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EFFECTIVE STRESS BEHAVIOR OF CLAYS IN UNCONFINED COMPRESSION TESTS

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ABSTRACT

Unconfined compression tests with the measurement of suction and CIU triaxial compression tests were carried out on a remolded and reconsolidated sample to evaluate whether the effective stress behavior in the unconfined compression tests could be explained through the results from the triaxial tests.

It is shown that: effective stress paths in unconfined compression tests are very similar to those in triaxial tests; and unconfined compressive strengths can be predicted well by using those relationships between A_f and the overconsolidation ratio and alternatively between the ratio of the undrained strength to the consolidation stress and the overconsolidation ratio obtained from triaxial tests.

Key words: cohesive soil, effective stress, overconsolidation, sample disturbance, suction, triaxial test, unconfined compression test, (**IGC**: D6)

INTRODUCTION

Unconfined or uniaxial compression tests are very widely carried out mainly for the purpose of determining undrained strengths of undisturbed clay samples. Results are applied for the estimate of in situ undrained strengths. The characteristic of the unconfined compression test can be characterized by the following:

(1) the initial effective stresses, which specimens possess at the beginning of the test, are not changed prior to the axial compression or shearing in the test;

(2) no information on the effective stresses can be obtained from the results; and

(3) unconfined compressive strengths are usually scattered even if specimens tested seem to have been subjected to the same stress history.

The effective stress for an undisturbed sample is usually different from its in situ effective stress (e.g. Skempton and Sowa, 1963). The difference reflects the degree of the disturbance that the sample had been subjected to. The term 'disturbance' is used, as in Nakase (1979), to refer to all the external agencies that will cause the change in the effective stress: for instance, the stress release and mechanical disturbance associated with the sampling and transportation of samples and some subsequent operations for preparing specimens.

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Specimens prepared from a remolded and reconsolidated sample may have been disturbed, too. The change in pore-water pressure that occurs in a series of processes for preparing specimens was measured by Kimura and Saito (1982). Abe and Kawakami (1980) intentionally caused various types of possible disturbances in specimens of a remolded and reconsolidated sample to examine the effects of the disturbance on the initial effective stress; they showed that the value for the initial effective stress may depend on a given type of disturbance. Karube and Ariyoshi (1981) examined the effects of swelling and drying on the unconfined compressive strength.

The disturbance decreases the effective stresses of the specimens; therefore specimens to be tested in laboratory are considered to have been overconsolidated. The degree of disturbance may be expressed by the degree of overconsolidation: Ladd and Lambe (1963) and Okumura (1974) defined it on the basis of the effective stresses of perfect samples.

Undrained behavior of overconsolidated saturated clays is controlled not only by their current effective stresses but also by the degree of overconsolidation which they have experienced. The effects of these two factors on the behavior can be investigated through triaxial tests: Nakase (1968), for example, investigated the relationship between the Skempton's coefficient of pore pressure, A_f, and the overconsolidation ratio, OCR; Mitachi and Kitago (1976) gave a mathematically sound expression for the relationship between the undrained strength and those factors.

One of purposes of the present study is to examine whether the manner in which effective stress paths depend on the degree of overconsolidation is the same between triaxial tests and unconfined compression tests. We should remember here that triaxial test specimens have been overconsolidated only by stress reduction if they are reconsolidated in the triaxial cell at pressures much higher than the in situ stresses; unconfined compression test specimens, however, have been overconsolidated by the mechanical disturbance in addition to the stress release.

This purpose was accomplished by comparing the results obtained from the triaxial tests and the unconfined compression tests. To perform such a comparison, the initial effective stress and the change in effective stresses during unconfined compression tests were measured.

Test specimens of clay samples, regaraless of whether they are undisturbed or whether they are reconstituted in the laboratory, possess the initial or residual pore-water pressure less than the atmospheric pressure under the unconfined atmospheric pressure condition. Under such a condition, the effective stress of a sufficiently saturated specimen equals the suction, which is the atmospheric pressure minus the pore water pressure. If gage pressure is used, the pore-water pressure takes on a negative value.

Various techniques for measuring the suction of unsaturated soils were compared by Abe and Kawakami (1987) and the method in which a thin ceramic plate is used is recommended; this technique can be applied also to measure the suction of highly saturated soils. Ohta (1983) proposed a method of estimating, prior to the triaxial tests, the residual pore-water pressure of undisturbed samples.

We can apply the ceramic plate technique to measure the change in effective stresses in unconfined compression tests (Abe and Kawakami, 1980). There has been little data, however, on the effective stress behavior in unconfined compression tests; it is questionable whether the effective stress behavior in the tests could be explained by analogy with the facts that have so far been found through triaxial tests on saturated samples.

In the present study, unconfined compression tests with the measurement of suction were carried out on a remolded and reconsolidated clay, as were isotropically consolidated and undrained (CIU) triaxial tests. In this paper we discuss the behavior, in terms of effective stresses, in unconfined compression tests and compare it with the behavior in triaxial tests. The homogeneity of the initial suction will briefly be discussed.

It will be shown that the behavior, including the strength, in unconfined compression tests is controlled by the principle of effective stress and it can be well explained in accordance with the behavior in triaxial tests. The conclusions obtained in the present study demonstrate the practical importance of the measurement of the initial suction.

EXPERIMENTS

Unconfined compression tests in which the suction was measured both prior to and during the compression and CIU triaxial compression tests were carried out on a remolded and reconsolidated clay sample.

