Consolidation characteristics of Nangton River clay deposit

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Abstract : It has been said from previous studies that the preconsolidation pressure (p_c)of Nangton River deposit is considerably less than the *in situ* effective burden pressure (p'_{vo}). Question has risen whether this small p_c vale is due to underconsolidation or unsuitable laboratory test including low sample quality. As a cooperative research program between PHRI (Port and Harbor Research Institute) and Pusan National University, an extensive soil investigation was carried out at a site of Yangsan, Pusan, using the Japanese sampler. It is found that although p_c value at the site is slightly greater than p'_{vo}, its over consolidation ratio (*OCR*) is quite small compared with aged normally consolidated clay in Japan.

INTRODUCTION

Soft marine clay is thickly deposited along Nangton River in the suburb of Pusan. Due to the recent rapid expansion of Pusan city, it has been required to develop this area for residential or industrial purposes. A lot of extensive geotechnical investigations have been carried out, and most of there reports indicate that the clay layer in this region is under consolidation, that is, the preconsolidation pressure (p_c) is lower than the in situ burden pressure (p'_{vo}).

Several geotechnical engineers have tried to explain the low p_c value for the clay layer. One group has insisted that the subjected too fast for consolidation after rising the sea level since the Ice Age. Some researchers have pointed out the artesian pressure in the sand layer underlying the objective clay layer. However, some group has doubted accuracy in the measured value, especially p_c form view points of sample quality as well as well as testing method for determining the p_c value.

Although many researchers have pointed out the importance of sample quality to obtain precise soil parameters, there still dose not exist any international standard on sampling, and various types of samplers as well as sampling techniques have been used in the world. Tanaka *et al.*(1996) have carried out a comparative study on sample quality using six different typical samplers at the site of Ariake, and reported that the strength from the unconfined compression test for the lowest quality sample is 60% of that for the highest sample quality.

As a cooperative study between PHRI and Pusan National University, a site investigation was carried out in 1998 and 1999. In this investigation, a sampler was brought from Japan and sampling was done in the same as Japan in order to get the same quality in Japan. Soil samples were performed (some tests are still under performance). Consolidation characteristics were studied using Constant Rate of Strain (CRS) and conventional Incremental Loading (IL) oedometer test. This paper will present fundamental characteristics results from these investigations and discuss consolidation properties of Nangton clay deposit.

TESTING METHOD

Sampling method

The Japanese standard sampling method (JGS 12211-1995) was employed for retrieving soil sample. Sampler's head as well as sampling tube were brought from Japan. The sampler is a fixed piston sampler whose diameter, length and thickness are 75 mm, 1,000 mm and 1.5 mm, respectively. A boring machine and operators were provided by Dong-A Cooperation and sampling was done under supervision of PHRI so that sampling procedures in even detail did exactly follow the Japanese standard.

Soil samples were transported using a commercial cargo, being kept in sampling tubes. It was confirmed from previous investigations (see Tanaka, 1999), soil disturbance due to the transportation is ignored.

Laboratory tests

Constant rate of strain oedometer test (CRS):

The diameter and the initial height of the specimen are 60 mm and 20 mm, respectively. The drainage is allowed at the upper part and the pore water pressure was measured at the bottom. The back pressure of 100 kPa was applied to the specimen. The specimen was subjected by a strain rate of 0.02 %/min.

Incremental loading oedometer test (IL):

The specimen size of this test is the same as that of CRS. The load is increased by double of the previous load and the duration of each load is 24 hours.

Unconfined Compression test (UCT):

Testing method was followed by the JGS standard (JGS T 511-1990): the size of specimen is 80 mm in height and 35 mm in diameter. The axial strain rate is 1 %/min.

Residual effective stress measurement:

Immediately after trimmed for the UCT, the specimen was placed on a ceramic disc with the air entry value of 200 kPa to measure the residual effective stress (p'_r). The specimen was left to get a constant p'_r value (usually less than one hour).

In situ tests

Field Vane Shear Test

Penetration type of the field vane shear (FVS), which was developed by Hanzawa et al. (1990), was used in this investigation. To reduce the friction between vane rods and the ground, the double rods system was employed: the vane rods were installed in the outer rod. The size of blade is 8 cm in height and 4 cm in diameter. The rotation speed of the vane is 6°/min.

