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 (su) and initial tangent modulus (Ei), initial effective stress (σ′i) and pore pressure (u) but increases axial strain at peak deviator stress (εp). 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 su, Ei, and σ′i of samples reduced while the values of εp 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 Jamiołkowski 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.
proposed strength and stiffness parameters for normally consolidated and overconsolidated Dhaka clay

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A corrected curve for disturbed undrained strength ratio ($s_u$ at $\sigma'$) 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 was 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 150 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/m$^3$, 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 = $\frac{D^2_e - D^2_i}{D^2_i}$ (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](image)

Table 1: Index properties and classification of the soil used

<table>
<thead>
<tr>
<th>Specific Gravity, $G_s$</th>
<th>Liquid Limit, LL</th>
<th>Plastic Limit, PL</th>
<th>Plasticity Index, PI</th>
<th>Activity, $A_c$</th>
<th>Grain Size Distribution</th>
<th>USCS Classification Symbol</th>
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</thead>
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<td>2.69</td>
<td>47</td>
<td>21</td>
<td>26</td>
<td>0.81</td>
<td>11</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 2: Dimensions of the tube samplers

<table>
<thead>
<tr>
<th>Sampler (Tube No.)</th>
<th>Thickness, $t$ (mm)</th>
<th>External Diameter, $D_e$ (mm)</th>
<th>Internal Diameter, $D_i$ (mm)</th>
<th>$D_e/t$ Ratio</th>
<th>Area Ratio (%)</th>
<th>OCA (Degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>1.5</td>
<td>41</td>
<td>38</td>
<td>27.3</td>
<td>16.4</td>
<td>5</td>
</tr>
<tr>
<td>T2</td>
<td>3.0</td>
<td>44</td>
<td>38</td>
<td>14.7</td>
<td>34.1</td>
<td>5</td>
</tr>
<tr>
<td>T3</td>
<td>4.5</td>
<td>47</td>
<td>38</td>
<td>10.4</td>
<td>53.0</td>
<td>5</td>
</tr>
<tr>
<td>T4</td>
<td>6.0</td>
<td>50</td>
<td>38</td>
<td>8.3</td>
<td>73.1</td>
<td>5</td>
</tr>
<tr>
<td>T5</td>
<td>3.0</td>
<td>44</td>
<td>38</td>
<td>14.7</td>
<td>34.1</td>
<td>10</td>
</tr>
<tr>
<td>T6</td>
<td>3.0</td>
<td>44</td>
<td>38</td>
<td>14.7</td>
<td>34.1</td>
<td>15</td>
</tr>
<tr>
<td>T7</td>
<td>3.0</td>
<td>44</td>
<td>38</td>
<td>14.7</td>
<td>34.1</td>
<td>20</td>
</tr>
</tbody>
</table>
150 kN/m²) to prepare normally consolidated (i.e., OCR = 1). The maximum vertical effective stress ($\sigma'_v$) of 150 kN/m² was reduced to 75 kN/m², 30 kN/m², and 15 kN/m² to prepare samples of OCR values of 2, 5, and 10, respectively. A back pressure 270 kN/m² 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 $O_P$, $O_2P$, $O_5P$, 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 $T_1$, $T_2$, $T_5$, $T_6$ 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 $O_1T_1$, $O_5T_5$, $O_1T_5$, and $O_{10}T_5$, 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/m² was used during $K_o$-consolidation and swelling of the samples. (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, $\sigma'_i$ 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 ($\sigma'_p$), of the respective four samples. The isotropic effective stress in a “perfect” saturated at in situ vertical and horizontal effective stresses of $\sigma'_i$ and $K_o\sigma'_i$, respectively, is given by the following expression [8]:

$$\sigma'_i = \sigma'_i [K_o + A_s(1 - K_o)]$$

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

$$A_s = \frac{\Delta u - \Delta \sigma_{hv}}{\Delta \sigma - \Delta \sigma_{hv}}$$

Where, $\Delta u$, $\Delta \sigma$ and $\Delta \sigma_{hv}$ are the change in pore pressure, vertical and horizontal stresses respectively.

The values of $\sigma'_p$ of Dhaka clay for OCR values of 1, 2, 5, and 10 were found to be 88.7 kN/m², 40.4 kN/m², 15.1 kN/m² and 7.2 kN/m² 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, $\sigma'_p$ 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, $\sigma'_i$ (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, $\sigma'_i$ decreases with the increase in OCR which is observed for “tube” $T_1$, $T_5$, $T_6$ 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].
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].

