Journal of Civil Engineering (IEB), 37(1) (2009) 11-30

Journal of Civil Engineering IEB

A comparative study on engineering properties of "Block" and "Tube" samples of a soft clay

Abu Siddique, Syed Fakhrul Ameen and M. Jahedul Islam[1]

Department of Civil Engineering, Bangladesh University of Engineering and Technology Dhaka 1000, Bangladesh

Received on 18 July 2006

Abstract

A comparative study of engineering properties of "block" and "tube" samples of a reconstituted normally consolidated soft clay was carried out. Reconstituted samples were prepared in the laboratory by K_0-consolidation of slurry. A pressure of 100 kPa was used during consolidation. "Block" samples were prepared by hand trimming of small blocks. "Tube" samples were obtained by steadily pushing sampling tubes into the large diameter sample in the consolidation cell. Unconsolidated undrained (UU) triaxial compression tests, unconfined compression tests and one-dimensional consolidation tests were conducted on "block" and "tube" samples.

Compared with the "block" sample, the values of undrained shear strength (s_u), and initial tangent modulus (E_i) of the "tube" samples decreased considerably. The values of axial strain at peak deviator stress (ε_p), initial void ratio (e_0), compression index (C_c) and expansion index (C_s) of the "tube" samples, however, increased. The values of coefficient of volume compressibility (m_v) and coefficient of consolidation (c_v) of the "tube" samples either increased or decreased compared with the "block" sample. Little change in the values of coefficient of permeability between "tube" and "block" samples. At a particular void ratio there is a trend of reduction in the value of the coefficient of vertical permeability of the "tube" samples compared with the "block" sample. Change in the measured soil properties between the "block" and "tube" samples has been found to depend markedly on the cutting shoe design of samplers. The values of s_u decreased by 17% to 62% and the values of E_i were reduced by 7% to 76% due to increase in area ratio of sampler from 16.4% to 73.1% (or decrease in external diameter to thickness ratio from 27.3 to 8.3). Values of ε_p, e_0, C_c and C_s have been found to increase by 33% to 200%, 16% to 55%, 13% to 30% and 20% to 40%, respectively due to increase in area ratio of sampler from 9.7% to 41.4%.

Keywords: Clays, sample disturbance, shear strength. Stiffness, compressibility, permeability

[1] Former post-graduate student

1. Introduction

The behaviour of foundation soil and the foundation is usually predicted on the basis of soil parameters obtained from laboratory investigation of the sampled soil. However, the inherent problem with the sampling process is that it disturbs the soil. Penetration of soil samplers causes significant shearing and distortion of the surrounding soil and subsequent compression of soil close to inside wall of sampler (Schjetne, 1971). This disturbance can be significant, such that the behaviour of the soil in the laboratory differs markedly from its behaviour in situ. Soil disturbance due to sampling operation is often regarded as a significant problem because it is likely to provide unrealistic soil parameters. During sampling, a clay soil is disturbed in two major ways. Firstly, mechanical disturbance caused when sampler is pushed into the soil. This disturbance is termed as tube penetration or tube sampling disturbance. Secondly, disturbance is caused by the release of the total in situ stress after the soil has been sampled. Such a disturbance is called "perfect" sampling disturbance. A number of research works were carried out to investigate the effects of tube sampling and "perfect" sampling on the undrained shear properties of reconstituted regional soils of Bangladesh (Sarker, 1994; Farooque, 1995; Siddique and Farooq, 1996; Siddique and Sarker, 1997; Bashar et al., 1997; Siddique et al., 2000; Rahman, 2000; Bashar et al., 2000).

Regarding the extent of sample disturbance in clays, one of the most important contributory factors is the precise design of the cutting shoe of the sampler being used (Hvorslev, 1949; Kallstenius, 1958; La Rochelle et al., 1981; Baligh et al., 1987; Siddique, 1990; Clayton et al., 1998; Siddique and Clayton, 1998; Clayton and Siddique, 1999). In fact, a sampling tube should be designed in such a way that it collects samples subjected to minimum disturbance. Investigations on the effect of the design parameters of a tube sampler (e.g., area ratio, external diameter to thickness ratio and outside cutting edge of sampler) on the laboratory measured undrained soil parameters have also been conducted for reconstituted regional soils of Bangladesh (Siddique and Sarker, 1996; Siddique et al., 2000; Bashar et al., 2000, Bashar, 2002).

Block samples can be obtained by hand at the bottom of excavations (Clayton et al., 1982) or from down a borehole (Lefebre and Poulin, 1979). In this method, the major forms of disturbance are those associated with the drilling of borehole, stress relief, transportation and storage, sample preparation and testing. With tube sampling, sample disturbance occurs due to drilling, tube penetration, stress relief, transportation and storage, sample preparation and testing. Because of the difference between these two approaches, block samples are taken as bench-mark against other technique is compared. Several workers compared the quality of block samples with that of tube samples. It has been found that block samples are always less disturbed than tube samples, and as a consequence provide higher undrained strengths (Conlon and Issacs, 1971; Mc Manis and Arman, 1979; Milovic, 1971a; Milovic, 1971b; Eden, 1971; Raymond et al., 1971; La Rochelle and Lefebvre, 1971; Department of Civil Engineering Lacasse et al., 1985). Block sampling can be modelled in the laboratory by releasing and trimming blocks from large oedometer samples.

In order to study specific effects of tube sampling disturbance only on soil behaviour, disturbances due to other sources should be eliminated. This can be achieved in laboratory using reconstituted soil in which disturbances due to boring and trimming of specimens can be eliminated. Natural intact soils are seldom uniform due to complex geological conditions in the field acted upon them. As such, from the test result on the samples collected from the field, it is rather difficult to study specific effects on soil properties due to disturbance caused by “tube” sampling. Therefore, it has been considered essential to use uniform reconstituted samples prepared under controlled conditions in the laboratory. Reconstituted samples are those, which are prepared by breaking down natural soils, mixing as slurry and reconsolidating them. Reconstituted samples enable to establish a general pattern of behaviour (Jardine, 1985). The major advantages of using data from reconstituted soils are that the ambiguous and substantial effects of sample inhomogeneity can be eliminated while representing composition of in-situ soils.

This paper presents a comparative study on strength-deformation-stiffness, compressibility, expansibility and permeability properties of the “block” and “tube” samples of reconstituted normally consolidated soft clay. Attempt has also been made to examine the effect of the design parameters of a tube sampler, namely area ratio, external diameter to thickness on the measured soil parameters of the clay.

2. Soil used and preparation of reconstituted sample

For the present study disturbed soils were collected from 3.5 m to 4 m below the surface of Institute of Diploma Engineers, Bangladesh (IDEB) building area at Kakrail, Ramna, Dhaka, Bangladesh. Disturbed samples were collected from the bottom of borrow pit through excavation by hand shovels. Table 1 shows the index properties, grain size fractions and classification of the soil used. Liquid limit and plasticity index of the soil are 52% and 34%, respectively. According to Unified Soil Classification System (USCS), the soil was a silty clay of high plasticity.

Table 1
Index Properties, Grain Size Fractions and Classification of the Soil Used

Specific Gravity, Gs	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Activity, A_c	Particle Size Distribution			USCS Symbol
					Sand (%)	Silt (%)	Clay (%)	
2.74	52	18	34	1.26	6	67	27	CH

Reconstituted samples of Dhaka clays were prepared in the laboratory by K_0-consolidation of uniform slurry of the clay in a cylindrical consolidation cell of 260 mm diameter and 230 mm in height which had a water content of approximately 1.5 times the liquid limit of the soil. Initially the slurry was allowed to consolidate by the self-weight of the sample and then gradually increased to 100 kN/m^2 over a period of about fourteen to fifteen days. A soil cake of about 125 mm to 138 mm (5 to 5.5 inch) thickness was obtained. The average water content and bulk density of the reconstituted normally consolidated soil samples were 35 ± 1% and 19.4 ± 0.07 kN/m^3, respectively.

