EFFECT OF VOID RATIO ON SWELLING AND PERMEABILITY OF BENTONITE

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ABSTRACT

A series of experiments has been conducted at the Geosphere Research Institute of Saitama University, Japan to evaluate the effect of void ratio on swelling and permeability of bentonite. Void ratio is the prime criterion for swelling and permeability of bentonite and bentonite-sand mixtures when it is used as a buffer material for waste disposal facilities. At the end of swelling void ratio increased 7 to 8 times when compared with the initial state of the bentonite and bentonite-sand mixture. Permeability is also increased as a result of an increase in void ratio.

1 INTRODUCTION

In many geoenvironmental engineering applications bentonite is extensively used by itself or as a component of mixture materials especially for nuclear waste disposal. Bentonite is a special type of clay. The micro-structural view of bentonite is shown in Figure 1. Disposal is the emplacement of waste in an approved, specified facility without the intention of retrieval. It may also include the approved direct discharge of effluents into the environment with subsequent dispersion. A disposal facility is to provide sufficient isolation of waste to protect human and the environment and not to impose any undue burden on future generations (Kumine *et al.*, 2001; Dixon *et al*., 1985 and 1996). Bentonite-sand mixtures are suitable for constructing filling zones with very low permeability as both bentonite and sand have long existed in the natural environment (Nakashima *et al*., 2001; Shirazi *et al*., 2004a, 2004b and 2006).

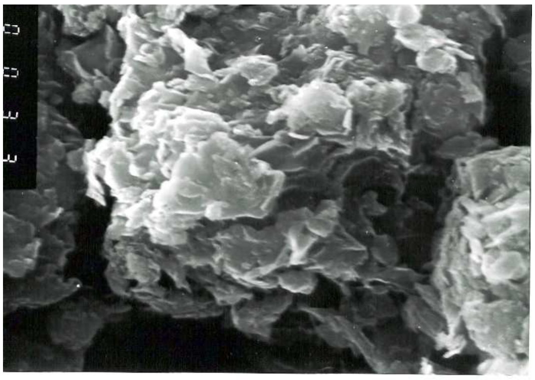

Figure 1: Micro structural view of super clay (Scale: 2 μ, x 1000) by Kazama 1996.

2 MATERIALS AND METHODS

Three types of powdered bentonite named as Akagi (A), Kunigel (K) and super clay (SC) were used in this experiment. Quartz sand number 3 and 5 are used as a mixture material with bentonite. The specific gravity of Akagi, Kunigel and super clay are 2.744, 2.797 and 2.857 respectively. Compacted bentonite and bentonite-sand mixture specimens were prepared usung a compaction device (Model No. CLP-200KNB) produced by Tokyo Sokki Kenkyuji Co. Ltd., Japan. Compacted bentonite-sand mixtures specimens have been prepared with bentonite at 30, 40, 50, 60, 70, 80 and 90% of bentonite in the bentonite-sand mixture. The initial dry density of the compacted bentonite-sand mixture specimens was about 2 g/cm^3. The compacted bentonite specimens had an initial dry density between about 1.29 and 1.97 g/cm^3 depending on the mass and compaction pressure exerted on them. The height of compacted specimens is about 1 cm. The compacted specimens were placed in an oedometer cell and axial swelling rate with elapsed time was calculated under 1.6, 3.2, 6.4 and 1.28 MPa static load. Silicon grease was added to the inner wall of the oedometer cell to minimize the frictional force. Swelling tests for every specimen took about 750 to 800 hours. At the end of swelling the maximum swelling rate and void ratio was calculated with the degree of saturation found to be about 98% to 100%. A permeability test using the falling head method was carried out at the end of swelling on every specimen. The vertical pressure of compacted bentonite and bentonite-sand mixture was measured using a digital strain meter (TC-31K, Tokyo Sokki Kekyuji Co. Ltd., Japan). Silicone grease was added at the inner side of the swelling pressure box to reduce the frictional force. The detailed swelling deformation and the pressure test procedure was described by Shirazi *et al.* (2005). A schematic diagram of the swelling pressure test apparatus is presented in Figure 2.

