INFLUENCE OF STRESS RELEASE ON SAMPLE QUALITY OF PLEISTOCENE CLAY COLLECTED FROM LARGE DEPTH IN OSAKA BAY

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ABSTRACT

A data set of unconfined compression strengths of Osaka Bay Pleistocene clays collected from large depths tends to be much scattered. This is because of large stress release in the collected sample. In more detail, the two following factors are possibly considered. A residual effective stress larger than 98.1 kPa is apparently impossible in a fully saturated soil because a negative pressure greater than a vacuum is non-existent, and some cracks are created in a sample when extruding it from the sampler and during trimming. In this study, a series of suction and unconfined compression tests for samples collected from 40-200 m depths in Osaka Bay was carried out to investigate the relationship between the residual effective stress and the undrained shear strength. Suction larger than 98.1 kPa was measured in undisturbed samples collected from large depths by applying a back air pressure. The disturbance ratio defined by Okumura (1974) ranges from 1.5 to 3, implying that the samples show a small strength reduction of up to 15%. It is concluded that the quality of the undisturbed Pleistocene clay sample collected from a large depth is very good, if the effective stress is of concern and no crack is created. However, the unconfined compression strength of Osaka Bay Pleistocene clay tends to show a large variance due to the crack type disturbance that is created when trimming the specimen.

Key words: Pleistocene clay, sample disturbance, sampling, suction, unconfined compression test (IGC: C6/D6)

INTRODUCTION

A number of studies have been carried out on the quality of undisturbed samples collected with different samplers and sampling techniques (La Rochelle et al., 1981; Hight et al., 1992; Tanaka et al., 1996 and 1998; Oka et al., 1996; and Lunne et al., 1997). In Japan, undrained shear strength for design is often determined by unconfined compression test, which is very sensitive to sample disturbance (Tsuchida and Tanaka, 1995). Tanaka et al. (1996) compared unconfined compression test results and reported that the quality of samples collected with a fixed piston sampler of a standard set by the Japanese Geotechnical Society (1995) is almost equal to the quality of samples collected with a high quality sampler, such as the Laval (LV) sampler (La Rochelle et al., 1981). Moreover, Tanaka et al. (1998) studied the sample quality of Louisville clay from eastern Canada, which is a well known cemented sensitive clay, by comparing the triaxial test results for samples collected variously with the modified Laval (MLV) sampler, LV sampler and JGS sampler. According to Tanaka et al. (1998), the sample quality of the JGS sampler is a little inferior to that of the MLV sampler, but it is almost the same as that of the LV sampler. They concluded that the quality of sample collected with the JGS sampler can be classified as very good.

On the other hand, Okumura (1974) attempted to evaluate the sample quality by measuring suction corresponding to the residual effective stress. Shimizu and Tabuchi (1993), Shogaki et al. (1995), Mitachi and Kudoh (1996), and Mitachi et al. (1998) proposed some methods for predicting in-situ undrained strength based on unconfined compression strength and residual suction. In addition, Mitachi and Kudoh (1996) attempted to apply their method to a Kaolin clay consolidated under a very high pressure. In their study, residual suction larger than 98.1 kPa was measured by placing the specimen under a back air pressure.

These previous researchers were mainly concerned with Holocene clays which are relatively young and taken from depths of up to about 30 m. Recently, as the greater scales of offshore structures are constructed in coastal areas, Pleistocene clay layers, which are deep and old deposits, have become more important in stability and deformation analysis. A typical example is the Kansai International Airport. The airport was constructed on an artificial island in the Osaka Bay, 5 km off the Senshu
area southwest of Osaka city. It was inaugurated in September 1994 when the first construction phase was completed. Since the present airport is being operated with only one runway, the second construction phase for an additional parallel runway was started in 1999. The area reclaimed in the second phase has an average water depth of 19.5 m, in contrast to 18.0 m in the first phase. The average thickness of the Holocene layer is 24 m (18 m in the first phase). Considering that the stress generated by the reclaimed landfill will reach a much deeper clay layer, several boring surveys with undisturbed sampling were carried out up to 400 m depth to construct the large-scale artificial island.