3. Regional geology

Bangladesh can be divided into three major physiographic units, namely, (i) the tertiary hill formations, (ii) the Pleistocene terrace, and (iii) the recent flood plains. According to the study of Morgan and McIntire (1959), there are two major areas of Pleistocene sediments, commonly known as the Modhuphur tract and Barind tract. The Madhupur block lies between the Jamuna and Old (18th century) Brahmaputra channels and 6-30 metres above mean sea level. Modhupur tract is bounded by faults; they appear to be uplifted and structurally complex. The Madhupur block has been tilted eastward

(Morgan and McIntire, 1959). Dhaka is situated on the southern tip of a Pleistocene Terrace, called the Madhupur Tract. Two characteristics units cover the city and surroundings, viz. Madhupur clay of Pleistocene age and alluvial deposits of recent age. The Madhupur clay is the oldest sediment exposed in and around city area having characteristic topography and drainage. The major geomorphic units of the city are the high lands or Dhaka terrace, the low lands or flood plain and depression and abandoned channels. Low lying swamps and marshes located in and around the city are other topographic feature. The subsurface sedimentary sequence, up to the explored depth of 300 m, shows three distinct entities, one of them is the Madhupur clay formation of pleistocene age and is characterised by reddish plastic clay with silt and very fine sand particles. This Madhupur clay formation uncomfortably overlies the Dupi Tila formation of Pleistocene age composed of medium to coarse yellowish brown sand and occasional gravel. The incised channels and depression within the city are floored by recent alluvial flood plain deposits and is further subdivided into lowland Alluvium and high land Alluvium. A description of soil profile over Dhaka is provided by Eusufzai (1967) and Ameen (1985). The soil deposits in the project area mainly consist of the following types of soils:

Alluvial silt and clay: It consists of medium to dark-grey silt to clay. Colour is darker as amount of organic material increases. It includes flood-basin silt, backswamp silty clay and organic-rich clay in sag ponds and large depressions. Some depressions contain peat.

Marsh clay and peat: Paludal deposits of marsh clay and peat are also underlain to some extent in this area. Paludal deposits are mainly grey or bluish grey clay, black herbaceous peat and yellowish grey silt. Alternating beds of peat and peaty clay are common in beels and large structurally controlled depressions.

Madhupur clay residuum: Madhupur clay residuum is composed of light yellowish-gray, orange, light to brick-red, and greyish-white, micaceous silty clay to sandy clay. The clay is plastic and abundantly mottled in upper 8 m and contains small clusters of organic matter. Sand fraction consists dominantly of quartz, minor feldspar and mica. Sand content increases with depth. Dominant clay minerals in this residuum are kaolinite and illite.

4. Dimensions and characteristics of tube samplers

Samplers of different area ratios but identical outside cutting edge taper angle were fabricated from locally available mild steel tubes. The internal diameter and outside cutting edge angle of four samplers used for triaxial and unconfined compression tests were 38mm and 5°, respectively. The thickness (t) of the sample tubes were 1.5mm, 3mm, 4.5mm and 6mm, whereas internal diameter and outside cutting edge angle of other four samplers used for direct shear and consolidation tests were 63.5 mm and 5°, respectively.

Eight open-drive samplers of the following two categories were used:

(i) For conducting triaxial and unconfined compression tests, four samplers with different area ratios but identical outside cutting edge angle (OCA) were fabricated. The area ratios of these samplers were varied by changing the thickness (t) of the tubes hence the external diameter of sampler tube (D_e) while keeping the internal diameter (D_i) of the samplers constant (38 mm). Sampler designations T with numeral subscript have been used to indicate sampler tubes used in this category.

(ii) For conducting one-dimensional consolidation tests, four samplers with different area ratios but identical out side cutting edge angle (OCA) were fabricated. The area ratios of these samplers were varied by changing the thickness (t) of the sample tubes hence the external diameter of sampler tube (D_e) while keeping the internal diameter (D_i) of the samplers constant (63.5mm). Sampler designations TT with numeral subscript have been used to indicate sampler tubes of this category.

Sampler designations and the dimensions and characteristic of the sampler are presented in Table 2. In Table 2 the outside cutting edge angle (OCA) has been defined as the angle which the outside edge of the cutting shoe makes with a vertical plane. Length of each sampler was 127 mm. Internal diameter of the sample tube and internal diameter at cutting shoe of each sampler were equal, as such each sampler had no inside clearance (i.e., inside clearance ratio = 0%). External diameter of the sample tube (D_e) and external diameter at cutting shoe of each sampler were equal, as such each sampler had no outside clearance (i.e., outside clearance ratio = 0%). The area ratio mentioned in Table 2, therefore, has been defined by the following equation (Hvorslev, 1949):

$$Area\ Ratio = (D^2_e - D^2_i) / D^2_i \quad (1)$$

Table 2
Dimensions and Characteristics of the Tube Samplers Used

Sampler Designation	t (mm)	D_e (mm)	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	44	38	14.7	34.1	5
T_3	4.5	47	38	10.4	53.0	5
T_4	6	50	38	8.3	73.1	5
TT_1	1.5	66.5	63.5	44.5	9.7	5
TT_2	3	69.5	63.5	23.2	19.8	5
TT_3	4.5	72.5	63.5	16.1	30.4	5
TT_4	6	75.5	63.5	12.6	41.4	5

5. The test samples

"Block" Sample

After extruding the reconstituted soil block from consolidation cell, the large soil block was sliced into small blocks by wire knife. The small blocks were trimmed by using piano wire, soil lathe and a split mould to prepare sample of nominal dimensions of 38 mm diameter by 76 mm high for Unconsolidated Undrained (UU) triaxial compression test and Unconfined compression test. These samples have been termed as "block" samples. To prepare a "block" sample for one-dimensional consolidation test, initially small slabs of clay were obtained out of reconstituted samples from large consolidation cell. Then a sample ring of 63.5 mm diameter by 25.4 mm high having its internal surface well covered with silicon grease was gradually and in stages pushed into the clay, which was continuously being trimmed away from the cutting edge of the ring with a knife.

"Tube" Sample

At first the reconstituted soil cakes were prepared from the disturbed samples in a large consolidation cell. Then sample tubes having respectively 38 mm and 63.5 mm inner diameter but of different area ratios as mentioned in Table 2 were steadily pushed into the reconstituted soil cake. 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 have been termed as “tube” samples. The sample designation and design parameters of different tube samplers have already been presented in Table 2.

6. Laboratory testing programme

The test programme consisted of carrying out three types of tests on “block” and “tube” samples. Tests on “block” samples were conducted to determine the reference undisturbed behaviour of the soft clay.

Unconsolidated undrained (UU) triaxial compression and unconfined compression tests were carried out on a “block” and “tube” samples. In these tests, samples were sheared with cell pressure 100 kPa at a deformation rate of 1.5 mm/min while in unconfined compression tests samples were sheared with at a deformation rate of 1.5 mm/min. Incremental loading one-dimensional consolidation tests were also carried out on a “block” and “tube” samples. A stress increment ratio of 1 (i.e., a load ratio of 2) was used. The vertical consolidation stresses applied in each test were 12.5 kPa, 25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, 800 kPa and 1600 kPa. The samples were also allowed to swell under stresses of 800 kPa, 400 kPa, 200 kPa, and 5 kPa. Duration of each loading and unloading step was approximately 24 hours. During all these tests drainage was permitted from top and bottom of the sample. For each loading step dial gauge recorded deformations at specified intervals of time.

7. Test results and discussions

Undrained stress-strain-strength, stiffness, compressibility, expansibility and permeability characteristics of the “block” and “tube” samples were determined from UU triaxial compression tests, unconfined compression tests and one-dimensional consolidation tests. The test results are presented and discussed in the following sections. Comparisons of the undrained shear parameters, compressibilty and permeability properties of “tube” samples with “block” sample are presented. The effects of cutting shoe design on undrained shear strength, stiffness, compressibility, expansibility and permeability properties of the soft clay has also been presented and discussed.

