Comparison of Sample Disturbance between Standard Sampling and Current Practices in Bangladesh

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

(Sharmin Akhtar)

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NOTATION

AR = Area Ratio;

C_c = Compression index;

I_p = Plasticity index;

q_u = Unconfined compressive strength

SPT = Standard penetration test;

w_L = Liquid limit;

w_n = Natural Water Content;

w_p = Plastic limit;

γ_d = Dry unit weight;

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ABSTRACT

Shelby tubes are usually used in Bangladesh for collecting undisturbed samples. Shelby tubes are cheaper as compared to any other tubes and easy to handle. However, the tubes used in Bangladesh do not conform to the standard specifications. The Conventional Shelby Tubes have highly frictional undulated surfaces, high area ratio and higher cutting edge angle. Thus Conventional Tube samples are expected to be disturbed during intrusion and extrusion. To overcome these shortcomings, a Modified Shelby Tube sampler was fabricated which have thin smooth wall surfaces, low area ratio and sharp cutting edge. To compare the extent of sample disturbance of both Conventional and Modified Shelby Tube samples, soil samples were collected by using both the samplers from the same location and depth, and taken to the laboratory to determine strength and compressibility characteristics of both samples.

From the test results it was observed, in general, Modified Shelby Tube samples had larger undrained shear strength as compared to those of Traditional Shelby Tube samples. Also, the Modified Shelby Tube samples showed less compressibility than those of Traditional Shelby Tube samples. Due to more disturbance, Traditional Shelby Tubes samples had larger compression index, coefficient of consolidation and coefficient of volume compressibility. Considering vertical permeability characteristics, Modified Shelby Tube sample showed greater permeability than those of Traditional Shelby Tube samples indicating that sample disturbance may reduce the permeability of clay. Finally it might be concluded that Traditional Shelby Tube samples yield more disturbed samples than Modified Shelby Tube.

CHAPTER 1
INTRODUCTION

1.1 General

For foundation problems in soils, the geotechnical engineer is concerned with the stability and deformations of soil strata. The problems include the design of pile and raft foundations, excavations, embankments and retaining walls. To solve these foundation problems, geotechnical engineers would require subsoil investigation data including properties of soil. The properties of soil can be estimated from field test data or directly obtained from laboratory testing on undisturbed samples. In the laboratory the stresses, deformations and boundary conditions can be more readily and accurately controlled and observed. However samples are greatly disturbed during drilling, sampling, transportation, extrusion, sample preparation and early stages of testing (Siddique, 2000). Current practice of undisturbed sampling in Bangladesh is not up to the mark. Usually undisturbed samples are collected using nonstandard Shelby tube samplers. Most of them have high area ratio, very rough inner surface, irregular cross sections and no specification for cutting edge. It has long been recognized that if side friction becomes too large the sample will have jamming in the tube. Apart from the inconvenience of low percentages of recovery, this is associated with very high levels of disturbance (Clayton and Siddique, 1999). This type of undisturbed sample may lead to very conservative design of foundations causing more foundation cost.

Regarding the extent of sampling disturbance in clays, one of the most important contributory factors is the design of the sampler. Soil disturbance can be minimized by careful sampling process and also to large extent by using properly designed sample tubes. The design of sampler is one of the most important aspect that should be considered for quality sampling.

1.2 Background of the Study

The engineering properties of soils needed for geotechnical analyses and designs are estimated either from results of in situ testing or laboratory investigation. In situ testing suffers from a number of disadvantages, such that it is not an entirely satisfactory procedure. These disadvantages include poorly defined boundary conditions in terms of stresses and deformations, and uncertain drainage conditions of the clay soil under investigation (Jamiolkowshi et al., 1985). The alternative approach entails describing and investigating a soil sample in the laboratory, having previously retrieved it from the ground using some form of sampling procedure. In the laboratory the stresses, deformations and boundary conditions can be more readily and accurately controlled and observed (Jamiolkowski et al., 1985). Sampling approach has therefore been widely adopted.

For convenience, samplers may be classified as either block, rotary or tube. In Bangladesh, tube sampling and laboratory testing provides the conventional method of obtaining geotechnical parameters from clays whether they be soft, firm, stiff or hard. Here conventional locally made thin-walled open drive mild steel tubes known as (Shelby tube) without piston is widely used for undisturbed sampling in clays and silts. As the cost of Shelby tube is less than the others, hence it is more economic.

Unfortunately, the Samplers in use today in Bangladesh do not conform to any standard specifications. The degree of disturbance varies considerably depending upon the precise design of the cutting shoe of sampler and the dimensions of the sampler tube (Hvorslev, 1949; Jakobson, 1954; kallstenius, 1958; Kubba, 1981; Andresen, 1981; La Rochelle et al., 1981; Baligh et al., 1987; Siddique, 1990; Siddique and Clayton, 1998; Clayton et al., 1998; Clayton and Siddique, 1999; Siddique et al., 2000; Bashar et al., 2000). It has long been recognized that if side friction becomes too great the sample will jam in the tube (Clayton and Siddique, 1999). This is associated with very high levels of disturbance. The way in which the samplers are maintained and used also has a significant effect on the quality of the sample. The tube should be smooth to reduce inside friction as far as possible. (Hvorslev, 1949) recognized the importance of controlling the way in which tube samplers are introduced in to the ground. Therefore, it is found that if the specifications of the samplers are not properly designed and the controlling of the sampling process is not maintained, the strength parameters of the testing soils will be less than the proper parameters. As a result the design of footing size, pile size will be increased and the design will be over designed. Hence, the total cost will also be increased. Those engineers who carry out site investigations in an attempt to obtain realistic soil parameters must take cutting shoe and sampler design into account if they are obtain suitable samples for advanced laboratory testing (Clayton and Siddique, 1999). Hence, in this test, precisely designed Shelby tubes were used by careful control of the whole sampling process to minimize the soil disturbance and then the test result will be compared with the usually used Shelby tube.

1.3 Objectives of the Study

The present study is aimed at the following objectives:

i. To design and fabricate Shelby Tube samplers.

ii. To compare undrained shear strength of samples collected by using Traditional and Modified Shelby Tube sampler.

iii. To compare compressibility properties of samples collected by using Traditional and Modified Shelby Tube samplers.

1.4 Methodology

Modified Shelby tubes are made as per recommendations of ISSMFE (1965) having inside diameter 72 mm, wall thickness 2 mm, area ratio 11.4%, no inside clearance, leading edge taper angle 60^0 up to thickness of 0.3 mm, cutting shoe taper angle 12^0, external diameter to thickness ratio 38 and smooth inner surface. Continuous undisturbed sampling was done in three locations, one in Narayanganj and other two are in Khulna city. In each location two borings were done within 1 m distance. In one boring, Traditional Shelby tube samplers of Bangladesh were used and in another boring, Modified Shelby tube samplers were used to collect undisturbed samples. Modified and Traditional Shelby tube samples were brought to Geotechnical Laboratory of BUET to perform routine index tests, unconfined compression tests and consolidation tests. Finally the results were compared to see the extent of sample disturbance of Modified and Traditional Shelby tube samples.

1.5 Organization of the Thesis

The thesis is arranged into five chapters and one appendix. In Chapter One, background and objectives of the research is described. Chapter Two contains the literature review where history, use and researches on Sample disturbance are described. In this chapter description of apparatus Shelby tube are given.

Chapter Three describe the testing arrangement and program. Chapter Four contains results and discussion. Chapter Five contains the conclusions and recommendations for further research. All graphs of testing results are presented in Appendix A.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The availability of good mechanical soil properties for design depends on careful testing. Testing may be performed in the field or in the laboratory, but in both the cases the most significant factor is controlling the quality of the results likely to be the avoidance of soil or sample disturbance. The mechanisms of sample disturbance have been well understood since 1940s (Hvorslev, 1940 and 1949; Jakobson, 1954; Kallstenius, 1958). Disturbances to soil in its widest sense occur during drilling, during the process of sampling itself and after sampling. A number of different procedures are adopted for measuring, analyzing and correcting the effects of soil sampling disturbance and, in order to highlight the importance of the present research, it is necessary to review previous investigations on sample disturbance.

There has been a wide range of reported observation on the effects of sample disturbance on different types of soils. Some direct investigations considered the effects of major causes of disturbances on the stress-strain and strength properties of soils while other indirect observations were concerned more with the design, use and maintenance of samplers and the development of sampling techniques. In this chapter, effects of sample disturbance on the mechanical behavior of clay soils, is discussed both qualitatively. The effect of design parameters, dimensions of sampler and sampling methods on the measured soil parameters are reviewed. The existing methods for assessing and correcting for sample disturbance are also presented.

2.2 Sample Disturbance in Clays

Any sample of cohesive soil being obtained from the ground, transferred to the laboratory and prepared for testing will be subjected to disturbance. The mechanisms associated with disturbance can be classified as follows (Hvorslev, 1949):

a) Changes in stress condition;

b) Mechanical deformation;

c) Changes in water content and voids ratio; and

d) Chemical changes.

Changes in stress conditions occur as total stresses being applied to the sample of soil change. Mechanical deformations applied to the soil sample while the sample experiences no change in volume. Changes in water content can be an overall swelling or consolidation of the sample, or a redistribution of moisture due to the setting up of pore pressure gradients. Chemical changes are associated with the change in chemical properties of the soil particles, inter-particle bonding or pore water. These mechanisms can occur at different stages during the process of transferring a soil sample from the ground to the laboratory, and during preparation for testing.

A geotechnical engineer is fundamentally concerned with the physical and stress-strain-strength, compressibility and permeability properties of the soil under investigation. If the effective stress, fabric or structural features in a sample of soil are altered during the sampling process, then the soil sample in laboratory will no longer exhibit the same physical properties as it would in situ. It is therefore important to understand where, in the sampling and testing process, the afore-mentioned mechanisms are occurring. It is important to know what affect, both qualitatively and quantitatively, they have on the physical properties being measured. In addition, it is important to establish whether the effects of these mechanisms on the physical properties being measured can be assessed and corrected.

2.2.1 **Causes of Sample Disturbance**

The physical process of obtaining samples has been recognized as a prime cause of sample disturbance. Causes of sampling disturbance have well been identified in the past (Hvorslev, 1949; Rutledge, 1944; Kallstenius, et al, 1981):

i. Disturbance of the soil to be sampled before the beginning of sampling as a result of poor drilling operation.

ii. Mechanical distortion during the penetration of the sampling tube into the soil

iii. Mechanical distortion and suction effects during the retrieval of the sampling tube.

iv. Release of the total in-situ stresses.

v. Disturbance of the soil during transportation, storage and sample preparation.

The first cause can be reduced by sampling with properly cleaned boreholes advanced by using bentonite slurry. The second and third causes are directly associated with sampler design and can be controlled to certain extent. The fourth cause is unavoidable even though its effects may be different depending on the depth of sampling and soil properties. The fifth cause can be reduced by storing samples for minimum time in controlled atmosphere and careful handling of samples during transportation and preparation.

Mechanism and causes of sampling disturbance were summarized by Clayton (1986). Detail descriptions of the disturbances caused during boring, excavating, sampling, transportation, storage and sample preparation were reported by a number of researchers (Hvorslev, 1949; Hight and Burland, 1990; Clayton, 1986; Bjerrum, 1973; Kallstenius, 1971; schjetne, 1971; Baligh, 1985; Chain, 1986; Baligh et al., 1987; Bozozuk, 1971; Arman and Mcmanis, 1976; La Rochelle et al., 1976; Kirkpatrick and Khan, 1984; Graham et al., 1987; Sone et al., 1971; Shackel, 1971; Kimura and Saitoh, 1982; Baldi et al., 1988; Brand, 1975; Chandler et al., 1993; Siddique, 1990; Hajj, 1990; Hopper, 1992; Siddique and Sarker, 1996; Rahman and Siddique, 2002).

2.2.2 Disturbance during Boring and Excavating

Disturbances occurring during the boring of a borehole or excavation of a trial pit are the starting point of sample disturbance. Formation of hole in the ground modifies the stresses, can impose strains, and even lead to failure of the soil at the base of the hole. The disturbances are dependent on both the type of boring or excavating technique, and the type of soil. Auger boring techniques can impose considerable downward thrusts on the base of the borehole, and can induce high suction forces during withdrawal. There is a risk of the auger loading on the base of the hole and causing disturbance; the base of the hole may be irregularly shaped. Percussion drilling can cause severe remolding at the base of the borehole, due to the chopping action of the boring technique. Hvorslev (1949), and Hight and Burland (1988), stated that rotary drilling techniques cause the least disturbance during boring. In soft clays rotary drilling, using a fish tail bit and upward baffles, is recommended to prevent scour ahead of the bit. Hvorslev (1949), ISSMFE (1965) and Broms (1980) stated that the borehole should always be cleaned out before sampling is commenced. BS: 5930 (1981) and Clayton (1986) commented on the importance of ensuring good maintenance of equipment, good drilling technique and expert and detailed supervision.

Reduction in total vertical and total lateral stresses due to removal of soil from the borehole is another principal cause of sample disturbance during drilling. Swelling at the base of borehole occurs as a consequence of stress relief. The process is fast and unavoidable in granular soil in cohesive soils; however, swelling can be reduced by sampling as quickly as possible following boring. The amount of swelling that occurs is proportional to the change of total stress occurring at the base of a borehole. Thus if the borehole is substantially empty of water there is likely to be more swelling than if the borehole is kept full of mud or water. Other severe effects of stress relief during drilling on soil are base heave, piping and caving (Clayton et al., 1982). Base heave can be thought of as foundation failure under decreased vertical stress. When t he total stress relief at the base of a borehole is very great compared with its untrained shear strength, plastic flow of soil may take place upwards into the borehole. Failure in a borehole by base heave can occur in very soft soils if the water level is kept too low (Begemann, 1977). When a borehole is inducing total stress relief, and water balance is insufficient to prevent high seepage pressure gradients in the soil at the base of the hole, large volumes of fine granular soil may move up into the casing. Soil below the bottom of the casing will be brought to very loose state. This phenomenon is called piping. Both base heave and piping can be reduced by keeping the hole full of water. Caving typically occurs when boreholes are advanced into soft, loose or fissure soils.

Material from the sides of the borehole collapses into the bottom of the hole and must be cleaned out before sampling can take place.

2.2.3 **Disturbance during Sampling**

Hvorslev (1949) described the two main groups of sub-surface sampling methods in cohesive soils as drive sampling and rotary boring. Drive sampling is further sub-divided into open-drive samplers and piston-drive samplers.