Most of these samples were used for standard oedometer tests and constant rate strain (CRS) oedometer tests to evaluate the biggest issue on this construction project: i.e. prediction of the settlement. Since it was the first geotechnical survey up to 400 m depth, a series of unconfined compression tests, which is the most common test method to evaluate the shear strength of clay in Japan, was carried out to investigate the shear strength of Pleistocene clays collected from large depths. Figure 1 shows the unconfined compression test results of borehole No. 56-9, which was for geotechnical investigation in the first phase construction; it includes (a) a variation of unconfined compression shear strength with depth and (b) relationship between elevation and strain at failure. The undrained shear strengths in Fig. 1(a) are very scattered and it is very difficult to determine the profile of shear strength with depth for design work. However, strain at failure in Fig. 1(b) is as small as about 1.5% for samples collected from a depth larger than 80 m.

It has been considered that for samples collected from very large depths, the unconfined compression test might not be an appropriate method to get a reliable test result. This is due to the fact that no negative pressure larger than a vacuum exists. Therefore, it is impossible to maintain residual effective stress larger than 98.1 kPa in a fully saturated sample, as shown in Fig. 2.

![Fig. 1. Unconfined compression test results: (a) unconfined compression strength with depth, (b) strain at failure with depth](image)

![Fig. 2. Stress condition in element collected from large depth](image)

![Fig. 3. Remolded type and crack type disturbance (after Tsuchida and Tanaka, 1995)](image)

Tsuchida et al. (1988), Tsuchida (1990), and Tsuchida and Tanaka (1995) showed that there are two different kinds of disturbances, i.e. one is remolding type disturbance and the other is crack type disturbance, as shown in Fig. 3. The shear strength of a sample collected from large depth determined by unconfined compression test
might be smaller than the actual value because of crack type disturbance. In fact, it is very easy to understand that crack type disturbance occurs in a Pleistocene clay sample, because this clay, which has been consolidated under a very high pressure and in which the structure has developed by aging effect, is very brittle. However, it is not yet clear when this crack type disturbance occurs during the procedure from sampling to laboratory testing. Then, there is the question of whether the sample itself is in good quality and crack type disturbance occurs during trimming, or the sample itself has crack type disturbance originally.

In the present study, qualities of undisturbed samples of Osaka Bay Pleistocene clay collected at 40 to 200 m depths were investigated by measuring residual effective stress in the samples and unconfined compression tests were carried out. These two kinds of tests are sensitively influenced by the sample disturbance. These depths up to 200 m were mainly considered for prediction of settlement, and it is said that the Osaka Bay Pleistocene clay at a depth of 200 m was deposited several hundred thousand years ago.

CHARACTERISTICS OF SAMPLES

Figure 4 shows (a) location of the Kansai International Airport and (b) the sampling point for this study. This is the same borehole for the research presented before by Watabe et al. (2000) on the triaxial shear strength. In the field investigation for the construction of the Kansai International Airport, a new wire-line sampling system was developed (Horie et al., 1984; and Kanda et al., 1991) for more efficient deep sampling. A hydraulic operated type piston sampler was used up to a depth of 120 m below the seabed. Different thickness tubes were used corresponding to the stiffness of clay. A 2 mm thick tube was for soft Holocene clay and a 4 mm thick tube was for Pleistocene clay. On the other hand, a Denison sampler was used for the very stiff clay deeper than 120 m. The inner diameter of these sampling tubes was 80 mm. In this study, all laboratory tests were carried out within one year after the sampling.

Figure 5 shows profiles of natural water content \( w_n \), liquid limit \( w_L \), and plastic limit \( w_p \), for Osaka Bay clay. The plasticity index \( I_p \) of clay layers is from 50 to 70 and low plastic sandy or silty soil layers are laid alternately. The liquidity index \( I_l \) of clay layers decreases with depth from 0.65 at \(-50\) m to 0.20 at \(-200\) m. Shearing characteristics of the Osaka Bay Pleistocene clay was studied by Watabe et al. (2000), in which a \( K_0 \) value of 0.5 was obtained by \( K_0 \)-consolidation test using a triaxial cell (Tsuchida and Kikuchi, 1991); this value was adopted for the recompression method (Bjerrum, 1973) in CAU (anisotropic consolidated undrained) compression and extension tests.