Dilatometer (DMT) test

Marchetti's dilatometer was used. Two pressures were measured in DMT: pressure at the membrane lift off of 0.1 mm (p_o) and pressure when the membrane expands by 1.1 mm (p_1). These measurements were done within 15 seconds after installing the blade at the testing depth, as recommended by Marchetti and Crapps (1981).

From DMT, two indices and one modulus for characterizing soil have been proposed by Marchetti and Crapps (1981):

Material Index (I_D)

$$I_D = (p_1 - p_0)/(p_1 - u_0) \quad (1)$$

Horizontal stress Index (K_D)

$$K_D = (p_0 - u_0)/\sigma'_{vo} \quad (2)$$

Dilatometer Modulus (E_D)

$$E_D = 34.7(p_1 - p_0) \quad (3)$$

where σ'_{vo} is the effective overburden pressure and u_0 is the hydrostatic pore pressure at tested depth.

PHYSICAL PROPERTIES

Physical properties at this site are presented by the companion paper (Locat and Tanaka) in this symposium.

P_c VALUES

The p_c values were measured by CRS as well as IL oedometer tests as indicating in

Fig. 1. The sand layer with 1.8 m thick was spread at this site three months before the sampling was carried out. The solid and dotted lines in this figure indicate the *in situ* effective burden pressure (p'_{vo}) for before (consolidation due to the filling dose not proceed) and after filling (the consolidation is completed), respectively. The degree of consolidation (U) is estimated as only 7 % from calculation by Terzaghi's consolidation theory. Therefore, it is judged that the p'_{vo} profile at this site may be indicated by the solid line in this figure.

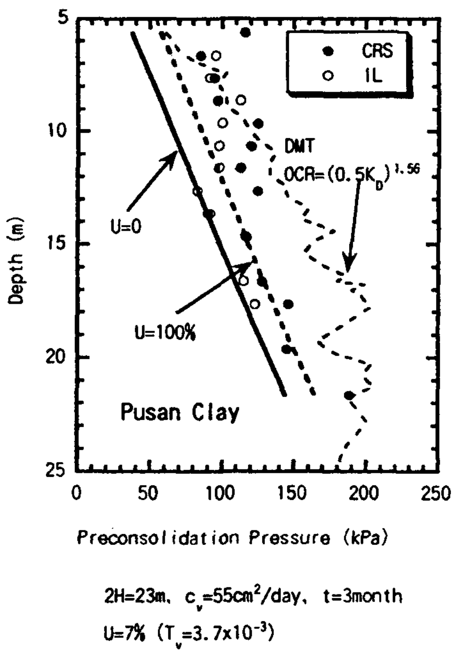

Fig. 1 Preconsolidation pressure measured by CRS and IL oedometer tests for Yangsan clay

The p_c value is nearly constant at depths between 5 m and 12 m, being around 100 kPa. However, at depth greater than 12 m, p_c increases as depth increase, and the p_c value at these depths is slightly larger than p'_{vo} before filling. The authors have carried out site investigation at several sites in Japan as well as overseas. Figures 2 and 3 show typical examples of p_c profile at Ariake site, Japan and at Bothkennar site, United Kingdom. As stated by Bjerrum (1967), the natural clay deposit is more or less overconsolidated due to ageing effects such as delayed consolidation or chemical bonding.

It is indicated that p_c value measured by IL test is definitely smaller than that by CRS. This is because of rate effect: i.e., the rate of strain at CRS is much faster than that at IL test (Leroueil and Jamiolkowski, 1991). The influence of the rate effect on p_c value was studied by a series of CRS test with different strain rates. The test result shows in Fig. 4 together with rate effects for other clays, which were done by authors. It is found that the rate effect on p_c is not dependent on plasticity index (I_p) and it varies with different regions. The rate effect for Yangsan clay is in the same order of most Japanese clays.