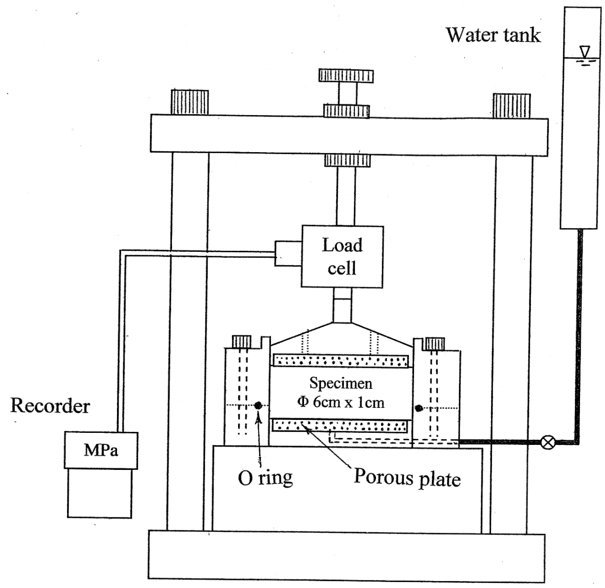

Figure 2: Swelling pressure test apparatus.

3 RESULTS AND DISCUSSION

Relationship between the initial void ratio and the dry density of different types of bentonite are presented in Figure 3. It was found that at the same initial void ratio the dry density of super clay was higher than Kunigel and Akagi bentonite. The fine particle size (<0.005 mm) of Super clay, Kunigel and Akagi was 87%, 75% and 56% respectively.

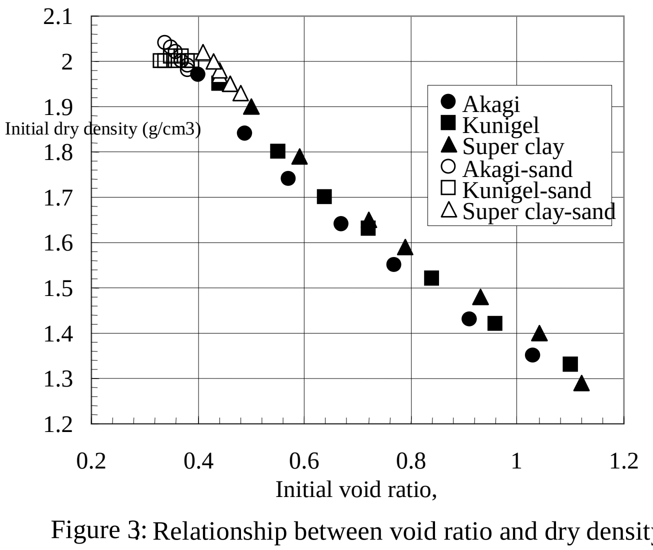

Figure 3: Relationship between void ratio and dry density of compacted specimens.

The loading effect of compacted bentonite and bentonite-sand mixture on swelling rate is shown in Figures 4 to 7. The static load and the content of bentonite are the important factors in the control of the swelling rate of compacted bentonite. The maximum swelling rate rapidly decreased when using a 0.16~0.64 MPa static load and after that the swelling rate slowly decreased with static load up to 1.28 MPa. At lower contents of Akagi bentonite swelling rate was negative but at higher static loads the swelling rate gradually increased to zero (i.e. to the original height of the specimen) and then positive at 1.28 MPa. This indicates that bentonite has a 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.