MEASUREMENT OF RESIDUAL EFFECTIVE STRESS

Evaluation of sample quality by measuring residual suction, which corresponds to residual effective stress, was attempted by Okumura (1974). Shimizu and Tabuchi (1993), Shogaki et al. (1995), Mitachi and Kudoh (1996), and Mitachi et al. (1998) measured the residual suction and attempted to evaluate the undrained shear strength based on the unconfined compression strength corrected by the residual suction. Since these investigations treated saturated Holocene clays, suction, which is more than the vacuum (98.1 kPa), was beyond the scope of their interest. Among them, however, Mitachi and Kudoh (1996) measured residual suction larger than 98.1 kPa in an artificial Kaolin clay, which was consolidated under a very high pressure (400 kPa), by applying back air pressure. This technique comes from research groups who are trying to measure matric suction to evaluate the effective stresses or pore-size distribution (e.g. Kawakami et al., 1978; and Fredlund and Xing, 1994). Relationships between degree of saturation and matric suction are well known as soil-water characteristic curves (Fredlund and Rahardjo, 1993). In unsaturated soil, matric suction is caused by meniscus between soil particles, and it is possible for its value to be more than 98.1 kPa. Therefore, Fredlund and Xing (1994) treat very wide-range suction from 0 to about 10^6 kPa. Since matric suction \( S \) is defined

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**Fig. 4.** (a) Location of Kansai International Airport and (b) point of borehole in present study

**Fig. 5.** Water content and consistency profile
as pore air pressure $u_a$ minus pore water pressure $u_w$, i.e. $S = u_a - u_w$, the suction can be obtained by applying some high air pressure $u_a$ (back air pressure) and measuring the relative water head $(u_a - u_w)$.

In the present study, measurement of residual effective stress larger than 98.1 kPa was attempted by adopting and simplifying the method to measure matric suction in unsaturated soils mentioned above. This is based on the concept that if a sample is collected from a large depth, negative pore pressure becomes the vacuum and fine invisible air foams form innumerable menisci; then residual effective stress, even that which is larger than 98.1 kPa but smaller than the air entry value AEV, possibly remains in the apparently saturated sample. The suction measuring system used in this study is schematically illustrated in Fig. 6. This system can measure residual effective stress, by placing a specimen under a certain high air pressure $u_a$ (back air pressure). The specimen trimmed to 35 mm in diameter and 80 mm in height is placed on the high air entry value ceramic filter (air entry value is 200 kPa), which is preliminary saturated with de-aired water. The cell is set up, then air pressure is increased up to a certain value $u_a$, and the valve in Fig. 6, which is placed between the inside of the ceramic filter and the inside of the cell, is opened for a moment to balance the pressures on both sides of the valve.

Figure 7 shows an example of data sets measured by suction tests, which were conducted on the specimens from the same depth of 93 m. While assembling the cell from 0 to about 200 sec, the specimens were under one atmospheric pressure. Then, a back air pressure of 50 kPa, 100 kPa or 200 kPa was applied to the specimen, except for the case noted as "0 kPa", which was conducted under atmospheric pressure. Normally, the time required to measure the suction for a Holocene clay collected from a shallower depth is a few minutes. In Fig. 7, however, the curves do not reach a plateau in 2 hours (7200 sec), implying that the response of this system is apparently very bad. This is caused by a fact that air bubbles are created in the deaired ceramic disk when the specimen with very high suction is put on this, and it requires a long time to dissolve the air bubbles under the back air pressure; i.e. under a positive water pressure in the ceramic. A peak or plateau value of $u_a - u_w$ is adopted as the matric suction; however, $u_a - u_w$ does not reach a peak or plateau for a deeper sample during the limited time of the test. In this case, $u_a - u_w$ at 2 hours (7200 sec) is adopted to prevent desiccation even though the bottom of the cell is filled with water and the specimen is surrounded by a small inner cell.