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

<table>
<thead>
<tr>
<th>OCR</th>
<th>Isotropic Effective Stress, $\sigma'_{ps}$ (kPa)</th>
<th>Initial Effective Stress, $\sigma'_i$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_1$</td>
<td>$T_2$</td>
</tr>
<tr>
<td>1</td>
<td>88.7</td>
<td>80.7</td>
</tr>
<tr>
<td>2</td>
<td>40.4</td>
<td>38.0</td>
</tr>
<tr>
<td>5</td>
<td>15.1</td>
<td>14.5</td>
</tr>
<tr>
<td>10</td>
<td>7.2</td>
<td>6.9</td>
</tr>
</tbody>
</table>

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.
(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.

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

<table>
<thead>
<tr>
<th>OCR</th>
<th>Sample Designation</th>
<th>( s_u ) (kPa)</th>
<th>( \varepsilon_p ) (%)</th>
<th>( E_i ) (kPa)</th>
<th>( E_{50} ) (kPa)</th>
<th>( A_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O1-I</td>
<td>56.6</td>
<td>9.7</td>
<td>28500</td>
<td>22950</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>O1-T1</td>
<td>44.2</td>
<td>11.0</td>
<td>19360</td>
<td>15280</td>
<td>-0.175</td>
</tr>
<tr>
<td></td>
<td>O1-T2</td>
<td>41.7</td>
<td>12.6</td>
<td>16490</td>
<td>12520</td>
<td>-0.176</td>
</tr>
<tr>
<td></td>
<td>O1-T3</td>
<td>38.3</td>
<td>13.6</td>
<td>14340</td>
<td>10960</td>
<td>-0.178</td>
</tr>
<tr>
<td></td>
<td>O1-T4</td>
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<td>10760</td>
<td>8060</td>
<td>-0.181</td>
</tr>
<tr>
<td></td>
<td>O1-T5</td>
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<td>13.0</td>
<td>15060</td>
<td>11510</td>
<td>-0.177</td>
</tr>
<tr>
<td></td>
<td>O1-T6</td>
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<td>14.0</td>
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<td>9760</td>
<td>-0.179</td>
</tr>
<tr>
<td></td>
<td>O1-T7</td>
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<td>14.3</td>
<td>11470</td>
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<td>-0.181</td>
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<td>5</td>
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<td>20450</td>
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</tr>
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<td>O5-T1</td>
<td>39.6</td>
<td>8.9</td>
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<td>13100</td>
<td>-0.142</td>
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<td></td>
<td>O5-T2</td>
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<td></td>
<td>O5-T3</td>
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<td></td>
<td>O5-T4</td>
<td>29.3</td>
<td>12.3</td>
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<td>O5-T5</td>
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<td></td>
<td>O5-T7</td>
<td>31.3</td>
<td>11.6</td>
<td>10140</td>
<td>7910</td>
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</table>
proposed strength and stiffness parameters for normally consolidated and overconsolidated Dhaka clay

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[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 $D/t$ 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 $D/t$ 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 $s_y$, $s_v$, $e_p$, $E_i$, 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 $D/t$ ratio) caused increasing reductions in the values of $s_y$, $s_v$, $E_i$, $E_{50}$ and $A_p$. However, an increase in the value of $e_p$ is observed with an increasing area ratio (or decreasing $D/t$ ratio) of the sampler. Figure 6 shows that the values of $s_y$, $s_v$, $E_i$, and $E_{50}$ reduce with increase in area ratio while the values of $e_p$ increase with increase in area ratio (or reducing $D/t$ ratio). The reduction in $A_p$ increases with increase in area ratio (or reducing $D/t$ ratio). Figure 7 also show the comparison of the change in $s_y$, $s_v$, $e_p$, $E_i$ and $E_{50}$ due to change in $D/t$ ratio of the samplers for normally and overconsolidated Dhaka clay respectively.

When compared with the “in situ” sample (as reference results for samples, $O_1$ and $O_{11}$ 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 $D/t$ ratio from 27.3 to 8.3) of samplers:

(i) Values of $\sigma_i$ reduced by 9.0% to 26.2% and 3.9% to 21.8% for OCR values of 1 and 5, respectively.
(ii) Values of $s_v$ decreased by 22% to 43% and 22% to 42% for OCR values of 1 and 5, respectively.
(iii) Values of $e_p$ 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 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
The reduction in $\sigma_i$ up to 42%, $s_u$ up to 35% and $E_i$ up to 49% and an increase in $\varepsilon_p$ 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 $\sigma_i$, $s_u$, $E_i$, $E_{50}$ and $A_p$. However, an increase in $\varepsilon_p$ is observed with an increasing OCA of sampler. Figure 8 shows the comparison of the change in soil parameters due to change in soil parameters due to increase in OCA for the samples normally consolidated and typical overconsolidated (OCR = 5) soils respectively. From Figure 8, it can be seen that values of $\sigma_i$, $s_u$, $E_i$ and $E_{50}$ reduce with increase in OCA while the values of $\varepsilon_p$ 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 $5^\circ$ to $20^\circ$ as below:

(i) Values of $\sigma_i$ 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 $\varepsilon_p$ 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 $\varepsilon_p$ of up to 81%, was observed due to increase in OCA from $4^\circ$ to $15^\circ$ 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.
Because of additional disturbances other than those occurred due to total stress release, the residual effective stress of “tube” sample, $\sigma'$ is usually less than the isotropic effective stress, $\sigma_{ps}'$ of a “perfect” sample. Based on the values of $\sigma_{ps}'$ of “perfect” samples and initial effective stress, $\sigma_i'$ for “tube” sample, degree of disturbance ($D_d$) has been calculated using the following equation, proposed by Okumura [9].

$$D_d = \frac{\sigma_r'}{\sigma_{ps}'}$$  \hspace{1cm} (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, $D/t$ 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 $D/t$ 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].

<table>
<thead>
<tr>
<th>OCR</th>
<th>Degree of Disturbance, $D_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_1$</td>
</tr>
<tr>
<td>1</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 5: Comparison of degree of disturbance for “Tube” sampling on normally consolidated (OCR = 1) and overconsolidated (OCR = 5) Dhaka clay
The sample is 1.36. It is found from the curve in Figure 13 that the initial effective stress due to tube sampling reduced for the strength ratio, stiffness ratio, and isotropic effective stress with increasing OCR. It can be seen from Figure 12 that the increase in overconsolidation ratio (OCR) shows the degree of reduction in initial effective stress decreases with increasing OCR for four “tube” samplers. It can also be observed from Table 3 that observed in Table 3. It can also be observed from Table 3 that for tube samplers with a particular cutting shoe geometry, the initial effective stress due to tube sampling disturbance are small.

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 ($\sigma'$) 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, the initial effective stress due to tube sampling disturbance are small with increasing OCR due to tube sampling disturbance involving 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 $\sigma_{uc}'$ is much greater than $\sigma_{uc}'$.

(ii) The equivalent overconsolidation ratio is found for the unconsolidated undrained test being corrected by measuring $\sigma_{uc}'$ and calculating $\sigma_{uc}'$ 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 $\sigma_{uc}'$ to $s_{u}'$ at $\sigma_{uc}'$) 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, $\sigma_{uc}' = 65.4$ kPa and maximum or isotropic effective stress $\sigma_{uc}' = 88.7$ kPa, OCR ($\sigma_{uc}'/\sigma_{uc}'$) 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 $\sigma_{uc}'$ to $s_{u}'$ at $\sigma_{uc}'$ 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 trend of small decrease in the reduction of $\sigma_{uc}'$ with increasing OCR was found.

(iii) The corrected strength is greater than the disturbed strength.

(iv) The strength ratio factor decreases with increasing OCR.

11.2 Analysis on the influence of stress history for tube sampling disturbance effects can be concluded as follows:

(i) The reduction in $\sigma_{uc}'$ reduced with the increase in overconsolidation ratio (OCR).

(ii) The trend of small decrease in the reduction of $s_{u}'$ at $\sigma_{uc}'$ and $E/\sigma_{uc}'$ with increasing OCR was obtained. However, significant increase in the reduction of $A_p$ with increasing OCR was found.

(iii) The values of $s_{u}'$, $E$, and $E_50$ decreased with increasing OCR. However, the degree of reduction in $s_{u}$, $E$, and $E_50$ with increasing OCR was found to be small.

(iv) The increase in $\varepsilon_p$ reduced with increasing OCR.

(v) The degree of disturbance reduced with increasing OCR.

![Figure 13: Untrained strength correction curve for Dhaka clay](image-url)
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 ($\sigma_i$), undrained shear strength ($s_u$), initial tangent modulus ($E_i$), secant stiffness at half of the peak deviator stress ($E_{s50}$) and Skempton’s pore pressure parameter A at peak deviator stress ($A_p$) while the value of axial strain at peak deviator stress ($\varepsilon_p$) 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 $\sigma_i$, $s_u$, $E_i$ and $E_{s50}$. The values of $\varepsilon_p$ however, increased with increase in area ratio (or decrease in $D_{it}$ 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 $D_{it}$ 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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REFERENCES


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