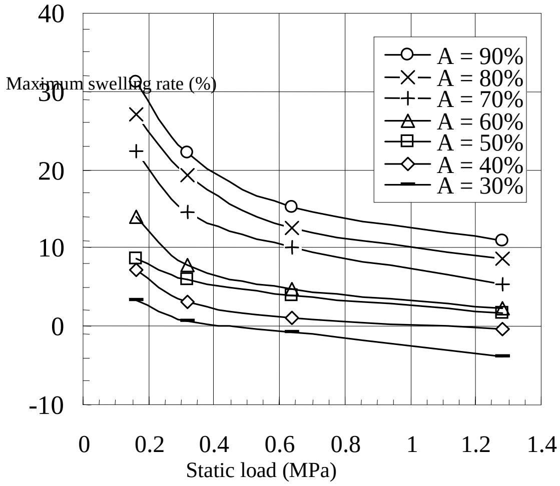

Figure 4: Loading effect on swelling rate of Akagi – Sand.

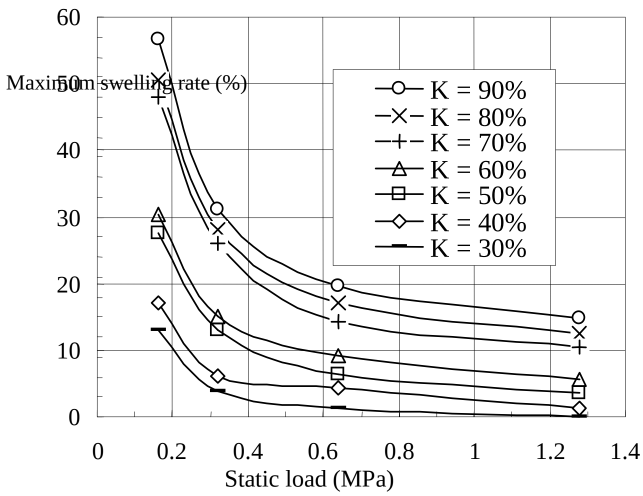

Figure 5: Loading effect on swelling rate of Kunigel-sand

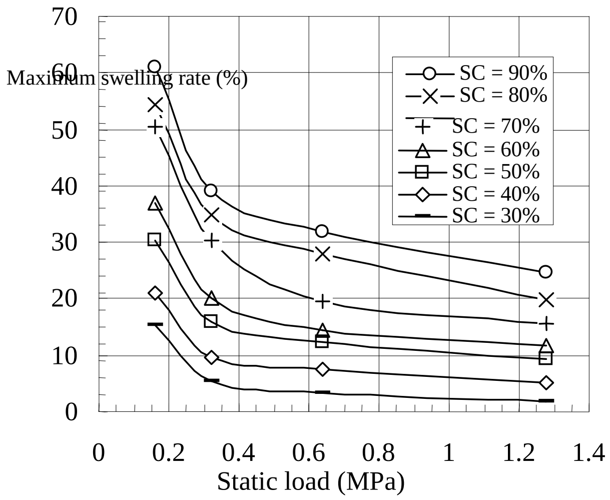

Figure 6: Loading effect on swelling rate of super clay - Sand

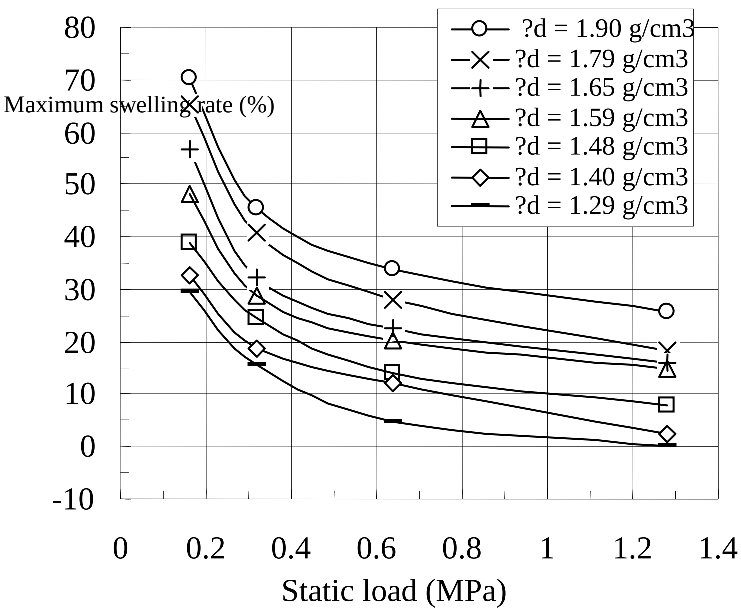

Figure 7: Loading effect on swelling rate of super clay