The test results conducted under 0 kPa were close to vacuum $(u_a - u_w = 98.1$ kPa under $u_a = 0$ kPa; i.e. $u_w = -98.1$ kPa), and thus this test result might show only apparent suction. Therefore the true residual effective stress could be greater than this. A similar tendency was observed in the test result, which was conducted under an air pressure $u_a$ of 50 kPa, approaching to $u_a - u_w = 148.1$ kPa; i.e. $u_w = -98.1$ kPa. On the other hand, almost the same residual stresses were measured for the tests, which were carried out under 100 kPa and 200 kPa, and the value of residual effective stress does not depend on the value of back air pressure. This should be the true residual effective stress in the specimen.

**TEST RESULTS OF RESIDUAL EFFECTIVE STRESS**

Figure 8 shows the variation of residual effective stress with depth for Osaka Bay Pleistocene clay, in which it is assumed that the measured matric suction is directly equal to the residual effective stress. Residual effective stresses in Pleistocene clays collected from large depths were about one fifth of effective overburden stresses. These values are consistent with the test results of Tanka, M. et al. (1995), who reported that the residual effective stress of Japanese Holocene clay is between one fourth and one sixth of overburden effective stress.

Since an undisturbed sample after being extruded from a sampling tube loses the confining pressure, it is in an isotropic stress condition under one atmospheric pres-
sure. During this procedure, the sample is maintained in an almost undrained condition. Then, if a sample was collected perfectly without any physical disturbance, the stress will follow a path of undrained extension from the in-situ stress on $K_o$-line until it reaches the isotropic condition. Ladd and Lambe (1963) developed a concept for the stress path during sampling and laboratory testing, as shown in Fig. 9. Point $P$ of the effective stress $\sigma'_e$ corresponds to the condition of perfect sampling, in which no disturbance except for the release of in-situ deviator stress is suffered by the sample. Mechanical disturbance, during sampling and laboratory testing, such as drilling, tube sampling, extrusion from the tube sampler and trimming are given to the soil sample and the pore water pressure within the specimen builds up. Finally, point $F$ with an effective stress of $\sigma'_e$ represents the residual effective stress of the specimen. The ideal undisturbed sample at

point $P$ is called “perfect sample” and its effective stress is noted as $\sigma'_e$. In the present study, $\sigma'_e$ is evaluated by CAU extension test (Watabe et al. 2000), in which the specimen is anisotropically consolidated under the overburden pressure $\sigma'_o$ with $K_o (=0.5)$ and $\sigma'_e$ is defined as an isotropic stress when $\sigma'_e$ decreases down to $\sigma'_o$, during the undrained extension shearing.

The residual effective stress is possibly a function of air entry value AEV that corresponds to the matric suction which can remain, plasticity index $I_p$ that corresponds to the soil type and swelling index $C_s$ that corresponds to the creation of negative pore pressure. Tanaka and Locat (1999) reported mercury intrusion test results of Osaka Bay Pleistocene clay as shown in Fig. 10, where, $R_o$ [µm] is the pore radius, and the vertical axis $dV/d\log R_o$ [cm³/g] is the pore volume frequency [cm³] corresponding to the pore radius of $R_o$ for a unit mass (1 g) of dry specimen. Marshall (1958) proposed the following equation for the minimum radius $R_p$ of the unsaturated pores:

$$u_a - u_s = 2T / R_p$$

where $T$ is the surface tension of water (75 kPa µm) and $u_a - u_s$ is the matric suction. In Fig. 10, the maximum pore radii are of the order of 1.0 µm at shallower depths and 0.5 µm at deeper depths. Using Eq. (1), the air entry value AEV or the maximum matric suction which can remain in the sample can be calculated with these values as 150 kPa and 300 kPa, respectively. These high air en-
try values greater than the measured residual effective stresses imply that the residual effective stresses observed in this study (Fig. 8) are reliable data.