7.1 Undrained Strength, Deformation and Stiffness Characteristics in UU Triaxial Compression Test and Unconfined Compression Test

Figure 1 shows plot of deviator stress verses axial strain of the “block” and “tube” in UU triaxial compression tests. Deviator stress verses axial strain plot of the “block” sample is also shown in Fig. 1 for comparison. The main observations from the plots of Fig. 1 are as follows:

(i) Like “block” sample, the peak undrained strength for all “tube” samples are mobilised at relatively small axial strains. The peak undrained strength of “tube” samples is mobilized at axial strain larger than that for “block” sample.

(ii) Like “block” sample, the strength mobilised at ultimate strain is slightly lower than that mobilized at peak. Slight strain softening is noticed but at lesser extent than that of “block” sample.

(iii) The stress-strain relationships are non-linear.

(iv) The natures of these curves are similar to that of “block” sample.

Figure 2 shows plot of compressive stress verses axial strain of the “block” and “tube” samples in unconfined compression tests. The salient features as can be seen from Fig. 2 are as follows:

(i) Similar to UU triaxial compression test, the peak undrained strength for all “tube” samples are mobilised at relatively small axial strains. The peak undrained strength of “tube” samples are mobilised at axial strain larger than that for “block” sample.

(ii) Like “block” sample, the strength mobilised at ultimate strain is slightly lower than that mobilised at peak. Slight strain softening is noticed but at very smaller extent than that of “block” sample.

(iii) The stress-strain relationships are non-linear.

(iv) The natures of these curves are similar to that of “block” sample.

From the stress-stain data of the “block” and “tube” samples, the values of s_u, ε_p and E_i of “block” and “tube” samples were evaluated which are summarised in Table 3. It can be seen from Table 3 that in both UU triaxial test and unconfined compression test, compared with the “block” sample, the values of s_u, and E_i of the “tube” samples decreased considerably due to disturbance caused by penetration of sampling tube. The values of ε_p of the “tube” samples, however, increased. In UU triaxial compression test, the values of s_u, and E_i decreased up to about 61% and 71%, respectively while in unconfined compression test the values of s_u and E_i decreased up to about 62% and 76%, respectively. Compared with the “block” sample, the values of ε_p increased up to 200% and 167% in UU triaxial compression test and unconfined compression test, respectively. Compared with “in situ” sample, reductions in the values of s_u and E_i and increase in the value of ε_p of “tube” samples have been reported for reconstituted normally consolidated Dhaka clay (Sarker, 1994; Siddique and Sarker, 1995; Siddique and Rahman, 2000) and reconstituted normally consolidated coastal soils from Chittagong (Siddique et al., 2000; Bashar et al., 2000).

Table 3
Comparison of Undrained Shear Properties of “Block” and “Tube” Samples from UU Triaxial and Unconfined Compression Test

Sample Designation	s_u (kN/m^2)		ε_p (%)		E_i (kN/m^2)	
	UU Triaxial Test	Unconfined Compression Test	UU Triaxial Test	Unconfined Compression Test	UU Triaxial Test	Unconfined Compression Test
“Block”	25.5	19.3	2.0	1.5	9423	5126
T_1	21.1	16.1	4.0	2.0	8758	4679
T_2	19.7	13.4	4.6	2.5	8199	2516
T_3	17.8	8.4	5.3	3.0	6665	2289
T_4	9.9	7.4	6.0	4.0	2726	1243

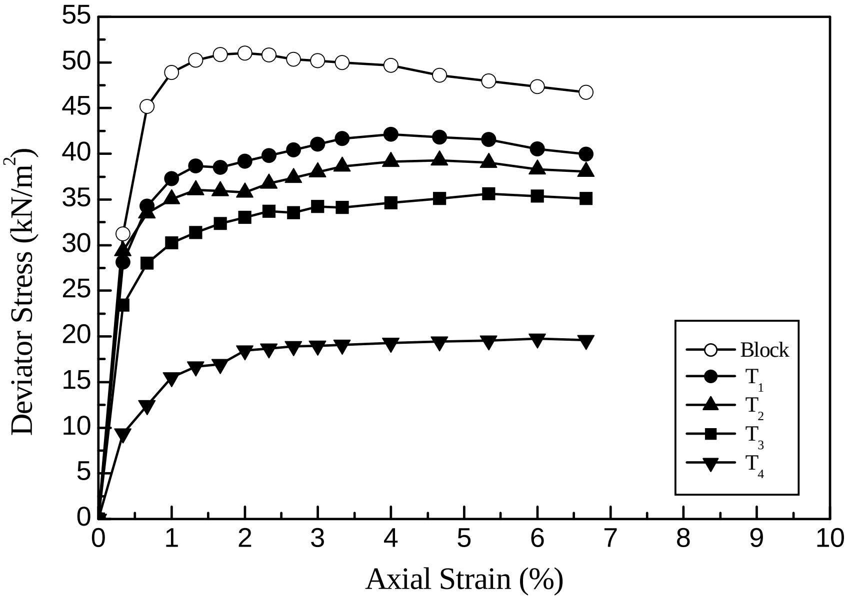

FIGURE 1 : Comparison of Deviator Stress vs Axial Strain Plots of "Block" and "Tube" Samples of Soft Dhaka Clay in UU Triaxial Test

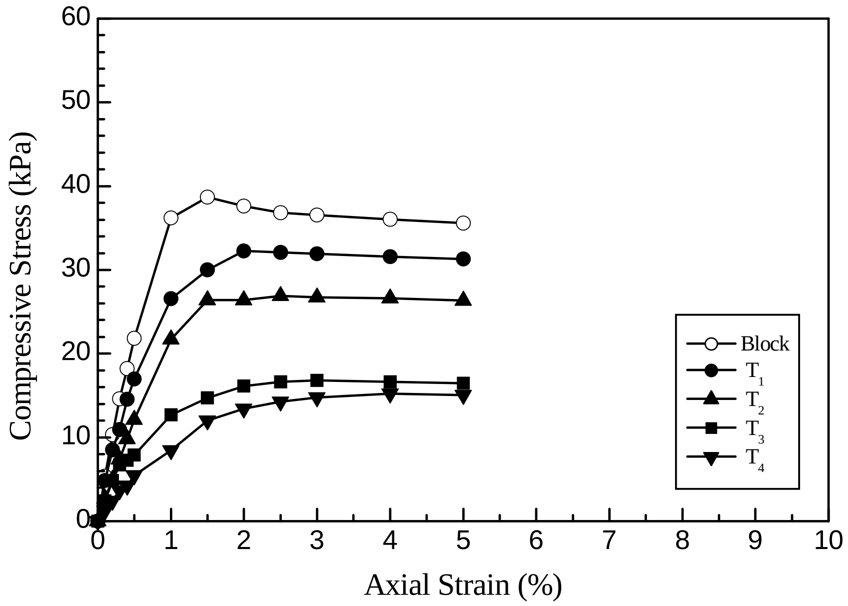

FIGURE 2 : Comparison of Compressive Stress vs Axial Strain Plots of "Block" and "Tube" Samples of Soft Dhaka Clay in Unconfined Compression Test

7.2 Compressibility and expansibility characteristics of "Block" and "Tube" samples

Coefficient of volume compressibility/expansibilty (m_v/m_s) was also calculated for each stress increment using the following expression:

$$m_v / m_s = \frac{\Delta e}{\Delta\sigma(1+e_i)} \tag{2}$$

where, Δe = change in void ratio for the stress increment
$\Delta\sigma$ = change in stress for a load increment
e_i = initial void ratio for the stress increment

Time - deformation curves were plotted for each pressure increment and from these plots, times corresponding to 90% consolidation, i.e., t_{90} were determined using Taylor's Curve Fitting Method (Das, 1983). Coefficients of consolidation, cv were calculated for each stress increment using the following expression:

$$c_v = \frac{0.848H^2}{t_{90}} \tag{3}$$

where, H is the average length of drainage path, i.e., half the height of sample at the end of 100% consolidation for a given stress increment.

The compressibility and expansibility characteristics of “block” and “tube” soft clay samples undergoing incremental loading in an oedometer are presented in Fig. 3 and Fig. 4. In Fig 3, void ratio (e) at the end of each loading and unloading stages have been plotted against logarithm of vertical effective consolidation pressure. Fig. 4 shows the plotting of coefficient of volume compressibility (m_v) and coefficient of volume increase (m_s) as a function of logarithm of vertical effective consolidation pressure. Table 4 shows a summary and comparison of the compressibility and expansibilty properties of “block” and “tube” samples.

