Experimental study to elucidate cementation effect on swelling pressure and montmorillonite basal spacing of bentonite ore

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WASEDA Geo-Lab

1. Introduction: Bentonite Buffer Material in Geological Disposal

Bentonite buffer material is required
- ✓ Low water permeation
- ✓ Gap sealing by **swelling** deformation
- ✓ Soundness for thousands of years

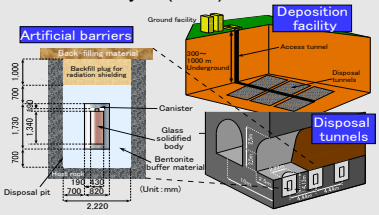
Placed in high temperature, pressure

・Solidified because of **cementation**, and swelling properties changed.

Reproduction of cementation is difficult by laboratory experiments

・Focusing on **bentonite ore as simulating buffer** altered by cementation

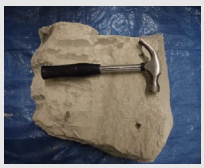
Research Objective
- ✓ Evaluation of **cementation effect on swelling pressure** of bentonite materials
- ✓ Elucidation of **mechanism of cementation effect on swelling** from microstructure analysis(XRD)



2. Material and Specimen Preparation

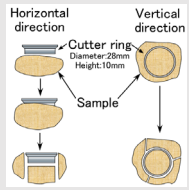
Fundamental properties of ore sample

Tsukinuno ore (Yamagata, Japan, geological age: 10 million years)			
Soil particle density (Mg/m^3)	2.77	CEC(cmol/kg)	39.3
Liquid limit(%)	419.1	Ion concentration (Na^+) (cmol/kg)	42.5
Plastic limit(%)	29.2	Ion concentration (Ca^{2+}) (cmol/kg)	10.2
Plasticity index	389.9	Ion concentration (Mg^{2+}) (cmol/kg)	0.8
Montmorillonite content(%)	44.7	Ion concentration (K^+) (cmol/kg)	Lower than 0.8
Swelling power(ml/2g)	12		

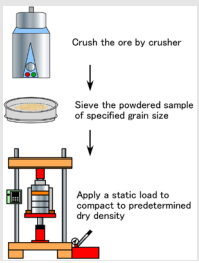


Appearance of Ore

★Specimen: Undisturbed and reconstituted specimen



Undisturbed specimen
(**Retained cementation**)
→Molded into column shape for specimens' size



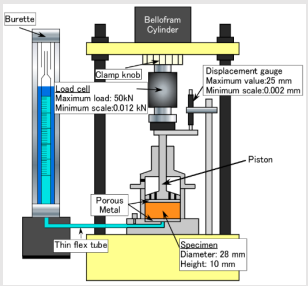
Reconstituted specimen
(**Removed cementation**)
→Crushed ore and made of powder (~0.425 mm, 0.850~2.00 mm), then compacted statically

3. Cementation Effect on Swelling pressure

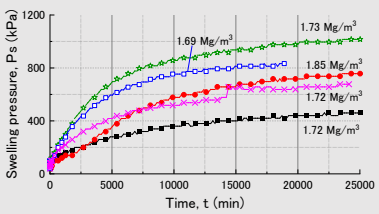
★**Swelling pressure test (Frame type device)**

・Suppression way for specimen volume change
- ✓ Horizontal: Restrained by stainless ring
- ✓ Vertical: Tightening the clamp knob and fixing piston

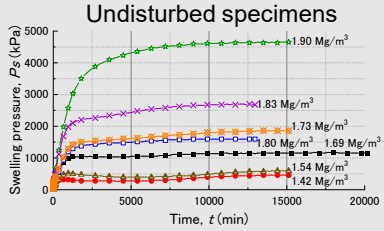
・Investigation
- ✓ Time course of swelling pressure (P_s)
- ✓ Maximum swelling pressure ($P_{s\,max}$) vs dry density