Okumura (1974) defined the disturbance ratio $R$ as the ratio of the residual effective stress of specimen $\sigma'_e$ to the effective stress of perfect sample $\sigma'_p$. He discussed the relationship between the shear strength reduction ratio, defined as the ratio of shear strength under residual effective stress $s_{u}$ to shear strength of perfect sample $s_{up}$, and the disturbance ratio $R$ for Yokohama clay, as shown in Fig. 11. According to this figure, when the disturbance ratio is less than three, the shear strength reduction ratio of Yokohama clay is more than 0.85, implying that the shear strength reduction is up to 15%. As a reference, the relationship for Boston Blue clay is also drawn in Fig. 11. Okumura (1974) indicated that there are two kinds of clay on remolding type disturbance as shown in Fig. 11. Taking account of the physical properties in Table 1, Osaka Bay Pleistocene clay can be considered as in the same family as Yokohama clay (a family of Japanese marine clays). Figure 12 shows distribution of disturbance ratio $R$ with depth obtained in the present study. The disturbance ratio $R$ for the Osaka Bay Pleistocene clay ranges from 1.5 to 3, implying that the quality of these undisturbed samples is very good with shear strength reduction up to 15% according to Fig. 11.

**UNCONFINED COMPRESSION TEST**

After measuring the residual effective stress with the suction test, unconfined compression tests were carried out for all of the specimens with an axial strain rate of 1.0%/min. The size of specimen was 35 mm in diameter and 80 mm in height. Figure 13 shows an example of the stress-strain relationship, in which compression stress $q$ is normalized by effective overburden pressure $q_{vo}$. For the Osaka Bay Pleistocene clay, after a peak strength at a strain of as little as 1%, the shear strength decreased remarkably showing very brittle failure. In this figure, the stress-strain relationship of an Ariake clay, which is one of the most typical Japanese Holocene marine clay (Hanzawa et al., 1990), is shown to compare with the Pleistocene clay. The Ariake clay reached peak strength at a relatively larger strain of 3%, and after that, strength did not decrease remarkably and the specimen showed very ductile failure. The difference in stress-strain relationship between the Osaka Bay Pleistocene clay and

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Table 1. Physical properties of clays

<table>
<thead>
<tr>
<th></th>
<th>Yokohama clay</th>
<th>Boston blue clay</th>
<th>Osaka Bay Pleistocene clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid limit $w_L$ (%)</td>
<td>93</td>
<td>33</td>
<td>60-100</td>
</tr>
<tr>
<td>Plastic limit $w_P$ (%)</td>
<td>42</td>
<td>13</td>
<td>30</td>
</tr>
<tr>
<td>Plastic index $I_p$</td>
<td>50</td>
<td>20</td>
<td>30-70</td>
</tr>
<tr>
<td>Compression index $C_c$</td>
<td>0.95</td>
<td>0.4</td>
<td>0.7-1.0</td>
</tr>
<tr>
<td>Swelling index $C_s$</td>
<td>0.11</td>
<td>0.08</td>
<td>0.07-0.11</td>
</tr>
<tr>
<td>Clay fraction ($&lt;2 \mu$m) (%)</td>
<td>29</td>
<td>54</td>
<td>20-40</td>
</tr>
</tbody>
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\[ q / q_{vo} \]

**Fig. 12. Profile of disturbance ratio with depth**

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\[ q / q_{vo} \]

**Fig. 13. Stress-strain relationships observed in unconfined compression tests**
the Ariake Holocene clay was caused by the difference in progression of failure. Specimens of the Osaka Bay Pleistocene clay failed with a vertical crack without a slip surface after peak strength. On the other hand, the specimens of the Ariake Holocene clay failed with a very fine oblique slip surface without any crack.

