PROPOSED STRENGTH AND STIFFNESS PARAMETERS FOR NORMALLY CONSOLIDATED AND OVERCONSOLIDATED DHAKA CLAY

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ABSTRACT

The undrained shear characteristics of reconstituted normally consolidated and overconsolidated samples of Dhaka clay are discussed. The disturbances on the soil structure result from sample penetration that reduces the values of undrained shear strength (s_u) and initial tangent modulus (E_i), initial effective stress (σ'_i) and pore pressure (u) but increases axial strain at peak deviator stress (ε_p). The changes in soil parameters between the "in situ" and "tube" samples are very much dependent on the geometry of the samplers used to retrieve "tube" samples. The values of s_u, E_i and σ'_i of samples reduced while the values of ε_p increased with increasing area ratio (or decreasing external diameter to thickness ratio) and increasing outside edge angle (OCA) of the samplers. For optimum and economic foundation design, the correction for undrained strength and stiffness parameters are proposed due to the soil sampling disturbance.

Keywords: *Overconsolidation, Sampling Disturbance, Soil Parameters, Triaxial Test, Tube Sampler, Undrained Strength*

1.0 INTRODUCTION

Numerous investigators have been attempted to assess the influence of tube sampling disturbances on engineering properties for both intact natural soils and laboratory prepared reconstituted soils [2-6]. Regarding the extent of sample disturbance in clays, one of the most important contributory factors is the design of the sampler. The soil disturbance can be minimised by careful sampling procedure and also to a large extent by using properly designed sampling tubes. The design of a sampler is one of the most important aspects that should be considered for quality sampling. The degree of disturbance varies considerably depending upon the dimensions of the sampler [4, 5]. It is therefore extremely important that geotechnical engineers should need a sound understanding of both qualitative and quantitative as to which the soil parameters are being used that would be affected by the sampling process as well as by the design of a sampler.

In situ testing has a number of disadvantages that include poorly defined boundary conditions in terms of stresses and deformations, and uncertain drainage conditions of the soil under investigation compared with the conditions in the laboratory. On the other hand, laboratory testing can be readily and precisely controlled and observed.

These facts have been reported by Jamiolkowski and co-researchers [1] in their study. This sampling procedure has been widely adopted. However, the inherent problem with the sampling procedure is that it disturbs the soil. During sampling, deep penetration of tube samplers may cause distortion and shearing of the surrounding soil. This disturbance can affect the results quite significantly considering the fact that the behavior of the soil in the laboratory differs markedly from its in situ behavior. The soil disturbance due to sampling operations is regarded as a major problem because it is thought to prevent acquisition of realistic soil parameters. Thus, the engineering properties of soils need to be investigated for geotechnical analyses and so that the designs can be estimated through the in situ or laboratory testing.

2.0 SOIL CHARACTERISTICS AND SAMPLE PREPARATION

This paper presents experimental results showing the influence of disturbance during tube sampling in normally consolidated and over consolidated clays. The effect of sampler characteristics namely area ratio, OCA and external diameter to thickness ratio of sampler, on the shear parameters has been investigated.

Table 1: Index properties and classification of the soil used

Specific Gravity, G_s	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Activity, A_c	Grain Size Distribution			USCS Classification Symbol
					Sand (%)	Silt (%)	Clay (%)	
2.69	47	21	26	0.81	11	62	27	CL

Table 2: Dimensions of the tube samplers

Sampler (Tube No.)	Thickness, t (mm)	External Diameter, D_e (mm)	Internal Diameter, D_i (mm)	D_e/t Ratio	Area Ratio (%)	OCA (Degree)
T_1	1.5	41	38	27.3	16.4	5
T_2	3.0	44	38	14.7	34.1	5
T_3	4.5	47	38	10.4	53.0	5
T_4	6.0	50	38	8.3	73.1	5
T_5	3.0	44	38	14.7	34.1	10
T_6	3.0	44	38	14.7	34.1	15
T_7	3.0	44	38	14.7	34.1	20

A corrected curve for disturbed undrained strength ratio (s_u at σ'_i/s_u at σ_{ps}) has been proposed.

In this investigation, the reconstituted soil specimens were prepared from the disturbed soils collected from residential building project Rupnagar at Mirpur, Dhaka, Bangladesh. Table 1 shows the index properties and classification of the soil. The composition of clay, silt and sand in the tested samples were found to be 27%, 62% and 11% respectively. The reconstituted soils which are prepared by breaking down natural soils and sieving through 40 no. sieve, mixing them as slurries and consolidating them up to 24 hours. The major advantages of using data from reconstituted soils are that the ambiguous effects of sample inhomogeneity can be eliminated. The reconstituted samples of the normally consolidated (OCR = 1) and three overconsolidated (OCR = 2, 5 and 10) soils were prepared in the laboratory by K_o-consolidation using a uniform slurry of sample in a cylindrical consolidation cell of 260 mm diameter and 305 mm in height. The slurry had a water content of approximately 1.5 times the liquid limit of the soil. A consolidation pressure of (P'_c) of l50 kN/m^2 was used. The properties and results for soils having OCR values of 1 (normally consolidated) and 5 (overconsolidated) have been discussed in detail in this paper. The water contents of the reconstituted normally consolidated and overconsolidated samples with OCR values of 2, 5 and 10, were found to be 28 ± 0.5%, 28.5 ± 0.5%, 29 ± 0.5%, and 30 ± 0.5% respectively and the respective values of bulk density were found to be 19.5 ± 0.2 kN/m³, 19 ± 0.2 kN/m^3, 19.5 ± 0.3 kN/m^3, and 18.2 ± 0.3 kN/m^3.

3.0 FABRICATION OF THE TUBE SAMPLERS

The samplers of different area ratio were fabricated and are shown in Table 2. Figure 1 illustrates the samplers with various dimensions. The outside cutting edge angle (OCA) is defined as the angle of the outside edge cutting shoe makes with a vertical plane. Hvorslev [7] defines area ratio as follows:

$$Area\ ratio = \frac{D^2_w - D^2_i}{D^2_i} \qquad (1)$$

4.0 TEST SAMPLERS USED

4.1 "In-Situ" Sample

The soil cake prepared by K_o-consolidation was extruded from the consolidation cell. The cake was sliced by the wire knife into small block and samples of nominal dimension of 38 mm diameter by 76 mm height prepared by trimming a block sample using piano wire, a soil lathe and a split mould. These samples were consolidated under K_o-consolidation in the triaxial cell on its "in situ" vertical effective stress, (P'_c i.e.,
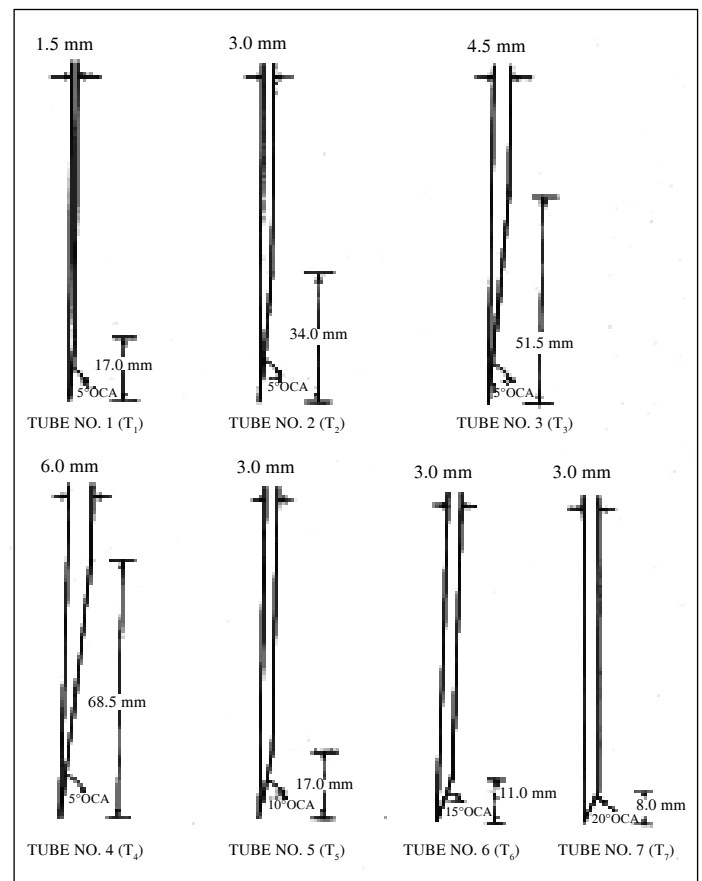

Figure 1: Samplers diagram with dimension

150 kN/m^2) to prepare normally consolidated (i.e., OCR = 1). The maximum vertical effective stress (σ'_{vc}) of 150 kN/m^2 was reduced to 75 kN/m^2, 30 kN/m^2, and 15 kN/m^2 to prepare samples of OCR values of 2, 5, and 10, respectively. A back pressure 270 kN/m^2 has been used during K_o-consolidation of the sample. These samples are termed as "in situ" samples. The "in-situ" samples prepared from the samples of OCR values of 1, 2, 5 and 10, are designated as O_1I, O_2I, O_5I, and $O_{10}I$, respectively.

4.2 "Perfect" Sample

This type of sample was prepared from "in situ" sample in the triaxial cell. The "in situ" shear stress, i.e., deviator stress of the "in situ" sample was released from its in situ anisotropic stress condition. At this time, the sample was subjected to an all-around isotropic stress (i.e., cell pressure). The cell pressure was then reduced to zero and thereby the sample was subjected to zero total stresses. This sample is termed as "perfect" sample. The "perfect" samples prepared from the samples of OCR values of 1, 2, 5, and 10, are designated as O_1P, O_2P, O_5P, and $O_{10}P$, respectively.

4.3 "Tube" Sample

Seven type tubes of 38 mm inner diameter each of varying area ratios and outside cutting edge angles (OCA) as mentioned in Table 2, were steadily pushed into the reconstituted soil cake in the large consolidation cell. The samples were then extruded manually from the tubes by pushing a steel solid shaft of diameter slightly less than the tube samplers into the sample tubes. These samples are termed as "tube" samples. The samplers are designated as T_1, T_2, T_3, T_4, T_5, T_6, and T_7 as shown in Table 2. The "tube" samples are prepared from the samples with OCR values of 1 and 5, which are designated as (O_1T_1, O_1T_2, O_1T_3, O_1T_4, O_1T_5, O_1T_6, and O_1T_7) and (O_5T_1, O_5T_2, O_5T_3, O_5T_4, O_5T_5, O_5T_6, and O_5T_7) respectively.

5.0 LABORATORY TESTING PROCEDURE

The test procedures on different samples were carried out as follows:
(i) Unconsolidated undrained (UU) triaxial compression tests were carried out on four "in situ" samples of OCR values of 1, 2, 5 and 10 to determine the reference result of the soils. In this test, after the completion of K_o-consolidation and swelling (samples of OCR = 1, 2, 5 and 10), the sample was sheared in undrained triaxial compression at a deformation rate of 0.02 mm per minute. A back pressure of 270 kN/m^2 was used during K_o-consolidation and swelling of the samples.
(ii) Unconsolidated undrained (UU) triaxial compression tests were carried out on four "perfect" samples of OCR values of 1, 2, 5 and 10. In these tests, after the simulation of "perfect" sampling in the triaxial cell, each sample was subjected to a cell pressure equal to the respective effective vertical stress of the "in situ" sample. After the equalisation of pore pressure, the sample was sheared at a deformation rate of 0.02 mm/minute in compression under undrained condition.

(iii) Unconsolidated undrained (UU) triaxial compression tests were carried out on twenty eight "tube" samples. In these tests, soon after the completion of saturation, the samples were sheared at a deformation rate of 0.02 mm per minute in compression under undrained condition.

6.0 INFLUENCE OF TUBE SAMPLING DISTURBANCE

6.1 Initial Effective Stress

In order to determine initial effective stress, σ'_i of a "tube" sample, relatively high cell pressure was applied on sample under undrained condition and a steady pore pressure generated within the sample was recorded. The initial effective stress has been calculated by subtracting pore water pressure from all-round cell pressure. The initial effective stress of the each "tube" samples were compared with the isotropic effective stress in a "perfect" sample (σ'_{ps}), of the respective four samples. The isotropic effective stress in a "perfect" saturated of each type of sample having in situ vertical and horizontal effective stresses of σ'_v and $K_o \sigma'_v$ respectively, is given by the following expression [8]:

$$\sigma'_{ps} = \sigma'_v [K_o + A_u (1 - K_0)] \qquad (2)$$

Where K_o is the coefficient of earth pressure at rest and A_u is the pore pressure parameter for the undrained release of the in-situ stresses that exist at K_o-conditions. The parameter A_u for a saturated clay (i.e., Skempton's B parameter is equal to unity) is given by:

$$A_u = \frac{\Delta u - \Delta \sigma_h}{\Delta \sigma_v - \Delta \sigma_h} \qquad (3)$$

Where, Δu, $\Delta \sigma v$ and $\Delta \sigma_h$ are the change in pore pressure, vertical and horizontal stresses respectively.

The values of σ'_{ps} of Dhaka clay for OCR values of 1, 2, 5, and 10 were found to be 88.7 kN/m^2, 40.4 kN/m^2, 15.1 kN/m^2 and 7.2 kN/m^2 respectively. Table 3 shows the comparison of initial effective stress of "tube" samples prepared using tubes of different sampler geometry with isotropic effective stress of respective "perfect" samples of Dhaka clay for different OCR values. It is observed from Table 3 that for each OCR value, the initial effective stress of all the "tube" samples reduced significantly when compared with the isotropic effective stress, σ'_{ps} of "perfect" samples. This reduction of initial stress of "tube" samples is due to the disturbance caused by penetration of tubes. Depending on area ratio and OCA (Table 2), initial effective stress, σ'_i (Table 3) decreased by 9.0% to 26.2%, 5.9% to 25.0%, 3.9% to 21.8% and 3.8% to 21.0% for OCR values 1, 2, 5 and 10, respectively. It is observed that the reduction of initial effective stress increases with higher area ratio irrespective of OCA. On the other hand when area ratio is fixed, σ'_i decreases with the increase in OCR which is observed for "tube" T_2, T_5, T_6 and T_7 with same area ratio of 34.1%. The reduction in effective stress due to tube sampling disturbance has also been reported in literature for the regional clays of Bangladesh [4-6].