It can be seen from Table 4 that, compared with the “block” sample, the values of initial void ratio (e_0) of the “tube” samples are relatively higher (about 15% to 54%). The values of compression index (C_c) were determined from the slope of the loading portion of logarithm of vertical effective consolidation pressure curves shown in Fig. 3. A comparison of the values of C_c is presented in also Table 4. It can be seen from Table 5.5 that compared with the “block” sample, the values of C_c increased between 13% and 30%. These results agree with those reported by Okumura (1971) who found an increase in C_c due to tube sampling disturbance. Sarker (1994), however, found that compared with “in situ” sample, values of C_c for “tube” samples of normally consolidated soft samples of Dhaka clay (LL = 45, PI = 23) did not change significantly. Farooq (1995) found that compared with “in situ” samples, the values of C_c either increased or decreased for “tube” samples of reconstituted normally consolidated soft coastal soils of Chittagong (LL = 43 to 57; PI = 18 to 33). Hight et al. (1987) found that same C_c-value for block, tube and in situ samples.

The values of expansion index (C_s) were determined from the slope of the unloading portion of logarithm of vertical effective consolidation pressure curves. A comparison of the value of C_s is presented in Table 4. It has been found that compared with the “block” sample, the changes in the values of C_s of the “tube” samples are insignificant. Similar results were also reported by Sarker (1994) and Farooq (1995) for reconstituted soft “in situ” and “tube” samples of Dhaka clay and Chittagong coastal soils.

It is evident from the plots of Fig. 4 that up to value of preconsoliudation stress (i.e., 100 kN/m^2), the values of coefficient of volume compressibilty (m_v) of the “tube” samples either increased or decreased compared with the "block" sample. Beyond the preconsolidation stress, however, there are insignificant changes in the values of m_v between the "block' and "tube" samples. Farooq (1995) reported a trend of reduction in the values of m_v of the "tube" samples up to the level of preconsolidation stress and beyond the preconsolidation pressure the values of m_v of the "in situ" and "tube" samples were almost similar. Sarker (1994) also reported similar results for "in situ" and "tube" samples of Dhaka clay. The findings obtained in the present investigation and those reported by Sarker (1994) and Farooq (1995), however, contrast to those reported by Bromhan (1971), Lacasse et al. (1985). Hight et. al. (1987) found that for both tube and block samples, the values of m_v were considerably smaller than the in-situ sample.

Fig. 5 shows the plots of coefficient of consolidation (c_v) as a function of vertical effective stress for "block" and "tube" samples. It can be seen from Fig. 5 that compared with the "block" sample the values of c_v of the "tube" samples either increased or decreased. However, it is also evident from Fig. 5 that beyond the preconsolidation pressure of 100 kPa, there are insignificant changes in the values of c_v between the "block" and "tube" samples. Similar behaviour of "in situ" and "tube" sample was also reported by Farooq (1995) and Sarker (1994). Therefore, it appears from the present investigation that disturbance due to penetration of tubes of different area ratio did not change the value of c_v for the "tube" samples. These results, however, contrast with those reported by Bromham (1971) for soft clay samples. Bromham (1971) found significant reduction in the values of c_v due to tube sampling disturbance.

Table 4
Comparison of Initial Void Ratio, Compression Index and Swelling Index of "Block" and "Tube" Samples

Sample Designation	Initial Void Ratio, e_o	Compression Index, C_c	Swelling Index, C_s
"Block"	0.9382	0.30	0.05
TT_1	1.0849	0.34	0.06
TT_2	1.1334	0.37	0.06
TT_3	1.2212	0.38	0.06
TT_4	1.4538	0.39	0.07

Table 5
Influence of Increasing Area Ratio (or Decreasing D_e/t Ratio) of Sampler on e_0, C_c and C_s

Test Type	Sample Designation	Area Ratio (%)	D_e/t ratio	*Ratio of		
				e_0	C_c	C_s
One-Dimensional Consolidation Test	TT1	9.7	44.5	1.16	1.13	1.20
	TT2	19.8	23.2	1.21	1.23	1.20
	TT3	30.4	16.1	1.30	1.27	1.20
	TT4	41.4	12.6	1.55	1.30	1.40

*Ratios are compared with the values of "block" samples

7.3 Permeability properties of "Block" and "Tube" samples

Coefficient of permeability of the samples was determined indirectly from one-dimensional consolidation tests. The coefficient of permeability, k were computed using the following expression:

$$k = c_V m_V \gamma_W \qquad (4)$$

where, c_v = coefficient of consolidation
m_v = coefficient of volume compressibility
γ_w = unit weight of water

In Fig. 6, the coefficient of vertical permeability (k) of "block" and "tube" samples has been plotted against vertical effective consolidation stress. It can be seen from Fig. 6 that there is little change in permeability between "tube" and "block" samples up to preconsolidation pressure of 100 kPa. Beyond preconsolidation pressure of 100 kPa however, there is practically no change in permeability in relation to changes in vertical effective consolidation stress. The results of present investigation, therefore, indicate that disturbance due to tube sampling has practically insignificant effect on the permeability characteristics of reconstituted soft clay samples of Dhaka clay. Similar results were also reported by Sarker (1994) for soft "in situ" and "tube" samples of relatively less plastic Dhaka clay (PI = 23).

A comparison of the plots of void ratio (e) versus logarithm of coefficient of vertical permeability of the "block" and "tube" samples is presented in Fig. 7. It can be seen from Fig. 7 that coefficient of vertical permeability increases with the increase in void ratio of the "block" and "tube" samples. Fig. 6 also shows that at a particular void ratio there is a trend of reduction in the value of the coefficient of vertical permeability of the "tube" samples compared with the "block" sample.

7.4 Effect of cutting shoe design

7.4.1 Effect of area ratio and De/t Ratio on undrained shear parameters

The effect of changes in area ratio and D_e/t ratio of sampler on stress-strain properties obtained from UU triaxial compression tests and unconfined compression tests on "tube" samples has been investigated. Fig. 8 and Fig. 9 show changes in s_u, ε_p and E_i in UU triaxial tests and unconfined compression tests, respectively, due to changes in area ratio of the samplers used to retrieve samples of soft Dhaka clay. Changes in the values of undrained shear strength (s_u), axial strain at peak deviator stress (ε_p) and initial tangent modulus (E_i) in UU triaxial tests and unconfined compression tests due to changes in D_e/t ratio of the samplers used to retrieve samples of soft Dhaka clay are presented in Fig. 10 and 11, respectively.

Compared with the "block" sample, the following effects on the measured undrained shear parameters obtained from UU triaxial tests and unconfined compression tests have been observed due to of increasing area ratio (or decreasing D_e/t ratio):

(i) Values of s_u decreased by 17% to 61% and 17% to 62% in UU triaxial compression and unconfined compression test, respectively due to increase in area ratio of sampler from 16.4% to 73.1% (or decrease in D_e/t ratio from 27.3 to 8.3).

(ii) Values of ε_p increased by 100% to 200% and 33% to 167% in UU triaxial compression and unconfined compression test, respectively due to increasing area ratio (or decreasing D_e/t ratio).

(iii) Values of E_i were reduced by 7% to 70% and 9% to 76% in UU triaxial compression and unconfined compression test respectively due to about 4.5 times increase in area ratio (or about 70% reduction in D_e/t ratio).