Preparation of Specimens

A kaolinitic clay that had been sieved to remove particles larger than 420 μm was used: $w_L=42\%$, $w_P=27\%$ and $G_s=2.66$. It was mixed with distilled water and remolded for two days, during which the water content was nearly twice its liquid limit. After the remolding, the slurry was one-dimensionally consolidated in a cylindrical mold of 25 cm in diameter and 30 cm in height. The vertical pressure was applied incrementally up to the maximum preconsolidation pressure p_0: the specified values for p_0 are 50 and 100 kPa. Water contents of the preconsolidated samples are shown in Table 1.

Each of preconsolidated samples was split into blocks with a wire saw as shown in Fig. 1. The blocks were coated with paraffin and then wrapped in aluminum foil. The coated blocks

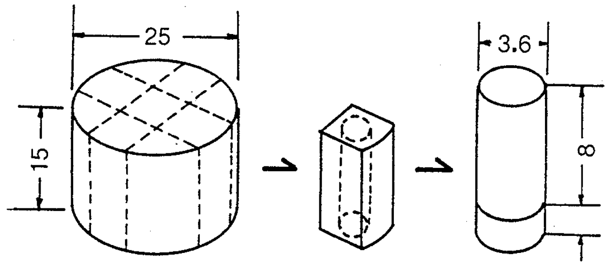


Fig. 1. Procedure for preparing specimens for unconfined compression tests

were immersed in water at a constant temperature of 20°C until they were tested.

Each of the blocks was trimmed with a wire saw into a cylindrical specimen of 3.6 cm in diameter; some of the specimens to be used for unconfined compression tests were further divided into two parts, long and short, as shown in Fig. 1. The short specimens were used only for the measurement of the initial suction; the long specimens were used for the unconfined compression tests. The method in which the suction is measured on a part of a specimen was reported by Karube and Ariyoshi (1981). Values for the initial suction of a pair of specimens, short and long, will be compared and the homogeneity of the suction will be discussed in the discussion section.

The procedure described above made specimens almost fully saturated; in fact, the degree of saturation was 95 to 100%.

Table 1. Batches for the remolding and preconsolidation

Batch No.	p_0[1] (kPa)	Water Content[2] (%)	Test
A	50	47.9–48.1	Unconfined compression
B	50	37.0–39.0[3]	
C	100	35.5–39.0	
D	100	36.5–37.4	
E	100	35.0–37.7	
F	50	48.1–48.7	Triaxial

Note:
[1]Vertical pressure applied in the preconsolidation
[2]Water contents of specimens at the beginning of the tests
[3]The water content at remolding was lower than that for other batches

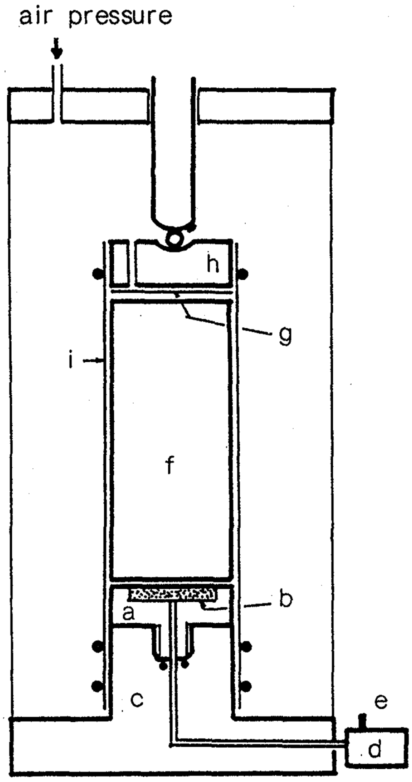
Unconfined Compression Tests with Measurement of Suction

The procedure for an unconfined compression test consists of two main steps: the first step is to measure the initial suction and the second step is to load in the axial direction. The method of measuring the initial suction, described below, was also adopted for the short specimens.

(a) Measurement of the initial suction

The system for the measurement of suction is schematically shown in Fig. 2.

(1) A brass mounting disc (**a** in Fig. 2) in



a: brass mounting disc
b: ceramic disc
c: base pedestal
d: pressure transducer
e: air release valve
f: specimen
g: plastic membrane filter
h: loading cap
i: latex membrane

Fig. 2. Schematic representation of the system for unconfined compression tests with measurement of suction

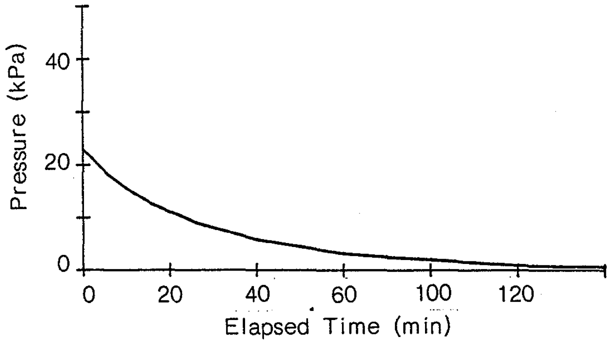


Fig. 3. The dissipation of the water pressure caused by closing the valve of the transducer

which a 1.5 mm thick saturated ceramic disc plate[1] **(b)** had been fixed was screwed into the base pedestal **(c)**, the valve **(e)** of the pressure transducer **(d)** being open. After screwing the mounting disc into the pedestal, the valve was closed. By closing the valve, the water filling the connection tube between the poorly permeable ceramic disc and the pressure transducer is compressed and the water pressure in the tube is increased. The increased water pressure, detected by the transducer, gradually dissipated; an example of the dissipation with time is shown in Fig. 3, in which we see that it took more than 120 minutes for the pressure to dissipate.

