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# COMPARISON OF COMPRESSIBILTY CHARACTERISTICS OF BUSAN LEACHED AND UNLEACHED CLAYS

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ABSTRACT: It is well known that the settlement of soft deposit increases with leaching process due to bond weakness of soil skeleton. This paper investigated the effect of leaching on the compressibility of Busan clay. The leached clay samples were obtained from the leaching procedure in laboratory with fresh water on the cell chamber. The initial salinity of about 17g/l in soil specimen, which was taken from Hwajeon industrial complex area, decreased to about 3g/l for 25 days. Compressible characteristics of the Busan leached clay were evaluated using the constant rate of strain test (CRS test), in which two kinds of strain rate, $\dot{\varepsilon} = 10^{-3}\%/\sec$ and $\dot{\varepsilon} = 10^{-4}\%/\sec$, were adopted. Mechanical characteristics and physical properties between natural clay and leached clay were compared on the samples with the same conditions except salinity. The experimental test results of CRS tests showed that the compressibility of Busan leached clay increased as its salinity decreased. However, the void ratio, liquid limit, preconsolidation pressure and hydraulic conductivity of the leached sample decreased than these of the unleached clay due to leaching.

Keywords: CRS test, leached clay, consolidation, salinity

## INTRODUCTION

Large-scale development projects for industrial complex are being performed on the estuary delta of Nakdong River since early 1990s, as shown in Fig. 1.

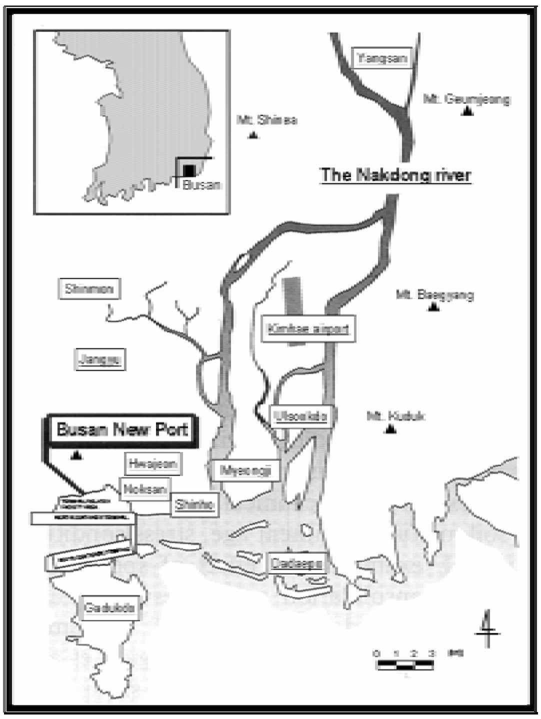


Fig. 1 Nakdong River and its vicinity (Kim 2008)

The soil deposits of the Nakdong River plain, called Busan clay, are very thick in which its thickness varies from 30m to 60m depending on site locations, especially more than 70m at the mouth of the Nakdong River.

Geotechnical profile of Busan clay is shown in Fig. 2. Under about 10m silty sand is sedimentary clay deposit of approximately 40m in thickness, followed by sandy layer which usually have gravel in its lower part. Sedimentary clay deposit consists of upper clay layer and lower clay layer. Upper clay layer with thickness of about 20m has N values from 0 to 7 and soil salinity ranged between 13g/l to 17g/l with an average value of 15g/l. However, lower clay layer has N value greater than 8. The soil salinity decrease from about 12g/l to 5g/l with an increase in depth. In Busan clay, it is noted that the salinity of the lower clay layer is significantly smaller than that of the upper clay layer. This clearly indicates the leaching of salt has been taking place for a long time. This natural leaching process was caused by upward flow of fresh water due to artesian pressure acting on the sand layer (Kim 2008).

The value of OCR in Fig. 2 was evaluated from the results obtained by the oedometer test. Since the soil disturbance may be induced by the sampling of undisturbed soil from deeper depth, Schmertmann's correction was applied for the determination of the

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*Note:* Discussion on this paper is open until June 2010