Table 3: Comparison of initial effective stress of "Tube" samples with isotropic effective stress of "Perfect" samples of normally consolidated and over-consolidated dhaka clay

OCR	Isotropic Effective Stress, σ'_{ps} (kPa)	Initial Effective Stress, σ'_i (kPa)						
		T_1	T_2	T_3	T_4	T_5	T_6	T_7
1	88.7	80.7	78.2	73.8	65.4	76.3	71.7	69.3
2	40.4	38.0	36.8	34.3	30.3	35.5	32.7	31.9
5	15.1	14.5	13.9	13.0	11.8	13.4	12.4	12.0
10	7.2	6.9	6.7	6.2	5.7	6.5	6.0	5.9

6.2 Effective Stress Paths

Figures 2(a) and (b) show the effective stress paths for "in situ" and "tube" samples of Dhaka clay respectively for both normally consolidated and typical overconsolidated (OCR = 5) soils. It can be observed from Figures 2(a) that the effective stress path of "in situ" sample for OCR equal to 1 only has normally consolidated state in nature but for OCR greater than 1 have overconsolidated state. It can also be observed from Figure 2(b) that the nature of effective stress paths of the overconsolidated "tube" samples has been changed from the respective "in situ" samples. The significant difference in effective stress path between normally consolidated "in situ" and "tube" samples had also been reported in the past for the regional clays of Bangladesh [4, 5]. Similar stress paths had been reported for over consolidated clays by Rahman and Siddique [6].

Figures 3(a) and (b) present the deviator stress versus axial strain plots for "tube" samples of Dhaka clay for normally consolidated (OCR = 1) and typical overconsolidated (OCR = 5) soils respectively. Deviator stress versus axial strain plots of the corresponding "in situ" samples are also shown in Figures 3(a) and (b) for comparison. The following are the main observations:
(i) The peak strength for all "tube" samples are gained in position at relatively larger axial strain than that of "in situ" sample.
(ii) Like "in situ" sample, the ultimate strength of "tube" samples are gained in position at larger strain, which are slightly less than that of peak strength. The "tube" samples, therefore, do not show any significant brittleness when sheared in compression.
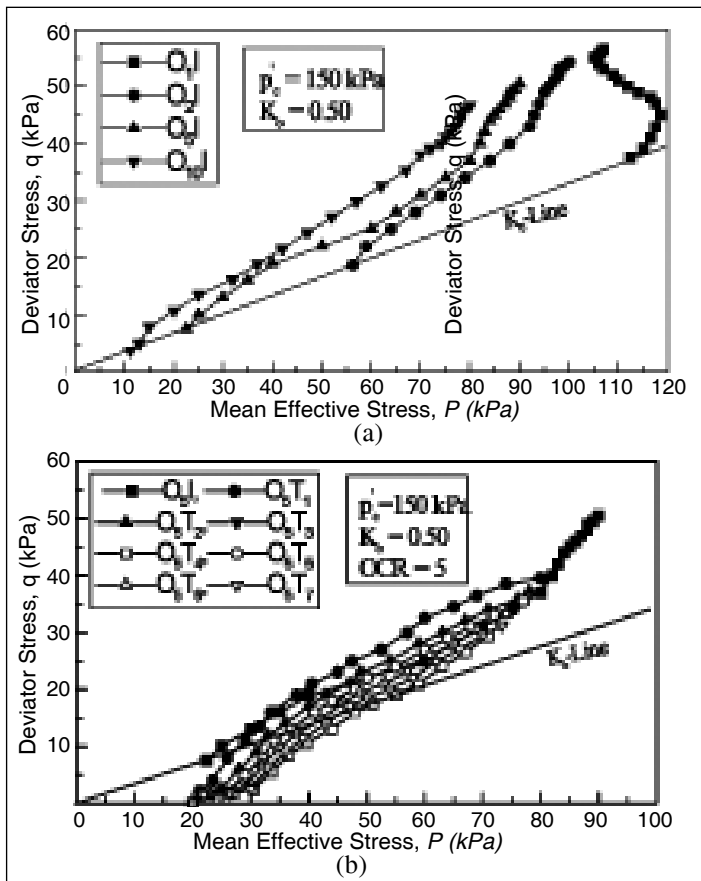(iii) The stress-strain relationships of the "tube" samples are approximately non-linear.

Figure 2: Effective stress paths for (a) "in situ" and (b) "tube" samples of Dhaka clay
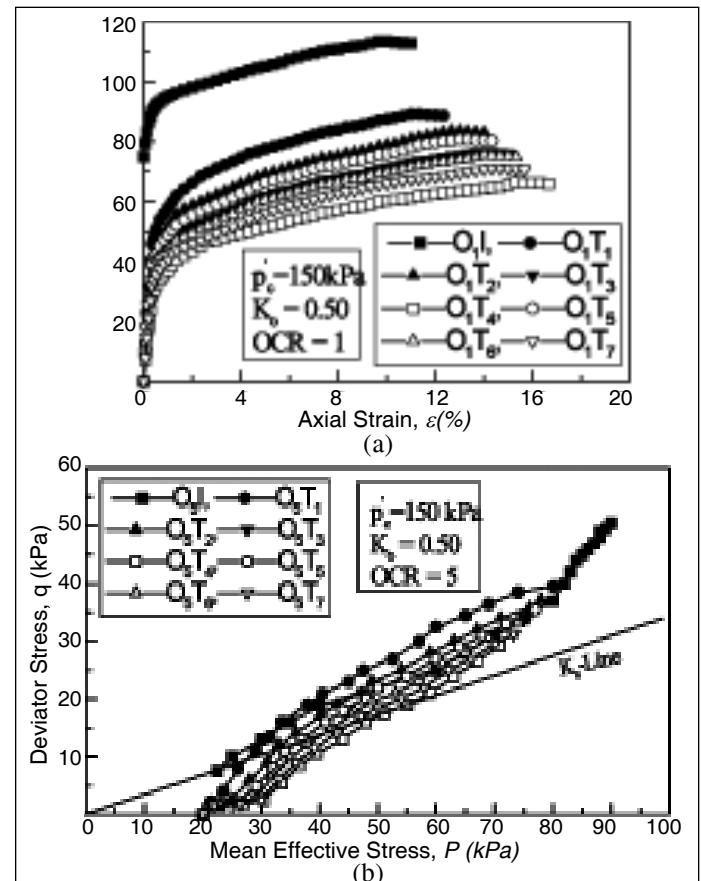

Figure 3: Deviator stress versus axial strain for "tube" samples (a) normally and (b) over consolidated

(iv) The trend of stress-strain curves for the "tube" samples is essentially similar to that of "in situ" samples.