Hvorslev (1949) described the forces acting on an element of soil while it is being sampled using a tube sample. There are two main forces associated with sampling. The first is that occurring as the soil is displaced by the advancing cutting edge. This can cause quite considerable shear strains, and possibly large forces. The second disturbing force in the soil during tube sampling is that caused by friction or adhesion between the samples to get altered. Bjerrum (1973) also reported that due to friction between the clay and the sampling tube, the outer zone of the sample becomes remolded. The greatest amount of disturbance is experienced in clays of low plasticity. Clays with pronounced cohesive properties will undergo fewer disturbances. In soft clay, remoulding at the periphery produces large positive pore pressures. During the period following sampling the pore pressures tend to equalize with those in the core of the sample causing an overall increase in pore water pressure (Kallstenius, 1971; Bjerrum, 1973; Schjetne, 1971). Kallstenius (1971) found that the outer zone of soft clay sample (w = 113.3-117.6%, LL = 135-145, PL = 38-41) was on average 1.5% dryer than the core of the sample, and this was due to water redistribution associated with the equalization of pore water pressure. Bjerrum (1973) has shown that due to remolding and moisture migration, the outer 5 mm of extruded plastic Drammen clay specimens (w = 52 %, LL = 61, PL = 32) typically have a moisture content, about 3 to 4 % lower than at the centre. Bjerrum (1973) concluded that the swelling of the core of the sample associated with water content redistribution was one of the major factors causing disturbance. Baligh (1985), Chin (1986) and Baligh et al. (1987) have predicted the strains imposed on a soil sample during the process of tube sampling using "Strain Path Method".

The "Strain path Method" is based on the superposition of stream functions to generate shapes and deformed grids which simulate the flow of soil around a sample tube. From the deformed shape of the streamlines, the nature and magnitudes of the strains imposed on a sample of soil due to tube sampling have been presented. This analysis based on the superposition of one single ring source and a uniform velocity field. This idealized sample tube has a curved tip and is termed the "Simple Sampler". Baligh (1985) observed that soil elements, at centre-line of the sampler, were subject to three distinct phases, namely:

i. An initial compression phase ahead of the sampler where axial strain increases from zero to a maximum value;
ii. An extension phase near the cutting edge of the sampler where the axial strains reverse from compression to extension and attain a maximum value in extension and attain a constant value.
iii. A second compressive phase inside the sampler tube where axial strain decreases and attains a constant value.

The principle of Baligh's (1985) "Strain Path Method" of streamlines was a significant step in improving understanding of the distortions caused by pushing a sample tube into the ground, but the solutions may not be realistic for real sample tube geometries.

Another important contributory factor to disturbance during sampling is due to release of in-situ total stresses. In response to the reduction of applied total stresses, the pore pressures in a sample will reduce and may normally be expected to become negative. In clays, a smaller average pore size normally precludes the penetration of air. Because of low permeability a considerable period of time may be required for water to penetrate and dissipate the negative pore pressures setup in the sample.

2.3 Sampler Design and its Effect on Sample Disturbance

The design of a sampler is one of the most important factors that should be considered for quality sampling. The amount of disturbance varies considerable depending upon the dimensions of the sampler and the precise geometry of the cutting shoe of the sampler (Hvorslev, 1949; Jakobson, 1954; Kallstenius, 1958; Kubba, 1981; Andresen, 1981; La Rochelle et al. 1981; Baligh et al., 1987; Siddique, 1990; Siddique and Clayton, 1995; Siddique and Sarker, 1996; Tanaka et al., 1996; Siddique and Clayton, 1998; Clayton et al., 1998; Siddique and Farooq, 1998; Clayton and Siddique, 1999, Siddique et al., 2000; Siddique and Rahman, 2000).

Hvorslev (1994) defined the geometry of a sampling tube in terms of its area ratio, length/diameter ratio, and inside clearance ratio, and the International Society for Soil Mechanics and Foundation Engineering (ISSMFE). Working party on Soil Sampling (1965) recognized the very significant importance of cutting-edge taper angle. More recently, Baligh (1995) has preferred to work in terms of diameter/thickness (D_e/t) ratio, rather than area ratio. Traditionally, when developing a new sampling device, a single (more or less) uniform soil would be sample using a range of samplers, and performance would be judged by reference to the average and scatter of some index parameter such as unconsolidated undrained strength. Investigations of these sorts showed the importance of the details of cutting shoe design, and subsequently led to the recommendations of the ISSMFE. Experience suggests that the most important factor governing sample disturbance is the combination of area ratio and cutting-edge taper angle.

2.3.1 **Effect of Diameter, thickness and Length of Sampler**

Hvorslev (1949) stated that the amount of disturbance would be decreased with increasing diameter of the sample. Berre et al. (1969) observed that larger tube samples showed more constant behavior than those from small tube samples. Ocdometer tests carried out on samples of soft marine clay in Norway indicated that a 95 mm piston sampler (area ratio, AR - 14%, inside clearance ratio, ICR = 1.4%) gave less disturbance than a 54 mm piston sampler (AR = 12%, ICR = 1.3%).

An investigation of the difference in quality of samples taken with large diameter fixed piston samples and the 50 mm diameter Swedish Standard piston sampler (AR = 21%, ICR = 0.4%, outside cutting edge taper angle = 5°) was carried out by Holm and Holtz (1977). The large diameter piston samplers used were the 95 mm NGI (Norwegian Geotechnical Institute) research sampler (AR = 14%, ICR = 1.4%, outside cutting edge taper angle = 10°), the 127 mm Osterberg sampler (AR = 18%, ICR = 0.4%, outside cutting edge taper angle = 7°) and the 124 mm SGI (Swedish Geotechnical Institute) research sampler (AR = 27%, ICR = 1.2%, outside cutting edge taper angle = 5°). The investigation has shown that the results of oedometer tests on 50 mm samples are more scattered, supporting findings of Berre et al. (1969). The undrained modulus obtained from 50 mm samples has been found to be lower.

Bozozuk (1971) performed undrained triaxial tests on 1.4 inch diameter samples of soft marine clay. Samples were obtained by the 54 mm NGI piston sampler (AR = 11%, ICR =1%) and the 127 mm Osterberg piston sampler (AR = 6%, ICR = 0.42%). Test results showed that the undrained strengths of samples cut from 127 mm tube sample were higher than those cut from 54 mm tube samples. Samples cut from 54 mm tube samples showed lower stiffness and pore pressure responses.

McManis and Arman (1979) investigated the effect of sampler diameter on the properties of undisturbed soil specimens. The soil types studies were soft organic silty clays and stiff, fissured pleistocene clays. For stiff fissured clay, the strength of the 76 mm diameter tube sample exceeded that of 127 mm diameter specimen. This was attributed to stress release and migration of moisture toward and along the fissure planes. Maguire (1975) also found that for stiff fissured overconsolidated clay the undrained strength increased with decreasing diameter of sample. However, for soft silty clay, McManis and Arman (1979) found that 127 mm tube specimens exhibited strengths greater than that of 76 tube specimens.

Conlon and Isaacs (1971) carried out unconsolidated undrained triaxial compression tests on specimens of sensitive lacustrine clay of medium to high plasticity. The clay was sampled using 73 mm outside dia. Thin-walled Shelby tube and 127 mm outside dia. fixed rod thin-walled piston sampler. Conlon and Isaacs (1971) observed that disturbance increased as the size of the tube decreased. An investigation of the difference in quality of samples taken with large diameter fixed piston samplers and the 50 mm diameter Swedish Standard piston sampler was carried out by Holm and Holtz (1977). The large diameter piston samplers used were the 95 mm NGI research sampler, the 127 mm Osterberg sampler and the 124 mm SGI research sampler. The investigation has shown that in general no significant differences between either the ratio (preconsolidation pressure/in-situ vertical stress) or undrained shear strength derived from laboratory tests on specimens obtained by the various devices, but there are indications that:

a) Results of oedometer tests on 50 mm samples are more scattered, supporting findings of Berre et al. (1969)

b) The undrained modulus obtained from 50 mm samples is lower.

Holm and Holtz (1977), however, concluded that for routine investigations in soft Swedish clays, there seems to be no need to perform sampling with large diameter piston samplers.

Kubba (1981) investigated the effect of thickness of tube on sampling disturbance for a reconstituted Spestone Kaolin (LL = 51, PI = 30). Tube samples were obtained by inserting 38 mm diameter tubes of different wall thickness into a 102 mm diameter "perfect” sample. Three tubes of thickness to diameter ratios of 0.039, 0.072 and 0.105 were used for sampling. Kubba (1981) found that increasing the ratio of wall thickness to diameter of the tube caused a qualitative increase in the degree of disturbance.

Sampler quality is also related to the length to diameter ratio of the sampler. One of the major factors controlling sampler jamming is the length to diameter ratio of the sampler. The optimum length to diameter ratios suggested for clays of different sensitivities are shown in Table 2.1 as follows (ISSMFE, 1965).

Table 2.1: Optimum length to diameter of sampler for various sensitivity of soil (after ISSMFE, 1965)

Sensitivity, S_t	Length to Diameter ratio
>30	20
5 to 30	12
< 5	1

2.3.2 Effect of Area Ratio and Cutting Edge Taper Angle

Area ratio is considered one of the critical parameters affecting the disturbance of soil during sampling. Increasing area ratio gives increased soil disturbance and remolding. The penetration resistance of the sampler and the possible of the entrance of excess soil also increase with increasing area ratio. For soft clays, area ratio is kept to a minimum by employing thin-walled tubes. For composite samplers, the area ratio, however, is considerable higher. In these cases, sample disturbance is reduced by tapering the outside of the sampler tube very gradually from a sharp cutting edge (Hvorslev, 1949), recommended a maximum 10^0, so that the full wall thickness is far removed from the point where the sample enters the tube.

Jakobson (1954) investigated the effect of sampler type on the shear strength of clay samples. Samples were collected using nine different types of samplers. These types differ from one another in area ratio, edge angle, inside clearance, drive velocity and other factors. Shear strength of samples was determined by carrying out the unconfined compression tests, the cone test and the laboratory vane test. It was found than an extremely small area ratio offers no special advantages and that the cutting edge taper angle does not seem to have any great influence. However, a very large area ratio or cutting edge taper angle is not recommendable. Kallstenius (1958) also studied the effect of area ratio and cutting edge taper angles on the shear strength of Swedish clays. He carried out tests similar to those reported by Jakobson (1954) on samples obtained using six types of piston samplers. Kallstenius (1958) recommended that a sampler ought to have a sharp edge and a small outside cutting edge taper angle (preferably less than 5^0).Very large OCA has also been not recommended by Jakobson (1954) and Andresen (1981). The combined requirements for area ratio and cutting edge taper angle of cause low degrees of disturbance were proposed by the International Society for Soil Mechanics and Foundation Engineering's Sub-Committee on Problems and Practices of Soil Sampling (1965). For samplers of about 75 mm diameter, they suggested the following (Table 2.2) combinations of area ratio and cutting edge taper:

Table 2.2: ISSMGE recommended outside cutting edge taper angle (after ISSMFE, 1965)

Area Ratio (%)	Outside Cutting Edge Taper (°)
5	5
10	12
20	9
40	5
80	4

Clayton and Siddique (1999) reported that sampling tubes having good sampler geometries are available, which are capable of reducing tube sampling strains to acceptably low levels. Siddique and Clayton (1995) reported that the higher the tube sampling strains, the greater is the changes in the undrained soil parameters.

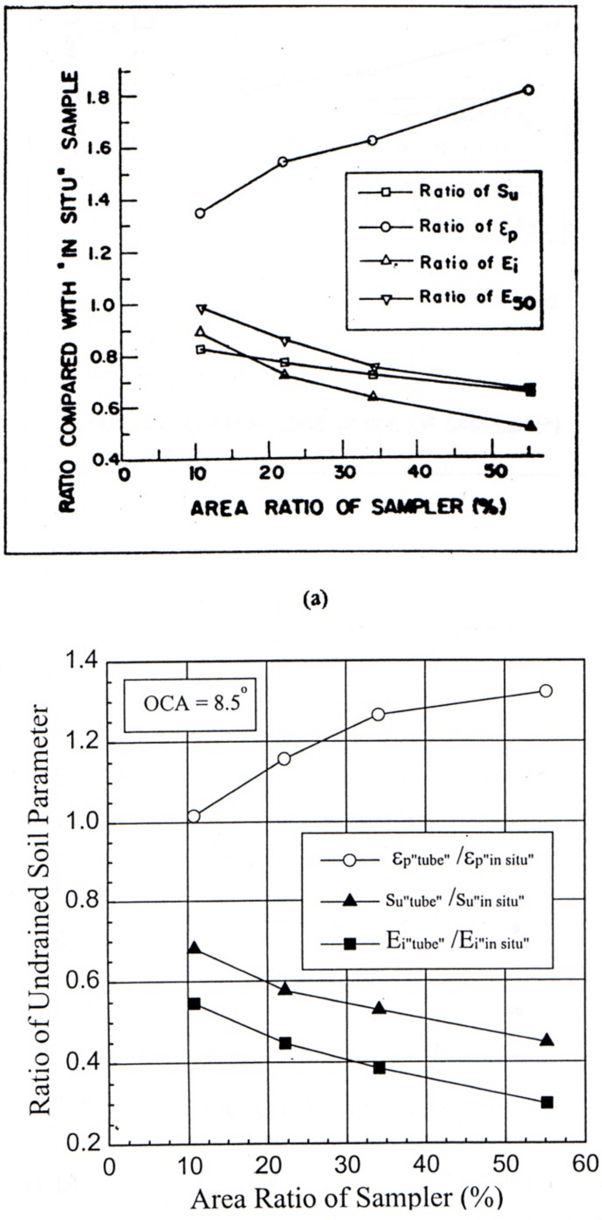
Siddique and Sarker (1996) investigated the effect of area ratio and outside cutting edge angle on undrained soil parameters of reconstituted Dhaka clay by carrying out undrained triaxial compression tests and one-dimensional consolidation tests on tube samples collected with samplers of varying area ratio and outside cutting edge angle. Siddique and Sarker (1996) reported that, for Dhaka clay, initial effective stress (σ'_i), undrained strength (S_u), initial stiffness (E_i) and secant stiffness (E_{50}) were reduced up to 41.5%, 35%, 49% and 34%, respectively, while axial strain at peak strength (ε_p) was increased up to 81% due to increase in area ratio from 10.8 to 55.2%. Siddique and Sarker (1996) also reported that σ_i', S_u, E_i and E_i, and E_{50} were reduced up to 36.9%, 32%, 41% and 31%, respectively while ε_p was increased up to 81% due to increase in OCA from 4° to 15° for Dhaka clay. They found that Skempton's pore pressure parameter, A at peak deviator stress, A_p reduced considerably as area ratio increased and the values of A_p of the "tube" samples of different area ratios are negative.