(2) A specimen **(f)** was put onto the mounting disc **(a)** after the dissipation of the increased water pressure. A thin plastic membrane filter[2] **(g)** and the loading cap **(h)** were put on the upper surface of the specimen **(f)**; the specimen was covered by a latex membrane **(i)** of 0.2 mm thickness. The loading cap is perforated to enable the application of the pore air pressure. The plastic membrane filter does not allow the passage of water vapor but it does allow the air to pass. By the use of the plastic membrane filter and the latex membrane, the specimen can be prevented from drying during the test.

The suction that a specimen possesses causes the migration of the water out of the ceramic disc and into the specimen: in fact, the moment the specimen was set on the mounting disc, the specimen began to suck the water in, and the pressure measured by the transducer began to decrease. See Fig. 4.

(3) The air pressure, u_a, of 100 kPa was applied in the cell to prevent the pore-water pressure from being negative. The air pressure can also be pore-air pressure because the loading cap is perforated.

[1] An electrolysis diaphragm made by Nikkato Inc., Japan, was used. The diaphragm is made of fine ceramics and very poorly permeable: the order of the coefficient of permeability is 10^{-5} cm/s. The air entry value was measured and found to be approximately 160 kPa.

[2] A microporous and waterproof film. A product by Advantec Toyo Inc., Japan, was used: thickness is 75 μm; pore size is 1.5 μm; and, according to Suzuki (1991), water with a pressure lower than 150 kPa cannot pass through the filter.

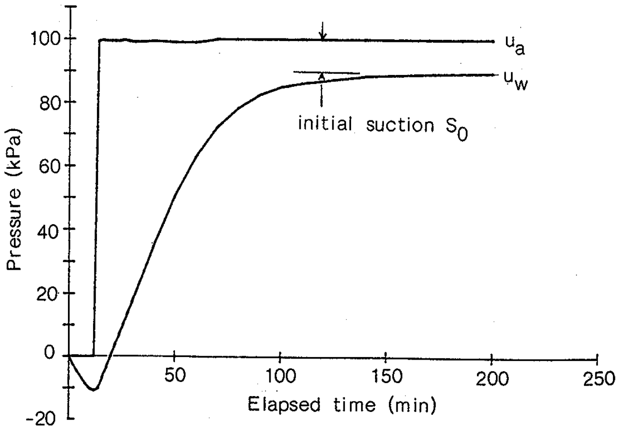


Fig. 4. An example of the variations of the air and water pressures with time. The constant value of the difference between them is the initial suction

The pressure u_w, which can be measured by the transducer, rises with the application of the air pressure as shown in Fig. 4; a few hours later, the pressure can reach the equilibrium state in which the difference between u_a and u_w becomes constant. The constant value of the difference is the initial suction of the specimen tested. The time in which the equilibrium state can be attained is different from specimen to specimen.

Steps (1) to (3), described above, were also applied to short specimens. When short specimens were tested, the equilibrium in Step (3) was reached earlier than that for the long specimens.

(b) Compression of specimens

The rate of axial strain has to be small enough to measure the pore water pressure, otherwise the measured pressure may be different from the pore water pressure. The adequate rate of compressive strain was determined to be 0.01%/min according to the preliminary investigation in which compression tests with three kinds of rates were carried out: 0.002, 0.01 and 1.0%/min. The results from those tests that were carried out with the rate of 0.01%/min will be presented to discuss the effective stress behavior in unconfined compression tests.

Triaxial Compression Tests

One of the purposes in carrying out triaxial tests is to find out how the sample used for the unconfined compression test behaves when it is consolidated with a higher consolidation pressure than the initial suction. Through the triaxial tests we can obtain the data on the strength characteristics and effective stress paths of the sample from which the effects of the disturbance have been removed. The results will be used to discuss the behavior in unconfined compression tests in terms of effective stresses.

DEFINITIONS OF STRESS PARAMETERS

Before the results from experiments are presented, the parameters that will be used hereafter are explained. We use the stress parameters, $\bar{p}$ and $\bar{q}$, defined as

$$\bar{p}=\frac{\sigma_1'+\sigma_3'}{2} \tag{1}$$

$$\bar{q}=\frac{\sigma_1'-\sigma_3'}{2} \tag{2}$$

where σ_1' and σ_3' are axial and lateral effective stresses under the triaxial stress condition. For the unconfined compression test, they can be determined by

$$\sigma_1'=(\sigma+u_a)-u_w \tag{3}$$

$$\sigma_3'=u_a-u_w \tag{4}$$

where σ is the applied compressive load per unit area of the specimen. We note here that u_a acts as confining pressure and σ acts as deviator stress; and therefore axially and laterally applied stresses are $\sigma+u_a$ and u_a, respectively. In Eqs. (3) and (4), the effective stresses are defined by taking $\chi=1$ in Bishop's equation for effective stresses for unsaturated soils (Bishop, 1960) because the specimens that were tested were almost fully saturated.

Fig. 5 shows a schematic representation of likely effective stress paths in the preparation of specimens and in the unconfined and triaxial compression tests. The notation for some values of the stress parameters is also shown.