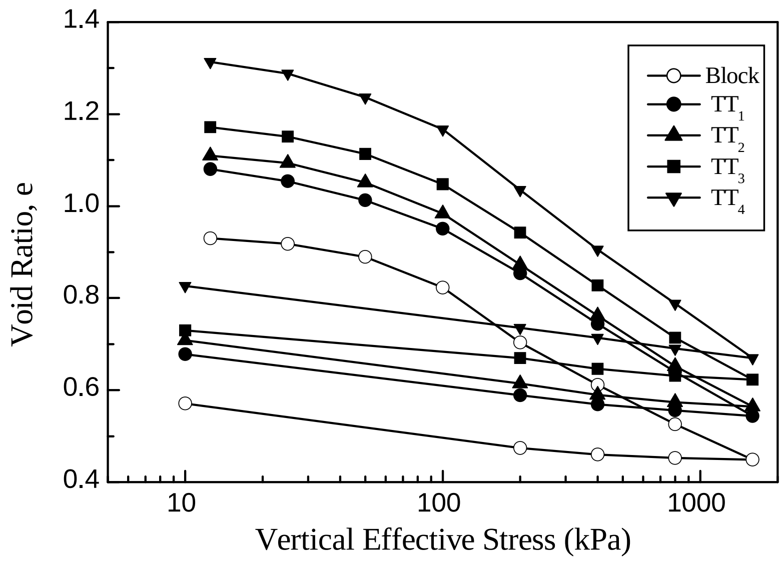

FIGURE 3: Comarison of Void Ratio vs Vertical Effective Stress Plots of "Block" and "Tube" Samples of Soft Dhaka Clay in One-Dimensional Consolidation Test

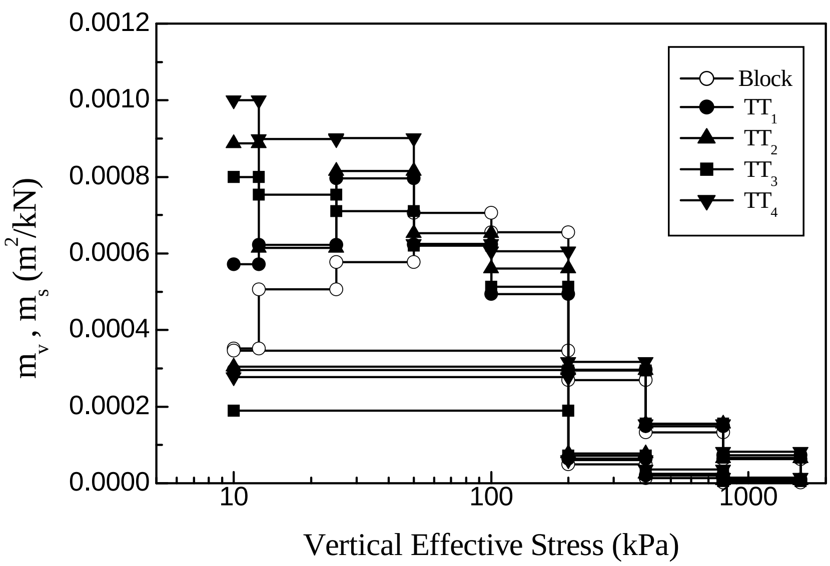

FIGURE 4 : Comparison of Coefficient of Volume Compressibility/Expansibility versus vertical Effective Stress Plots of "Block" and "Tube" Samples of Soft Dhaka Clay

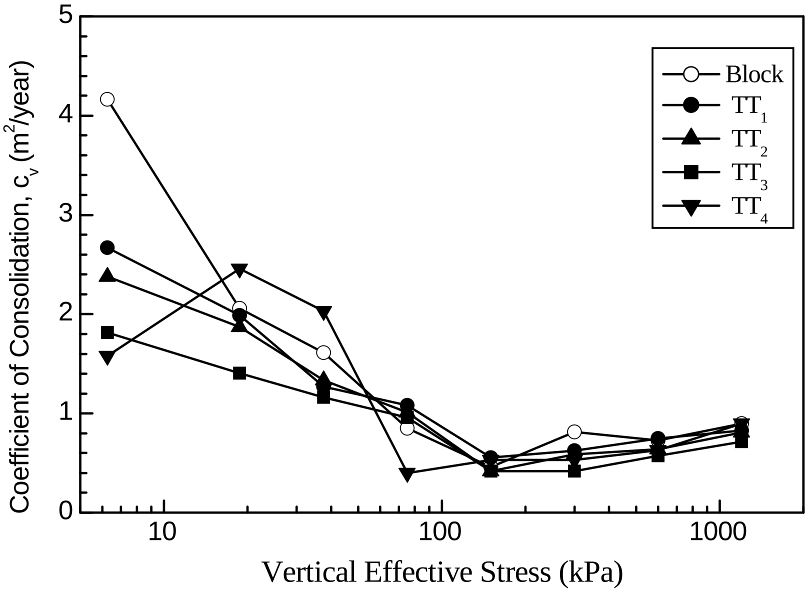

FIGURE 5 : Comparison of Coefficient of Consolidation vs Vertical Effective Stress Plots of "Block" and "Tube" Samples of Soft Dhaka Clay

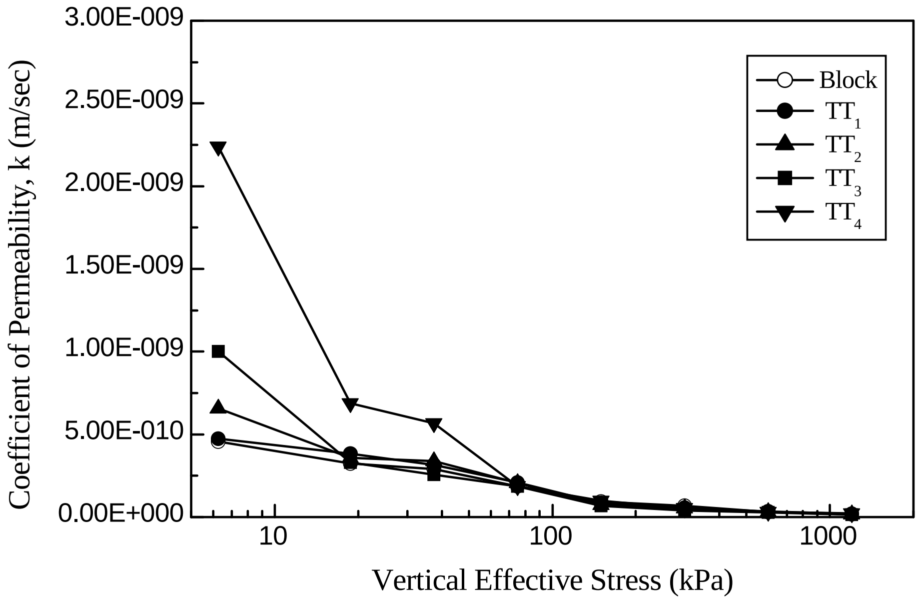

FIGURE 6 : Comparison of Coefficient of Permeability vs Vertical Effective Stress Plots of "Block" and "Tube" Samples of Soft Dhaka Clay

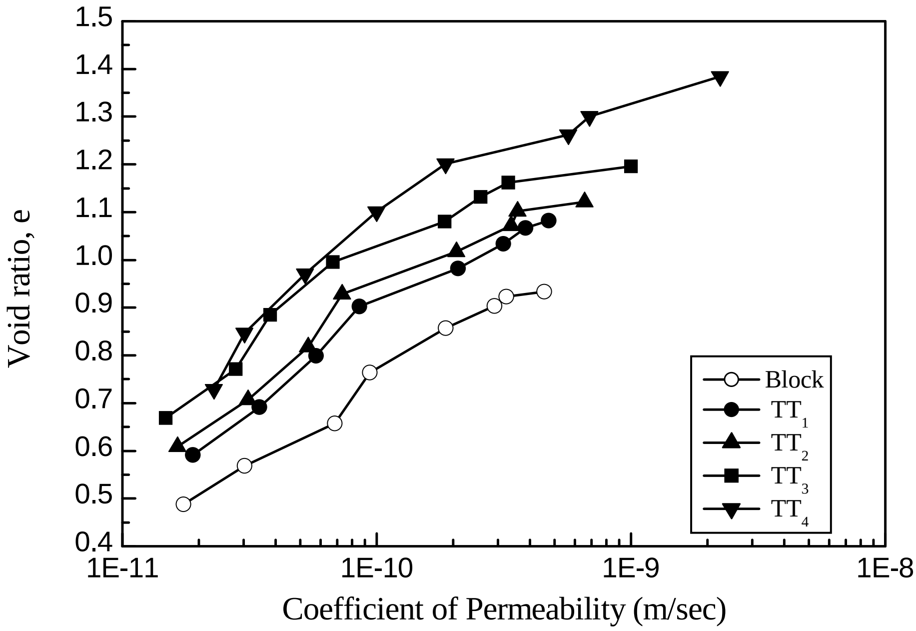

FIGURE 7 : Comparison of Void Ratio vs Coefficient of Permeability Plots of "Block" and "Tube" Sample of Soft Dhaka Clay