Siddique et al. (2000) reported that σ_i', S_u, E_i reduced while ε_p increased due to increase in area ratio and OCA for three Chittagong coastal soils. Siddique et al. (2000) also found that A_p reduced considerably due to increase in area ratio and OCA. Siddique and Rahman (2000) also reported that increase in area ratio of sampler caused increasing reductions in σ_i', S_u, E_i, E_{50} and increasing the area ratio of the sampler, however, caused an increase in ε_p. The results are shown in Table 2.3. Compared with "in situ" samples, it has been found that the values of A_p are decreased significantly with the increase of area ratio.

The effects of area ratio of samplers on undrained soil parameters for samples of Dhaka clay (Siddique and Rahman, 2000) and a coastal soil (Siddique et al., 2000) are presented in Figs. 2.1 (a) and 2.1 (b), respectively. It can be seen from Figs. 2.1 (a) and (b) that strength and stiffness's decrease with the increase in area ratio while strain at peak strength increases with the increase in area ratio of "tube" samples. Increase in the degree of disturbance due to increasing area ratio and outside cutting edge angle has been reported by Kallstenius (1958), Andresen (1981) and has also been predicted numerically by Clayton et al. (1998).

Table 2.3: Effects of Area Ratio (AR) and OCA on Soil Sampling of Samples of Normally Consolidated Reconstituted Regional Soils of Bangladesh.

Location of soil	Sampler dimensions			% Change in properties compared with "in situ" sample					Reference
	t (mm)	AR (%)	OCA (°)	Reduction of p'_o	Reduction of s_u	Increased of ε_p	Reduction of E_i	Reduction of E_{50}	
Dhaka LL=45 PI = 23	1.5	10.8	8.5	18.5	17	35	11	1	Siddique and Sarker (1996)
	3.0	22.2	8.5	26.2	23	54	28	14	
	4.5	34.1	8.5	33.8	28	62	36	25	
	7.0	55.2	8.5	41.5	35	81	49	34	
	4.5	34.1	4	21.5	21	54	15	8	
	4.5	34.1	15	36.9	32	81	41	31	
Patenga LL =44 PI =18	1.5	10.8	8.5	8.3	32	19	34	—	Siddique et al. (2000)
	3.0	22.2	8.5	10.1	38	46	42	—	
	4.5	34.1	8.5	17.3	43	67	50	—	
	7.0	55.2	8.5	33.5	55	78	74	—	
	4.5	34.1	4	13.7	42	62	47	—	
	4.5	34.1	15	23.6	46	70	61	—	
Fakirhat LL=43 PI =22	1.5	10.8	8.5	7.3	34	4	31	—	
	3.0	22.2	8.5	11.8	47	6	42	—	
	4.5	34.1	8.5	16.4	47	26	62	—	
	7.0	55.2	8.5	30.0	55	32	70	—	
	4.5	34.1	4	14.5	46	21	56	—	
	4.5	34.1	15	20.9	48	27	69	—	
Kumira LL-57 PI - 33	1.5	10.8	8.5	5.7	34	4	31	~	
	3.0	22.2	8.5	10.0	47	6	42	--	
	4.5	34.1	8.5	12.6	51	8	52	—	
	7.0	55.2	8.5	22.7	56	13	76	—	
	4.5	34.1	4	11.8	50	8	50	—	
	4.5	34.1	15	18.7	51	11	62	—	
Dhaka LL = 47 PI = 26	1.5	16.4	5	9.0	22	13.4	32	33	Siddique and Rahman (2000)
	3.0	34.1	5	11.8	26	29.9	42	45	
	4.5	53.0	5	16.8	32	40.2	50	52	
	6.0	73.1	5	26.2	43	57.7	62	65	



(a)

(b)

Fig.2.1 Influence of area ratio of sampler on undrained soil parameters for samples: (a) Dhaka clay (after Siddique and Sarker, 1996), (b) Fakirhat soil (after Siddique et al. 2000).

Siddiquc and Rahman (2000) and Siddique et al. (2000) investigated the effects of outside cutting edge angles (OCA) of samplers on undrained soil parameters for samples of Dhaka clay and a coastal soil. Fig. 2.2 shows the influence of OCA on undrained soil parameters. It can be seen from Figs. 2.2 (a) and (b) that strength and stiffness's decrease with the increase in OCA while strain at peak strength increases with the increase in OCA of "tube" samples. The effects of area ratio and outside cutting edge angles (OCA) on soil properties due to tube sampling for the regional clays of Bangladesh are also summarized in Table 2.3.

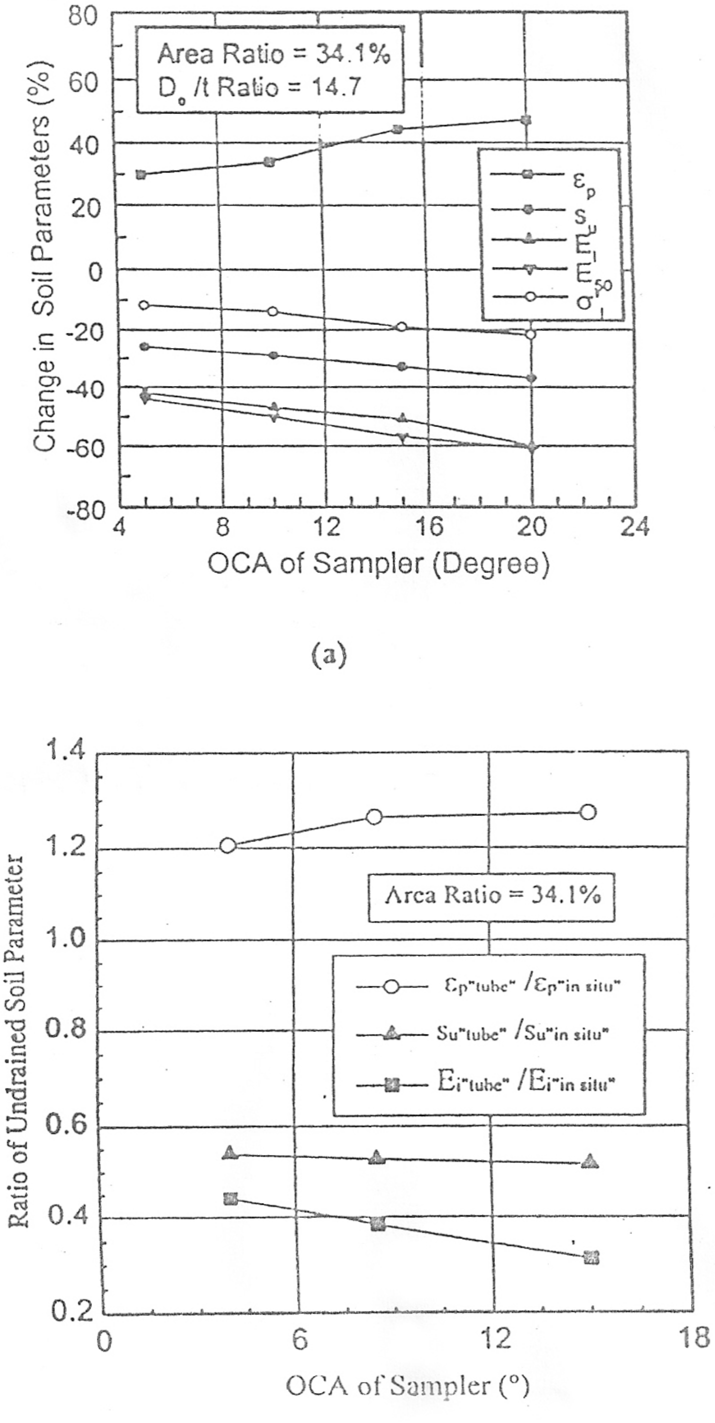
Clayton et al. (1998) implemented a method via a finite element approach to assess the influence of cutting shoe geometry (AR, OCA, ICR, cutting edge taper angles) on tube sampling disturbance. Degree of disturbance has been assessed in terms of predicted tube sampling strains in compression and extension at the centerline of soil sample. Figs. 2.3 and 2.4 show the variation of peak axial strain in compression with area ratio and outside cutting edge angle of sampler, respectively. It can be seen from Figs. 2.3 and 2.4that the peak axial strains in compression increase with increasing area ratio and outside cutting edge angle of sampler. It can be seen from Fig. 2.3 that the imposed tube sampling strains predicted numerically and the predicted strains increased with increasing area ratio of the samplers. It can also be seen from Fig. 2.4 that the predicted strain increased with increasing outside cutting edge angle of the samplers.

Clayton et al. (1998) concluded that in order to restrict the degree of disturbance (peak axial strain in compression) to less than 1%, a sampler should have the following values of design parameters:

The sampler should have a low area ratio, preferably not more than 10%.

The sampler should have a moderate inside cutting edge taper angle of 1 to 1.5°.

The sampler should have a small outside cutting edge taper angle, preferably not more 5°.



(a)

(b)

Fig.2.2 Influence of Outside Cutting Edge Angle (OCA) of Sampler on Undrained Soil Parameters for Samples (a) Dhaka Clay (after Siddique and Rahman, 2000), (b) Fakirhat Clay (after Siddique et al., 2000)

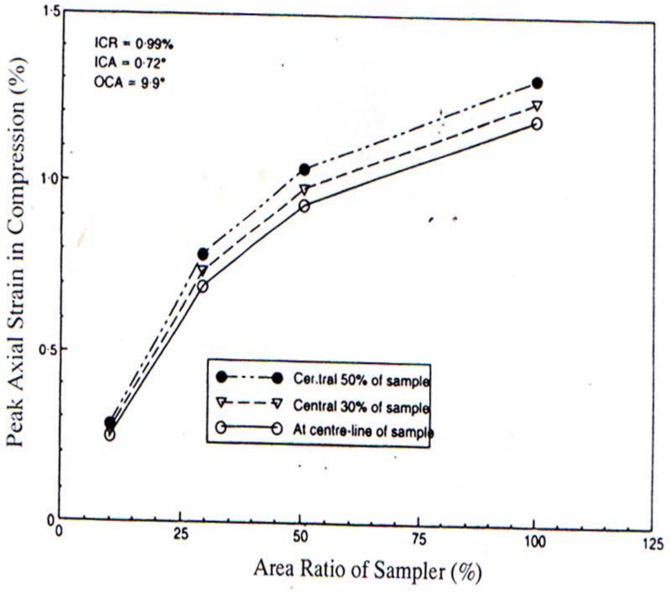


Fig. 2.3 Variation of Peak Axial Strain in Compression with Area Ratio of Samplers (after Clayton et al., 1998)

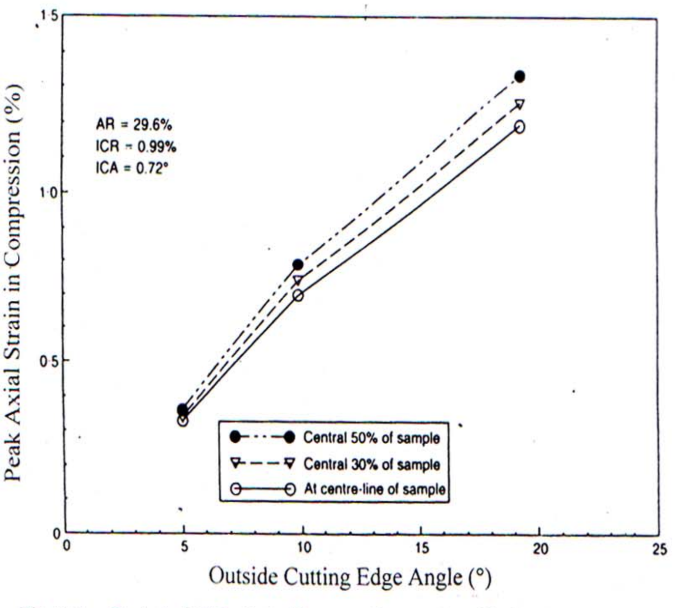


Fig. 2.4 Peak Axial Strain in Compression vs. Outside Cutting Edge Angle of Samplers (after Clayton et al., 1998).

Bashar et al (2000) also investigated the effect of area ratio on three soils collected from Chittagong coastal region. It has been found that increasing area ratio caused increasing reductions in S_u E_i and $E_{50.}$ Increasing area ratio of sampler, however, caused an increase in $E_{50.}$ Compared with the A_p values of the "in-situ" samples, it has been found that the pore pressure responses of the "tube" samples collected with varying area ratio are considerably less, resulting in significantly lower values of A_p. Compared with the "in-situ" sample, the following effects on the measured soil parameters have been observed due to increasing area ratio of samplers:

a) Values of S_u decreased from 27% to 51.5%, 25.8% to 44.5% and 23.5% to 41.4% in samples from Banskhali, Anwara and Chandanaish, respectively due to increase in area ratio from 16.4 to 73.1%.

b) Values of E_{50} increased from 35% to 64.3%, 26% to 58% and 21.3% to 47.7% in samples from Banskhali, Anwara and Chandanaish, respectively due to increasing area ratio.

c) Values of E_i decreased by 374% to 72%, 35.5% to 67.8% and 33.7% to 65.2% in samples from Banskhali, Anwara nad Chandanaish, respectively due about 4.5 times increase in area ratio.

d) Values of E_{50} decreased by 41.2% to 70.7%, 38.2% to 69% and 36.8% to 67.2% in samples from Banskhali, Anwara and Chandanaish, respectively due about 4.5 times increase in area ratio.

The influence of area ratio on undrained shear properties of three coastal soils as reported by Bashar et al (2000) is summarized in Table 2.4.

Table 2.4: Influence of Increasing Area Ratio of Sampler on Undrained Shear Properties of Samples of the Three Coastal Soils (after Bashar, 2000).

Sample designation	Area ratio (%)	D_e/ t ratio	Ratio of			
			S_u (kPa)	ε_p (%)	E_i (kPa)	E_{50} (kPa)
BT	16.4	27.33	0.73	1.35	0.626	0.588
BM	34.1	14.67	0.676	1.53	1.536	0.490
BH	73.1	8.33	0.485	1.64	0.280	0.293
AT	16.4	27.33	0.742	1.26	0.645	0.618
AM	34.1	14.67	0.692	1.44	0.542	0.525
AH	73.1	8.33	0.555	1.58	0.322	0.310
CT	16.4	27.33	0.765	1.21	0.663	0.632
CM	34.1	14.67	0.716	1.31	0.565	0.537
CH	73.1	8.33	0.586	1.48	0.348	0.328

The effects of area ratio of samplers on undrained soil parameters for samples of a coastal soil (Bashar et al, 2000) are presented in Fig. 2.5. It can be seen from Fig. 2.5 that strength and stiffness’s decrease with the increase in area ratio while strain at peak strength increases with the increase in area ratio of “tube” samples.