The value of $\bar{p}$ at the end of the isotropic consolidation in CIU triaxial tests is denoted by $\bar{p}_c$ and its maximum value by $\bar{p}_{c\max}$. Overconsolidation ratio, $\bar{R}$, is defined as

$$\bar{R}=\frac{\bar{p}_{c\max}}{\bar{p}_c}. \tag{5}$$

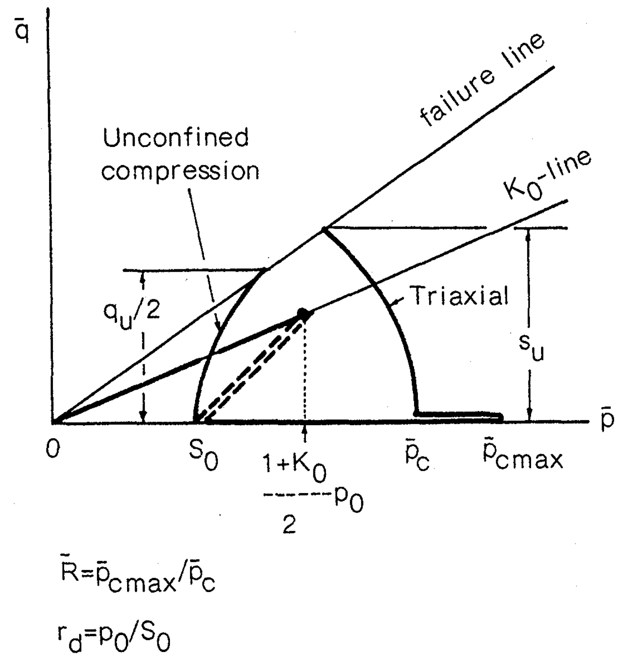


Fig. 5. Schematic representation of effective stress paths and notations used

It should be noted that unconfined compression test specimens are overconsolidated under the K_0 condition whereas triaxial test specimens are overconsolidated under isotropic stress conditions. To take into account such a difference in the conditions for the overconsolidation, the parameter $\bar{R}$ has been introduced instead of the conventional overconsolidation ratio, usually denoted by OCR. Wroth and Houlsby (1985) used a similar alternative parameter, to express the overconsolidation ratio, which is defined in terms of effective mean stress. The OCR, however, is defined in terms of the effective vertical stress.

For unconfined compression tests, $\bar{p}_c$ is the initial suction S_0, and $\bar{p}_{c\,max}$ can be related to p_0, the maximum vertical pressure applied in the K_0-preconsolidation, as follows

$$\bar{p}_{c\,max}=\frac{1+K_0}{2}p_0$$

(for unconfined compression tests). (6)

To express the degree of the disturbance of unconfined compression test specimens, we introduce the disturbance ratio, r_d, which is defined as

$$r_d=\frac{p_0}{S_0}. \qquad (7)$$

The concept of disturbance ratio will be used only for unconfined compression tests; the physical meaning of r_d, however, is similar to that of the OCR. We should note that for the definition of r_d the applied vertical pressure in the K_0-preconsolidation, p_0, is used because the value for K_0 was not measured. By substituting the relations of Eq. (6) and $\bar{p}_c=S_0$ into Eq. (5), r_d can be related to $\bar{R}$ as

$$\bar{R}=\frac{1+K_0}{2}r_d$$

(for unconfined compression tests). (8)

The degree of disturbance was alternatively defined by Okumura (1974) and Ladd et al. (1964). They simulated the change in effective stresses due to sampling through triaxial tests; the degree of the disturbance in their stusies was defined as the ratio of the effective consolidation stress of the perfect sample (a sample taken without disturbance), to that of samples which were taken with disturbance. In the present study, however, the state of effective stresses of the perfect sample is not realized and therefore their definition is not used.

RESULTS AND DISCUSSION

Behavior in Triaxial Tests

The effective stress paths in CIU triaxial tests are shown in Fig. 6. In this figure, stress parameters, $\bar{p}$ and $\bar{q}$, are normalized by $\bar{p}_{c\,max}$.

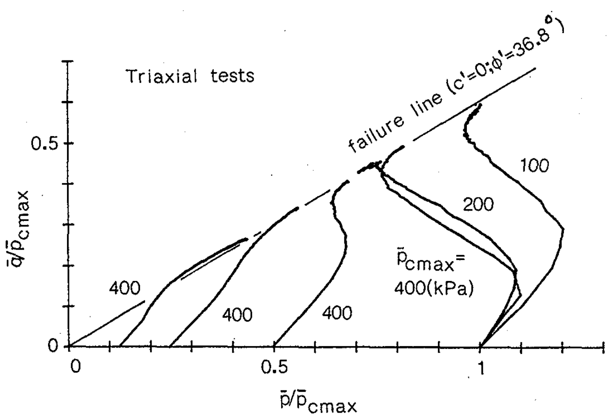


Fig. 6. Effective stress paths in CIU triaxial tests.

The strength parameters were determined as $c'=0$ and $\phi'=36.8°$. In the figure, the specimen normally consolidated at $\bar{p}_{c\,max}=100$ kPa seems to be peculiar in comparison with other specimens normally consolidated at $\bar{p}_{c\,max}=200$ and 400 kPa. This result can be understood by considering that specimens isotropically consolidated at not much higher stress than the stress having been applied in K_0 preconsolidation tend to show relatively low values for A_f and high undrained strengths (e.g. Brand, 1975).

Behavior in Unconfined Compression Tests

Results of a representative unconfined compression test are presented in Fig. 7. In this example, the pore-water pressure increases in the beginning of the compression and gradually decreases with the development of compression; and therefore the suction decreases in the beginning and subsequently increases.

Effective stress paths obtained from unconfined compression tests are shown, in Figs. 8(a) and (b), in terms of normalized stress parameters $\bar{p}/p_0$ and $\bar{q}/p_0$. To avoid the complication of the curves, all the results are not shown in the figures. We can observe that the values of initial suction, along with the effective stress paths, are different between specimens. We should note that these differences occurred even though the specimens were not intentionally disturbed during the preparation process.