From DMT, Marchetti (1980) has proposed a method for OCR from K_D value indicated by eq.(4)

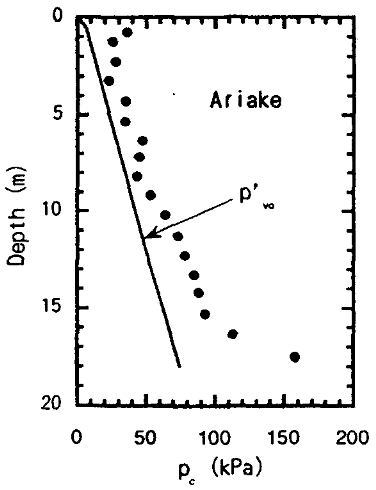

Fig. 2 p_c profile at the site of Ariake

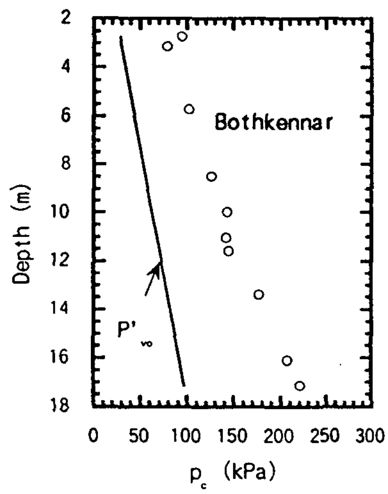

Fig. 3 p_c profile at the site of Bothkennar

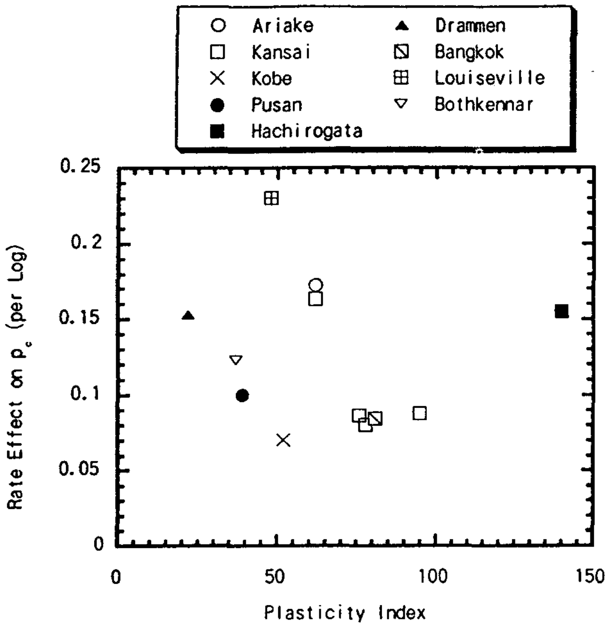

Fig. 4 Strain effect on preconsolidation pressure for various clays

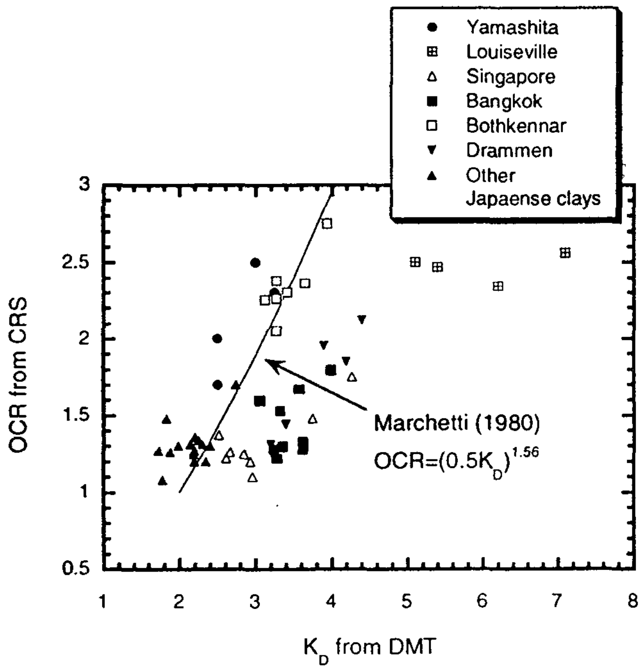

Fig. 5 Comparison of OCR between measured and estimated by DMT (Data were obtained by the previous investigations at various sites)