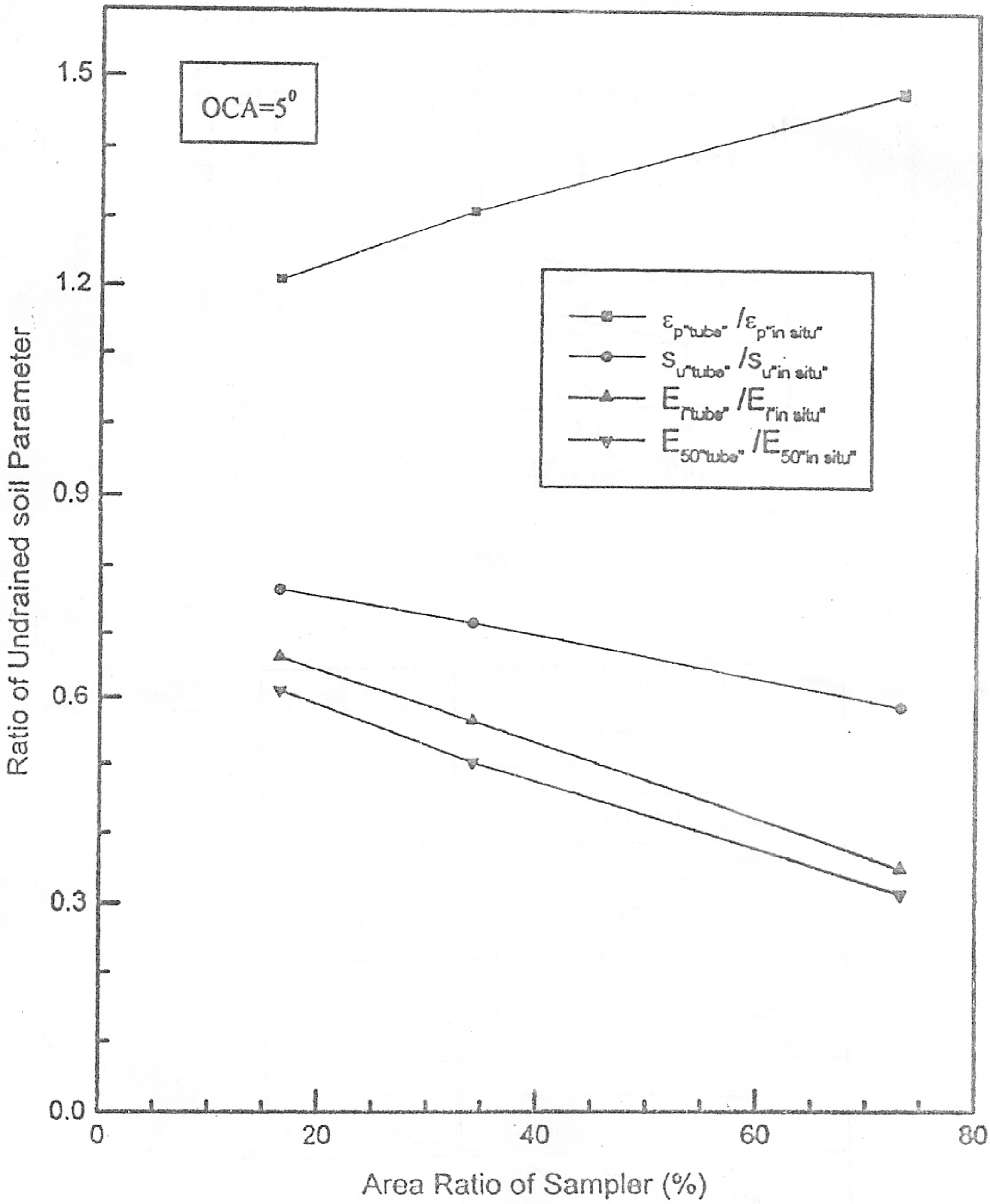


Fig. 2.5: Influence of Area Ratio of Sampler on Undrained Soil Parameters for Samples from Chandanaish (reproduced after Bashar et al, 2000)

Area ratio is considered one of the critical parameters affecting the disturbance of soil during sampling. Hvorslev (1949) defined area ratio as follows:

$$Area.Ratio = \frac{D_e^2 - D_c^2}{D_c^2}$$

Where D_e is the external diameter of the sampler tube and D_c is the internal diameter of the sampler cutting edge as shown in Fig. 2.6.

2.3.3 **Effect of Inside and Outside Clearance Ratio**

Inside wall friction is one of the principal causes of disturbance of the sample (Hvorslev, 1949). One of the methods of reducing of eliminating wall friction between the soil and sampler is to provide inside clearance by making the diameter of the cutting edge, D_c, slightly smaller than the inside diameter of the sampler tube, D_i. The inside clearance ratio is expressed as follows (Fig. 2.6)

Inside Clearance Ratio = $\frac{D_i - D_c}{D_c}$

Inside clearance should be large enough to allow partial swelling and lateral stress reduction but it should not allow excessive soil or loss of the sample when withdrawing from the sampling tube. Hvorslev (1949) suggests an inside clearance ratio of 0.75 to 1.5 % for long samplers and 0 to 0.5% for very short samplers. Kallstenius (1958) on the basis of Swedish clays sampled by six different piston samplers also recommends that a sampler ought to have a moderate inside clearance. The clearance reduces the wall friction and probably counteracts to a certain extent the disturbance from displacement of soil caused by the edge and sampler wall during the driving operation. If the inside clearance and the edge angle are moderate, the above positive effects outweigh the disturbance caused by deformation when the sample tends to fill the clearance. The existence of inside clearance may have detrimental effects on sample disturbance as pointed out by La Rochelle et al. (1981) developed a new sampler with no inside clearance for sampling in soft sensitive soils. This sampler, called the Laval Sampler, is of large diameter (208 mm inside diameter and 218 mm outside diameters) and also without a piston. The area ratio, B/t ratio, and outside cutting edge taper angle of this sampler 10 %, 43.6 and 5^0 respectively. In order to reduce outside wall friction, samplers are often provided with outside clearance which is expressed as follows (Fig. 2.6)

$$\text{Outside Clearance Ratio} = \frac{D_e - B}{B}$$

An outside clearance ratio of a few per cent may decrease the penetration resistance of samplers in cohesive soils. Although outside clearance increases the area ratio, a clearance of 2 to 3 % can be advantageous in clay (Hvorslev, 1949).

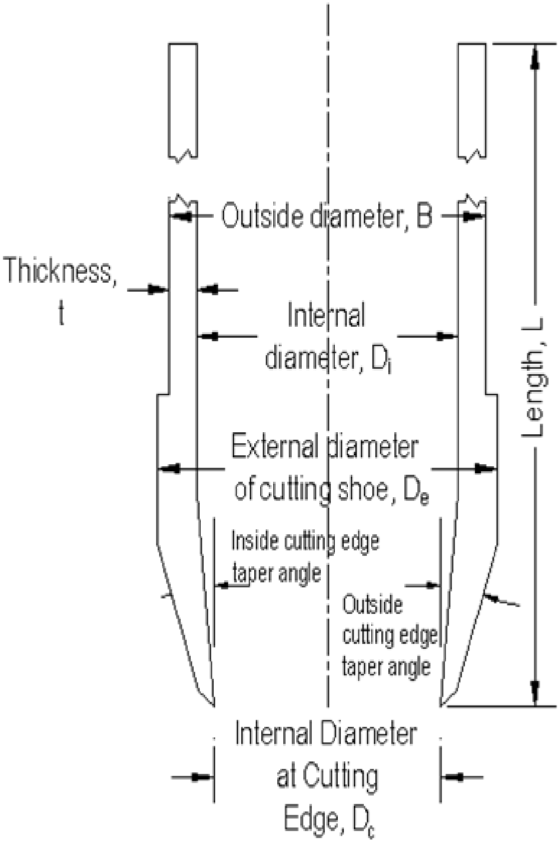


Figure 2.6: Dimensions of a Tube Sampler

2.3.4 Effect of External Diameter to Thickness Ratio (B/ t) of Sampler

Kubba (1981) investigated the effect of thickness of tube on sampling disturbance for a reconstituted Spestone Kaolin (LL = 51, PI = 30). Tube samples were obtained by inserting 38 mm diameter tubes of different wall thicknesses into a 102 mm diameter "perfect" sample. Three tubes of thickness to diameter ratios of 0.039, 0.072 and 0.105 were used for sampling. Kubba (1981) found that increasing the ratio of wall thickness to diameter (t/D_c) of the tube caused a qualitative increase in the degree of disturbance. Kubba (1981) also reported a qualitative increase in the degree of disturbance due to increase in the ratio of thickness to diameter of the samplers.

Chin (1986) showed that, for thin-walled simple samplers (B/t »1), both maximum axial strain in compression and extension at the centerline of sampler is approximately given by the following expression;

$$\varepsilon_{\max} = 0.385\ t/B$$

Siddique and Clayton (1998) and Clayton and Siddique (1999) also reported that both the peak axial strain in compression ahead of the sampler and the maximum axial strain in extension inside the sampler are dependent on the external diameter (B) to thickness (t) ratio of the sampler. From a numerical study on the effect of cutting shoe geometry of a number of realistic samplers on tube sampling strains, it has been observed that peak axial centre line strain in compression and extension decrease with increasing B/t ratio.

Siddique and Sarker (1997), Siddique et al. (2000) and Siddique and Rahman (2000), investigated the degree of disturbance in clays of tube sampling at selected regional soils of Bangladesh. Siddique and Sarker (1996) reported that the values of D_d increased from 0.19 to 0.42 due to increase in area ratio from 10.8 to 55.2 (decrease in B/t ratio from 40.0 to 10.1) and also the values of D_d increased from 0.22 to 0.37 due to increase in OCA from 4° to 15° for reconstituted Dhaka clay. Siddique and Rahman (2000) investigated the variation of degree of disturbance, D_d with the variation of area ratio or B/t ratio for reconstituted Dhaka clay and found similar results as Siddique and Sarker (1996). Siddique et al. (2000) also reported that similar effect of area ratio, OCA and D/t ratio on degree of disturbance obtained for reconstituted three coastal soils.

2.4 Effect of Compressibility on Sample Disturbance

Siddique et al. (2009) investigated the compressibility and expansibility characteristics of “block” and “tube” soft clay samples undergoing incremental loading in an oedometer are presented in Fig. 2.7 and Fig. 2.8. In Fig 2.7, void ratio (e) at the end of each loading and unloading stages have been plotted against logarithm of vertical effective consolidation pressure for samples collected with different area ratio but of fixed OCA (5°). Fig. 2.8 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 for the “tube” samples retrieved with tubes of varying area ratio but of fixed OCA (5°). In Figs. 2.7 and 2.8, the plots of “block” samples are also shown for comparison.

Table 2.5 and table 2.6 show a summary and comparison of the compressibility and expansibility properties of “block” and “tube” samples. It can be seen from table 2.5 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%). It is also evident that the values of e_0 increase with increasing level of disturbance.

A comparison of the values of C_c is presented also in table 2.5 that compared with the “block” sample, the values of C_c increases (between 13% and 30%) and that the values of C_c increases with the increasing level of disturbance. 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 the values of C_c for “tube” samples of normally consolidated soft samples of Dhaka clay (LL = 45, PI = 23) did not change significantly due to disturbance. Farooq (1995) found that compared with “in situ” samples, the values of C_c either increased or decreased for reconstituted normally consolidated soft samples of three coastal soils of Chittagong (LL = 43 to 57; PI = 18 to 33). Hight et al. (1987) found same C_c-value for block, tube and in situ samples.

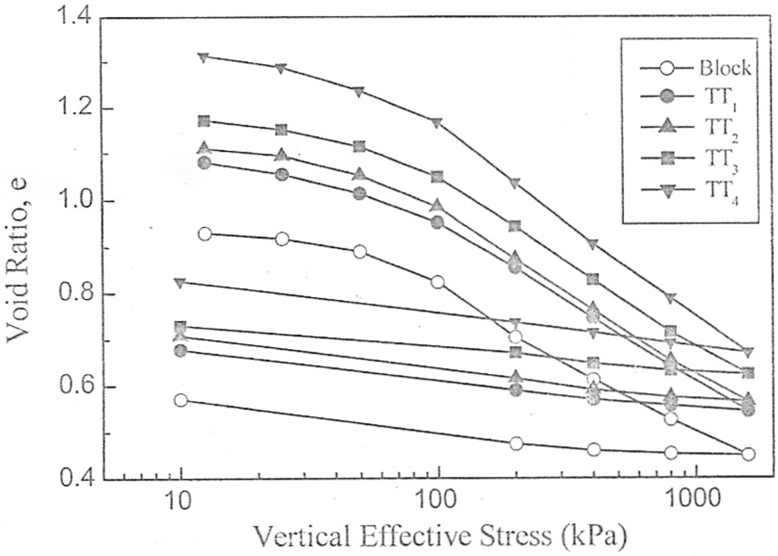


Fig. 2.7: Comparison of Void Ratio vs Vertical Effective Stress Plots of “Block” and “Tube” Samples of Soft Dhaka Clay (after Siddique et al, 2009)

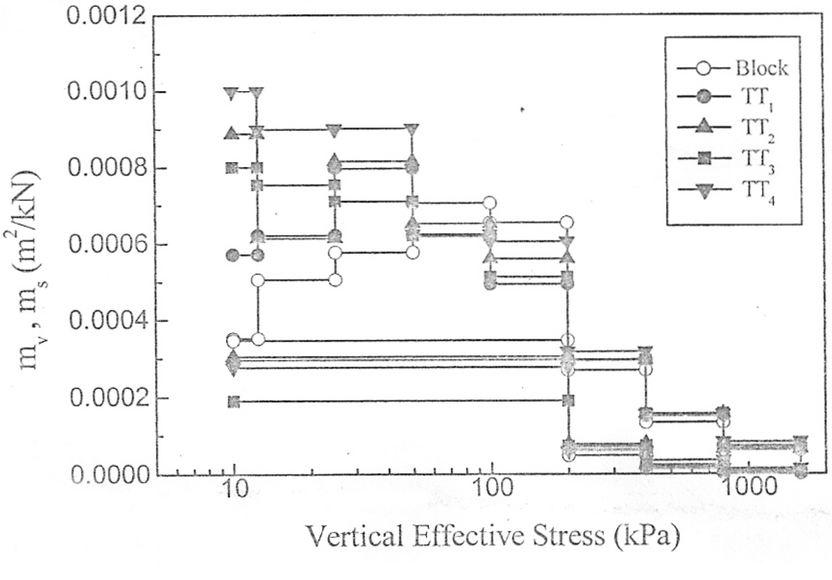


Fig. 2.8: Comparison of Coefficient of Volume Compressibility / Expansibility vesus Vertical Effective Stress Plots of “Block” and “Tube” Samples of Soft Dhaka Clay (after Siddique et al, 2009)