Changes in the experimentally measured values of s_u, ε_p and E_i between "in situ" samples and "tube" samples retrieved with different area ratios and D_e/t ratios have also been reported for reconstituted normally consolidated Dhaka clays and a number of coastal soils of Bangladesh (Siddique and Saker, 1996; Siddique and Rahman, 2000; Siddique et al., 2000; Bashar et al., 2000). Siddique and Sarker (1996) and Siddique and Rahman (2000) reported reduction in s_u and E_i and an increase in ε_p in reconstituted normally consolidated soft Dhaka clay (LL = 45-47, PI = 21-23) due to increase in area ratio of samplers. Due to increase in area ratio, Siddique et al. (2000) and Bashar et al. (2000) also reported significant reduction of s_u and E_i values and increase in ε_p-values in Chittagong coastal soils of varying plasticity (LL = 34 to 57, PI = 10 to 33). Jakobson (1954) recommended that a sampler should not have a very large area ratio. IS (1986) recommends small area ratio for thin walled open-drive samplers for high quality sampling in clays. Kubba (1981) reported a qualitative increase in the degree of disturbance due to increase in the ratio of thickness to diameter of the samplers. Andreson (1981) also reported a qualitative increase in degree of disturbance due to increase in area ratio.

7.4.2 *Effect of area ratio and D_e/t ratio on compressibility, expansibility and permeability properties*

The effect of changes in area ratio and D_e/t ratio on the measured consolidation properties obtained from one dimensional consolidation tests on "tube" samples has also been assessed. Table 5 summarizes the influence of increasing area ratio (or decreasing D_e/t ratio) on the measured consolidation properties as obtained from one-dimensional consolidation tests.

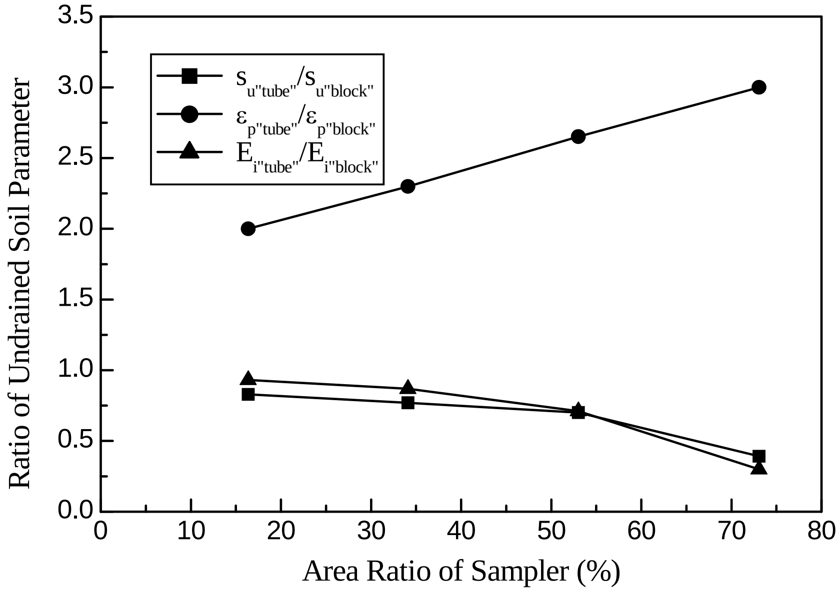

FIGURE 8 : Influence of Area Ratio of Sampler on Measured Soil Parameters from UU Triaxial Compression Test for Soft Dhaka Clay Samples

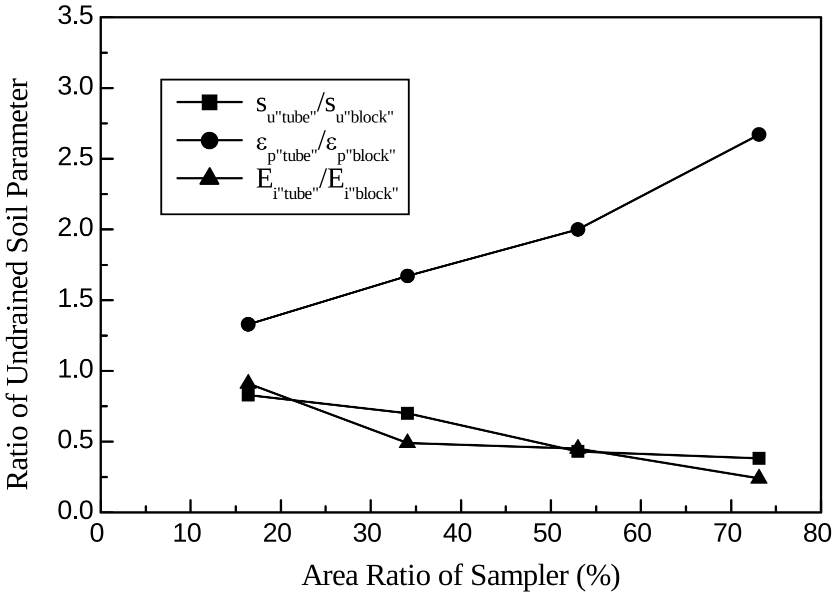

FIGURE 9 : Influence of Area Ratio of Sampler on Measured Soil Parameters from Unconfined Compression Test for Soft Clay Samples

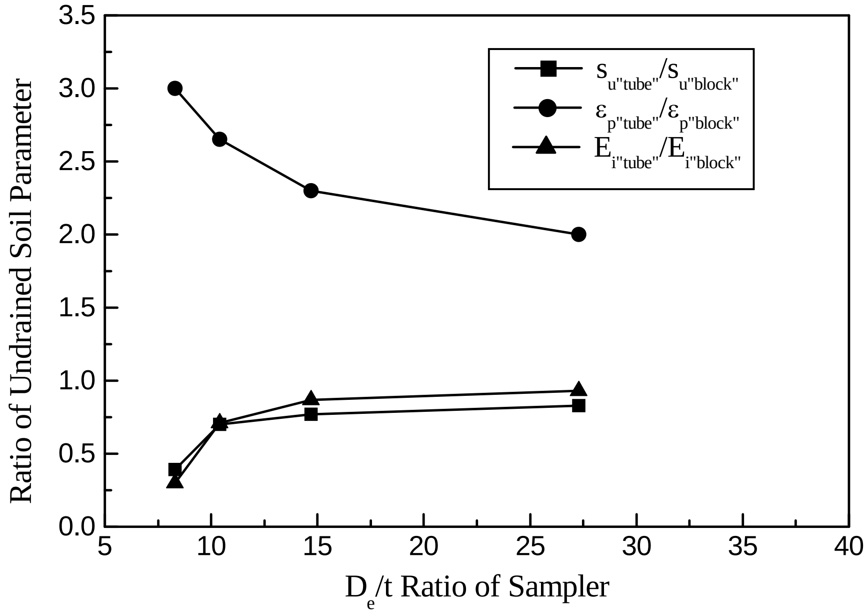

FIGURE 10 : Influence of D_e/t Ratio of Sampler on Soil Parameter from UU Triaxial Compression Test for Soft Dhaka Clay Samples