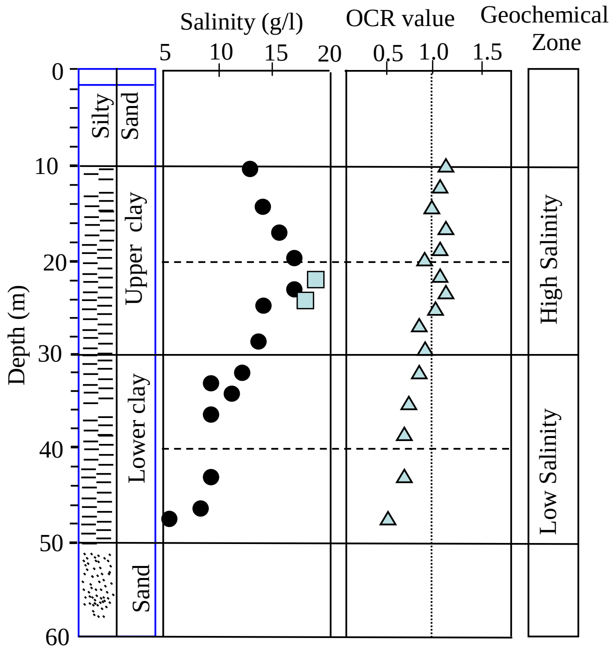



Fig. 2 Soil profile and geo-chemical analysis for clay at BH4, Hwajeon site (Rao 2004)

maximum past pressure. The results show that the values of OCR in upper clay deposit are about 1 while those in lower clay deposit become less than 1. This may be due to the artesian pressure applied to the lower portion of the soil layer and one of the specific characteristics of Busan clay (Kim 2008)

Marine clays deposited along a coastal area usually contain an amount of soluble salt in the pore of soil skeleton. The soil salinity depended on the salt concentration of water or seawater environmental deposition. The salinity of seawater from which the marine clays are sedimented is of the order 35g/l (Sverdrup et al. 1942).

It has been well known that leaching affects plasticity and compressibility of soft clay. Kim (2008) reported a valuable discussion regarding to leaching effects on geotechnical properties based on both laboratory and in-situ test results. The liquidity index ($I_L$) at Shinho and Yangsan showed almost constant through depth with a value of unity. Main concern is that liquidity index in the lower portion of the clay layer is as high as unity even in the depth of 30m. Of course, this is due to the leaching, which causes the decrease of liquid limit while maintaining almost constant natural water content.

Leaching effects on the properties of clay was also researched by many authors through a series of leaching and consolidation experiments. In the decades of 1950s, Rosenqvist (1953), Skempton and Northey (1952), and Bjerrum (1954) investigated leaching effects on physical properties of Norwegian clay. They demonstrated in Norwegian clay that when the soil salinity was reduced to very low values by leaching action of fresh water, it was transformed into quick clay. The decrease of soil salinity caused an increase in soil compressibility (Torrance 1974 and Moore 1977). More typical details regarding to physical and compressibility of leached samples were shown in Table 1.

The leaching of Busan clay started much later than Norwegian and Canadian quick clays, which were produced by melting of glaciers in the Pleistocene glacial age. Continuous leaching of Busan clay is likely to take place in the geological history (Kim 2008). Moreover, there is no study on leaching effect on the compressibility characteristics of Busan clay neither in laboratory nor in the field.

The objective of this study is to investigate the effect of leaching on the compressibility of Busan clay. The leached specimens were obtained from leaching procedure with distilled water for long period. The CRS tests were performed on the samples to compare the compressibility characteristics between the leached and the unleached Busan clays.

## MATERIALS AND PREPARING SAMPLES

Undisturbed samples using thin-walled tube were taken from the Hwajeon area, Busan. Two tubes of samples were used in this study which was chosen at the depth about 20m with the highest salinity in field.

Two pairs of specimens at each HJ A-8 and HJ A-10 with same soil conditions, but different soil salinities were prepared for CRS tests. One sample was tested in its natural salinity and the other was leached prior to testing. The physical properties and initial soil salinity were shown in Table 2.

Soil salinity and water salinity was determined by salinitymeter CPC-401, which measured the value in g/l of sodium chloride (NaCl) concentration.

## LEACHING PROCEDURE AND CONSOLIDATION

In order to get undisturbed leached specimens, the specimens were trimmed by CRS ring which dimension $D$=6.35cm, $H$ =2.54cm. Then, the specimens were

Table 1 Literature review of leaching effects

| Parameters | Natural clay | Leached clay | Reference |
|---|---|---|---|
| Initial unit weight | 1.69 | 1.57 | Ismale (1993) |
| Initial void ratio, $e_o$ | 1.14 | 1.23 | Ismale (1993) |
| Water content, $W$ (%) | 40.4 | 41.0 | Bjerrum (1954) |
| Liquid limit | 43.4 | 27.4 | Bjerrum (1954) |
| Preconsolidation pressure, $\sigma'_{pc}$ (kPa) | 50 | 45 | Ismale (1993) |