Table 2.5: Comparison of Initial Void Ratio, Compression Index and Swelling index of "Block and "Tube" Samples (after Siddique et al, 2009)

Sample Designation	Initial Void Ratio, e_0	Compression Index, C_c	Swelling Index, C_s
"Block"	0.9382	0.30	0.05
TT1	1.0849	0.34	0.06
TT2	1.1334	0.37	0.06
TT3	1.2212	0.38	0.06
TT4	1.4538	0.39	0.07

Table 2.6: Comparison of Coefficient Volume Compressibility (m_v) and Coefficient of Volume Expansibility (m_s) of "Block" and "Tube" Samples (after Siddique et al, 2009)

Pressure Range (kPa)	Coefficient of Volume Compressibility (m_v)	Coefficient of Volume Compressibility (m_v)	Coefficient of Volume Compressibility (m_v)	Coefficient of Volume Compressibility (m_v)	Coefficient of Volume Compressibility (m_v)
	"Block"	TT1	TT2	TT3	TT4
0-12.5	3.52E-04	5.72E-04	8.88E-04	1.78E-03	4.56E-03
12.5-25	5.06E-04	6.22E-03	6.15E-04	7.53E-04	8.99E-04
25-50	5.78E-04	7.96E-04	8.15E-04	7.10E-04	9.01E-04
50-100	7.06E-04	6.24E-04	6.53E-04	6.20E-04	6.25E-04
100-200	6.55 E-04	4.94 E-04	5.61 E-04	5.13 E-04	6.06 E-04
200-400	2.70 E-04	2.97 E-04	2.95 E-04	2.94 E-04	3.17 E-04
400-800	1.33 E-04	1.49 E-04	1.56 E-04	1.56 E-04	1.55 E-04
800-1600	6.26 E-05	7.36 E-05	6.59 E-05	6.66 E-05	8.23 E-05
1600-800	2.67E-06	1.05 E-06	7.50 E-06	6.16 E-06	1.51 E-06
800-400	1.33 E-05	2.01 E-05	2.47 E-05	2.47 E-05	3.56 E-05
400-200	4.98 E-05	6.45 E-05	7.78 E-05	7.22 E-05	6.08 E-05
200-10	3.46 E-04	2.96 E-04	3.05 E-04	1.89 E-04	2.78 E-04

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 2.5. 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 samples of Dhaka clay and Chittagong coastal soils.

It is evident from the plots of Fig. 2.8 that up to value of preconsolidation stress (i.e., 100 kN/m^2), 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. Farooq (1995) reported attend 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. The values of m_v and m_s of the “block” and “tube” samples are summarized in Table 2.6. Sarker (1994) also reported similar results for “in situ” and “tube” 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. (19985). 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.

Zahid (2002) reported 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 behavior 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.

2.5 Current Practice of Sampling using Shelby Tube in Bangladesh

Most of the Shelby tube samplers used in Bangladesh have high area ratio, very rough inner surface, irregular cross sections and no specification for cutting edge (Fig. 2.9). Sampler is pushed into soil by impact loading instead of static thrust. It has long been recognized that if side friction becomes too great the sample will jam in the tube. Apart from the inconvenience of low percentages of recovery, this is associated with very high levels of disturbance (Clayton and Siddique, 1999). This type of undisturbed sample may lead to very conservative design of foundations causing more foundation cost.

More energy is needed to drive sampler into the soil. Soil encounters more resistance to enter into sampler, resulting more disturbances to soil. During pulling of soil sample after it entered into sampler, more energy is needed. In rare case they apply chain pulley system. Result is sample disturbance. During extrusion, soil becomes plugged into the sample due to high friction and undulation. So soil becomes near to remold after extrusion. We are getting less shear strength than it actually has. The result is expensive foundation.

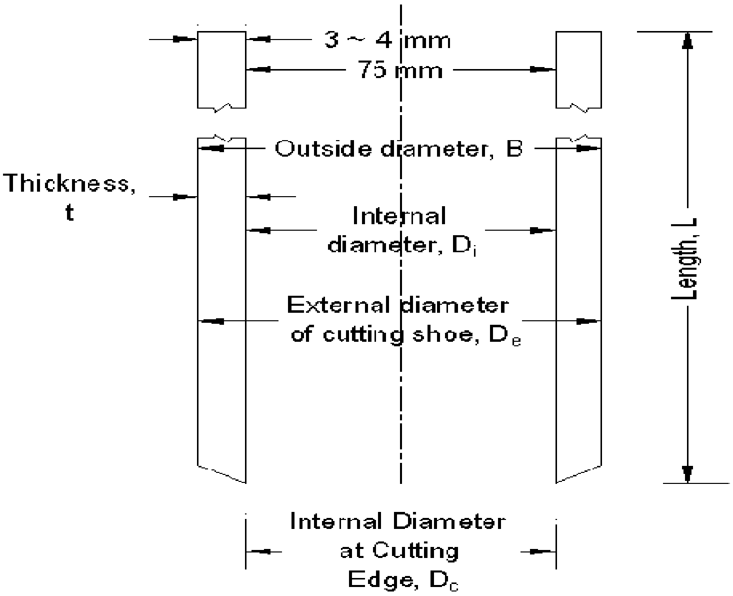


Figure 2.9: Schematic view of a Currently Practiced Shelby Tube Sampler

Figure 2.10: General view of a Currently Practiced Shelby Tube Sampler

2.6 Concluding Remarks

Most of the researches mentioned above studied the effect of sample disturbance on reconstituted samples. Very few studies were done on undisturbed samples collected from field. As it was expected that Traditional Shelby Tube samples would be highly disturbed, it is necessary to investigate the extent of disturbance of Traditional Shelby Tube samples compared to Modified Shelby Tube samples. Modified Shelby Tubes were designed and fabricated to overcome the shortcomings of Traditional Shelby Tubes.

CHAPTER 3
INSTRUMENTAION, TEST PROGRAM AND PROCEDURE

3.1 General

This chapter describes the experimental program. At first Shelby tubes were fabricated with specifications recommended by ISSMFE (1965), hereafter it is called Modified Shelby Tube. Traditional Shelby tubes were available in the Geotechnical Laboratory. Undisturbed soil samples were collected by Modified Shelby tubes and Traditional Shelby tubes at three selected locations, one is in Narayanganj area and the two others are in Khulna city. Bhulta of Narayanganj area was selected to have stiff clay soil and Khulna was selected to have soft clay soil so that sampling disturbance in stiff soil and soft soil would be quantified. The samples collected by the two types of tubes were brought to the geotechnical laboratory of Civil Engineering Department of Bangladesh University of Engineering and Technology (BUET). In the laboratory, sieve analysis and index properties tests were performed to classify the soil and to find out that the soil profile of samples of the same location collected by different type of sampler are the same or not. Then unconfined compression test and consolidation tests were performed. Finally, the test results were compared.

3.2 Fabrication of Modified Shelby Tube

International Society for Soil Mechanics and Foundation Engineering (ISSMFE) has made specific recommendations about leading edge, area ratio and length to diameter ratio for a good tube sampler (ISSMFE, 1965). Siddique (2000) reported the current practices of soil sampling in Bangladesh. As a first attempt to implement good quality Shelby tube sampling in the field in Bangladesh, this study compared the unconfined compressive strength and consolidation properties of undisturbed soil samples collected by using locally available currently practiced Shelby tube samplers and Modified Shelby tube samplers . Modified Shelby tubes was fabricated as per recommendations of ISSMFE (1965) having inside diameter 72 mm, wall thickness 1.9 mm, area ratio 10%, inside clearance ratio 0.0%, leading edge taper angle 60^0 up to thickness of 0.3 mm, cutting shoe taper angle 12^0, B/t ratio 38 and smooth inner/outer surface. Figure 3.1 shows the Modified Shelby tube dimensions. Sampler quality parameters of both modified and traditional Shelby tube samplers are given in Table 3.1.

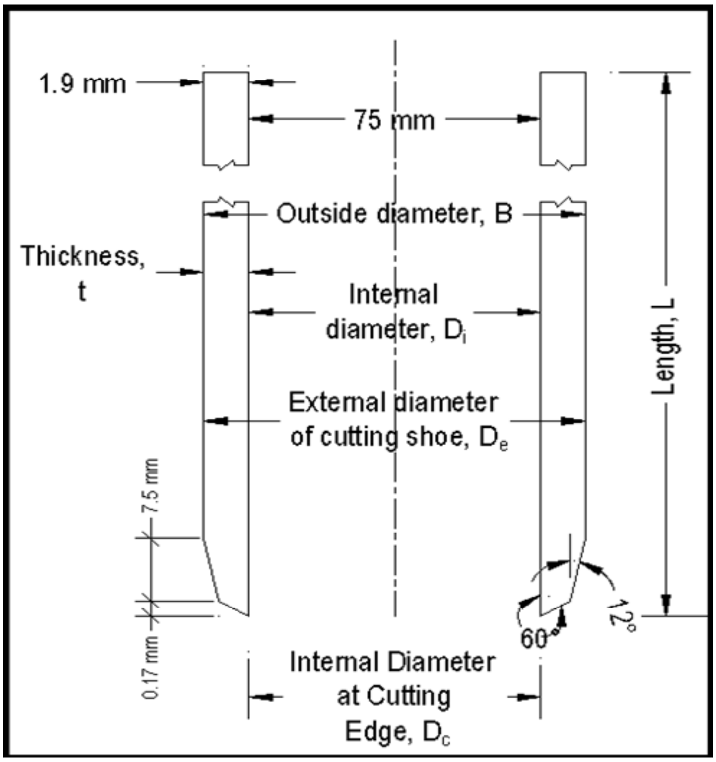


Fig. 3.1: Schematic diagram of Modified Shelby tube

Table 3.1. Sampler quality parameters of Modified Shelby tube used in this study and Traditional Shelby tube usually used in Bangladesh

Parameter	**Modified Shelby Tube**	**Traditional Shelby Tube**
Leading Edge Taper Angle	60^o up to 0.3 mm	n/a
Cutting shoe taper angle	12^o	45^o
Area Ratio, AR	10%	18%
L/D ratio	8	8
Material	Stainless Steel	Mild Steel
Surface Roughness	Smooth	Rough and Undulated

3.3 Undisturbed Sampling in Field

Three sites were selected for sampling, one site is in Bhulta, Narayanganj and one site is in Atomic Medical Centre, Khulna and the other one is in Sheikh Abu Naser Hospital, Khulna. At each site two bore holes were drilled with 1 m spacing between them. In one bore hole, Traditional Shelby tube samplers were used to collect undisturbed samples and in the other bore hole, Modified Shelby tube samplers were used to collect undisturbed samples.

Initially, boreholes were drilled up to 1.2 m depth by wash boring technique. Wash boring is the process in which a hole is advanced by combination of chopping and jetting to break the soil or rock into small fragments called cuttings, and washing to remove the cuttings from the hole. Water was pumped through a string of hollow boring rods (wash pipe) and was released under pressure through narrow holes in a chisel attached of the lower end of the rods. The soil was loosened and broken up by the water jets and the up-and-down movement of the chisel. The soil particles between the rods and the side of the borehole were washed to the surface through the annular space between the borehole and the boring rod. The washed materials were allowed to settle out in a sump. Typical arrangement for wash boring is shown in figure 3.2 and 3.3.

After thoroughly cleaning of borehole by circulating slurry, the sampler is pushed into soil by hammering. It is recommended that the Shelby tube should be pushed into the soil by static thrust not by impact loading. In Bangladesh usually hammering is used to push the sampler into the soil. That was why hammering was used to push the sampler into the soil. Both the Modified and Traditional Shelby tubes were driven into the soil in the same way. After drilling 1.2 m deep hole, continuous sampling was done in both the borehole which was 1 m apart from each other. After collection of each sample the borehole was widened and cleaned before next sampling to minimize the side friction of sampler. Boiling candle was then poured (Fig. 3.4 and 3.5) at the two ends of sampler in a thick layer to keep the sample airtight and was covered by the plastic tightly. The samplers were then brought to the geotechnical lab for test.

Fig. 3.2: Arrangement for performing Wash boring

Fig. 3.3: SPT hammer release arrangement

Fig. 3.4: Pouring candle up to the sample for keeping field water content

Fig. 3.5: Covering the sampler with plastic packet to make the sample airtight

3.4 Laboratory Tests

All the tests performed at the geotechnical laboratory of BUET were to determine the index properties, shear strength properties and compressibility properties of the collected disturbed and undisturbed samples. In order to identify the index properties, grain size distribution and specific gravity (G_s) were determined. Index properties tests were performed to classify the soil samples and to find out that the soil samples collected by different samplers were the same or not. Besides, natural water content (w_n), unit weight, liquid limit (w_L), plastic limit (w_p), and grain size distributions were determined using undisturbed samples.

Unconfined compressive strength tests were performed on undisturbed cohesive soil samples for the determination of unconfined compressive strength of soils of different samplers to compare the strength properties.

For the determination of the consolidation parameters such as compression index (C_c), coefficient of consolidation (c_v), coefficient of volume compressibility (m_v) etc., one-dimensional consolidation tests were performed on undisturbed soil samples. The laboratory test programs of different soil samples collected by the modified Shelby tube and Traditional Shelby tube are shown in Table 3.2.

Table 3.2: Laboratory Testing Program

Location	Depth (ft)	Modified Shelby Tube	Traditional Shelby Tube	Laboratory Tests Performed
Bhulta (Narayanganj)	9.5	UD-6$_{M}$	UD-6$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	12.5	Ud-8$_{M}$	Ud-8$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	15.5	UD-10$_{M}$	UD-10$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	17.0	UD-11$_{M}$	UD-11$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	18.5	UD-12$_{M}$	UD-12$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	21.5	UD-14$_{M}$	UD-14$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	23.0	UD-15$_{M}$	UD-15$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	24.5	UD-16$_{M}$	UD-16$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	26.0	UD-17$_{M}$	UD-17$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	27.5	UD-18$_{M}$	UD-18$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	30.5	UD-20$_{M}$	UD-20$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	32.0	UD-21$_{M}$	UD-21$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	33.5	UD-22$_{M}$	UD-22$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	35.0	UD-23$_{M}$	UD-23$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	36.5	UD-24$_{M}$	UD-24$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	38.0	UD-25$_{M}$	UD-25$_{T}$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	39.5	UD-26$_{M}$	UD-26$_{T}$	Specific gravity test, index properties,

				grain size distribution, unconfined compression test.
Atomic Medical Center (Khulna)	1.5	UD-1$_M$	UD-1$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	6.5	UD-4$_M$	UD-4$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	10.5	UD-7$_M$	UD-7$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	15.0	UD-10$_M$	UD-10$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	19.5	UD-13$_M$	UD-13$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	24.0	UD-16$_M$	UD-16$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
Sheikh Abu Naser hospital (Khulna)	1.5	UD-1$_M$	UD-1$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	3.0	UD-2$_M$	UD-2$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.
	4.5	UD-3$_M$	UD-3$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	6.0	UD-4$_M$	UD-4$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	7.5	UD-5$_M$	UD-5$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test.
	9.0	UD-6$_M$	UD-6$_T$	Specific gravity test, index properties, grain size distribution, unconfined compression test, one- dimensional consolidation test.