$$\mathrm{OCR}=(0.5K_D)^{1.56} \quad (4)$$

The p_c value is calculated based on the p'_{vo} value before filling, using OCR estimated by eq(4). As shown in Fig. 1, p_c values at shallower depths are relatively in good agreement with measured by laboratory test. However, the p_c value estimated by DMT at most depths is considerably larger than measured ones. Of course, as will be discussed later, p_c values at these greater depths might be under-evaluated by soil disturbance. Comparison of p_c values between estimated and measured is made in Fig. 5, for varuous clays in the world. There are considerable scatters in this relation. It should be in mind that applicability of empirical relations including eq. (4) is strongly dependent on region (see, for example, Tanaka, 1994), and careful examination is required when these empirical relations are applied.

e-log*p* CURVE

The *e*-log*p* curve for intact clay presents non linearity after consolidation pressure (*p*) exceeds p_c value (normally consolidated state). It appears more pronouncedly on the *e*-log*p* curve measured by CRS, which is able to obtain continuous *e* and *p* relation. That is, the gradient of the *e*-log*p* curve, which is called the compression index (C_c), is not constant, but dependent on *p* even at normally consolidated state. However, C_c becomes constant when *p* is beyond a certain value. A typical *e*-log*p* curve is presented in Fig. 6. To make clearer change in C_c according to *p*, Fig. 7 is plotted in normalized C_c/C_{cl} and p/p_c

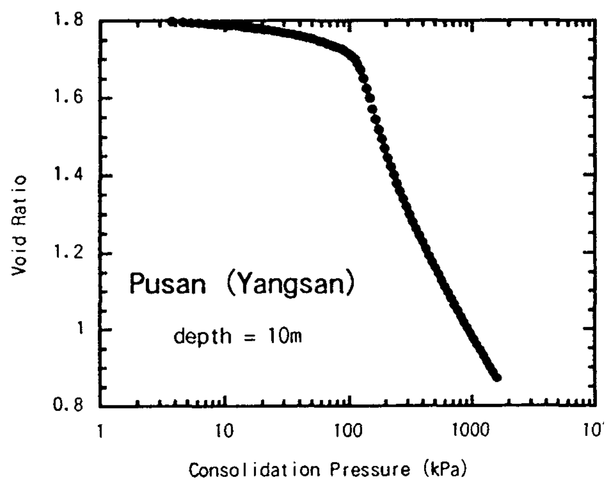

Fig. 6 A typical *e*-log*p* curve of Yangsan clay deposit

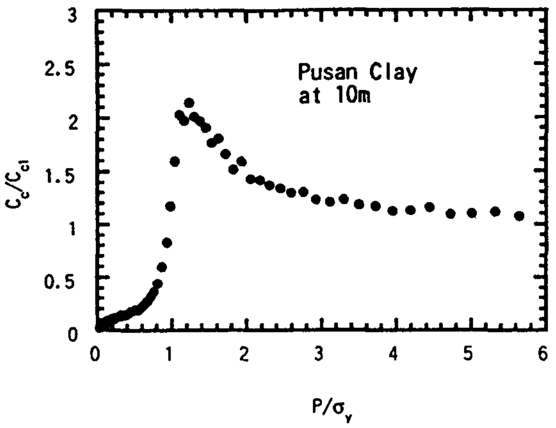

Fig. 7 A typical relation of normalized compression index and consolidation pressure for Yangsan clay

