial state using a lower level static load. After that, the void ratio gradually decreased using a higher static load. A schematic model of swelling deformation at low density and at high density are shown in Figure 9 and 10, respectively. These show that for low density of compacted bentonite its original height decreased at the end of the swelling deformation test due to a decrease in its void ratio compared to the initial state. For higher initial dry density of compacted bentonite the void ratio increased compared with initial state of the specimen.

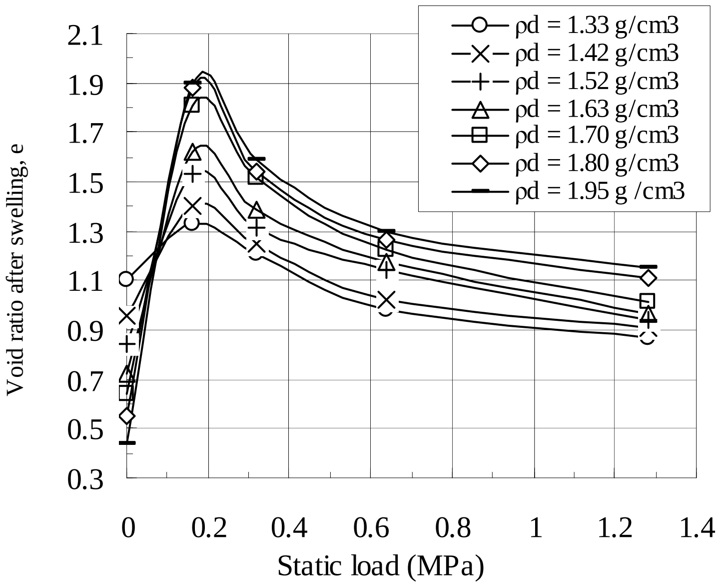

Figure 8 Loading effect on void ratio

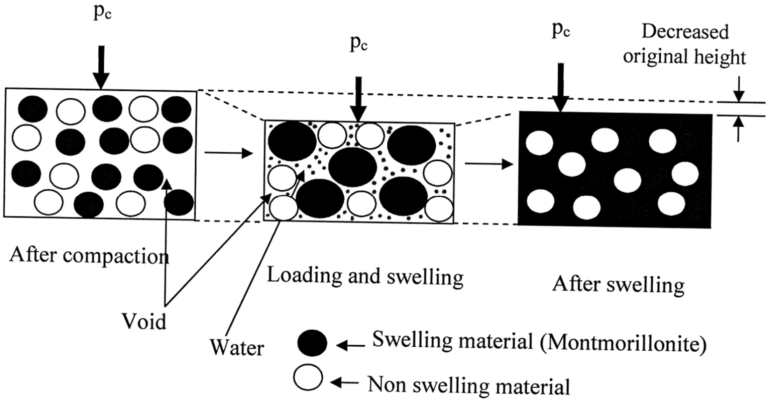

Figure 9: Schematic model of swelling deformation at low density.

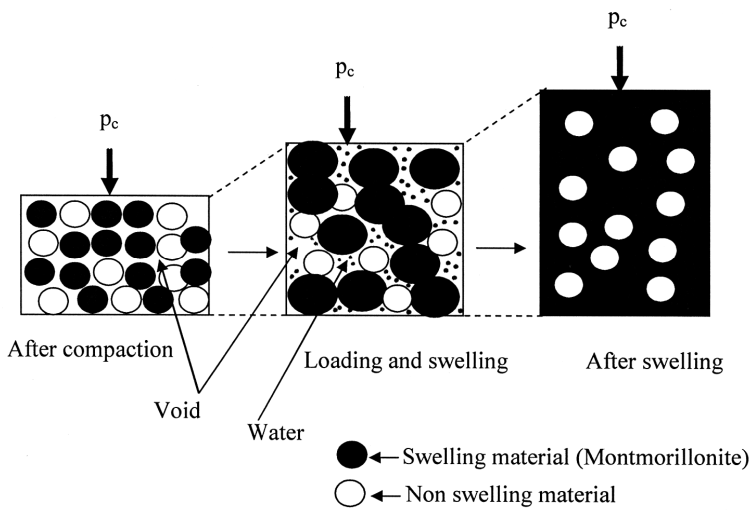

Figure 10: Schematic model of swelling deformation at high density.

The relationship between swelling pressure, fluctuation pattern and elapsed time are presented in Figure 11. The initial dry density is the main influencing parameter for swelling pressure developed in bentonite. The maximum swelling pressure noticeably increased due to the initial dry density. Generally the swelling pressure developed in bentonite is dependent on some factors e. g. types and content of clay minerals, structural arrangement of clay particles, initial water content and ion content in pore water etc. It has been observed that for low initial dry density two peaks are present. The first peak was observed following 25~30 hour elapsed time and second peak at about 90~100 hour. Specimens at higher level initial dry density did not develop these peaks but after reaching its peak the maximum swelling pressure fluctuated due to temperature. Comparison of maximum swelling pressure with other researcher results is presented in Figure 12. At the same initial dry density maximum swelling pressure might be varied by using different compaction pressure. The relationship between maximum swelling pressure and temperature are shown in Figure 13. This figure shows that swelling pressure increased due to temperature. Although at the same density the maximum swelling pressure was not affect noticeably by temperature, there is a general tendency that swelling pressure increased at higher temperature.