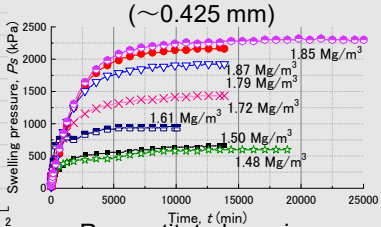
Swelling pressure test device (Frame type)



Undisturbed specimens



Reconstituted specimen (~0.425 mm)



Reconstituted specimen (0.850~2.00 mm)

★**Results**

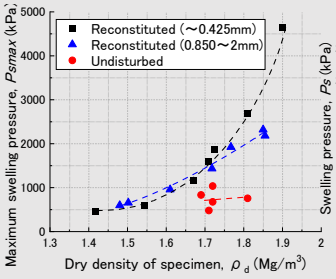
・**Time course of P_s**

Undisturbed specimens: Slowly increased, more than 15,000 min for constant.
Reconstituted specimens: Sharply increased, about 5000 min for constant.
→Soil structure of undisturbed specimen gets complicated by cementation, water absorption and associated increase in P_s might be delayed.

・ **P_{smax} vs dry density of specimen**

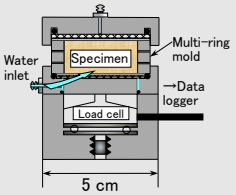
Reconstituted specimens:
P_{smax} increase as dry density increase irrespective of particle size.
Undisturbed specimens:
P_{smax} vary widely but be smaller than reconstituted specimens.

→ P_{smax} declines to about half with same dry density because of cementation.

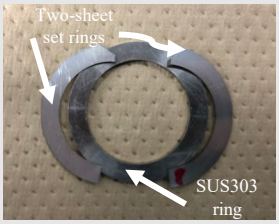


4. Elucidation of mechanism of cementation effect on swelling from microstructure(XRD)

★**Aim:** Revealing mechanisms of declining P_{smax} by cementation in terms of **montmorillonite basal spacing (d_{001})**
→XRD was applied to specimens before and after swelling pressure test to measure d_{001}.



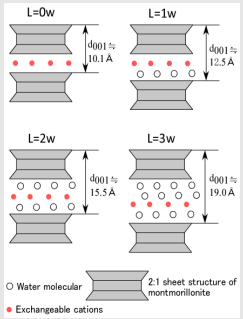
Swelling pressure test device with separate mold



Composition of mold


XRD test device (RINT-Ultima Ⅲ, Rigaku)

Measurement condition of XRD	
Optical system	Focal geometry
Incident wave source	CuKα
Measurement range	2.7 ~ 20°
Scanning step	0.02°
Scanning speed	10°/min
Divergence slit	1/8°
Scattering slit	8.00 mm
Light-receiving slit	13.00 mm



Changes in d_{001} with water absorption

★Testing program

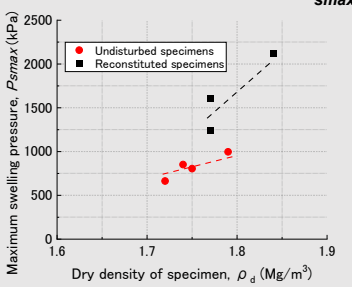
(1)Mold was composed of two or three SUS303 rings of 2 mm thickness, and two rings of 0.30 mm thickness.
(2)Specimen was inserted into the mold.
(3)XRD measurements were performed.
(4) was measured for predetermined period.
(5)After measuring the swelling pressure, the specimens were taken out, then specimens were sliced by 2 mm using a 0.20 mm thick saw.
(6)XRD was measured again, and water content was also measured.