Table 2 Initial soil properties of two samples

| No | Sample No | Depth (m) | $\gamma$ (kN/m$^3$) | $W$ (%) | Initial Salinity (g/l) | $G_s$ | Atterberg Limits | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Plastic limit, $W_P$ (%) | Liquid limit, $W_L$ (%) | Plastic index, $I_P$ (%) | Liquidity index, $I_L$ (%) |
| 1 | HJ A-8 | 22-22.8 | 16.95 | 60.13 | 17.96 | 2.65 | 30.14 | 69.15 | 39.01 | 0.77 |
| 2 | HJ A-10 | 20-20.8 | 17.21 | 53.26 | 16.26 | 2.72 | 21.18 | 61.07 | 39.89 | 0.80 |

placed in the CRS chamber. All the CRS samples were set up with seating load of 25 kPa to reduce the swelling effect after taking from the depth of about 20m.

The leaching procedure to obtain a leached specimen required permeating distilled water through the specimen. The schematic diagram of leaching procedure was shown in Fig. 3. The initial soil salinity and the initial water salinity were checked before leaching. Leaching procedure was finished as the values of salinity reached to the target value equaled to 3g/l for Busan clay.

A hydraulic gradient of 10 is required to achieve salt removal from a low permeability material in a reasonable period of time. In this procedure, the distilled water of 0g/l salinity flows from the top to the bottom of the sample. Fig. 4 shows the variation of soil salinity with the cumulative of collecting water.

As expected, the salinity decreased with time because of permeating distilled water. Finally, the target value of water salinity reached to about 3 g/l for 25 days and 24 days of the HJ A-8 and HJ A-10 specimens, respectively.

After finishing leaching procedure, a series of constant rate of strain (CRS) tests were carried out with the specific strain rate such as $\dot{\varepsilon} = 10^{-3}\% / \text{sec}$ and $\dot{\varepsilon} = 10^{-4}\% / \text{sec}$ on the leached and unleached specimens to investigate the compressibility characteristics of these specimens. Excess pore water pressure and vertical displacement were measured by pore pressure transducer and LVDT, respectively.

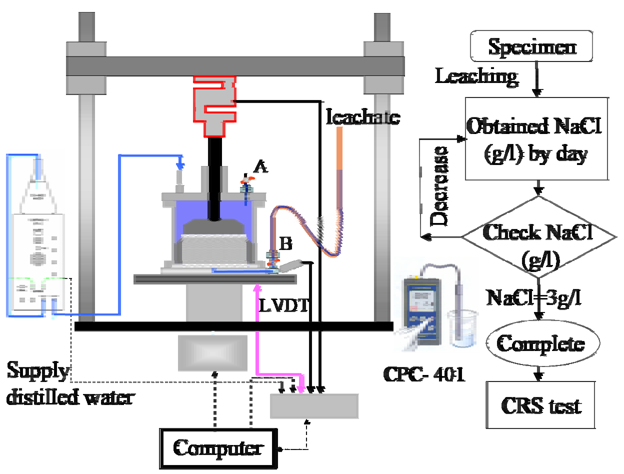



Fig. 3 Schematic diagram of leaching procedure and assembly on the CRS apparatus

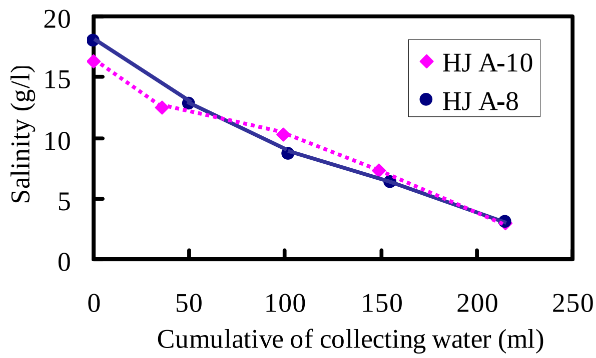



Fig. 4 Variation of soil salinity with the cumulative of collecting water

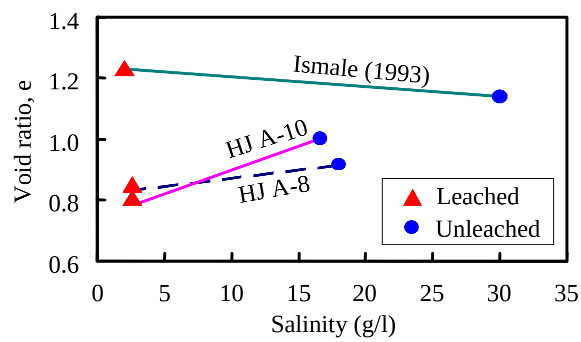



Fig. 5 Void ratio change with salinity at the end of CRS test

## EXPERIMENTAL TEST RESULTS AND DISCUSSION

### Effect of Leaching on Physical Properties

After CRS test with loading and unloading stages, the specimens were dismantled as soon as possible, so that the water content was determined accurately at the end of test. Then, liquid limits were examined on both the unleached and leached specimens.