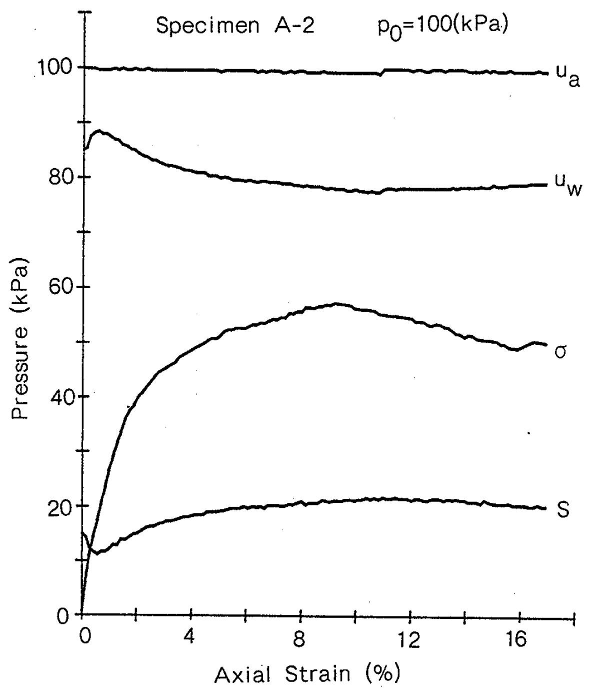


Fig. 7. Typical results of an unconfined compression test

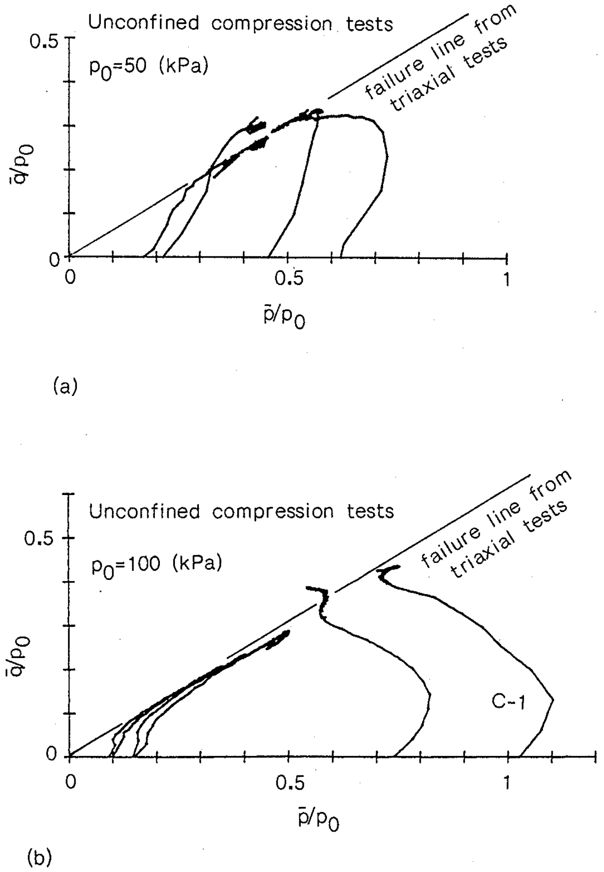


Fig. 8. Effective stress paths in unconfined compression tests: (a) $p_0=50$ kPa; and (b) $p_0=100$ kPa

Such differences might be explained by two major reasons: the inevitable disturbance that individual specimens were subjected to when they were prepared, and the probable nonuniformity of effective stresses in the K_0 preconsolidation. The results shown in Figs. 8(a) and (b) suggest that the degree of the inevitable disturbance will be different from specimen to specimen.

It is also seen that all specimens, except one in each figure, fail on a straight line, which is the failure line determined from CIU triaxial tests. This indicates that the strength parameters c' and ϕ' are the same between unconfined compression tests and triaxial tests and that the failure in unconfined compression tests can be well defined by Terzaghi's concept of the principle of effective stress.

Although different variables are used in Figs. 6 and 8(a) and (b), the effective stress paths in unconfined compression tests are very similar to those in triaxial tests. This implies that the effective stress behavior in unconfined compression tests is not particular but it is one that can be expected from the behavior of overconsolidated specimens in triaxial tests; furthermore there is the possibility of assessing the unconfined compressive strengths based on the concept of the overconsolidation ratio or the disturbance ratio.

Relationship between A_f and r_d

An aspect of effective stress paths can be characterized by Skempton's pore pressure coefficient A_f (Skempton, 1954). From the similarity of effective stress paths in unconfined compression tests to ones in triaxial tests, pointed out already, we can expect that the relation of A_f to the degree of overconsolidation or disturbance will coincide in both tests. In fact, as shown in Fig. 9, the manner in which A_f varies with $\bar{R}$ for triaxial tests is very similar to that in which A_f varies with r_d for unconfined compression tests.