The effect of loading on void ratio at the end of swelling of compacted bentonite-sand mixtures is shown in Figures 8 to 10. The void ratio at the end of swelling is greatly influenced by the loading pressure and content of bentonite in bentonite-sand mixture. At 0.64 and 1.28 MPa static load the void ratio slightly decreased but in the rest of the specimens the void ratio increased noticeably.

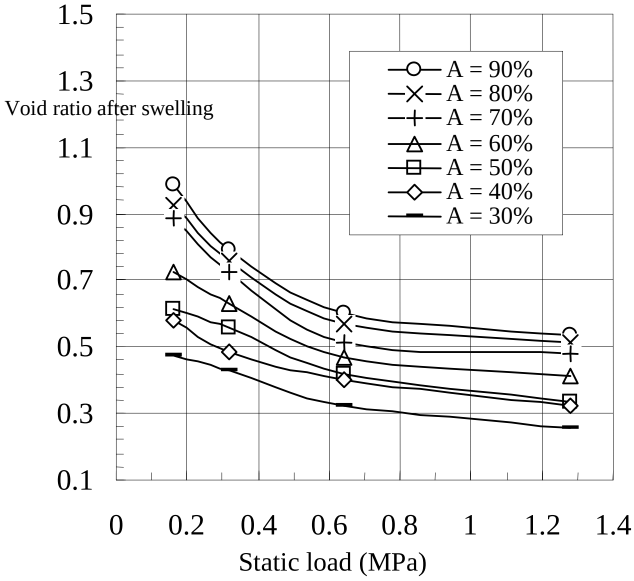

Figure 8 : Loading effect on void ratio of Akagi-sand.