Implementation cases of the experiment				
	Specimen dry density (Mg/m^3)	Specimen Height (mm)	Test period (day)	XRD observation with swelling pressure measurement
Undisturbed specimen	1.79	4	5	Only after
	1.74	6	2	Only after
	1.75	4	5	Before and after
	1.72	4	6	Before and after
Reconstituted specimen	1.77	4	5	Only after
	1.77	6	2	Only after
	1.84	4	5	Before and after

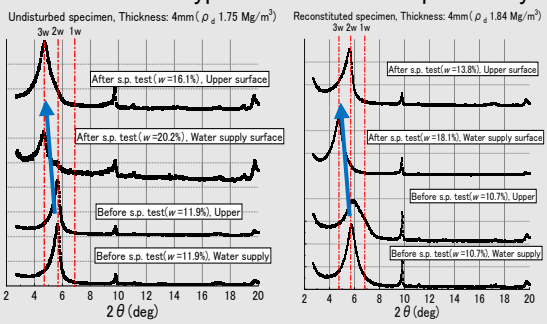
★Results

・ ***P_{smax} vs dry density***

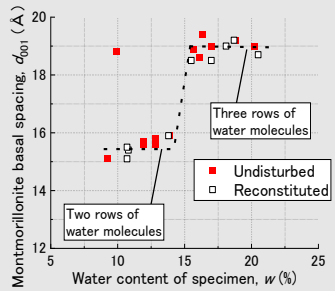
Measured values and trends of P_{smax} were similar to Frame Type device in **3**. →Repeatability of this result was confirmed.



Relation between P_{smax} and dry density



XRD results before and after swelling pressure test



Relation between d_{001} and water content

・**XRD observations before and after swelling pressure test**

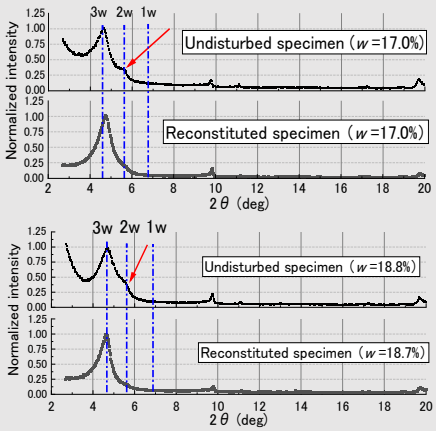
In both the undisturbed and reconstituted specimens, water molecules penetrated between the montmorillonite layers of before and after the swelling pressure test.

・**Relation between d_{001} and water content**

d_{001} equal to two rows of water molecules at w=9-14%, three rows at w=15-20%.
d_{001} is almost same in undisturbed and reconstituted specimens.
→Particularly addressing maximum peak, cementation effect on d_{001} is slightly visible.

・**Peak shape comparison in same water content (w=17.0, 18.8%)**

Reconstructed specimen: Three rows is dominant.
⇔Undisturbed specimen: Two rows remains besides three rows (arrow in the figure).
→At same w, **water molecules between montmorillonite layers in the undisturbed specimens is fewer than reconstituted specimens**.
→Decline of swelling pressure of the undisturbed specimens was identified as the inhibition of water molecule penetration between montmorillonite layers by cementation.



5. Conclusion

This study was conducted for evaluation of change in swelling characteristics by cementation of bentonite buffer material during geological disposal. Bentonite ore produced by diagenesis in natural ground was used for experiments of swelling pressure and montmorillonite basal spacing as a similar material to the consolidated buffer. Following points are conclusions of this paper.

- ✓ Undisturbed specimens have a longer convergence time to reach P_{smax}. P_{smax} is about half of the reconstituted specimens with same dry densities.
- ✓ When d_{001} was measured by XRD before and after swelling pressure measurement, the relation between d_{001} and w of the undisturbed specimens and the reconstituted specimens was almost identical when particularly addressing maximum peak.
- ✓ At w of 17.0% and 18.8%, peaks for two rows of water molecules remained in the undisturbed specimens. Therefore, the undisturbed specimens might have fewer water molecules between the montmorillonite layers than the reconstituted specimens. In the undisturbed specimens, the cementation effects inhibited the movement of water molecules between the montmorillonite layers. Consequently, the swelling pressure of undisturbed specimens was reduced to about half.