It can also be seen from the results in Table 4 that the decrease in values of s_u, E_i and E_{50} reduced with increasing OCR. Similar effects have been reported for over consolidated clays [3].

Figures 4(a) and 4(b) present the secant stiffness versus axial strain plots of "tube" samples of Dhaka clay for normally consolidated (OCR = 1) and typical overconsolidated (OCR = 5) respectively. The corresponding plot for the "in situ" sample is also shown in Figure 4 for comparison. The stiffness of "tube" samples reduce in larger strain levels like "in situ" sample. The values of E_{50} of the "tube" samples are lower than those of "in situ" samples. The reduction in stiffness for tube samples have been reported [4-6].

7.0 PORE PRESSURE RESPONSE

Figures 5(a) and (b) show the plots of change in pore pressure during shearing against axial strain for "tube" samples of Dhaka clay for normally consolidated (OCR = 1) and typical overconsolidated (OCR = 5) stages respectively. The corresponding plot for the "in situ" sample is also shown for comparison. It can be observed from Figures 5(a) and (b) that the changes in pore pressure in "tube" samples are less than that of "in situ" sample. Also, the pore pressure change increased up to a strain level about 3% and then reduced sharply up to strain at failure. For both the normally consolidated and overconsolidated "tube" samples, the pore pressure changes are negative at peak strength. Similar pore pressure responses in reconstituted soft normally consolidated "in situ" and "tube" samples were reported by Siddique *et al.*,
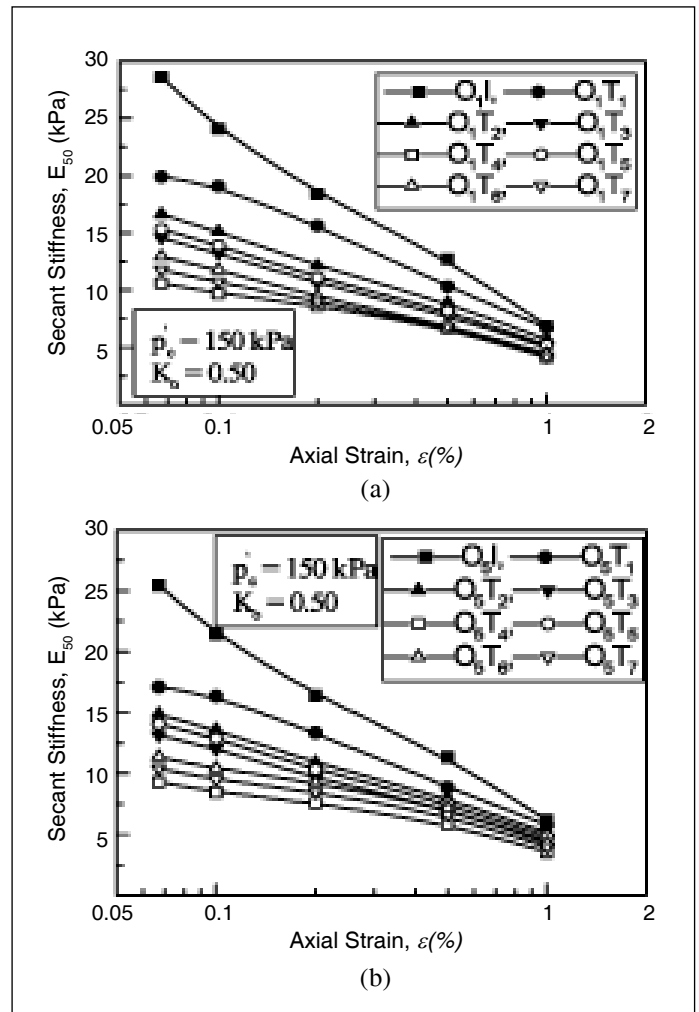

Figure 4: Secant stiffness versus axial strain of "tube" samples (a) normally and (b) overconsolidated

Table 4: Comparison of undrained shear properties of "In Situ" and "Tube" samples for normally consolidated and over-consolidated (OCR = 5) Dhaka clay

OCR	Sample Designation	s_u (kPa)	ε_p (%)	E_i (kPa)	E_{50} (kPa)	A_p
1	O_1-I	56.6	9.7	28500	22950	0.42
	O_1-T_1	44.2	11.0	19360	15280	-0.175
	O_1-T_2	41.7	12.6	16490	12520	-0.176
	O_1-T_3	38.3	13.6	14340	10960	-0.178
	O_1-T_4	32.4	15.3	10760	8060	-0.181
	O_1-T_5	40.4	13.0	15060	11510	-0.177
	O_1-T_6	37.6	14.0	13630	9760	-0.179
	O_1-T_7	35.4	14.3	11470	8880	-0.181
5	O_5-I	50.4	7.6	24380	20450	0.14
	O_5-T_1	39.6	8.9	17210	13100	-0.142
	O_5-T_2	37.2	10.3	14340	11230	-0.145
	O_5-T_3	34.8	11.0	12910	9940	-0.148
	O_5-T_4	29.3	12.3	9320	7050	-0.153
	O_5-T_5	35.5	10.3	13630	10650	-0.147
	O_5-T_6	33.1	11.6	11470	8630	-0.149
	O_5-T_7	31.3	11.6	10140	7910	-0.150
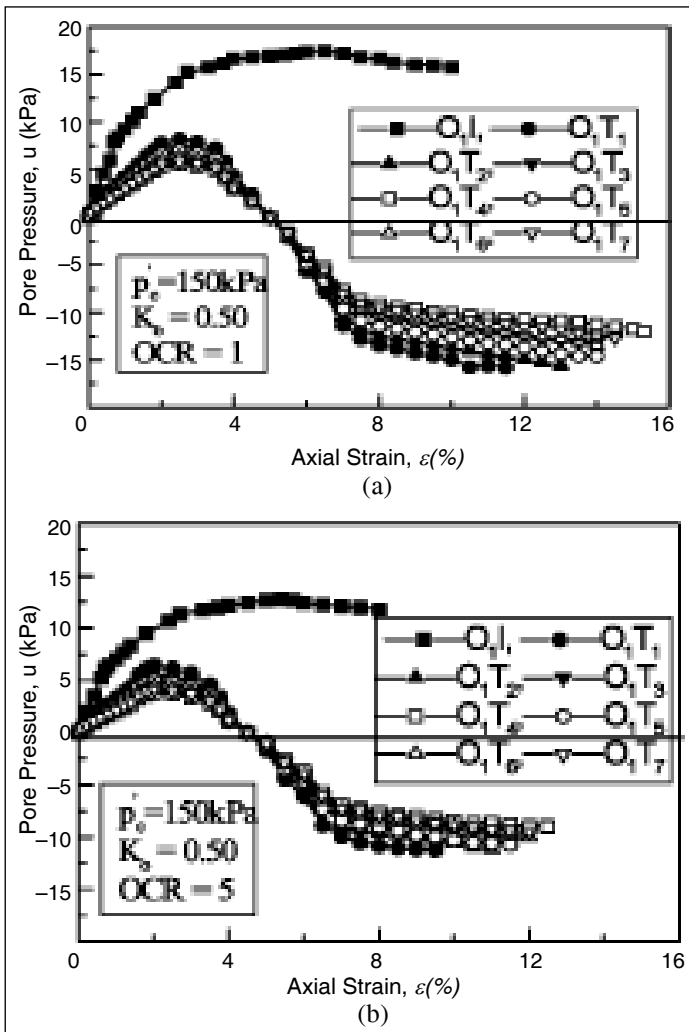
Figure 5: Pore pressure against axial strain of "tube" samples
(a) normally and (b) overconsolidated