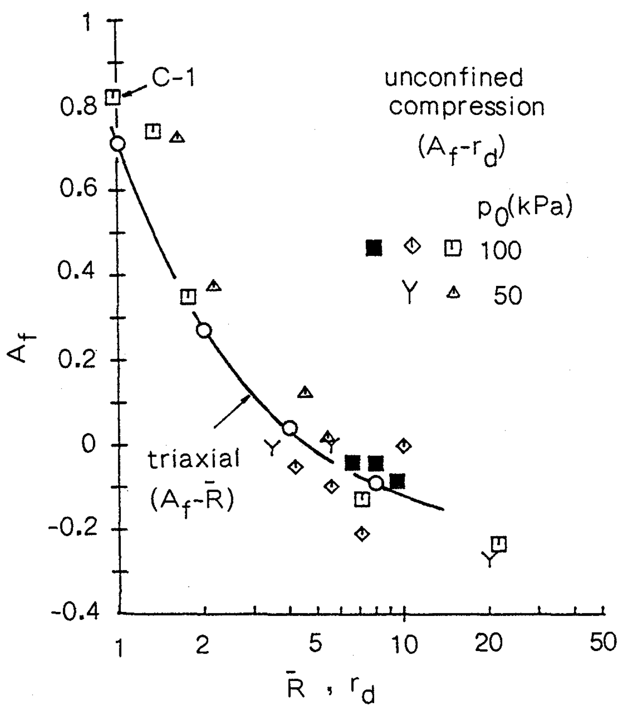


Fig. 9. Variations of A_f with $\bar{R}$ and r_d

The value for $\bar{R}$ of unconfined compression test specimens could be estimated from r_d by using Eq. (8) if the value for K_0 were known. In fact, $\bar{R}$ would be 0.7 times r_d with the assumption of $K_0=0.4$: Jaky's equation that $K_0=1-\sin\phi'$ was used with $\phi'=36.8°$. Thus, by shifting the plots for unconfined compression tests in Fig. 9, we can estimate the relation of A_f and $\bar{R}$ even for unconfined compression tests. By such a shift, almost all the plots for unconfined compression tests will lie beneath the relationship for triaxial tests; in other words, A_f might be less for any $\bar{R}$ for unconfined compression test specimens than for triaxial ones.

Assessment of Unconfined Compressive Strengths by Triaxial Tests

In the preceding sections, we showed two facts:

(1) Effective stress paths in unconfined compression tests are similar to those in triaxial tests for any degree of overconsolidation; and

(2) the relationship of A_f to $\bar{R}$, which was obtained from triaxial tests, is similar to that of A_f to r_d, obtained from unconfined compression tests.

These two facts confirm the possibility of assessing unconfined compressive strengths, q_u, based on the concept of $\bar{R}$ or r_d. In this section, we try to actually assess them in terms of $\bar{R}$ and r_d.

Undrained shear strength, $s_u(=\bar{q}$ at failure), of saturated soils in CIU triaxial tests with constant cell pressure can be given by

$$s_u=\frac{\bar{p}_c\sin\phi'}{1+(2A_f-1)\sin\phi'} \tag{9}$$

where it was assumed that $c'=0$ because the value for c' of remolded and reconsolidated clay samples is negligibly small even if they are overconsolidated (Murthy et al., 1981; Shimizu, 1982).

The similarity of effective stress paths, pointed out in Figs. 6 and 8(a) and (b), also can make us suppose that the equation above will be used for the estimate of unconfined compressive strength, $q_u/2$, where q_u is defined as the maximum compressive stress in the range of strain less than 15%. By replacing $\bar{p}_c$ in Eq. (9) by S_0, the estimate for $q_u/2$ can be given as

$$\frac{q_u}{2}=\frac{S_0 \sin \phi'}{1+(2A_f-1)\sin \phi'}\,. \tag{10}$$

We have two alternative ways for predicting unconfined compressive strengths on the basis of Eq. (10): one is to apply the $A_f-\bar{R}$ relationship which was obtained from triaxial tests; the other is to use the relationship between $s_u/\bar{p}_c$ and $\bar{R}$ from triaxial tests.

(a) Prediction from $A_f-\bar{R}$ relationship

In Fig. 10, $q_u/2$ calculated by Eq. (10) is compared with $q_u/2$ measured in unconfined compression tests; to calculate it, r_d was assumed to be identical to $\bar{R}$, i.e., it was assumed that $K_0=1$, and the $A_f-\bar{R}$ relation for triaxial tests in Fig. 9 was used.

Fig. 10 shows that unconfined compressive strength can well be predicted by Eq. (10). However we should recall that, if r_d were correctly converted to $\bar{R}$, values for A_f would be larger than those which were actually used for the prediction; therefore the prediction with the assumption that $r_d=\bar{R}$ (or $K_0=1$) might overestimate the unconfined compressive strengths.

Such an effect of the difference between r_d and $\bar{R}$ must be included in the results shown in Fig. 10. The predicted strength, however, can be related to the measured strengths without much scatter. As a conclusion that can be derived from the results shown in the figure, specimens for unconfined compression tests behaves as overconsolidated triaxial specimens, and they can mobilize their proper strengths corresponding to their degree of disturbance which can be expressed by r_d or $\bar{R}$.

(b) Prediction from $s_u/\bar{p}_c-\bar{R}$ relationship

There is another way of predicting the unconfined compressive strengths with the results from triaxial tests. Eq. (9) shows that $s_u/\bar{p}_c$ is a function of A_f and therefore $\bar{R}$; and, if we can develop some relationship between $s_u/\bar{p}_c$ and $\bar{R}$ with experimental data, we will be able to use this relationship to derive a relationship between $q_u/2$ and $\bar{R}$ or r_d. In fact, $s_u/\bar{p}_c$ is plotted against $\bar{R}$ with data from triaxial tests in Fig. 11.