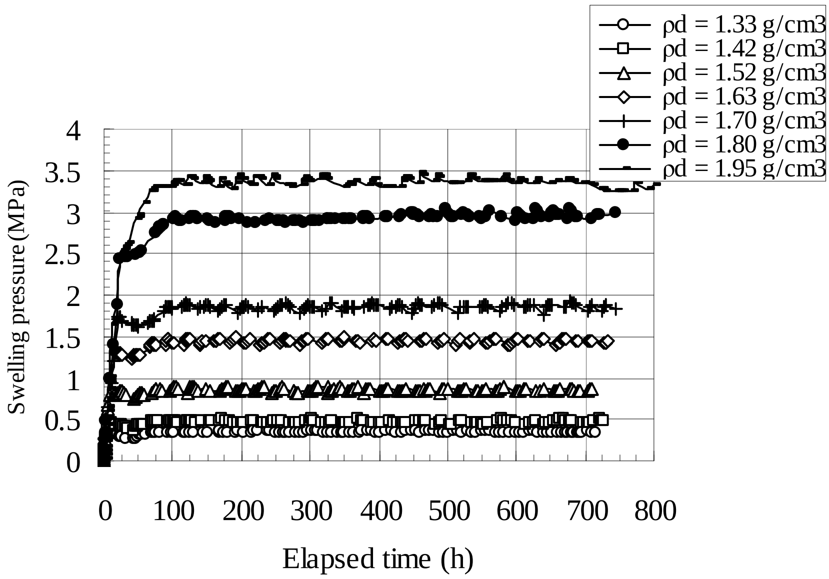

Figure 11 Swelling pressure of compacted bentonite

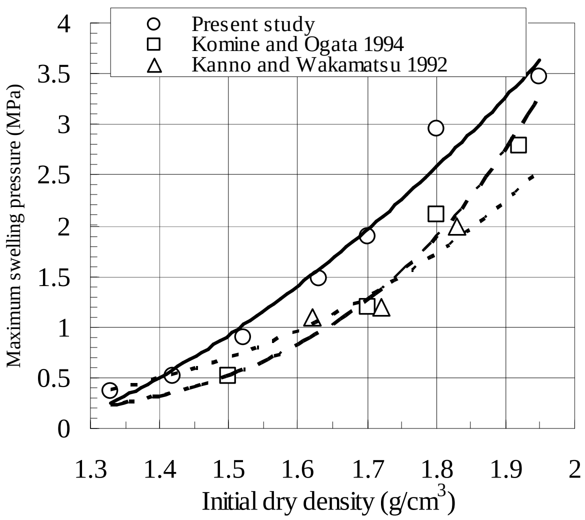

Figure 12 Relationship between maximum swelling pressure and initial dry density

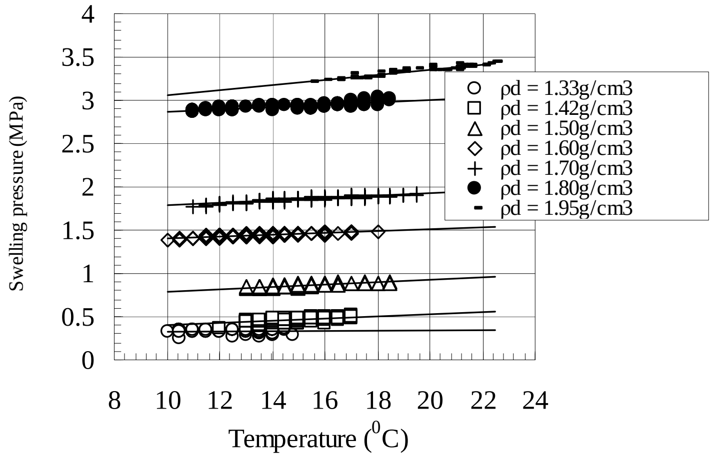

Figure 13 Relationship bentween temperature and swelling pressure

6 CONCLUSIONS

Bentonite and bentonite-sand mixture are essential as buffer materials for waste disposal as previously established. The present research investigates the main character of bentonite and bentonite-sand mixture i.e. swelling pressure and deformation. Based on the results presented in this paper the following conclusions are drawn:

- Initial dry density, content of bentonite and temperature are the controlling parameters for the swelling deformation of compacted bentonite. Static load is also another factor which influenced the swelling rate of bentonite. For low density of compacted bentonite the void ratio decreased compared to the initial state but in the case of high density the void ratio increased when subjected to static load.
- Swelling pressure of compacted bentonite and bentonite-sand mixture fluctuates with respect to temperature. Swelling pressure exhibited higher values for higher temperature with compacted specimens. Maximum swelling pressure is dependent on initial dry density and content of bentonite.

7 ACKNOWLEDGEMENTS

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