Figure 6: Change in soil parameters due to area ratio of "tube"
samples (a) OCR = 1 and (b) OCR = 5

[4, 5]. Skempton's pore pressure parameter A at peak strength (A_p) of the "tube" samples were calculated. It can be seen from test results that the values of A_p "tube" samples of Dhaka clay are negative for all OCR values. The negative A_p values for the "tube" samples were also reported [4, 6].

8.0 INFLUENCE OF SAMPLER GEOMETRY ON UNDRAINED SOIL PARAMETERS

8.1 Effect of Area Ratio and D_e/t Ratio

The experimentally measured undrained soil parameters of the "tube" samples retrieved with samplers of different area ratio have been compared with those of the "in situ" sample. It has been found that area ratio and D_e/t ratio of a sampler have a profound influence on the measured undrained triaxial shear parameters. Figures 6(a) and (b) show the comparison of the change in s_i, s_u, ε_p, E_i and E_{50} due to change in area ratio for samples of Dhaka clay for normally consolidated (OCR = 1) and typical overconsolidated (OCR = 5) soils respectively. It can be observed that increasing area ratio (or reducing D_e/t ratio) caused increasing reductions in the values of s_i, s_u, E_i, E_{50} and A_p. However, an increase in the value of εp is observed with an increasing area ratio (or decreasing D_e/t ratio) of the sampler. Figure 6 shows that the values of
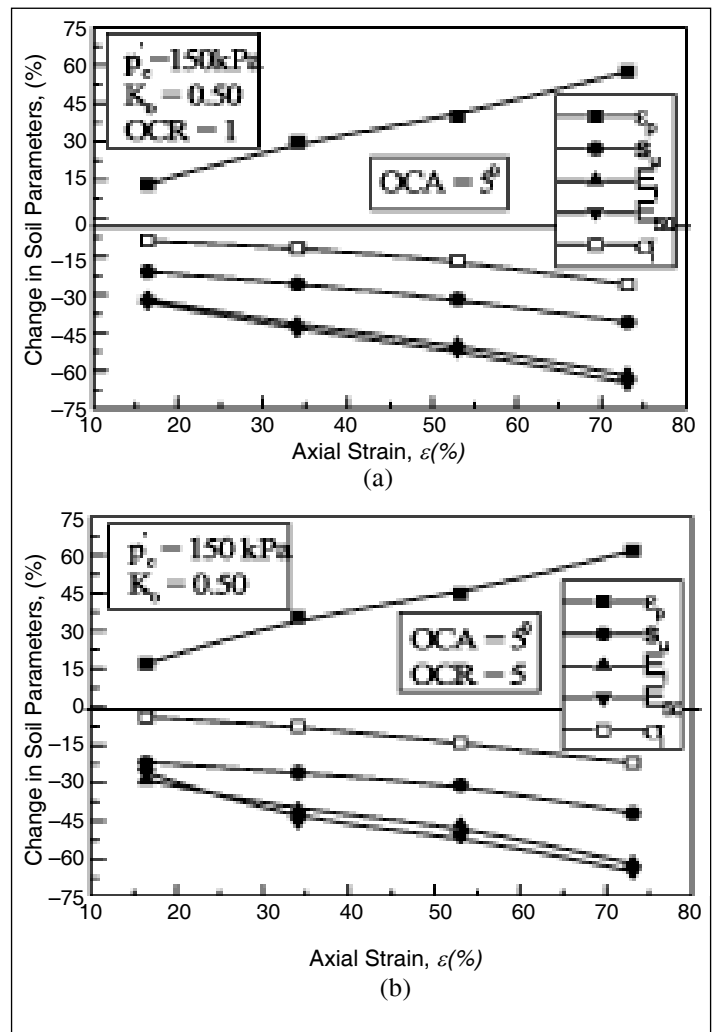
s_i, s_u, E_i and E_{50} reduce with increase in area ratio while the values of ε_p increase with increase in area ratio (or reducing D_e/t ratio). The reduction in A_p increases with increase in area ratio (or reducing D_e/t ratio). Figure 7 also show the comparison of the change in s_i, s_u, ε_p, E_i and E_{50} due to change in D_e/t ratio of the samplers for normally and overconsolidated Dhaka clay respectively.

When compared with the "in situ" sample (as reference results for samples, O_1I and O_1I in Table 4), the following effects on the measured soil parameters have been observed due to increase in area ratio from 16.4% to 73.1% (or decrease in D_e/t ratio from 27.3 to 8.3) of samplers:

(i) Values of σ_i reduced by 9.0% to 26.2% and 3.9% to 21.8% for OCR values of 1 and 5, respectively.

(ii) Values of s_u decreased by 22% to 43% and 22% to 42% for OCR values of 1 and 5, respectively.

(iii) Values of ε_p increased by 13% to 58% and 17% to 52% for OCR values of 1 and 5, respectively.

(iv) Values of E_i reduced by 32% to 62% and 29% to 62% for OCR values of 1 and 5, respectively.

(v) Values of E_{50} reduced by 33% to 65% and 36% to 66% for OCR values of 1 and 5 respectively.