Figure 14 shows the profile of shear strength $q_0/2$ determined by the unconfined compression test. In this figure, for comparison, undrained shear strengths determined by CAU test with an axial strain rate of 0.1%/min (Watabe et al., 2000) using assumed coefficient of earth pressure at rest ($K_0=0.5$) under in-situ overburden pressure are also shown. Generally, it is said that the average shear strength $s_{u(AVE)}$ of compression shear strength $s_{u(C)}$ and extension shear strength $s_{u(ED)}$ tends to be coincident with the unconfined shear strength $q_0/2$ for Japanese Holocene marine clays (Hanzawa and Kishida, 1982). In this study, even for the Pleistocene clay collected from a large depth, a similar tendency is observed.

The regression line is calculated as $q_0/2=2.19z$ with a CV (coefficient of variation) of 0.28, and $s_{u(AVE)}=2.34z$ with a CV of 0.07, where $z$ is depth below the seabed. Thus, test results of $q_0/2$ are much more scattered than test results of $s_{u(AVE)}$. However, the variance of $q_0/2$ in Fig. 14 is smaller than that in Fig. 1(a) and is almost the same as that for Holocene clays. In particular, trimming a Pleistocene clay sample is very difficult. For example, even if a wire-saw is used to cut into the sample, some part of the specimen can be chipped off easily. Therefore, it must be trimmed very carefully, little by little, but rapidly to prevent desiccation. In spite of the fact that an unconfined compression test seems to be very simple, it requires a skilled technique and concentration when dealing with Pleistocene clay. In the case of Fig. 14, samples were trimmed very carefully because this test program is designed for research. Thus it can be said that the reasons for scattered data in Fig. 1(a) are not only reliability of the test method itself and heterogeneity of the specimen, but also trimming technique of the technician. Additionally, as a practical problem, the contractors have to report all test results including heterogeneity specimens or disturbed specimens, because they have to follow the specifications of the order. Therefore, it can be concluded that the unconfined compression test is not practically applicable to brittle clays like the Pleistocene clay collected from great depth, even if the sample is high quality. In order to determine the reliable shear strength of the Pleistocene clay, a recompression method such as CAU compression and extension tests is recommended.

CONCLUSIONS

In this study, measurement of residual effective stress and unconfined compression test were conducted to investigate sample qualities of Osaka Bay Pleistocene clay, which were collected from large depths as a geotechnical survey for the second construction phase of the Kansai International Airport. The test results yielded the following conclusions:

1) Trimming a Pleistocene clay sample collected from a large depth is very difficult; even though a wire-saw is used to cut into the sample, some part of the specimen can easily be chipped off. Therefore, it must be trimmed very carefully, little by little, but rapidly to prevent desiccation. This requires a skilled technique and concentration when dealing with a Pleistocene clay.

2) An attempt to measure a residual effective stress larger than 98.1 kPa in an undisturbed sample was made by adopting and simplifying a method to measure suction in unsaturated soils. As a result, a high residual effective stress could be measured by placing the specimen under a back air pressure.

3) It was clarified that suction greater than 98.1 kPa can remain in an undisturbed and apparently saturated Pleistocene clay sample collected from a great depth.

4) For Osaka Bay Pleistocene clay, residual effective stress is about one fifth of effective overburden stress. This is very similar to the case of Japanese Holocene marine clay.

5) The disturbance ratio defined by Okumura (1974) ranged from 1.5 to 3 for Osaka Bay Pleistocene clay. According to Okumura's chart (Fig. 11), these samples are classified as very good, with strength reduction of up to 15%. It can be said that the sample quality of undisturbed Pleistocene clays collected from large depths are better than was anticipated.

6) Stress-strain relationships observed in unconfined compression tests for Osaka Bay Pleistocene clay were very brittle, in which axial strain at failure was only 1% and sudden reduction of the resistance was observed. Therefore, trimmed specimens have a tendency to have crack type disturbance because the crack can easily be created during trimming (as mentioned in Conclusion 1).