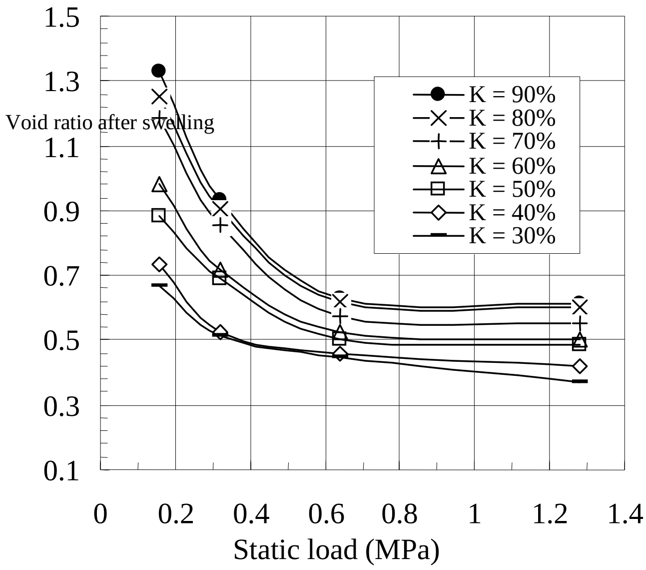

Figure 9:: Loading effect on void ratio of Kunigel-sand

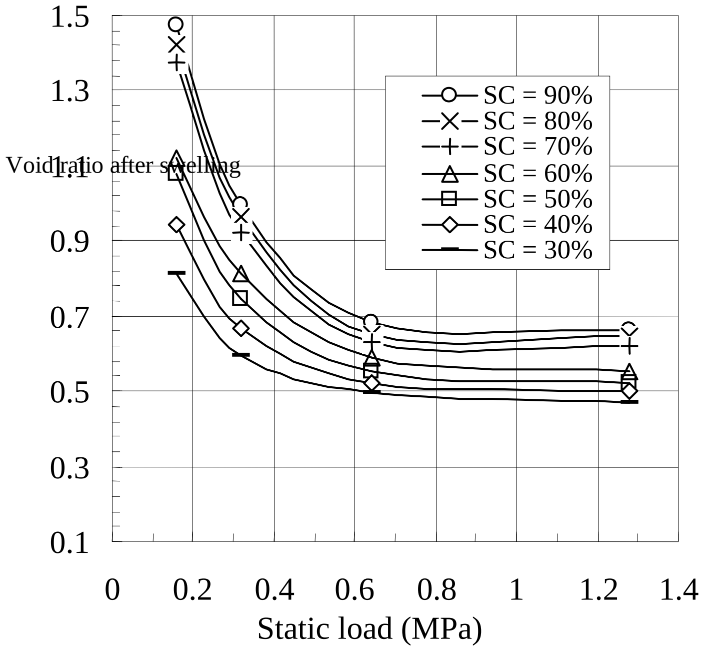

Figure 10: : Loading effect on void ratio of super clay-sand

The relationship between the initial and final void ratio of compacted bentonite-sand specimens is shown in Figure 11. The initial void ratios of the compacted bentonite-sand mixture were 0.33 to 0.45 but final void ratio increased to about 0.22 to 1.45.

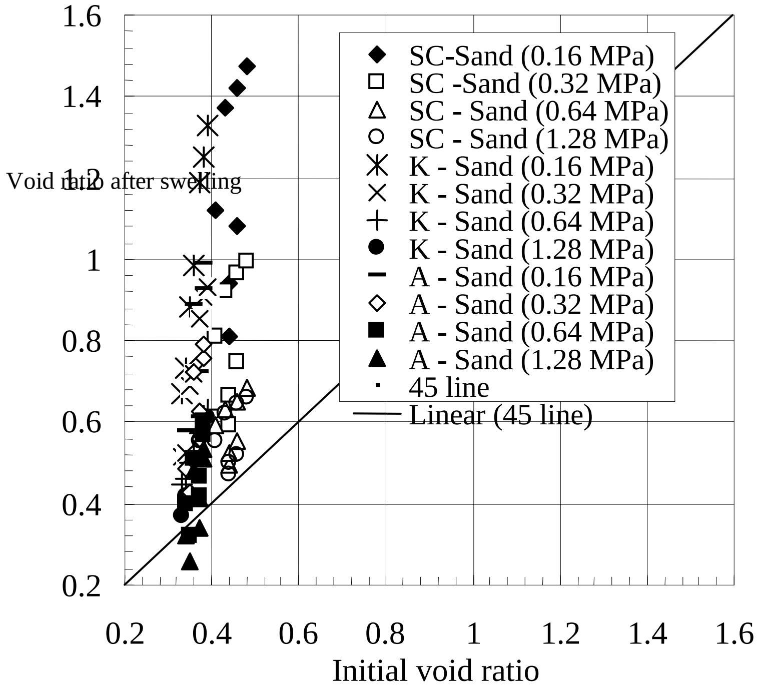

Figure 11: : Relationship between initial and final void ratio of bentonite-sand mixture

The relationship between the initial and final void ratio of compacted bentonite at the end of swelling is illustrated in Figures 12 and 13 where the initial void ratio ranged from 0.61 to 1.11 using different types of bentonite. At the end of swelling the void ratio varied from about 0.62 to 1.91. In some cases due to the higher static load the void ratio decreased from initial condition for Akagi and Kunigel. It is noticeable that at the end of free swelling the void ratio increased about 5 to 8 times when compared with initial conditions.