In the figure a sound linear relationship can be found. It was shown by Mitachi and Kitago (1976) and Mayne (1980) that such a linearity

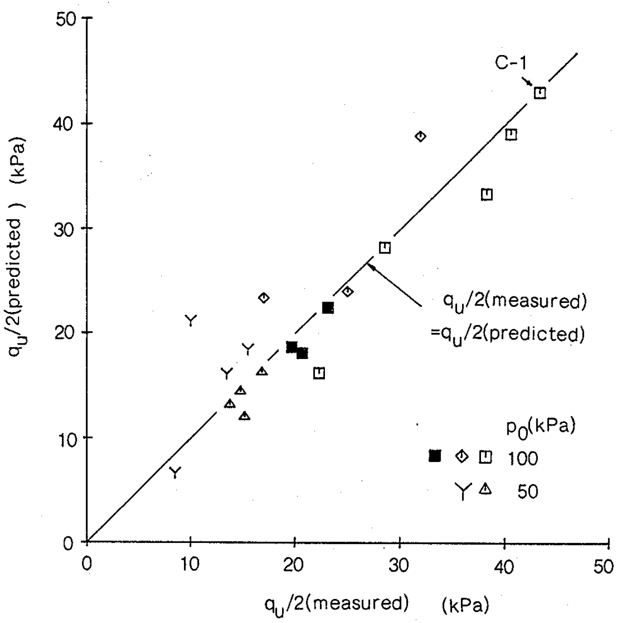


Fig. 10. The comparison of unconfined compressive strengths predicted by $A_f-\bar{R}$ relationship obtained from triaxial tests with measured ones

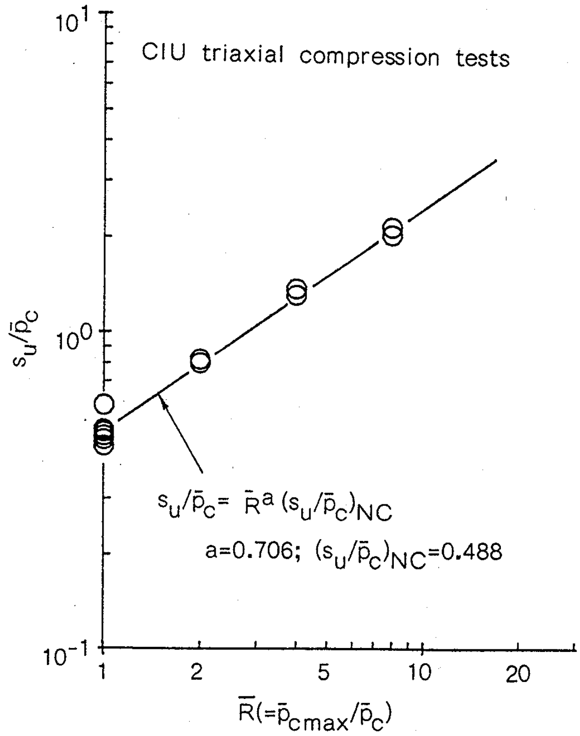


Fig. 11. The relationships between the ratio of the triaxial undrained strength, s_u, to the consolidation pressure, $\bar{p}_c$, and the overconsolidation ratio R. Results from CIU triaxial tests

could be seen for many kinds of clays. The line drawn in the figure was determined by the method of least-squares; the line can be expressed as:

$$\frac{s_u}{\bar{p}_c}=\bar{R}^a\left(\frac{s_u}{\bar{p}_c}\right)_{NC} \tag{11}$$

where $a=0.706$ and $(s_u/\bar{p}_c)_{NC}=0.488$. The term $(s_u/\bar{p}_c)_{NC}$ is the value of $s_u/\bar{p}_c$ when $\bar{R}=1$, i.e., the undrained strength ratio determined from CIU triaxial tests on normally consolidated specimens.

Eq. (11) can be modified to predict the unconfined compressive strength: we replace s_u and $\bar{p}_c$ by $q_u/2$ and S_0, respectively; and furthermore $\bar{R}$ by the disturbance ratio r_d with Eq. (8). These modifications result in the following expression

$$\frac{q_u/2}{S_0}=r_d^a\left(\frac{1+K_0}{2}\right)^a\left(\frac{s_u}{\bar{p}_c}\right)_{NC}. \tag{12}$$

The results from unconfined compression tests are shown in Fig. 12, in which $(q_u/2)/S_0$ is plotted against r_d. The lines drawn in the figure were determined from Eq. (12) with the assumption that $K_0=1$ and $K_0=0.4$. We can see that the relationship predicted by the results from triaxial tests can well explain the experimental results although the prediction depends on the assumed K_0 value.

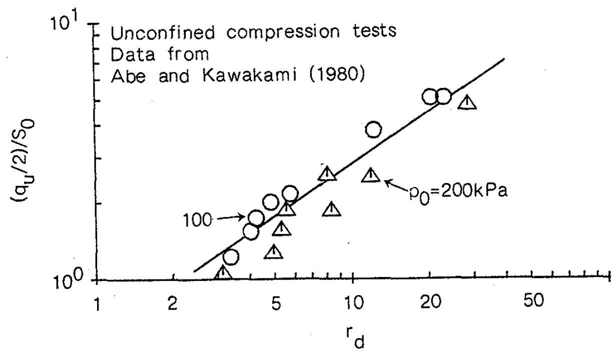


Fig. 13. The relationships between the ratio of the unconfined compressive strength, $q_u/2$, to the initial suction, S_0, and the disturbance ratio, r_d; replotted from results in Abe and Kawakami (1980)

Such behavior as shown in Fig. 12 can also be seen in the results of Abe and Kawakami (1980), who intentionally caused various types of disturbances in specimens of a remolded and reconsolidated sample: see Fig. 13. In the figure, the unconfined compressive strengths are not compared with the undrained strength of triaxial tests because the data on the latter are not available in the reference.