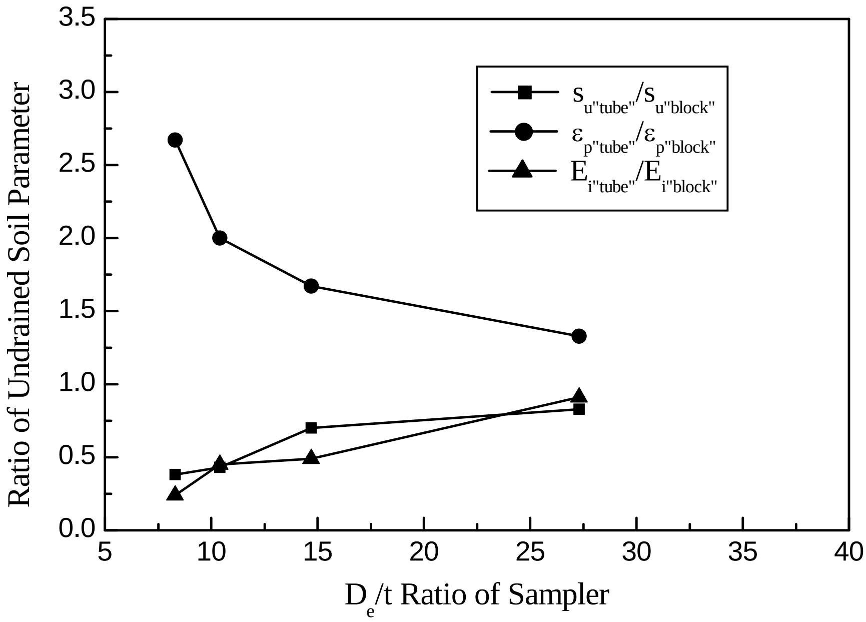

FIGURE 11 : Influence of De/t Ratio of Sampler on Soil Parameter from Unconfined Compression Test for Soft Dhaka Clay Samples

The following effects have been observed on the measured consolidation properties:

(i) Values of e_0 increased by 16% to 55% due to increase in area ratio of sampler from 9.7% to 41.4% (or decrease in D_e/t ratio from 44.5 to 12.6).

(ii) Values of C_c increased by 13% to 30% to increase in area ratio (or decrease in De/t ratio).

(iii) Values of C_s also increased by 20% to 40% due to about 4.25 times increase in area ratio (or about 72% reduction in D_e/t ratio).

8. Conclusions

In this research a comparative study on behaviour and engineering properties of "block" and "tube" samples of reconstituted normally consolidated soft Dhaka clay has been carried out. These geotechnical parameters were determined from unconsolidated undrained (UU) triaxial compression tests and unconfined compression tests. Permeability and compressibility, and expansibility properties of "block" and "tube" samples were determined by performing one-dimensional consolidation tests. Attempts have also been made to investigate the influence of cutting shoe design of tube sampler (e.g., area ratio and external diameter (D_e) to thickness (t) ratio, i,e., D_e/t ratio on the experimentally measured undrained shear properties and, compressibility and permeability properties. The main findings and conclusions of the present investigation can be summarised as follows:

- Like "block" sample, the peak undrained strength for all "tube" samples in UU triaxial compression and unconfined compression tests are mobilised at relatively small axial strains. The peak undrained strength of "tube" samples are mobilised at axial strain larger than that for "block" sample. Like "block" sample, the strength mobilised at ultimate strain for the "tube" samples are slightly less than that mobilised at peak. Strain softening has been noticed in "block" and "tube" samples. The stress-strain relationships for both "block" and "tube" samples are non-linear.
- In both UU triaxial test and unconfined compression test, compared with the "block" sample, the values of $s_{u,}$ and E_i of the "tube" samples decreased considerably due to disturbance caused by penetration of sampling tube. The values of ε_p of the "tube" samples, however, increased.
- Values of s_u decreased by 17% to 61% and 17% to 62% in UU triaxial compression and unconfined compression test, respectively due to increase in area ratio of sampler from 16.4% to 73.1% (or decrease in D_e/t ratio from 27.3 to 8.3).
- Values of ε_p increased by 100% to 200% and 33% to 167% in UU triaxial compression and unconfined compression test, respectively due to increasing area ratio (or decreasing D_e/t ratio).
- Values of E_i were reduced by 7% to 70% and 9% to 76% in UU triaxial compression and unconfined compression test respectively due to about 4.5 times increase in area ratio (or about 70% reduction in D_e/t ratio).
- The findings of the previous and present investigations on Dhaka clay clearly demonstrate that the design of a sampler tube has profound influence on sample disturbance. In order to minimise disturbance due to sampling in Dhaka clay, area ratio 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%.
- Compared with the "block" sample, the values of initial void ratio (e_0) of the "tube" samples are relatively higher. Values of e_0 increased by 16% to 55% due to increase in area ratio of sampler from 9.7% to 41.4% (or decrease in D_e/t ratio from 44.5 to 12.6).
- Compared with the "block" sample, the values of compression index (C_c) of the "tube" samples increased. Values of C_c increased by 13% to 30% due to increase in area ratio (or decrease in De/t ratio). Values of expansion index (C_s) also increased

by 20% to 40% due to about 4.25 times increase in area ratio (or about 72% reduction in D_e/t ratio).

- The values of coefficient of volume compressibility (m_v) of the "tube" samples either increased or decreased compared with the "block" sample. Beyond the preconsolidation stress, however, there is an insignificant change in the values of m_v between the "block' and "tube" samples.
- Compared with the "block" sample the values of c_v of the "tube" samples either increased or decreased. However, beyond the preconsolidation pressure of 100 kPa, there are insignificant changes in the values of c_v between the "block" and "tube" samples. Therefore, it appears from the present investigation that disturbance due to penetration of tubes of different area ratio did not change the value of c_v for the "tube" samples.
- Little change in the values of coefficient of permeability between "tube" and "block" samples up to preconsolidation pressure of 100 kPa has been observed. Beyond preconsolidation pressure of 100 kPa however, there is practically no change in permeability in relation to changes in vertical effective consolidation stress. The results of present investigation, therefore, indicate that disturbance due to tube sampling has practically insignificant effect on the permeability characteristics of reconstituted soft clay samples of Dhaka clay.
- It has been found that coefficient of vertical permeability increases with the increase in void ratio of the "block" and "tube" samples. At a particular void ratio there is a trend of reduction in the value of the coefficient of vertical permeability of the "tube" samples compared with the "block" sample.

References

Ameen, S.F. (1985), "Geotechnical Characteristics of Dhaka Clay", M. Sc. Engineering thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Andresen, A. (1981)) "Exploration, Sampling and In-Situ Testing of Soft Clay" Chapter 3 of Soft Clay Engineering, Edited by Brand, E.W. and Brenner, R.P., Published by Elsevier Scientific Publishing Company, pp. 241-254.

Baligh, M.M., Azzouz, A.S. and Chin, C.T. (1987) "Disturbance Due to Ideal Tube Sampling Disturbance", Journal of the Geotech. Engng. Div., ASCE, Vol. 113, No. GT7, pp. 739-757.

Bashar, M.A. (2002), "Stress-Deformation Characteristics of Selected Coastal Soils of Bangladesh and their Sampling Effects", Ph.D thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Bashar, M.A., Siddique, A. and Safiullah, A.M.M. (1997), "Effect of Stress Relief Disturbance on Undrained Shear Properties of Chittagong Coastal Soils", Journal of Civil Engineering, The Institution of Engineers, Bangladesh, Vol. CE 25, No. 1, pp. 65-77.

Bashar, M.A., Siddique, A. and Safiullah, A.M.M. (2000), "Sampling Disturbance Effects in Reconstituted Coastal Soils", Soils and Foundations, Journal of the Japanese Geotechnical Society, Vol. 40, No.5, pp. 49-63.

Bromham, S.B. (1971) "The measurement of Disturbance in Samples of Soft Clay", Proc., Specialty Session on Quality in Soil Sampling, 4th Asian Conf., Int. Soc. Soil Mech. and Found. Engng., Bangkok, pp. 68-72.

Clayton, C.R.I. and Siddique, A. (1999) "Tube Sampling Disturbance – Forgotten Truths and New Perspectives", Geotechnical Engineering Journal, Institution of Civil Engineers, London, Vol. 137, pp. 127-135.