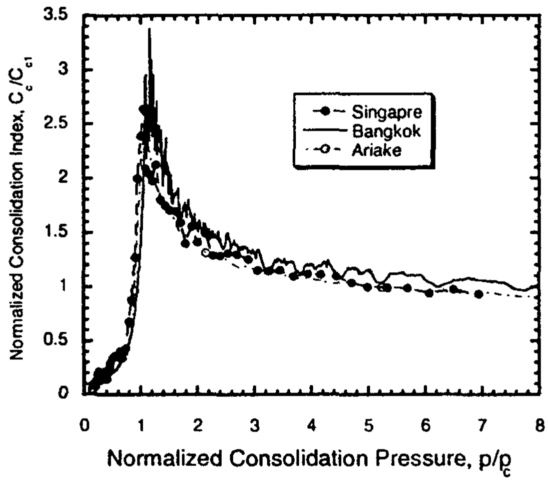

Fig. 8 Relation of normalized compression index and consolidation pressure for various clays

ratios, where C_{cl} is C_c at p large enough to become constant. As shown in Fig. 7, C_c suddenly increase as much as 2 times of C_{cl} values just after p exceed p_c. However, when p increases more than two times of p_c, C_c becomes nearly constant. These tendencies are observed in other clays as seen in Fig. 8.

The C_c value has been tried to be correlated with index properties, especially w_L by many researchers, since Terzaghi proposed the following formula:

$$C_c = 0.009(w_L - 10) \qquad (5)$$

It has been reported (for example, Ogawa and Matsumoto, 1978) that most relation between C_c and w_L for intact clay are located above the relation of eq. (5): i.e., C_c is relatively greater than that expected by eq.(5). The C_{cl}, which is the C_c at large enough p as described before, is plotted against w_L in Fig. 9 for Yangsan clay as well as other clays obtained from authors' database. It can be seen that C_{cl} for all clays including Yangsan clay have strong relation with w_L and distributed along the line expressed by eq. (5).

Leroueil *et al.* (1983) reviewed the relation the initial void ratio (e_0) and the largest C_c (C_{cmax}) and found that these relations are strongly correlated with sensitivity (S_t). This relation for Yangsan clay is plotted in Fig. 10, as well as clays from the the same database as Fig. 9. It is found that the relation of e_o and C_{cmax} for Yangsan clay fall in the same relation as for Bothkennar and Singapore clays.

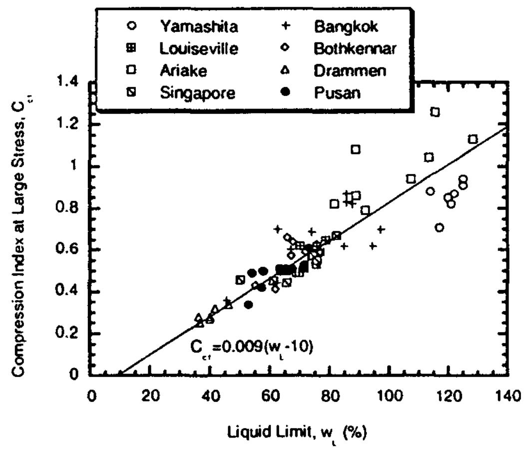

Fig. 9 Relation of C_{cl} and w_L

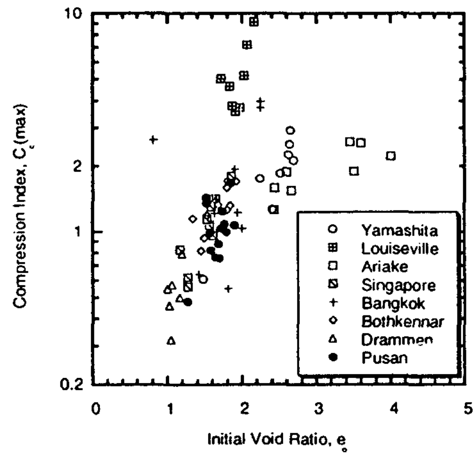

Fig. 10 Relation of C_{cmax} and initial void ratio

It may be concluded from these observations that consolidation characteristics of Yangsan clay are not special but quite ordinal.

SAMPLE DISTURBANCE

Influence of disturbance on e-logp curve

As many researchers have pointed out, consolidation characteristics are affected by sample quality. Figure 11 shows a typical example revealing the importance of sample quality (Tanaka, et al., 1999). Test results are compared for soil samples collected by the Japanese sampler and the Shelby tube. In case of the Japanese sampler, a borehole was drilled by a rotary boring machine, which is the standard practice in Japan. While in Shelby tube sampling, a wash boring method was employed to make a borehole, which is a typical sampling technique in Southeast Asia.