3.4.1 **Unconfined Compressive Strength Test**

This test method covers the determination of the unconfined compressive strength of cohesive soil in the undisturbed, remolded, or compacted condition, using strain-controlled application of the axial load. This test method provides an approximate value of the strength of cohesive soils in terms of total stresses. For determination of unconfined compressive strength of the samples, at first the sample extruder was used which is capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube, at a uniform rate, and with negligible disturbance of the sample. Conditions at the time of sample removal may dictate the direction of removal, but the principal concern is to keep the degree of disturbance negligible. Then the specimens of the soil sample were made with a minimum diameter of 1.5 inches and sample length of 3 inches. After preparing the test specimen, it was put on the compression device and the test was performed.

3.4.2 **One-Dimensional Consolidation Test**

This test method covers procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. The test is performed by the consolidometer device which holds the specimen in a ring that is either fixed to the base or floating (supported by friction on periphery of specimen) with porous disks on each face of the specimen. The inside diameter of the ring is determined to a tolerance of 0.075mm (0.003 in.).The consolidometer also provides a means of submerging the specimen, for transmitting the concentric vertical load to the porous disks, and for measuring the change in height of specimen. In this test method soil specimen was restrained laterally and loaded axially with total stress increments. Each stress increment was maintained until excess pore water pressures are completely dissipated. During the consolidation process, measurements are made of change in the specimen height and these data were used to determine the relationship between the effective stress and void ratio or strain, and the rate at which consolidation can occur by evaluating the coefficient of consolidation. The standard load increment duration was 24h. For at least two load increments, including at least one load increment after the preconsolidation pressure has been exceeded; the height or change in height, d, was recorded at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15 and 30min, and 1, 2, 4, 8 and 24h measured from the time of each incremental pressure application. Sufficient readings were taken near the end of the pressure increment period to verify that primary consolidation is completed.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 General

Field and laboratory test data on soil samples obtained from six boreholes at three locations were analyzed to develop soil profile along the study area. The laboratory test results on undisturbed soil samples are presented in this chapter. Level of disturbances of Modified Shelby tube samples and Traditional Shelby tube samples are compared based on laboratory test results.

4.2 Laboratory Test Results and Discussions

Modified and Traditional Shelby Tubes were used to collect undisturbed soil samples at the same location and depth at 1 m apart horizontally. All samples were taken to laboratory and following tests were performed to compare the extent of sample disturbance in both types of samples.

4.2.1 Grain Size Distribution

Wet sieving was performed on cohesive soil samples of three locations as per ASTM D 421-422 in order to determine the sand fraction of the collected cohesive soil samples at different depths. Percentages of sand fractions are presented in Table 4.1, 4.2 and 4.3. It may be noted that sand fraction ranges from 1.0% to 40.0% in the subsoil layers of the area of Bhulta in Narayanganj and 0.2% to 2.0% in the area of Khulna.

4.2.2 Specific Gravity

Specific gravity was determined from disturbed samples at different depth and different borehole locations. ASTM D 854-98 described method was used to determine specific gravity for inorganic clay or silt. Table 4.3 shows the summary of the values of specific gravity soil samples at different depth and different borehole locations. It may be noted that specific gravity of the inorganic clay samples ranges from 2.58 to 2.86. The usual range of specific gravity for inorganic clay varies between 2.68 and 2.75 (Bowles, 1997). The reason of lower than usual value may be attributed to the presence of some organic matter and the difference of upper range of value may be due to the presence of significant amount of colloidal particles. The usual values of specific gravity for organic clay vary from 2.14 to 2.17 (BRTC, 2003) or may be even less than 2.0 (Bowles, 1978).

4.2.3 **Atterberg Limits**

ASTM D4318-86 described method of Atterberg Limits Test was performed on undisturbed samples at different depths of different borehole locations to determine liquid limit, plastic limit, and plasticity index. The liquid limit test was performed using Casagrande’s apparatus. A summary of the liquid limit (w_L) and plastic limit (w_p) is shown in Table 4.1, 4.2 and 4.3.

4.2.4 **Criteria for Identical Soil Samples**

At each site two bore holes at 1 m apart from each other were drilled to collect undisturbed soil samples. Modified Shelby Tube samplers were used to collect undisturbed samples from one borehole and Traditional Shelby Tube samplers used in another bore hole. To see the effect of sample disturbance on geotechnical characteristics of the soil samples, it is necessary to make sure that soil samples of same depth should be identical. Percentage of sand fraction, liquid limit, plastic limit and natural moisture content were considered to be the parameters for defining identical soil sample. If anyone parameter differed significantly between Modified Shelby Tube sample and Traditional Shelby Tube sample, samples were labeled as not identical. Thus sample number UD-6, 11, 14 and 17 in Table 4.1, UD-4 in table 4.2 and UD-2 in Table 4.3 were not identical. Other soil samples were found identical based on four parameters mentioned above. Here identical means soil samples collected by Modified Shelby Tube and Traditional Shelby Tube from the same depth did not have significant difference in sand fraction, Liquid Limit, Plastic Limit and natural moisture content. Therefore, any difference in shear strength or other properties of soil samples is due to the extent of sample disturbance of the both types of Shelby Tubes.

4.2.5 **USCS Classification of Soil Samples**

Unified Soil Classification System (ASTM D 2487-00, 2006) was used to classify the soil samples. Table 4.4, 4.5 and 4.6 showed the USCS classification of soil samples based on the percentages of sand fraction and Atterberg Limits. In Bhulta, Narayanganj soil samples were Fat Clay, Lean Clay, Lean Clay with Sand and Sandy Lean Clay. In Khulna area soil samples were Fat Clay, Lean Clay and Organic Clay. Organic Clay was identified by determining Liquid Limit before and after oven drying the sample.

4.2.6 **Shear Strength Characteristics**

ASTM D2166-86 described method was used to determine unconfined compressive strength of undisturbed cohesive soil samples collected from 2.90 m to 12.96 m depth from EGL at Bhulta, Narayanganj, 0.46 m to 7.32 m at Atomic Medical Center, Khulna Medical College, Khulna and 0.46 m to 2.74 m at Sheikh Abu Naser Hospital in Khulna. The values of natural moisture content, dry density and unconfined compressive strength obtained from these tests are summarized in Table 4.7 and 4.8. From the test results it has seen that the unconfined compressive strength of the soil sample of Modified Shelby Tube is always greater than that of Traditional Shelby Tube. Reduction of shear strength is associated with sample disturbance. The more the disturbance of sample the more will be the reduction of shear strength. Therefore it is proved that extent of sample disturbance is more in Traditional Shelby Tube than Modified Shelby Tube.

The unconfined compressive stress vs axial strain curve of soil samples collected by Modified and Traditional Shelby Tube are shown in Figures 4.1 to 4.10. It is clear from the figures that Traditional Shelby tube samples are more disturbed than that of Modified Shelby Tube samples. In Table 4.7 and 4.8, it is shown that percent difference of unconfined compressive strength between Traditional and Modified Shelby Tube samples. Positive sign in percent difference indicates Modified Shelby Tube samples have more shear strength than Traditional Shelby Tube samples. Shear strength of Modified Shelby Tube samples are 4% to 76% greater than that of Traditional Shelby Tube samples. The differences are more in soft soils of Khulna sites than stiff soils in Bhulta, Narayanganj sites. That means soft soils are more vulnerable to sample disturbance than stiff soils.

Unconfined compressive strengths of samples from different depths are plotted in Figure 4.11 and 4.12 for Narayanganj and Khulna area respectively. It is seen that soft clay has more effects of disturbance than stiff clay. In most of the depths unconfined compressive strengths of Modified Shelby tubes are greater than that of Traditional Shelby Tube samples.

During driving the samplers into soil by dropping SPT hammers, it was observed that Traditional Shelby Tubes, being highly frictional and thick wall, required number of hammer drops more than that required for Modified Shelby tube. Sampler parameters such as area ratio, cutting edge angle etc. of both the samplers are shown in Table 3.1 for comparison. Due to undulated and rough surface, thick wall, high cutting edge angle of Traditional Shelby Tube samplers, sample get more frictional resistance during entering into sampler. Therefore more energy is required to drive the sampler into the soil. Since the soil samples were 100% saturated clay, it is not possible to be become compacted during sample intrusion, rather it become remolded and disturbed. This is the main reason of reduction of shear strength of highly disturbed Traditional Shelby Tube samples compared to Modified Shelby Tube samples.

4.2.7 **Compressibility Characteristics**

Following ASTM D2435-96 one-dimensional consolidation tests were performed to determine compressibility properties of undisturbed soil samples collected from different depth at six boreholes. The results obtained from these tests are discussed below.

4.2.7.1 **Compression Index**

Typical e-logp curve of Bhulta, Narayanganj and Sheikh Abu Naser Hospital, Khulna site are shown in Figure 4.13 and 4.14. Initial void ratio of Modified Shelby Tube is much lower than that of Traditional Shelby Tube which is an indication of extensive sample disturbance in Traditional Shelby Tube samples. In case of soft soil (Khulna sites) the difference of initial void ratio is larger than that of stiff soil (Bhulta, Narayanganj). Compression Index is also larger in Traditional Shelby Tube samples due to the more sample disturbance. Summary of Compression Index are shown in Table 4.9 and 4.10 for Bhulta, Narayanganj site and Khulna sites respectively. Variation of Compression Index with depth is shown in Figure 4.15 and 4.16 Bhulta, Narayanganj site and Khulna sites respectively.

Compression Index and initial void ratio are required to calculate the total consolidation of soil deposit due to foundation pressure. Traditional Shelby Tubes having thick and rough wall and large cutting edge angle, sample become highly disturbed during intrusion and extrusion of soil sample. This is the reason why Compression Index and initial void ratio were significantly altered in Traditional Shelby Tube samples. As a result conservative foundation design would lead to high cost of foundation.

4.2.7.2 **Coefficient of Consolidation**

Coefficient of consolidation, c_v values were also affected by sample disturbance. Figure 4.17 shows the variation of c_v values with pressure for Modified and Traditional Shelby Tube of soil samples of Bhulta, Narayanganj site. Figure 4.18 shows the same for Sheikh Abu Naser Hospital, Khulna site. Coefficients of Consolidation are summarized in Tables 4.11 and 4.12. Greater values of coefficient of consolidation indicates faster rate of consolidation. Thus Fig. 4.17 and 4.18 showed that Traditional Shelby Tube samples have faster rate of consolidation than that of Modified Shelby Tube samples. Because of more sample disturbance Traditional Shelby Tube samples had higher initial void ratio and less stiffness. Therefore these more disturbed samples had faster rate of consolidation.

4.2.7.3 **Coefficient of Volume Compressibility**

The coefficient of volume compressibility, m_v has been determined and summarized in Tables 4.11 and 4.12. Variation of coefficient of volume compressibility with pressure is shown in Fig. 4.19, 4.20, 4.21 and 4.22. From the test results it is found that the values of m_v of samples obtained by Traditional Shelby Tubes are greater than those of Modified Shelby Tubes. As the sample disturbance is higher in Traditional

Shelby Tube and initial void ratio is greater, these samples are more compressible than less disturbed Modified Shelby Tube samples.

4.2.7.4 **Coefficient of Permeability**

The coefficient of permeability, k values have been determined from the consolidation test results and summarized in Tables 4.11 and 4.12. Variations of coefficient of permeability with pressure are shown in Figure 4.23, 4.24 and 4.25. From the test results it is found that the values of k obtained by Traditional Shelby Tubes are less than that of Modified Shelby Tubes. Sample disturbance is higher in Traditional Shelby Tube samples than Modified Shelby Tube samples. Sample disturbance break the initial permeable structure and stratification of soil sample which might be reason of less permeability in more disturbed samples.

4.3 Concluding Remarks

Traditional Shelby Tubes are made of mild steel which become highly frictional due to rusting. More over due to thick wall, area ratio is high. Cutting edge is not sharp enough to drive the sampler into the intact soil without disturbance. As a result undisturbed samples collected by Traditional Shelby Tube are greatly disturbed during intrusion and extrusion. On the other hand Modified Shelby Tubes are made of stainless steel with thin wall and sharp cutting edge. As a result sample disturbances could be minimized significantly. Strength and compressibility characteristics of soil samples collected by using both samplers showed the extent of sample disturbances and proved that Traditional Shelby Tube samples are highly disturbed.

Table 4.1: Index properties of soil samples collected from Bhulta site in Naryanganj.

Sample depth (m)	Sample ID	Sand Fraction (%)		Liquid Limit (LL)		Plastic Limit (PL)		Natural Moisture Content (w_n)		Remarks
		Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	
2.90	UD-6	6.5	2.5	56	64	17	18	20.9	27.6	Not identical
3.81	UD-8	1.8	2.9	58	60	16	19	24.7	23.1	Identical
4.73	UD-10	4.0	3.0	56	65	14	21	28.4	26.5	Identical
5.18	UD-11	2.5	3.3	65	63	22	21	30.5	23.6	Not identical
5.64	UD-12	4.0	6.1	44	40	14	19	29.2	30.7	Identical
6.55	UD-14	18.0	25.5	38	33	19	16	24.8	16.7	Not identical
7.01	UD-15	14.4	14.5	47	43	15	14	19.2	20.7	Identical
7.93	UD-17	8.8	9.8	48	44	18	15	18.9	22.5	Not identical
9.30	UD-20	24.8	26.7	30	29	11	11	15.9	14.2	Identical
10.21	UD-22	13.4	13.1	45	43	19	16	19.6	20.0	Identical
11.13	UD-24	22.2	16.1	44	42	14	16	23.3	22.6	Identical
11.60	UD-25	8.9	7.9	56	60	25	28	21.3	18.4	Identical
12.04	UD-26	6.2	4.6	63	73	23	27	22.7	21.0	Identical
12.96	UD-28	38.3	40.0	25	27	11	12	20.0	17.8	Identical

Table 4.2: Index properties of soil samples collected from Atomic Medical Center site in Khulna.