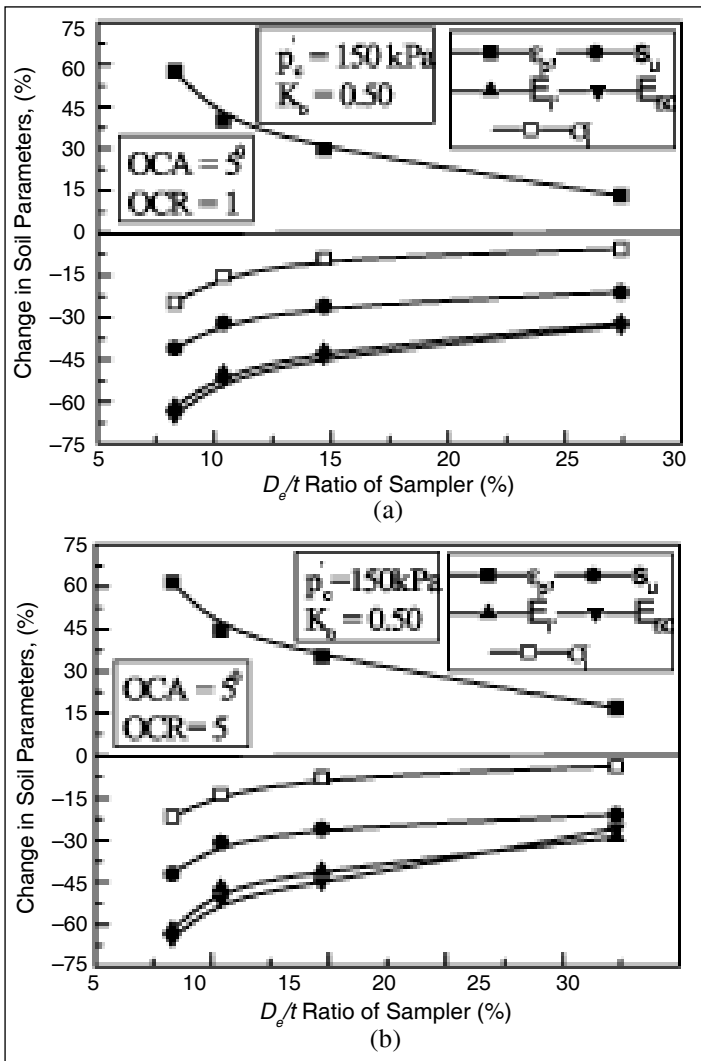(vi) A_p reduced by 146% to 148% and 201% to 209% for OCR values of 1 and 5, respectively.

*Figure 7: Change in soil parameters due to D_e/t ratio of "tube"
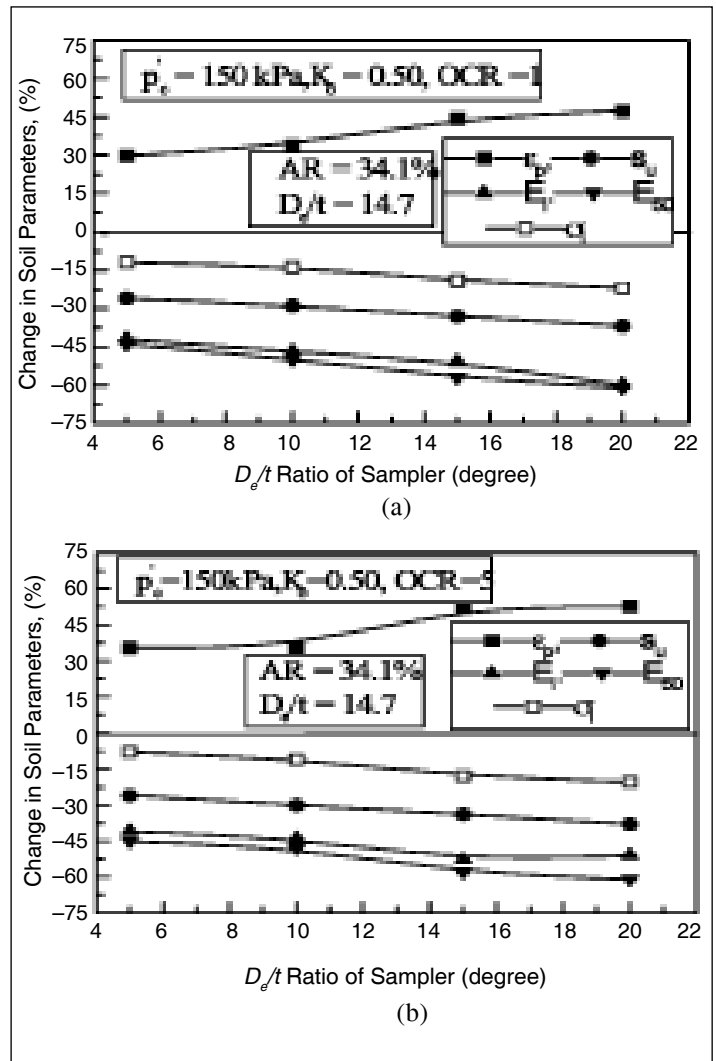samples (a) OCR = 1 and (b) OCR = 5*

*Figure 8: Change in soil parameters due to OCA of "tube" samples
(a) normally and (b) over Consolidated Dhaka clay for OCR
values of 1 and 5 respectively.*

The reduction in σ_i up to 42%, s_u up to 35% and E_i up to 49% and an increase in ε_p up to 81% was observed in Dhaka clay due to increase in area ratio of samplers from 10.8% to 55.2% [4].

8.2 Influence of Outside Cutting Edge Angle

OCA of a sampler has a marked influence on the measured undrained triaxial shear parameters. Increasing OCA caused increasing reductions in σ_i, s_u, E_i, E_{50} and A_p. However, an increase in ε_p ia observed with an increasing OCA of sampler. Figure 8 shows the comparison of the change in soil prameters due to change in OCA for the samples normally consolidated and typical overconsolidated (OCR = 5) soils respectively. From Figure 8, it can be seen that values of σ_i, s_u, E_i and E_{50} reduce with increase in OCA while the values of ε_p increases with increase in OCA. The reduction in A_p increases with increase in OCA.

Compared with the "in situ" sample, the changes on the soil parameters have been observed due to increase in OCA from *5°* to *20°* as below:

(i)   Values of σ_i reduced by 11.8 to 21.9% and 7.8 to 20.4% for OCR values of 1 and 5, respectively.

(ii) Values of s_u reduced by 26% to 37% and 26% to 38% for OCR values of 1 and 5, respectively.

(iii) Values of ε_p increased by 30% to 47% and 35% to 53% for OCR values of 1 and 5, respectively.

(iv) Values of E_i reduced by 42% to 60% and 41% to 58% for OCR values of 1 and 5, respectively.

(v)   Values of E_{50} reduced by 45% to 61% and 45% to 61% for OCR values of 1 and 5, respectively.

(vi) A_p reduced by 146% to 148% and 203% to 207% for OCR values of 1 and 5, respectively.

The reduction in s_u and E_i of up to 32% and 41%, respectively, while, an increase in ε_p of up to 81%, was observed due to increase in OCA from *4°* to *15°* in normally consolidated soft Dhaka clay [4].

9.0 QUANTITATIVE ASSESSMENT OF SAMPLES DISTURBANCE

The degree of disturbance can be assessed by investigating the behavior of the least disturbed sample which is usually a laboratory simulated "perfect" sample.