A clear bending point corresponding to p_c can be observed on the *e*-log*p* curve for the specimen collected by the Japanese sampling method. When p is smaller than p_c, the change in void ratio (e) is very small. But when p exceeds p_c value, suddenly a large volume change occurs. The C_c is not constant even at the normally consolidated stage, the largest C_c is attained immediately after p_c and it gradually becomes smaller with increasing consolidation pressure. The above observations are the same as in Fig. 6.

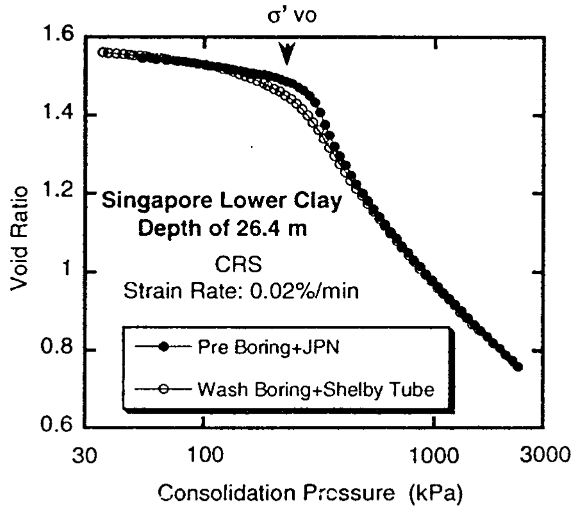

Fig. 11 Comparison of the *e*-log*p* curves for samples collected by different sampling techniques

In Fig. 11, the *e*-log*p* curve for the sample at the same depth but collected by the Shelby tube is compared. The shape of the *e*-log*p* curve for the specimen collected by this method is pronouncedly different from that of the Japanese method; a considerable shift in the void ratio can be observed at p'_{vo}. The p_c is not clearly identified, and also C_c becomes practically constant in the normally consolidated stage.

There might be possibility that p_c value for Yangsan clay in this investigation is evaluated too small due to soil disturbance, even though soil sample was retrieved by the Japanese sampling method.

Sample disturbance

Many methods have been proposed to quantify sample quality. Volumetric strain (ε_v) caused by applying the pressure equal to p'_{vo} is often used to judge sample disturbance (Anderson and Kolstad, 1979). When the sample is disturbed, a large ε_v is observed when the pressure is applied to p'_{vo}, as shown in Fig. 11. Figure 12 shows ε_v profiles for soil sample collected by different sampling methods in Singapore. It may be said that the boundary of ε_v for identifying high quality sample is about 3 % in this investigation. Figure 13 shows the ε_v measured in the Yangsan site. Although it is very difficult to mention whether the sample retrieved at this site is disturbed or not, the order of ε_v in this investigation is relatively large.

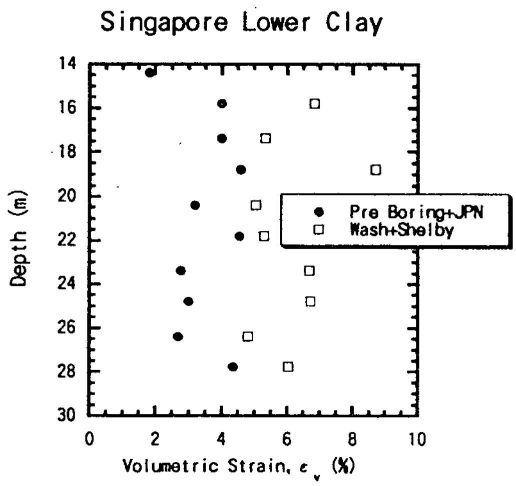

Fig. 12 Comparison of volumetric strain yielded in different sample quality in Singapore