Sample depth (m)	Sample ID	Sand Fraction (%)		Liquid Limit (LL)		Plastic Limit (PL)		Natural Moisture Content (w_n)		Remarks
		Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	
0.46	UD-1	0.8	1.1	56	53	23	22	39.0	39.5	Identical
1.83	UD-4	0.3	0.6	52	54	24	27	39.2	31.1	Not identical
3.20	UD-7	0.6	0.9	44	49	22	21	47.2	46.5	Identical
4.57	UD-10	1.9	2.3	80	72	38	39	37.9	40.6	Identical
5.95	UD-13	0.8	0.5	57	53	27	25	41.6	42.9	Identical
7.32	UD-16	0.6	0.3	32	33	16	16	44.7	45.1	Identical

Table 4.3: Index properties of soil samples collected from Sheikh Abu Naser Hospital site in Khulna.

Sample depth (m)	Sample ID	Sand Fraction (%)		Liquid Limit (LL)		Plastic Limit (PL)		Natural Moisture Content (w_n)		Remarks
		Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	Modified Shelby Tube	Traditional Shelby Tube	
0.46	UD-1	0.2	0.1	53	54	24	26	55.2	54.5	Identical
0.91	UD-2	0.3	0.6	58	56	28	27	65.3	58.2	Not identical
1.37	UD-3	0.4	0.3	30	29	11	11	37.6	37.0	Identical
1.83	UD-4	1.1	1.8	45	43	19	16	33.8	32.8	Identical
2.29	UD-5	0.8	0.5	44	42	14	16	39.3	37.7	Identical
2.74	UD-6	0.4	0.3	89	73	23	27	80.1	79.5	Identical

Table 4.4: USCS Classification of soil samples collected from Bhulta site in Narayanganj.

Sample depth (m)	Sample ID	Average Sand Fraction (%)	Average Liquid Limit (LL)	Average Plasticity Index (PI)	USCS Classification
3.81	UD-8	2.4	59	42	Brown Fat Clay (CH)
4.73	UD-10	3.5	61	43	Brown Fat Clay (CH)
5.64	UD-12	5.1	42	26	Brown Lean Clay (CH)
7.01	UD-15	14.5	45	31	Brown Lean Clay (CL)
9.30	UD-20	25.8	30	19	Brown Lean Clay with Sand (CL)
10.21	UD-22	13.3	44	27	Brown Lean Clay (CL)
11.13	UD-24	19.2	43	28	Brown Lean Clay with Sand (CL)
11.60	UD-25	8.4	58	27	Brown Fat Clay (CH)
12.04	UD-26	5.4	68	43	Brown Fat Clay (CH)
12.96	UD-28	39.2	26	15	Brown Sandy Lean Clay (CL)

Table 4.5: USCS Classification of soil samples collected from Bhulta site in Narayanganj.

Sample depth (m)	Sample ID	Average Sand Fraction (%)	Average Liquid Limit (LL)	Average Plasticity Index (PI)	USCS Classification
0.46	UD-1	1.0	55	32	Dark Gray Fat Clay (CH)
3.20	UD-7	0.8	47	25	Dark Gray Lean Clay (CL)
4.57	UD-10	2.1	76	38	Black Organic Clay (OC)
5.95	UD-13	0.7	55	29	Dark Gray Fat Clay (CH)
7.32	UD-16	0.5	33	17	Dark Gray Lean Clay (CL)

Table 4.6: USCS Classification of soil samples collected from Bhulta site in Narayanganj.

Sample depth (m)	Sample ID	Average Sand Fraction (%)	Average Liquid Limit (LL)	Average Plasticity Index (PI)	USCS Classification
0.46	UD-1	0.2	54	29	Dark Gray Fat Clay (CH)
1.37	UD-3	0.4	30	19	Dark Gray Lean Clay (CL)
1.83	UD-4	1.5	44	27	Dark Gray Lean Clay (CL)
2.29	UD-5	0.7	43	28	Dark Gray Lean Clay (CL)
2.74	UD-6	0.4	81	56	Black Organic Lean Clay (CL)

Table 4.7: Summary of Natural Moisture Content (w_n), Dry Density (γ_d) and Unconfined Compressive Strength (q_u) of Soil Samples Collected from Bhulta site in Narayanganj.

Location	Sample Depth (m)	Sample ID	Natural Moisture Content, w_n (%)		Dry Density, γ_d (kN/m^3)		Unconfined Compressive Strength, q_u (kPa)		Percent difference of q_u
			Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	
Bhulta (Narayanganj)	3.81	UD-8	24.8	23.1	15.0	16.6	245	236	+4%
	4.73	UD-10	28.5	26.5	15.4	16.1	244	233	+5%
	5.64	UD-12	29.2	30.7	15.0	14.6	86	78	+10%
	7.01	UD-15	19.2	20.8	17.8	17.5	208	179	+16 %
	9.30	UD-20	16.0	14.2	19.3	18.8	277	219	+27%
	10.21	UD-22	19.7	20.0	16.5	17.6	299	243	+23%
	11.13	UD-24	23.4	22.6	16.4	17.2	285	218	+31%
	11.60	UD-25	21.3	18.4	17.2	17.2	349	232	+50%
	12.04	UD-26	22.8	21.0	17.0	16.9	193	144	+34%
	12.96	UD-28	20.1	17.9	17.2	17.9	82	59	+39%

Table 4.8: Summary of Natural Moisture Content (w_n), Dry Density (γ_d) and Unconfined Compressive Strength (q_u) of Soil Samples Collected from Khulna Area.

Location	Sample Depth (m)	Sample ID	w_n (%)		γ_d (kN/m^3)		q_u (kPa)		Percent difference of q_u
			Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	
Atomic Medical Center	0.46	UD-1	39.1	39.6	12.9	12.0	153	131	+17%
	3.20	UD-7	47.3	46.5	12.0	11.4	29	22	+30%
	4.57	UD-10	38.0	40.7	10.5	9.8	56	40	+39%
	5.95	UD-13	41.6	42.9	12.1	11.0	57	33	+76%
	7.32	UD-16	44.7	45.1	11.5	11.2	45	30	+50%
Sheikh Abu Naser Hospital	0.46	UD-1	55.2	54.5	10.0	10.6	73	57	+29%
	1.37	UD-3	37.6	37.0	12.8	13.0	68	53	+28%
	1.83	UD-4	33.9	32.8	13.8	13.8	84	62	+35%
	2.29	UD-5	39.3	37.7	12.6	12.6	42	31	+33%
	2.74	UD-6	80.1	79.5	7.9	8.1	21	15	+41%

Table 4.9: Summary of Compression Index (C_c) of Soils of Bhulta Site in Narayanganj.

Location	Sample Depth (m)	Sample ID	Compression Index, C_c	
			BH-2 (Modified Shelby Tube)	BH-3 (Traditional Shelby Tube)
Bhulta (Narayanganj)	3.81	UD-8	0.14	0.20
	7.01	UD-15	0.12	0.15
	9.30	UD-20	0.13	0.18
	10.21	UD-22	0.09	0.12
	11.13	UD-24	0.09	0.11

Table 4.10: Summary of Compression Index (C_c) of Soils of Khulna Area

Location	Sample Depth (m)	Sample ID	Compression Index, C_c	
			BH-2 (Modified Shelby Tube)	BH-3 (Traditional Shelby Tube)
Atomic Medical Center	0.46	UD-1	0.25	0.41
	5.95	UD-13	0.33	0.47
Sheikh Abu Naser Hospital	0.46	UD-1	0.39	0.45
	2.74	UD-6	0.52	0.59

Table 4.11: Summary of c_v , m_v, and permeability of soils of Narayanganj Area

Location	Sample Depth (ft)	Sample ID	$c_{v(avg)}$ (m^2/yr)		m_v (m^2/kN)		$k_{(avg)}$ (m/s)	
			Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)
Bhulta (Narayanganj)	3.81	UD-8	15.80	11.83	3.4E-04	4.2E-04	1.6E-09	1.2E-09
	7.01	UD-15	11.79	7.10	3.1E-04	3.9E-04	2.7E-07	2.3E-09
	10.21	UD-20	7.79	7.35	4.6E-04	4.7E-04	1.8E-07	1.2E-09
	11.13	UD-22	9.84	8.96	5.7E-04	5.2E-04	2.7E-07	3.6E-10

Table 4.12: Summary of c_v, m_v, and permeability of soils of Khulna Area

Location	Sample Depth (ft)	Sample ID	$c_{v(avg)}$ (m^2/yr)		m_v (m^2/kN)		$k_{(avg)}$ (m/s)	
			Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)	Modified Shelby Tube (BH-2)	Traditional Shelby Tube (BH-3)
Atomic Medical Center	0.46	UD-1	7.82	7.28	4.7E-04	5.6E-04	1.5E-09	1.3E-09
	5.95	UD-13	9.27	4.29	4.2E-04	5.6E-04	1.4E-09	5.6E-10
Sheikh Abu Naser Hospital	0.46	UD-1	2.33	3.94	3.1E-04	3.9E-04	2.7E-07	2.3E-09
	2.74	UD-6	9.84	8.96	5.7E-04	5.2E-04	2.7E-07	3.6E-10

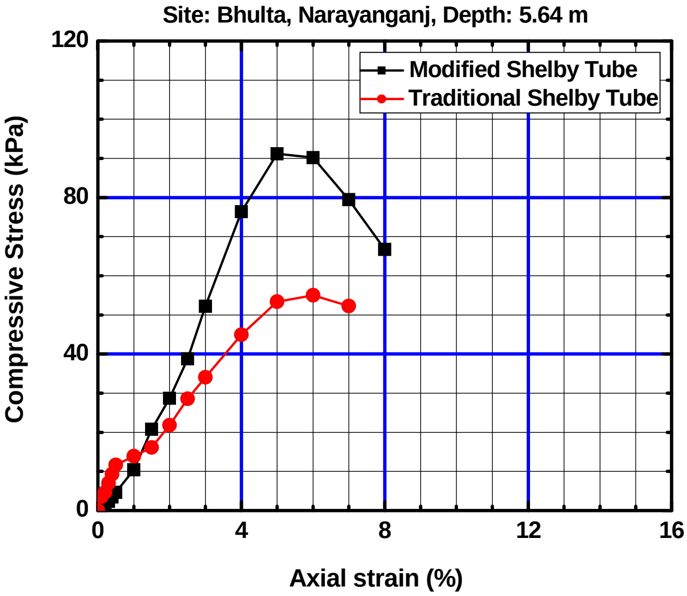


Fig 4.1: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-12)

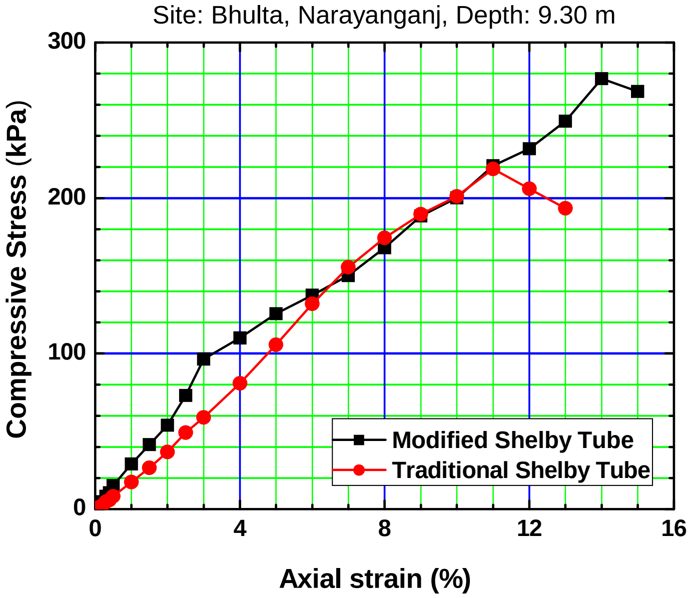


Fig 4.2: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-20).

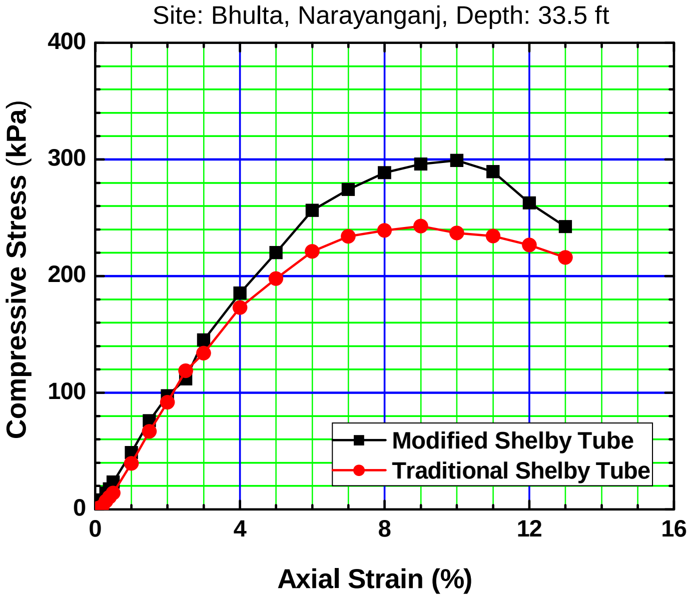


Fig 4.3: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-22).

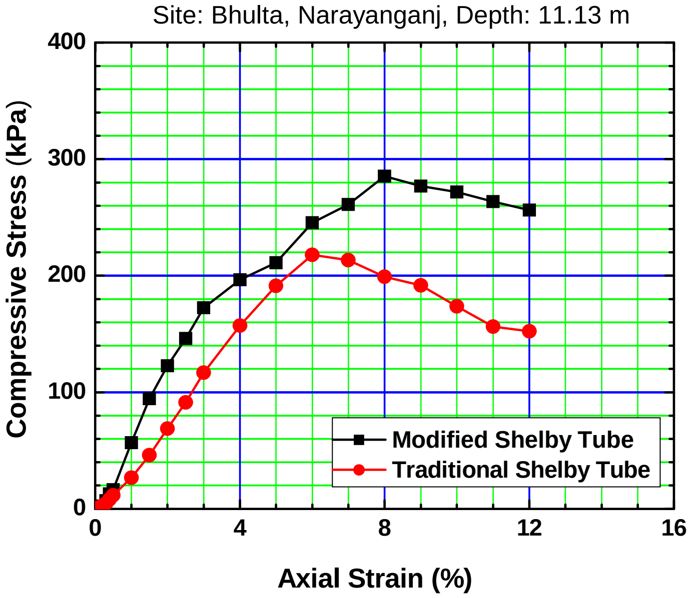


Fig 4.4: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-24).