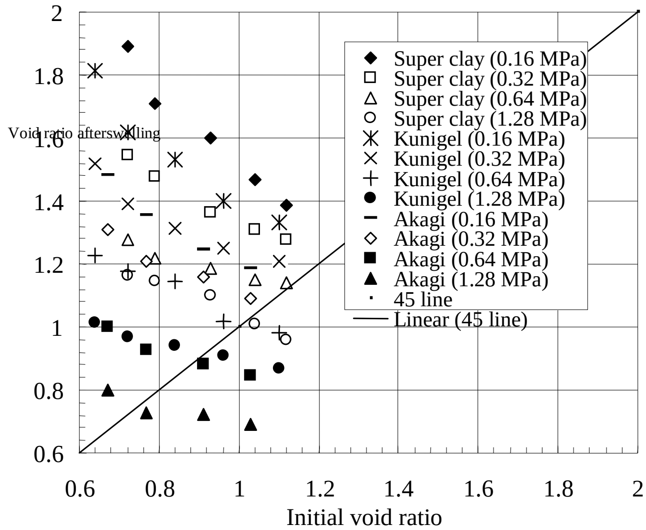

Figure 12: Relationship between initial and final void ratio of bentonite under static load

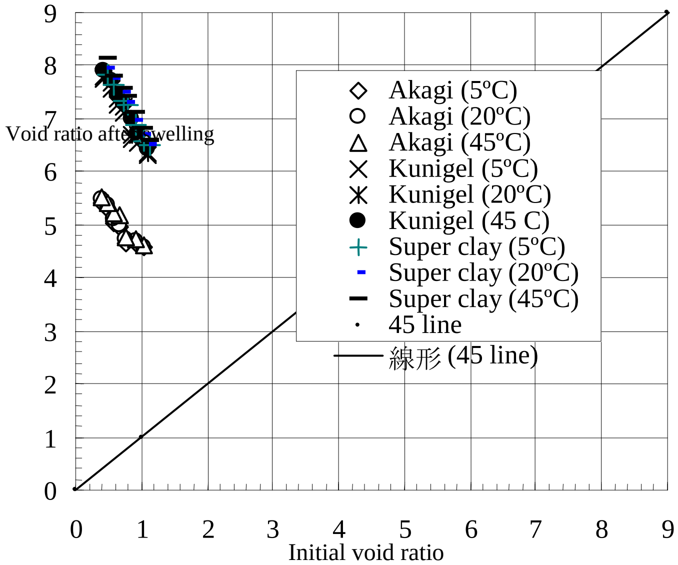

Figure 13: Relationship between initial and final void ratio of bentonite at end of free swelling

The maximum swelling pressure fluctuation pattern of compacted bentonite is presented in Figures 14 and 15. The initial dry density for all specimens was about 2 g/cm^3. The swelling pressure rapidly increased and reaching its peak within a short period of time and after that continued with little fluctuation. Changes in the maximum swelling pressure with elapsed time might be due to temperature (Shirazi *et al.,* 2005). At the same percentage of bentonite content in the bentonite-sand mixture the maximum swelling pressure markedly varied due to variation of mineral content in the bentonite.