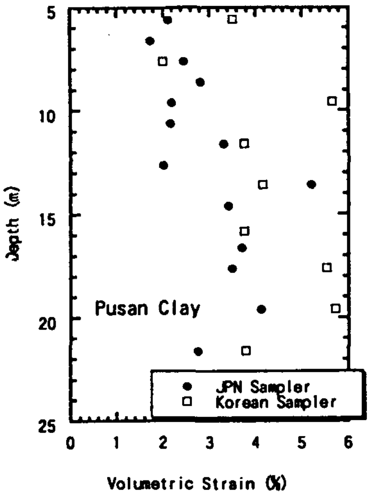

Fig. 13 Volumetric strain for Yangsan clay

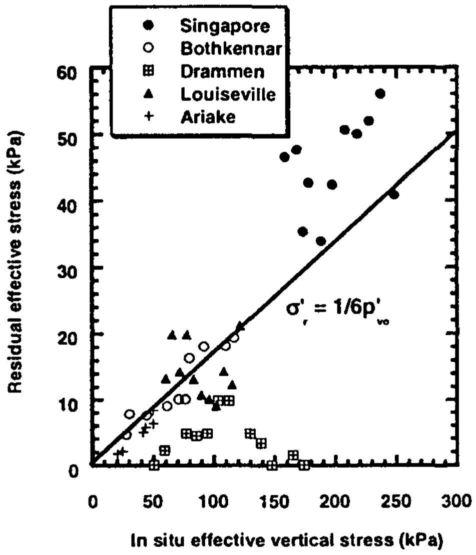

Fig. 14 Residual effective stress for sampled soil collected in various areas

Residual effective stress

Another method for evaluating sample quality is magnitude of residual effective stress (p'_r) in the specimen. When a soil element is sampled from the *in situ*, part of the confining pressure remains in the soil element in the form of negative pore water pressure, which is sometimes called the residual effective stress. The degree of p'_r is dependent on many factors, such as soil properties especially sample quality. Tanaka et al. (1996) showed that the p'_r/p'_{vo} ratio for normally consolidated or slightly overconsolidated marine clays is ranged between 1/5 and 1/6, as shown in Fig. 14, provided that the soil sample be properly collected.

Figure 15 shows p'_r value for Yangsan clay. It is found that p'_r values at shallower depths, i.e., shallower than 10 m, p'_r increase with depth and its p'_r/p'_{vo} ratio is about 1/5, which is a typical number observed in the previous studies. However, when depth is greater than 15 m, p'_r decreases with depth. The p'_r/p'_{vo} ratio at a depth of 20 m is as low as 1/20. Such small p'_r suggest that soil sample be disturbed.

Undrained shear strength from UC and Field Vane tests

The undrained shear strengths (s_u) measured by unconfined compression (UC) and Field vane (FV) tests are shown in Fig 16. The

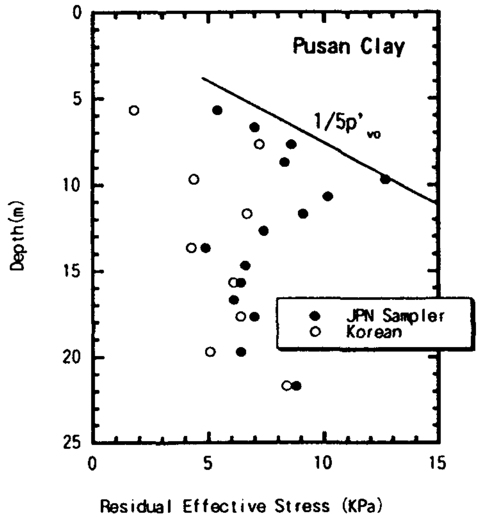

Fig. 15 Residual effective stress measured in Yangsan clay

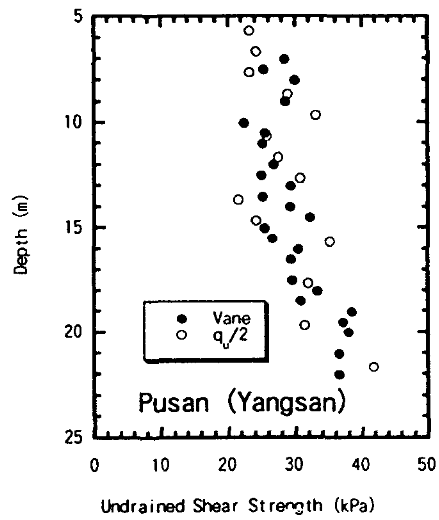

Fig. 16 Undrained shear strength measured by Unconfined compression andField vane tests