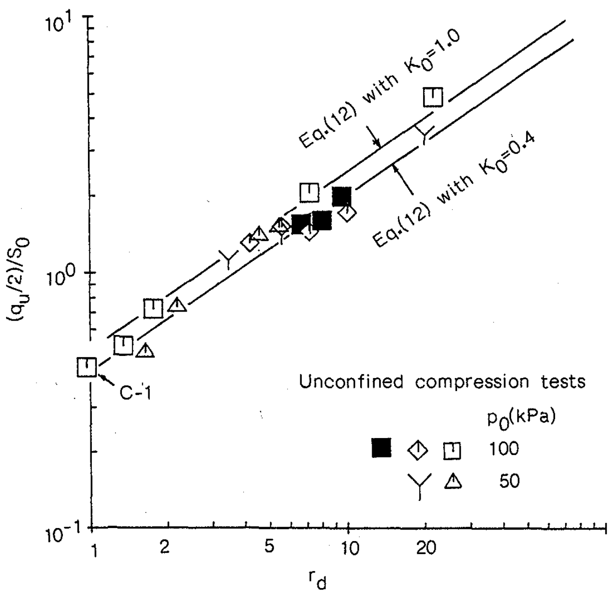


Fig. 12. The relationships between the ratio of the unconfined compressive strength, $q_u/2$, to the initial suction, S_0, and the disturbance ratio, r_d; results from unconfined compression tests

Distribution of Initial Suction

The initial suction was measured for a short specimen and a long specimen trimmed from each block of a sample preconsolidated in the way described in the previous section. These two values of the initial suction are compared in Fig. 14, in which S_{0L} denotes the initial suction of the long specimen and S_{0S} that of the short specimen.

We can not observe any definite tendency in the figure: which is larger, S_{0L} or S_{0S}? We can see, however, that the difference between S_{0L} and S_{0S} is smaller in the blocks subjected to a higher initial suction than in those subjected to a lower initial suction. This indicates that the distribution of the initial suction is more uniform in the less disturbed blocks.

We see in the figure that both S_{0S} and S_{0L} of a specimen, denoted by C-1, are nearly equal to 100 kPa. This value is unexpected because maximum effective mean stress applied in the K_0 preconsolidation must be much less than

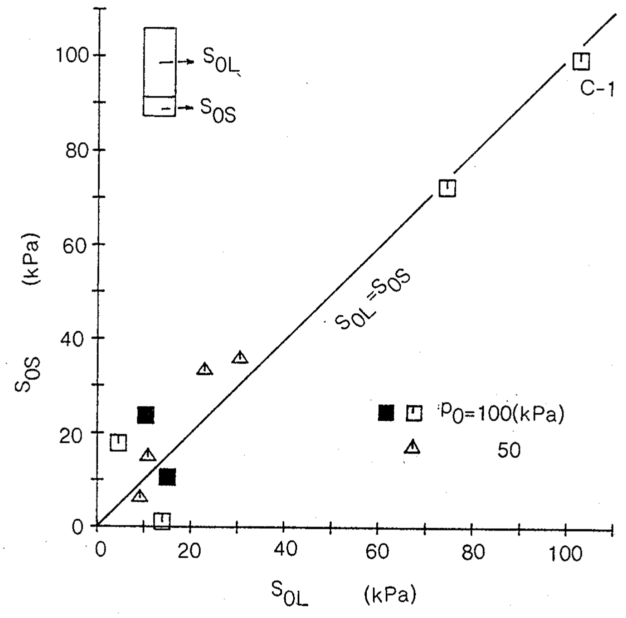


Fig. 14. The comparison of the initial suction measured for long specimens S_{0L} and short ones S_{0S}

100 kPa. A possible cause for such high values of the initial suction is drying the specimen; but the specimen C-1 was not dried, in fact, it was almost fully saturated. In Figs. 8(b), 9, 10, 12 and 14, the results for this specimen are distinguished by the mark 'C-1'. As seen in these figures, the results of the C-1 specimen do not seem to be peculiar. Thus it cannot be believed that much error is included in the measured values for the initial suction of this specimen although it cannot be explained reasonably why such high values were measured.

CONCLUSIONS

Unconfined compression tests with the measurement of suction and CIU triaxial compression tests were carried out on a remolded and reconsolidated sample. It was examined if the effective stress behavior in unconfined comptession tests could be explained through the results from the triaxial tests.

It was shown that:

(1) The values of the initial suction can be different between specimens even if they have been prepared from the same sample block. In the portions adjacent to each other the initial suction can be different, but the difference was less for blocks subjected to higher values of initial suction;

(2) effective stress paths in unconfined compression tests are very similar to those of specimens overconsolidated in triaxial tests; and

(3) the relationship of A_f to the degree of overconsolidation which was obtained from triaxial tests is similar to that obtained from unconfined compression tests.

The last two conclusions confirm the possibility of assessing unconfined compressive strengths based on the concept of the degree of overconsolidation. They were actually assessed in terms of the degree of overconsolidation, and it was shown that

(4) unconfined compressive strengths can be well predicted by using the relationships between A_f and the overconsolidation ratio and alternatively between the ratio of the undrained strength to the consolidation stress and the overconsolidation ratio, which were obtained from triaxial tests.

The scattering of unconfined compressive strengths seems to be caused by the scattering of the initial effective stresses; however the strengths can properly be mobilized according to the principle of effective stress. The strengths are controlled by the initial effective stress and the degree of the disturbance or the overconsolidation ratio, and therefore it is important to measure the initial suction of specimens to be tested for unconfined compression tests and to estimate the in situ state of effective stresses.

As recommended by Abe and Kawakami (1987), the method adopted in this study for measuring the suction is believed to be effective even though it may not be the best method. One disadvantage of this method is that a long time is required for the measurement of the suction; and results shown in this study have been derived from tests performed at a low rate of strain. The problem of strain rate effects remains to be solved.

Further research is required to examine if the results obtained here could be applied to undisturbed samples.

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