*Table 5: Comparison of degree of disturbance for "Tube" sampling on normally
consolidated (OCR = 1) and overconsolidated (OCR = 5) dhaka clay*

OCR	Degree of Disturbance, D_d						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7
1	0.09	0.12	0.17	0.26	0.14	0.19	0.22
5	0.04	0.08	0.14	0.22	0.11	0.18	0.20

Because of additional disturbances other than that occurred due to total stress release, the residual effective stress of "tube" sample, σ_i' is usually less than the isotropic effective stress, σ_{ps}' of a "perfect" sample. Based on the values of σ_{ps}' of "perfect" samples and initial effective stress, σ_i' for "tube" sample, degree of disturbance (D_d) has been calculated using the following equation, proposed by Okumura [9].

$$D_d = \frac{\sigma_r'}{\sigma_{ps}'} \qquad (4)$$

The values of degree of disturbance (D_d) for the "tube" samples of normally consolidated and overconsolidated Dhaka clays are shown in Table 5. It can be observed from Table 5 that the values of degree of disturbance varied from 0.09 to 0.26 and 0.04 to 0.22 for the 'tubes' samples of Dhaka clay for OCR values of 1 and 5 respectively.

The degree of disturbance has been plotted against area ratio, D_e/t ratio and OCA of sampler as shown in Figures 9, 10 and 11 respectively for the "tube" samples of normally consolidated and overconsolidated Dhaka clay.

It can be observed from Figure 9 that the values of D_d increase with increasing values of area ratio for sampler. It can be seen from Figure 10 that the values of D_d decrease with increasing values of D_e/t ratio for sampler. It can be seen from Figure 11 that the values of D_d increase with increasing values of OCA for sampler. The values of D_d increase with increasing values of area ratio and OCA has also been reported for reconstituted normally consolidated soft samples of Dhaka clay [4] and soft samples of coastal soils [5].
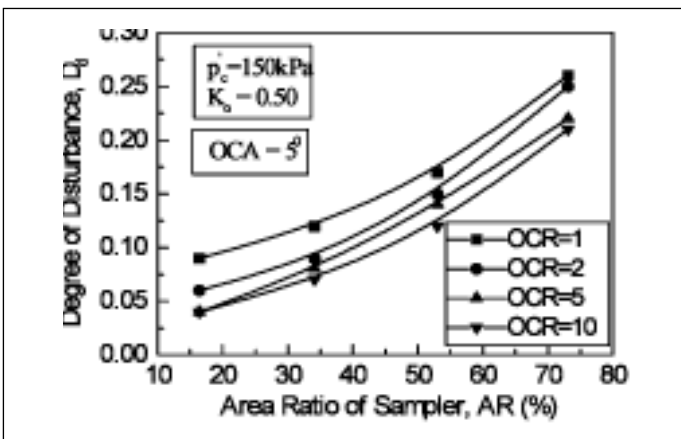

Figure 9: Degree of disturbance varied due to area ratio of "tube" samples for Dhaka clay
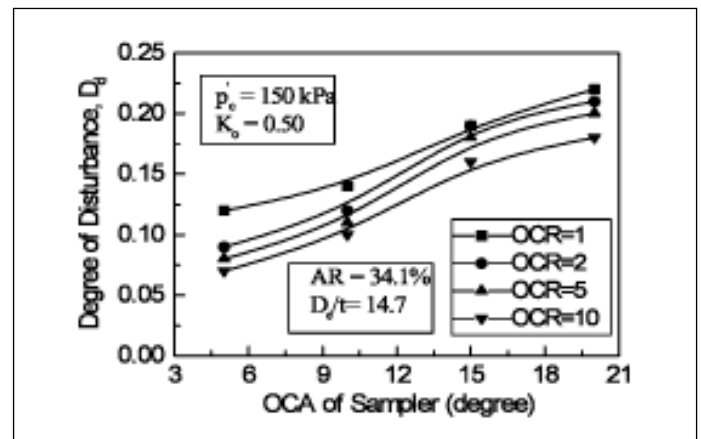

Figure 11: Degree of disturbance varied due to OCA of "tube" samples for Dhaka clay
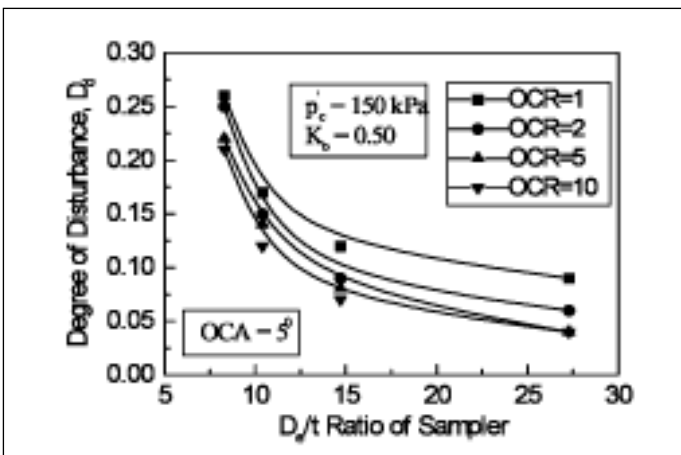

Figure 10: Degree of disturbance varied due to D_e/t of "tube" samples for Dhaka clay
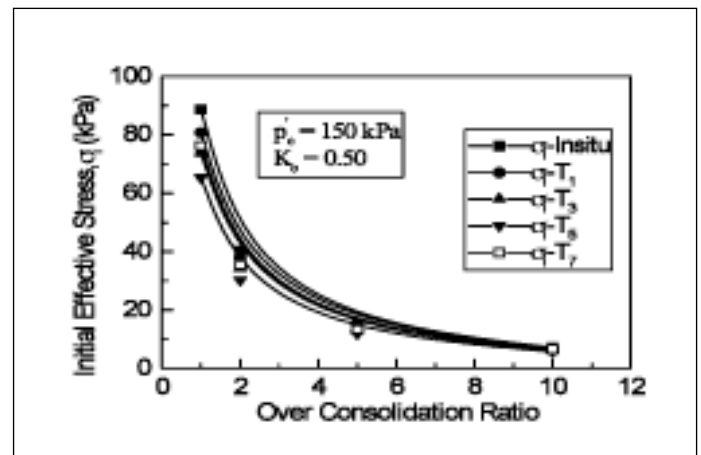

Figure 12: Initial effective stress varied due to OCR of "tube" samples for Dhaka clay

*Table 6: Summary of the influence of "Tube" sampling disturbance on normally consolidated (OCR = 1)
and over consolidated (OCR = 5) Dhaka Clay*

OCR	Change in properties as compared with 'in situ' samples, (%)				
	Reduction in s_u/σ_{vc}	Increase in ε_p	Reduction in E_i/σ_{vc}	Reduction in E_{50}/σ_{vc}	Reduction in A_p
1	22.0 – 43.0	13.4 – 57.7	32.1 – 62.2	33.4 – 64.9	146 – 148
5	21.4 – 41.9	12.1 – 52.6	29.4 – 61.8	35.9 – 65.5	201 – 209

9.1 Influence of Stress History on Tube Sampling Disturbance Effects

The extent of disturbance due to "tube" sampling in Dhaka clay has been found to depend on stress history (normally consolidated and overconsolidated) of the samples. The reduction in initial effective stresses (σ_i) of "tube" samples are observed in Table 3. It can also be observed from Table 3 that for tube samplers with a particular cutting shoe geometry, degree of reduction in initial effective stress decreases with the increase in overconsolidation ratio (OCR). Figure 12 shows the typical plots of reduction in initial effective stress with OCR for four "tube" samplers. It can be seen from Figure 12 that the initial effective stress due to tube sampling reduced with increasing OCR.