s_u measured by these tests are almost identical at even deeper depths where p'_r becomes low. Since the UC test is done under unconfined condition, unconfined compression strength (q_u) should be dependent on p'_r value. In other words, $q_u/2$ at deeper depths should be smaller than the vane strength, which is measured under the *in situ* burden pressure. The same trend was observed at the site of Drammen, which is famous for low plasticity index (I_p) (Tanaka, 1999). At this site, the $q_u/2$ value is the same as the vane shear strength, even though p'_r value in a soil sample is considerably small. It might be considered that the vane strength is also affected by disturbance due to insertion of the vane blade into the ground.

CONCLUSIONS

Nangton clay deposit was investigated and test results were presented in this paper, being focused mainly on consolidation characteristics. Preconsolidation pressure (p_c) is quite small and is nearly the same as the *in situ* effective burden pressure (p'_{vo}) below a depth of 14 m. The main findings from the present investigation are as follows:

1) The compression index at large consolidation pressure (C_{cl}) is well correlated with w_L: $C_{cl}=0.009(w_L-10)$.
2) The largest C_c, which is observed when consolidation pressure exceed p_c, (C_{cmax}) is the same order as other clays of the authors' database if C_{cmax} is plotted against the initial void ratio (e_o).
3) From the above findings, it may be said that consolidation characteristics for Nangton clay deposit are quite usual as clay deposit.
4) The residual effective stress (p'_r) becomes small below a depth of 10 m. This indicates that the soil sample at these depths is considerably disturbed. However, the evidence of such disturbance cannot be clearly detected by the volumetric strain at p'_{vo}.
5) In addition, the strength reduction of the unconfined compression strength (q_u) is unremarkably observed because the $q_u/2$ is nearly the same as the vane shear strength.
6) It is said that the effect of sample disturbance is not so strong on p_c value as on q_u value. In this sense, the p_c value measured by the present study is likely to be accurate.

Other laboratory tests are still under performance at PHRI. These test results will help to interpret mysterious p_c value at Yangsan site.

REFERENCES

1) Anderson, A and Kolstad, P. (1979):"The NGI 54 mm samplers for undisturbed sampling of clays and representative sampling of coaster materials." Proc. of the International Symposium on soil sampling, Singapore 1979, pp.13-21.
2) Bjerrum, L.(1967):"Engineering geology of Norwegian normally consolidated marine clays as related to settlements of building," Geotechnique, Vol. 17, No.2, pp.83-118.
3) Hanzawa, H., Fukaya, T. and Suzuki, K. (1990):"Evaluation of engineering properties for an Ariake clay." Soils and Foundations, Vol.30, No.4, pp.11-24.
4) Leroueil, S., Tavenas, F. and Le Bihan, J. P. (1983):Proprietes caracteristiques des argiles de l'est du Canada," Canadian Geotechnical J., Vol. 20, No.4, pp.681-705
5) Leroueil, S. and Jamiolkowski, M. (1991): "Exploration of soil and determination of design parameters," Proceedings of the international conference on geotechnical engineering for Coastal development, Vol.2, pp.969-998.
6) Marchetti, S. and Crapps, D. K. (1981): "Flat Dilatometer Manual," GPE, Inc., Gainesville, Florida, USA .
7) Ogawa, F. and Matsumoto, K. (1978): "Correlation of the mechanical and index properties of soils in harbour districts." Report of the Port and Harbour Research Institute, Vol. 17, No.3, pp.3-89 (in Japanese).
8) Tanaka, H. (1994):"Vane shear strength of Japanese marine clays and application of Bjerrum's correction factor," Soils and Foundations, Vol. 34, No. 3, pp.39-48.
9) Tanaka, H., Sharma, P., Tsuchida, T. and Tanaka, M. (1996):"Comparative study on sample quality using several types of samplers," Soils and Foundations, Vol. 36, No.2, pp.57-68.

10) Tanaka, H.(1999): "Sample quality of cohesive soils: "Lessons from three sites, Ariake, Bothkennar and Drammen," Soils and Foundations," accepted.