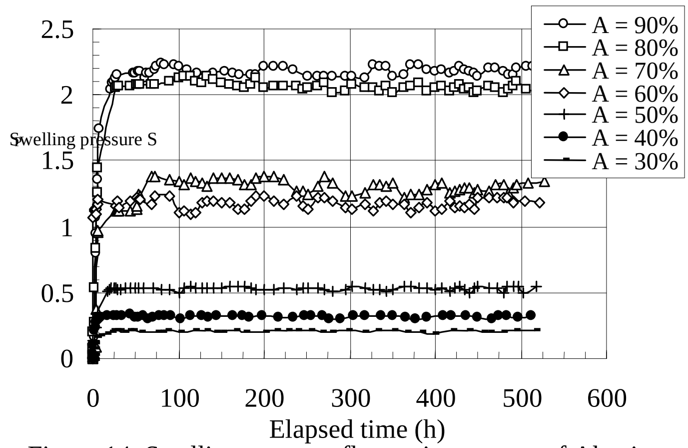

Figure 14: Swelling pressure fluctuation pattern of Akagi-sand mixture

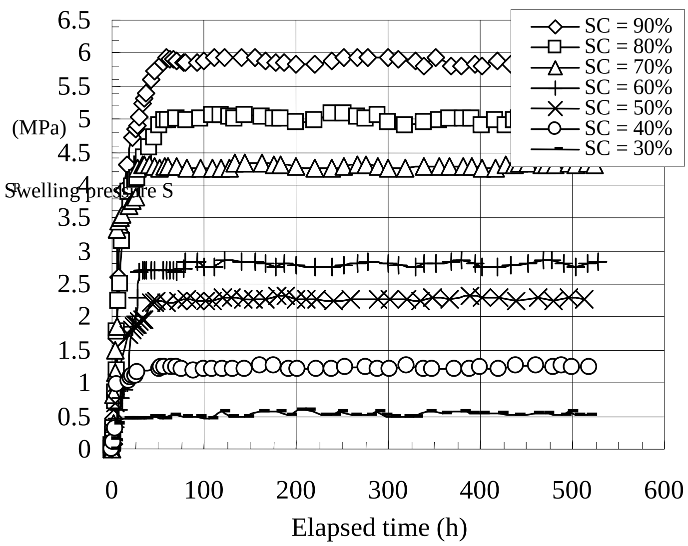

Figure 15:: Swelling pressure fluctuation pattern of super clay - sand mixture

The permeability noticeably decreased with the increasing content of bentonite in the bentonite-sand slurry as shown in Figure 16. At the same bentonite content the void ratio varied due to different types of bentonite and has an ultimate effect on the permeability.

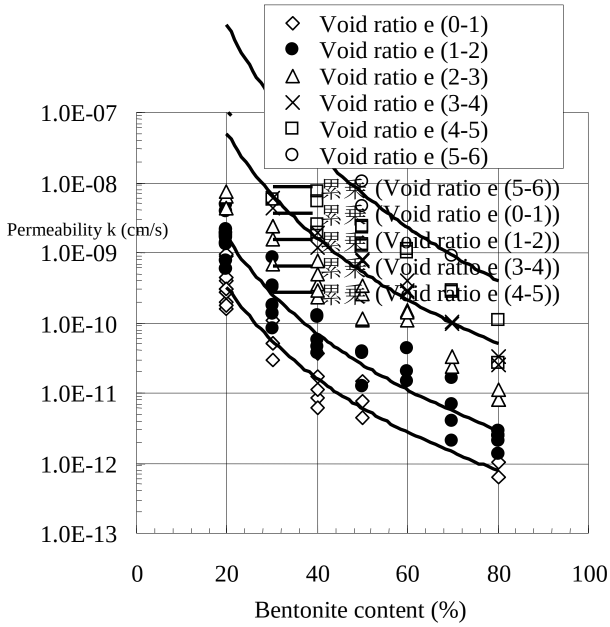

Figure 16: Relationship between permeability and bentonite content

The permeability of different types of compacted bentonite-sand mixtures at the end of swelling are presented in Figures 17 to 19. These figures illustrate that permeability decreased with an increase of bentonite at the same void ratio. The permeability of Akagi, Kunigel and super clay mixtures varied from about 10^{-8} to 10^{-11}cm/s, from 10^{-8} to 10^{-11}cm/s and from 10^{-9} to 10^{-13} cm/s respectively. The coefficient of permeability of specimens containing 30% to 50% bentonite is significantly different from the samples with content of 60% to 90% bentonite.