Figure 5 shows the decrease of the void ratio due to leaching. The void ratios of leached and unleached specimens were obtained at the end of loading stage of CRS test

However, as shown in Table 1, Ismale (1993) presented the increase of initial void ratio due to

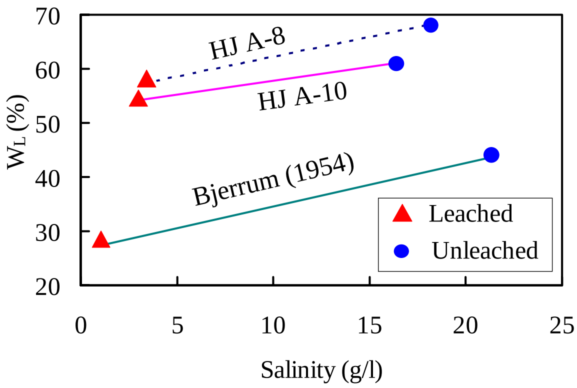



Fig. 6 Variation of liquid limit ($W_L$) with salinity

leaching by calculating the water content and unit weight after leaching. In this study, all the initial conditions of the leached and unleached specimens were assumed to be the same except salinities. In order to have the undisturbed specimens for CRS test, the water content and other physical properties could not be investigated just after leaching procedure. The decrease of void ratio leads to an increase of settlement by change in fabric due to leaching. It was known from the earlier experience that the natural quick clays (leached clays) exhibited more orientation of clay particles than unleached clays (Kazi 1972). Therefore, the increase orientation caused a change from the flocculated structure of marine clay to the dispersed structure of leached clay.

Figure 6 shows a decrease of liquid limit which are 11.38% and 19.22% for HJ A-10 and HJ A-8, respectively. It was agreed with the Bjerrum (1954) and Skempton and Northey (1952), and can be explained by the meta-stable structure caused by leaching (Skempton and Northey 1952).

## Effect of Leaching on Compressibility Characteristics

CRS tests with two typical strain rates, $\dot{\varepsilon}=10^{-3}\%/\sec$ and $\dot{\varepsilon}=10^{-4}\%/\sec$ were performed on the leached and unleached specimens.

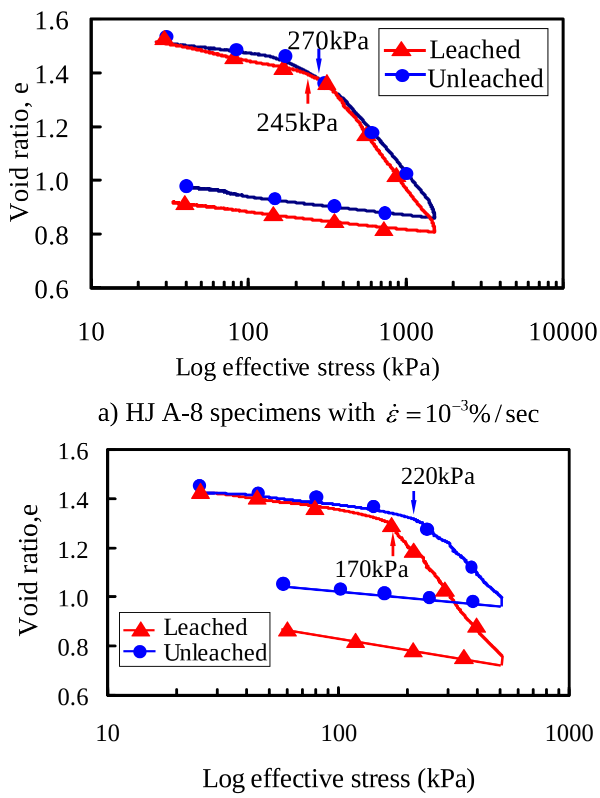
For the unleached specimens, the cell chamber was filled up with the water having the same salinity value of the soil. All the conditions and steps were conducted in the same way for the leached and unleached clays.