7) If an unconfined compression test is conducted very carefully for Osaka Bay Pleistocene clay, the strength...
coincides with the average strength of compression and
extension strength of in-situ stressed sample under the
recompression method (Fig. 14). This relation is well
known for Holocene clays and this fact supports Conclu-
sion 5 mentioned above. However, generally, the un-
confined compression strength of Osaka Bay Pleistocene
clay showed large variance due to the crack type distur-
bance (Fig. 1). Therefore, in treating a brittle Pleistocene
clay, it cannot be said that the unconfined compression
test is applicable for practical purposes even if the sample
is of high quality. In order to determine the reliable shear
strength of the Pleistocene clay, a recompression method
such as CAU compression and extension is recommend-
ed.

REFERENCES

on soft clays and structurally unstable soils. State of the Art
Report, Proc. of the 8th ICMSFE, 111-159.
2) Fredlund, D. G. and Rahardjo, H. (1993): Soil mechanics for unsat-
saturated soils, John Wiley and Sons.
characteristic curve, Canadian Geotechnical Journal, 31, 521-532.
confined strength of soft clay deposits, Soils and Foundations, 22
(2), 1-14.
gineering properties for an Ariake clay, Soils and Foundations, 30
(4), 21-24.
6) Hight, D. W., Böse, R., Butcher, A. P., Clayton, C. R. I. and
Smith, P. R. (1992): Disturbance of the Bothkennar clay prior to
laboratory testing, Géotechnique, 42 (2), 199-217.
ing properties of marine clay in Osaka bay, (Part-I) Boring and
sampling, Technical Note of The Port and Harbour Research In-
disturbed soil sample using thin-walled tube sampler with fixed
piston, JGS, 1221-1995.
vestigation at the Kansai International Airport, Proc. of GEO-
COAST '91, 1, 33-38.
tion on unconfined compression strength, Proc. of 13th Annual
Meeting of JSSMF, 313-316 (in Japanese).
clay determined from undrained tests, ASTM, STP-361, Labora-
tory Shear Testing of Soils, 342-371.
12) La Rochelle, P., Sarraillh, J., Tavenas, F., Roy, M. and Leroueil,
S. (1981): Causes of sampling disturbance and design of a new sam-
pler for sensitive soils, Canadian Geotechnical Journal, 18 (1), 52-
66.
effects in soft low plastic Norwegian clay, Proc. of Int. Sympo. on
Recent Developments in Soils and Pavement Mechanics, Rio De
Janeiro, 81-102.
14) Marshall, T. J. (1958): A relation between permeability and size dis-
confined strength of clays based on the suction value and un-
confined compressive strength, Journal of Geotechnical Engineer-
confined compression test results based on the residual effective
stress and correction of q value, Journal of Geotechnical Engineer-
Application of Laval type large diameter sampler to soft clay in
18) Okumura, T. (1974): Study on the disturbance of clay and improve-
ment of sampling method, Technical Note of The Port and Har-
bour Research Institute, (193) (in Japanese).
clays in unconfined compression tests, Soils and Foundations, 33
Method for predicting in-situ undrained strength of clays by un-
confined compression test with suction measurements, Proc. of
Comparative study on sample quality using several types of sam-
ples, Soils and Foundations, 36 (2), 57-68.
22) Tanaka, H., Hamouche, K. K., Tanaka, M., Watabe, Y.,
Champlain sea clay, Proc. of the 1st International Conference on
Geotechnical Site Characterization, Atlanta, 439-444.
of Osaka Bay clay: the impact of microfossils on its mechanical be-
lation of unconfined compression strength and suction on un-
disturbed clay samples, Proc. of 30th Annual Meeting of JGS,
gineer's technique on the results of soil investigation, Tsuchi-
to-Kiso, Japanese Geotechnical Society, 36 (9), 49-54 (in Japanese).
of clayey ground by means of triaxial tests, Technical Note of The
Port and Harbour Research Institute, Ministry of Transport,
disturbed clays by means of triaxial cell, Soils and Foundations, 31
(3), 127-137.
clay deposits A review of unconfined compression strength of clay-
Report of Port and Harbour Research Institute, Ministry of
Transport, Japan, 34 (4), 1-37.
strength of Pleistocene clay in Osaka Bay and its effect on the stabili-
ity of a large scale seawall structure, Proc. of the International
Symposium on Coastal Geotechnical Engineering in Practice, IS-