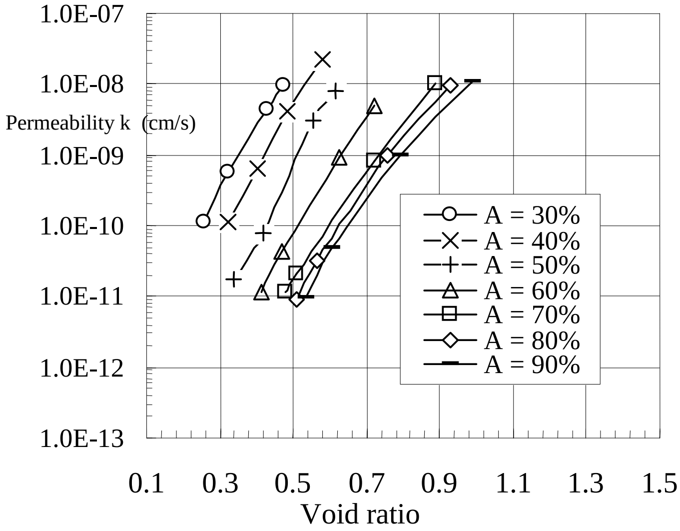

Figure 17: : Permeability of Akagi - sand mixture

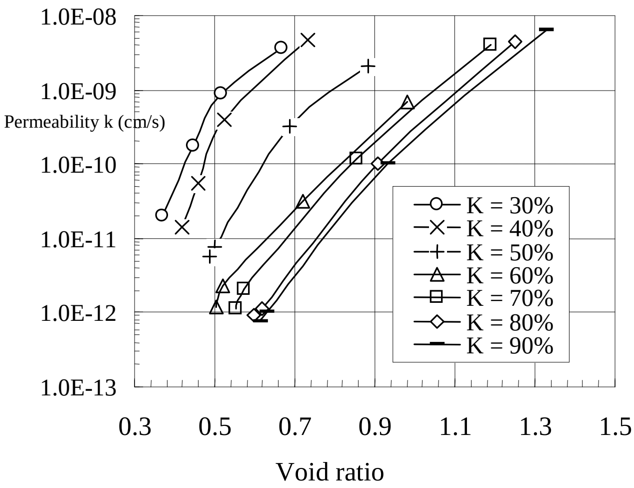

Figure 18: Permeability of Kunigel - sand mixture

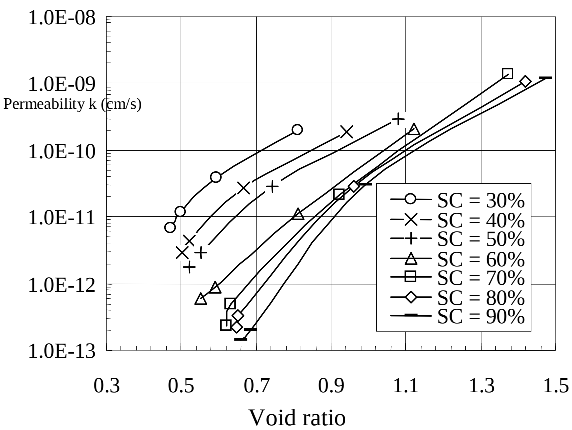

Figure 19: Permeability of Super clay - sand mixture

4 CONCLUSIONS

The initial void ratio and the type of bentonite are the important factors in the swelling deformation of compacted bentonite. At the same initial dry density the swelling rate of compacted bentonite and bentonite-sand mixtures is noticeably different due to mineral content. Temperature affects the swelling rate with an increase in the swelling rate with an increase in temperature for all types of bentonite and bentonite-sand mixture. The temperature may be accelerating the activity of the clay particles.

At the end of swelling the void ratio increased noticeably when compared with the initial condition under loading or unloading for different types of bentonite and bentonite-sand mixtures. At the end of free swelling the final void ratio increased by about 7~8 times the initial state. The static load is also another factor which influenced the swelling rate of bentonite. For low density compacted bentonite the void ratio decreased when compared to initial the state but in the case of high density compacted samples the void ratio increased with the static load.

5 ACKNOWLEDGEMENTS

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