Test results were shown in the form e-log$\sigma'$ plots in Fig. 7. The specimen HJ A-8 was tested with the strain rate as 10 times higher than the specimen HJ A-10 to check the effects of different strain rates.

It was observed that the void ratios of the leached specimens had smaller values up to 10.23 % and 30.60 % than the leached specimens of HJ A-8 and HJ A-10, respectively. The results from CRS test for both the leached and unleached specimens of HJ A-8 and HJ A-10 indicated that an increase of deformation was induced by leaching because at the initial stage, all the conditions of two samples were the same except salinity.

Fig. 8 shows the comparison of stress-strain curve of leached clay with different strain rates. It was found that the higher strain rate, the higher effective stress of the leached clay.

Only a slightly difference in the stress-strain relationship occurred in the OC region. After reaching the preconsolidation pressure, the effective stress of $10^{-3}$%/sec strain rate have a little higher than $10^{-4}$%/sec strain rate at a given strain. This result indicated that stress-strain relationship depended on the strain rate




a) HJ A-8 specimens with $\dot{\varepsilon}=10^{-3}\%/\sec$

b) HJ A-10 specimens with $\dot{\varepsilon}=10^{-4}\%/\sec$

Fig. 7 CRS tests with unleached and leached specimens

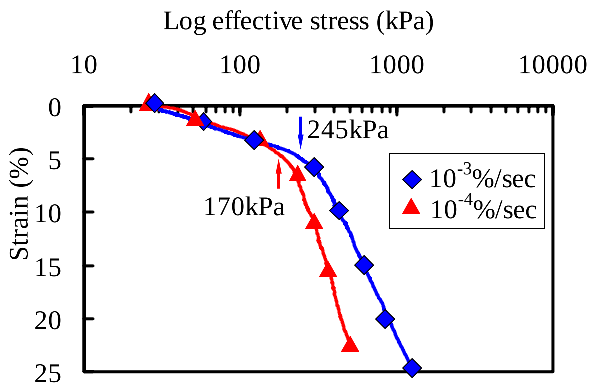



Fig. 8 Strain rate effects on leached specimens

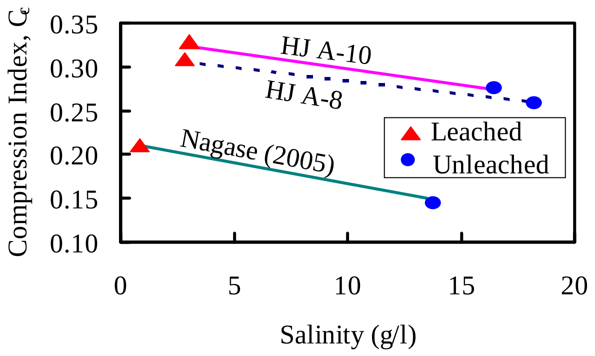



Fig. 9 Variation of compression index with salinity

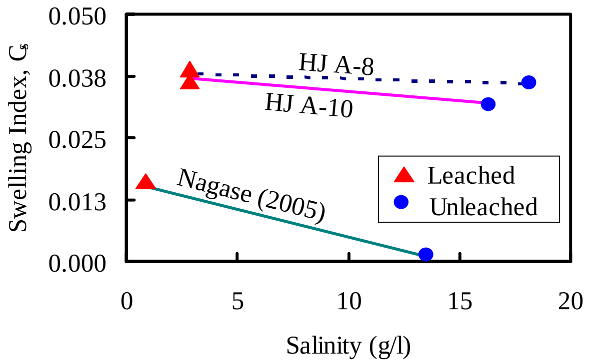



Fig. 10 Variation of swelling index with salinity

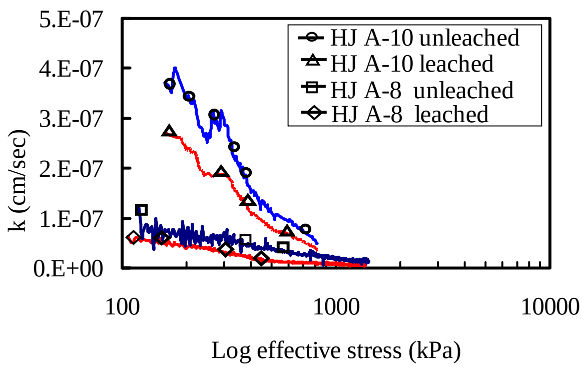



Fig 11 Hydraulic conductivity compare of leached and unleached specimens

occurred in the soil deposit (Bjerrum 1967; Leroueil 1985; Kim and Leroueil 2001).