Table 6 shows a summary on the effects of "tube" sampling disturbance for the strength ratio, stiffness ratio, ε_p and A_p of normally consolidated and overconsolidated samples of Dhaka clay. It can be observed from Table 6 that there is a reduction of s_u/σ_{vc} and E_i/σ_{vc} with increasing OCR. On the other hand, reduction in undrained shear strength and stiffness with increasing OCR due to tube sampling disturbance are small in amount. However, a large reduction in A_p with increasing OCR was found. The values of ε_p also reduced with increasing OCR.

10.0 CORRECTION OF UNDRAINED STRENGTH FOR DHAKA CLAY

Based on the procedure suggested by Ladd and Lambe [8] the method for correcting undrained shear strength due to the sample disturbance involves the following steps:

(i) The undrained shear strength is reduced for sampling disturbance effects due to overconsolidation ratio using isotropically consolidated undrained tests on specimens at σ'_{ps} is much greater than σ'_i.

(ii) The equivalent overconsolidation ratio is found for the unconsolidated undrained test being corrected by measuring σ'_i and calculating σ'_{ps} by Equation No. 2 and

(iii) The shear strength correction value is obtained for the particular overconsolidation ratio obtained from strength ratio (s_u at σ'_i to s_u at σ'_{ps}) versus OCR curve.

The application of the strength correction curve can be explained that for the test result of sampler T_4 in Table 4. For values of initial effective stress, σ'_i = 65.4 kPa and maximum or isotropic effective stress σ'_{ps} = 88.7 kPa, OCR (σ'_{ps}/s'_i) of the sample is 1.36. It is found from the curve in Figure 13 that

corresponding OCR = 1.36, the ratio of s_u at σ'_i to s_u at σ'_{ps} is equal to 0.90. The measured s_u of the sample in Table 4 is 33.2 kPa and the corrected strength is 33.2/0.90 = 36.9 kPa.

11.0 CONCLUSIONS

11.1 Conclusions that can be drawn from the correction curve for sampling disturbance are:
   (i) The strength correction curve is drawn from test data.
   (ii) The application of the strength correction curve is not complex.
   (iii) The corrected strength is greater than the disturbed strength.
   (iv) The strength ratio factor decreases with increasing OCR values.

11.2 Analysis on the influence of stress history for tube sampling disturbance effects can be concluded as follows:
   (i) The reduction in σ'_i reduced with the increase in overconsolidation ratio (OCR).
   (ii) The trend of small decrease in the reduction of s_u/σ_{vc} and E_i/σ_{vc} with increasing OCR was obtained. However, significant increase in the reduction of A_p with increasing OCR was found.
   (iii) The values of s_u, E_i and E_{50} decreased with increasing OCR. However, the degree of reduction in s_u, E_i and E_{50} with increasing OCR was found to be small.
   (iv) The increase in ε_p reduced with increasing OCR.
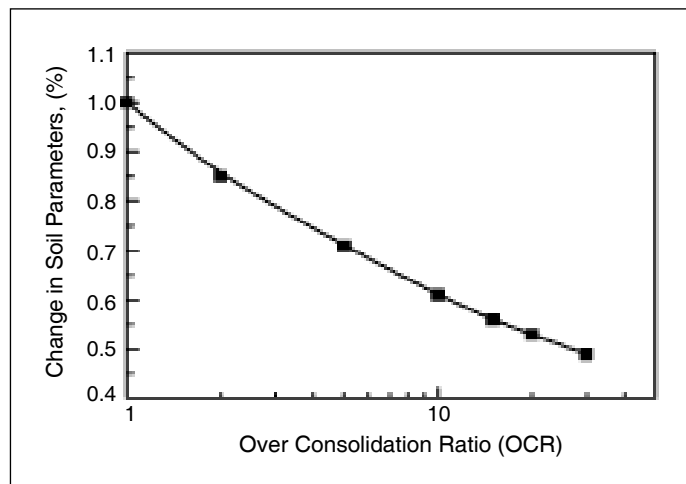   (v) The degree of disturbance reduced with increasing OCR.

Figure 13: Untrained strength correction curve for Dhaka clay

11.3 The effects of tube sampling disturbance on undrained stress-strain, strength, stiffness and pore pressure characteristics have been investigated for reconstituted normally consolidated and overconsolidated samples of Dhaka clay. The major findings and conclusions of the investigation are summarised below:

(i) Disturbance due to tube sampling led to reduction in the values of initial effective stress (σ_i), undrained shear strength (s_u), initial tangent modulus (E_i), secant stiffness at half of the peak deviator stress (E_{50}) and Skempton's pore pressure parameter A at peak deviator stress (A_p) while the value of axial strain at peak deviator stress (ε_p) increased due to disturbance.

(ii) It was found that the nature of the effective stress paths of the normally consolidated "tube" samples differed from that of the respective "in situ" sample. However, the nature of the effective stress paths of the overconsolidated "in situ" and "tube" samples was, in general, similar.

(iii) As compared with "in situ" samples, the pore pressure changes of the "tube" samples were significantly less, resulting in much lower values of A_p for the "tube" samples than those of the "in situ" samples. The values of A_p of the "tube" samples were found to be negative.

(iv) The results indicated that compared with normally consolidated Dhaka Clay, tube sampling caused relatively little degree of disturbance in overconsolidated Dhaka Clay.

(v) The changes in undrained soil parameters between the "in situ" and "tube" samples were found to depend significantly on the design of sampling tube. The higher the area ratio and OCA of sampler, the greater was the reduction in σ'_i, s_u, E_i, and E_{50}. The values of ε_p however, increased with increase in area ratio (or decrease in D_e/t ratio) and increase in OCA.

(vi) The quantitative values of degree of disturbance (D_d) of "tube" samples increased significantly with the increase in area ratio (or decrease in D_e/t ratio) and increase in OCA of sampler.

It is evident that disturbance due to tube sampling depends considerably on the design of a sampler. For good quality sampling, a sampler ought to have a well combination of area ratio and OCA. In order to minimise disturbance due to sampling in normally consolidated and overconsolidated Dhaka clays, area ratio and outside cutting edge angle of sampler should be kept as low as possible.

From practical point of view, the area ratio of a tube sampler should not exceed 10% and the outside cutting edge of a tube sampler should preferably be less than 5°. It has been observed from the present study that strength and stiffness of "tube" samples are always less than those of "in situ" samples.

From practical point of view, although geotechnical analysis and design based on strength and stiffness of soils obtained from laboratory tests of "tube" sample would be corrected that it could lead to uneconomic and over design of structures. For optimum and economic foundation design, disturbed strength and stiffness parameters of the soils, therefore, should be corrected before being used in the design. ∎

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