Clayton, C.R.I., Siddique, A. and Hopper, R.J. (1998) "Effects of Sampler Design on Tube Sampling Disturbance – Numerical and Analytical Investigations", Geotechnique, Journal of the Institution of Civil Engineers, London, Vol. 48, No. 6, pp. 847-867.

Clayton, C.R.I., Simons, N.E. and Matthews, M.C. (1982) "Site Investigation", Granada Publishing Limited, London.

Conlon, R.J. and Isaacs, R.M.F. (1971) "Effect of Sampling and Testing Techniques on the Shear Strength of a Glacial-Lacustrine Clay from Welland, Ontario", Symposium on Sampling of Soil and Rock, ASTM STP 483, pp.10-29.

Das, B. M. (1983) “Advanced soil Mechanics”, Hemisphere Publishing Corporation, New York.

Eden, W.J. (1971) "Sampler Trials in Overconsolidated Sensitive Clay", Symposium on Sampling of Soil and Rock, ASTM STP 483, pp. 132-142.

Eusufzai, S.H.K. (1967),), “Soil Profile Across Dacca the Capital City of East Pakistan”, Proceedings of the Second South East Asian Conference on Soil Engineering, Singapore, pp. 73-80.

Farooq, S. M. (1995) “Effects of Sampling Disturbance on Engineering Behaviour of Coastal Soils from Chittagong”, M. Sc. Engg. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Hight, D.W., Jardine, R.J. and Gens, A. (1987) "The Behaviour of Soft Clays", Chapter 2 in Embankments on Soft Clays, Special Publication, Bulletin of the Public Works Research Center, Athens, pp. 33-158.

Hvorslev, M.J. (1949) "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes", Waterways Experimental Station, Vicksburg, Mississippi, Reported by Siddique (1990).

Jakobson, B. (1954) "Influence of Sampler Type and Testing Method on Shear Strength of Clay Samples", Proc., Royal Swedish Geotechnical Institute, No. 8, pp. 1-58.

Jardine, R.J. (1985) "Investigations of Pile-Soil Behaviour With Special Reference to the Foundations of Offshore Structures", Ph.D.Thesis, Imperial College, University of London.

Kallstenius, T. (1958) “Mechanical Disturbances in Clay Samples Taken With Piston Samplers”, Proc., Royal Swedish Geotechnical Institute, No. 16, pp.1-75.

Kubba, L.M. (1981) "The Effect of Sampling Disturbance on the Deformation of Clay", Ph.D. Thesis, University College, Cardiff, University of Wales, U.K.

La Rochelle, P. and Lefebvre, G. (1971) "Sampling Disturbance in Champlain Clays", Symposium on Sampling of Soil and Rock, ASTM STP 483, pp. 143-163.

La Rochelle, P., Sarrailh, J., Tavenas, F., Roy, M. and Leroueil, S. (1981) "Causes of Sampling Disturbance and Design of a New Sampler for Sensitive Soils", Canadian Geotechnical Journal, Ottawa, Vol. 18, No. 1, pp. 52-66.

Lacasse, S., Berre, T. and Lefebvre, G. (1985) "Block Sampling of Sensitive Clays", Proc., 11th Int. Conf. Soil Mech. and Found. Engng., San Francisco, Vol. 2, pp.887-892.

Lefebvre, G. and Poulin, C. (1979) "A New Method of Sampling in Sensitive Clay", Canadian Geotechnical Journal, Vol. 16, No. 1, pp. 226-233.

Mcmanis, K.L. and Arman, A. (1979) "Evaluation of Design Parameters Obtained by Conventional Sampling", Proc., 7th Int. European Conf. Soil Mech. and Found. Engng., Brighton, England, Vol. 2, pp. 81-86.

Milovic, D.M. (1971a) "Effect of Sampling on Some Soil Characteristics", Symposium on Sampling of Soil and Rock, ASTM STP 483, pp. 164-179.

Milovic, D.M. (1971b) “Effect of Sampling on Some Loess Characteristics”, Specialty Session on Quality in Soil Sampling, 4th Asian Conf. Int. Soc. Soil Mech. and Found. Engng., Bangkok, pp. 17-20.

Morgan, J.P. and Mcintire, (1959), “Quarternary Geology of the Bengal Basin, East Pakistan and India”, Bulletin of the Geological Society of America, Vol. 70, pp. 319-336.

Okumura, T. (1971) "The Variation of Mechanical properties of Clay Samples Depending on its Degree of Disturbance", Proc., Specialty Session on Quality in Soil Sampling, 4th Asian Conf., Int. Soc. Soil Mech. and Found. Engng., Bangkok, pp. 73-81.

Rahman, M.M. (2000) “Effects of Sampling Disturbance on Mechanical Properties of Reconstituted Normally Consolidated and Overconsolidated Dhaka Clay”, M. Sc. Engg. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Raymond, G.P., Townsend, D.L. and Lojkasek, M.J. (1971) "The Effect of Sampling on the Undrained Soil Properties of a Leda Soil", Canadian Geotechnical Journal, Ottawa, Vol. 8, No. 4, pp. 546-557.

Sarker, J.K. (1994) "An Experimental Investigation of Sampling Disturbance in Dhaka Clay", M.Sc. Engg. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Schjetne, K. (1971) "The Measurement of Pore Pressure During Sampling", Proc., Specialty Session on Quality in Soil Sampling, 4th Asian Conf., Int. Soc. Soil Mech. and Found. Engng., Bangkok, pp. 12-16.

Siddique, A. (1990) "A Numerical and Experimental Study of Sampling Disturbance", Ph.D. Thesis, University of Surrey, England, U.K.

Siddique, A. and Clayton, C.R.I. (1995) "Influence of Tube Penetration Disturbances on Undrained Shear Characteristics of a Clay", Indian Geotechnical Journal, Indian Geotechnical Society, Vol. 25, No. 4, pp. 415-428.

Siddique, A. and Clayton, C.R.I. (1998) "Numerical Prediction of Tube Sampling Strains for Realistic Samplers", Proc., 12th Engineering Mechanics Conference, ASCE, La Jolla, California, pp. 558-561.

Siddique, A. and Farooq, S.M. (1996) "Effects of Stress Release on the Strength of Coastal Soils", Indian Geotechnical Journal, Indian Geotechnical Society, Vol. 26, N0. 3, pp. 169-285.

Siddique, A. and Rahman, M. (2000) "Influence of Tube Sampling Disturbance in Dhaka Clay", Proceedings, Geotechnical Engg. Conf. `Year 2000 Geotechnics`, AIT, Bangkok, Thailand.

Siddique, A. and Sarker, J.K. (1995) "Effect of Tube Sampling Disturbance in a Soft Clay", Proc., 10th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Beijing, China, pp. 79-82.

Siddique, A. and Sarker, J.K. (1996) "Experimental Investigation of Sampler Design on Undrained Shear Properties of a Clay", Journal of the Institution of Engineers (India), Civil Engineering Division, Vol. 77, pp. 135-139.

Siddique, A., Farooq, S.M. and Clayton, C.R.I. (2000) "Disturbances Due to Tube Sampling in Coastal Soils", Journal of Geotechnical and Geoenvironmental Engineering, Vol. 126, No. 6, pp. 568-575.

Notations

A_c	=	activity
C_c	=	compression index
C_s	=	swelling index
c_v	=	coefficient of consolidation
D_i	=	internal diameter of the cutting edge of the sampler
D_s	=	inside diameter of the sampler tube
D_e	=	external diameter of the sampler
e	=	void ratio
e_0	=	initial void ratio
E_i	=	initial tangent modulus
E_{50}	=	secant stiffness at half the peak deviator stress
k	=	coefficient of permeability
LL	=	liquid limit
m_s	=	coefficient of volume expansion
m_v	=	coefficient of volume compressibility
OCA	=	outside edge cutting angle
PL	=	plastic limit
PI	=	plasticity index
q_u	=	unconfined compressive strength
s_u	=	undrained shear strength
t	=	thickness of the sampler
t_{90}	=	time corresponding to 90% consolidation
UU	=	unconsolidated undrained test
ε_p	=	axial strain at peak deviator stress
γ_w	=	unit weight of water