Compression index $C_c$, and swelling index $C_s$ are very important parameters to calculate settlement of soil deposits. These values are shown in Figs. 9 and 10. Compression index and swelling index increased with the decrease in soil salinity which gave more settlement due to leaching.

The hydraulic conductivity obtained from CRS test was shown in Fig 11. It was found that the hydraulic conductivity of leached specimens is less than the unleached specimens. This can be explained with the decrease of the void due to leaching.

As shown in Fig. 12, leaching resulted in decrease in the preconsolidation pressure due to the removal of salt concentration ranged from 17.96 g/l of HJ A-8 and 16.26 g/l of HJ A-10 to about 3 g/l. This result indicated that leaching process resulted in the bond weakness of soil skeleton, consequently the increase in compressibility and decrease in preconsolidation pressure.

Leroueil (1996) presented that the preconsolidation pressure deduced from CRS tests was typically 25% higher than that deduced from conventional 24h tests. In other hand, the preconsolidation pressure increase with the increase in strain rate.

For Busan clay, the correlation of strain rate-dependent preconsolidation pressure was established as in Eq. (1) (Cho 2007),

$$\log \sigma'_{pc} = 0.045 \log \dot{\varepsilon} + 2.434 \qquad (1)$$

In this study, the preconsolidation pressures of leached and unleached specimens were shown in Fig. 13. The preconsolidation pressure after interpolation at the strain rate $10^{-7}$%/sec of conventional oedometer test can be interpolated by using Eq. (1).

It was found that the OCR values of two unleached samples were around 1. This result was agreed with the research of the upper clay layer which was normally-consolidated clay (Tanaka et al. 2001). After leaching

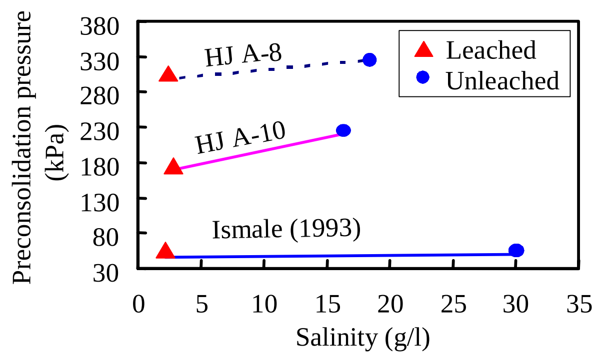



Fig. 12 Variation of preconsolidation pressure with salinity

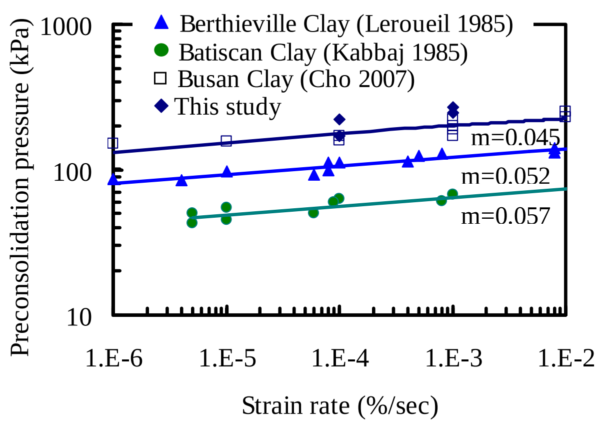



Fig.13 Linear relation between preconsolidation pressure and strain rate

procedure, the preconsolidation pressure decreased, consequently the OCR values of leached specimens were less than 1.

## CONCLUSIONS

1. The leaching procedure was taken almost 25 days for the natural samples of Hwajeon clays to reduce gradually the soil salinity from 17.96 g/l and 16.26 g/l to about 3 g/l with distilled water.

2. The CRS test results on the leached and unleached specimens with the same conditions except salinity showed that the compressibility of Busan leached clay increased as its salinity decreased. However the void ratio, liquid limit, hydraulic conductivity of the leached clay decreased than these of the unleached clay due to leaching.

3. The CRS test results indicated that the higher the strain rate, the higher the effective stress of leached clay. The stress-strain curve depended on strain rate occurred in leached clay.

4. Compression index and swelling index increased due to the bond weakness of soil skeleton after leaching. Consequently, the decrease in preconsolidation of leached specimens led to the OCR values less than 1. It was one of the specific characteristic of the Busan leached clay.

## ACKNOWLEDGMENT

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