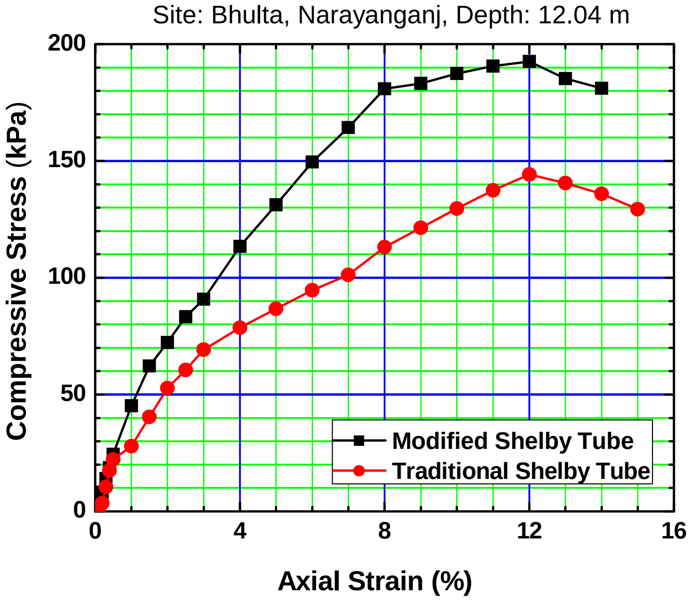


Fig 4.5: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-26).

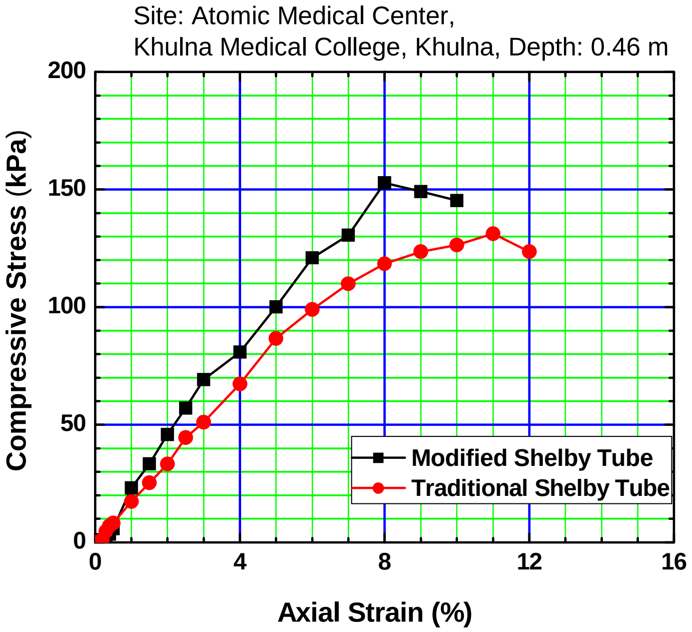


Fig 4.6: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-1).

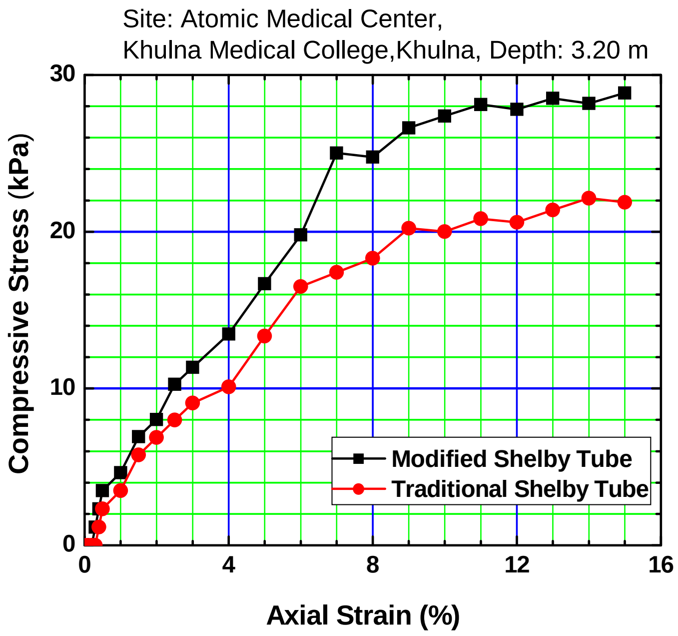


Fig 4.7: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-7).

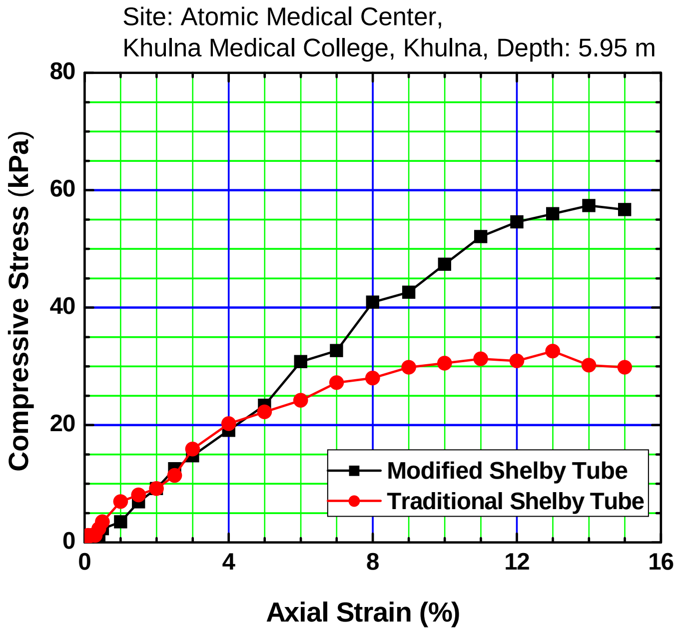


Fig 4.8: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-13).

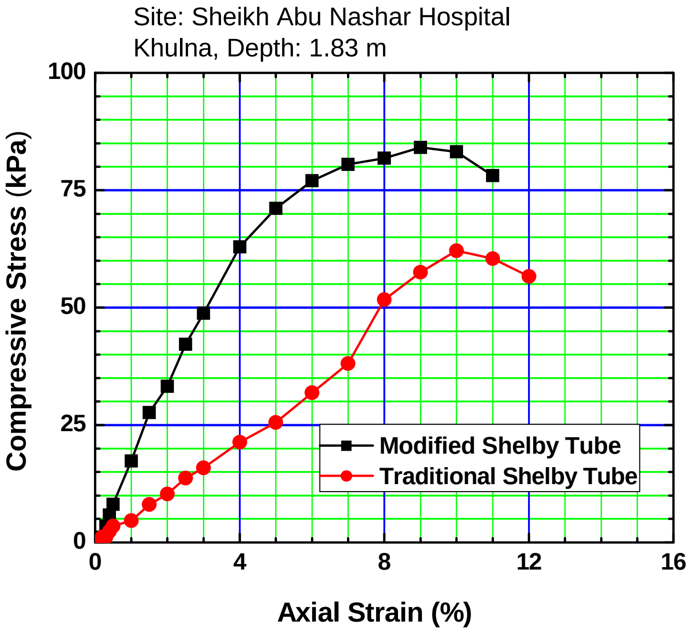


Fig 4.9: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna UD-4).

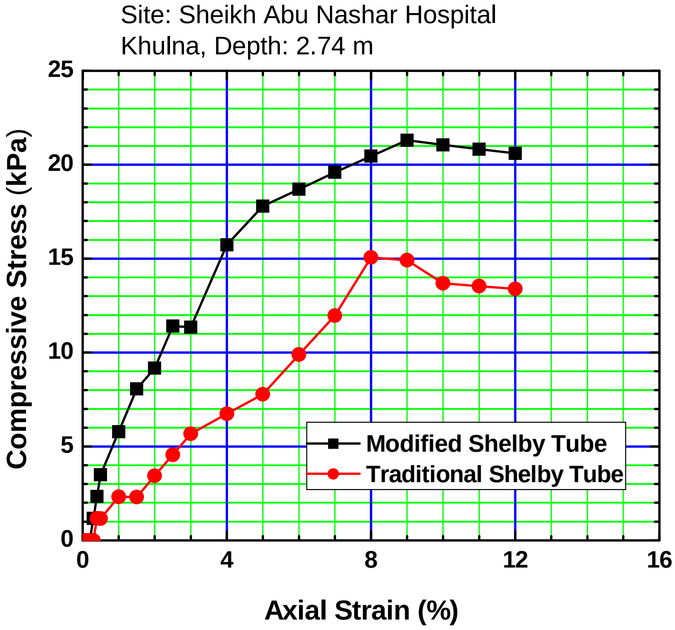


Fig 4.10: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna (UD-6).

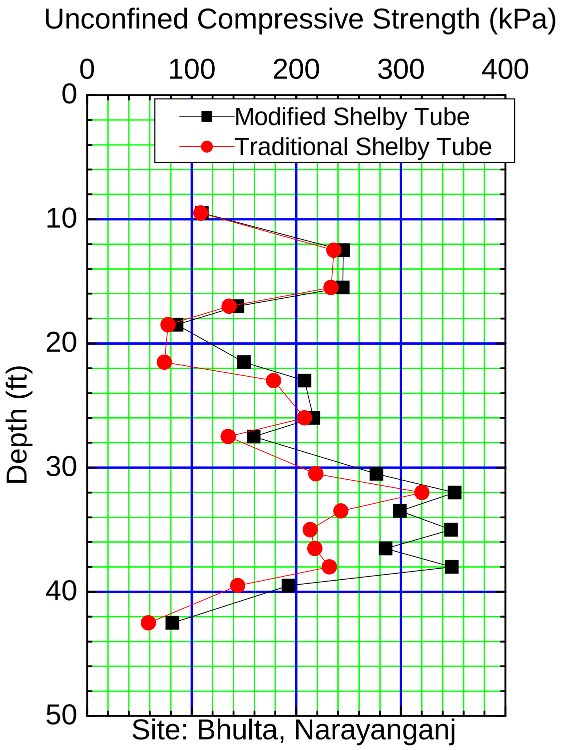


Fig 4.11: Unconfined compressive strength of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj.

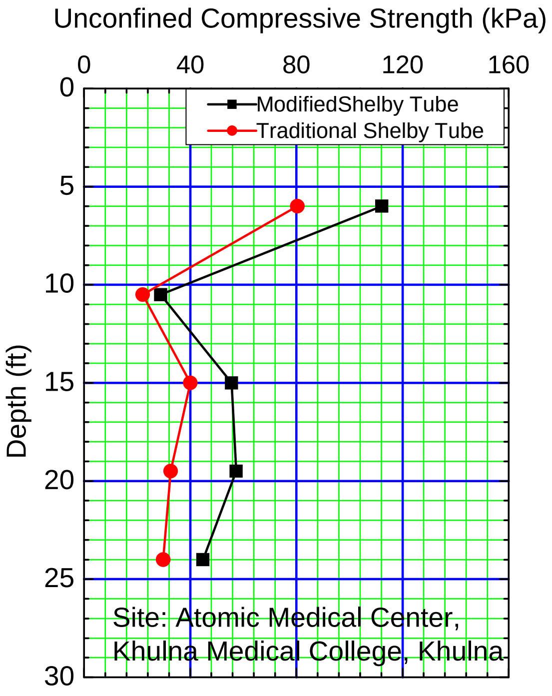


Fig 4.12: Unconfined compressive strength of samples collected by Modified and Traditional Shelby tube from Atomic Medical center site in Khulna.

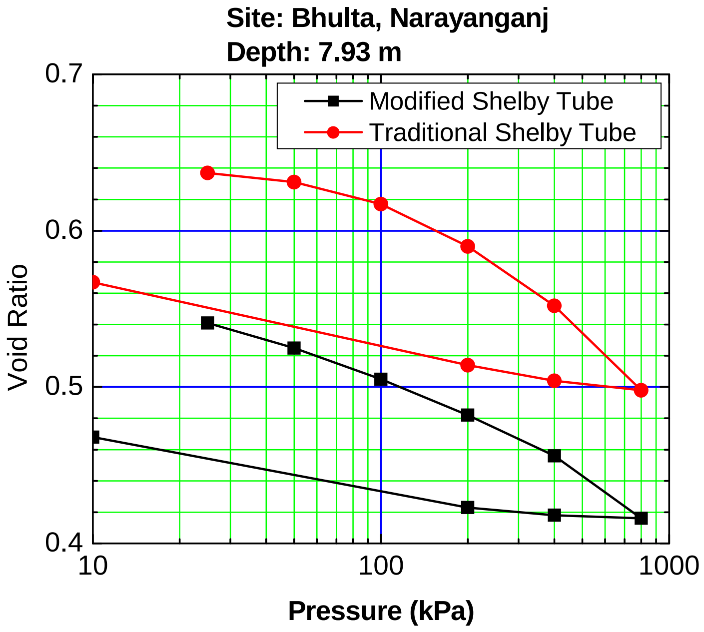


Fig. 4.13: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-17).

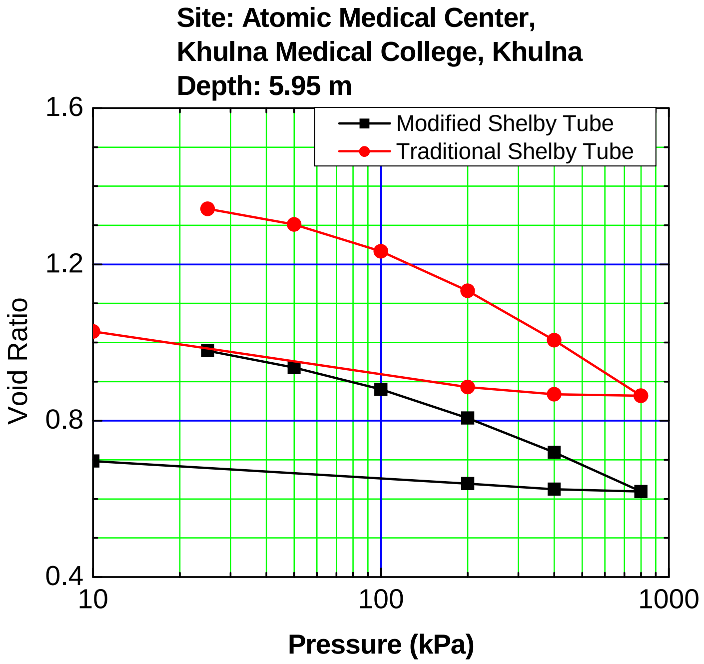


Fig. 4.14: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-13).

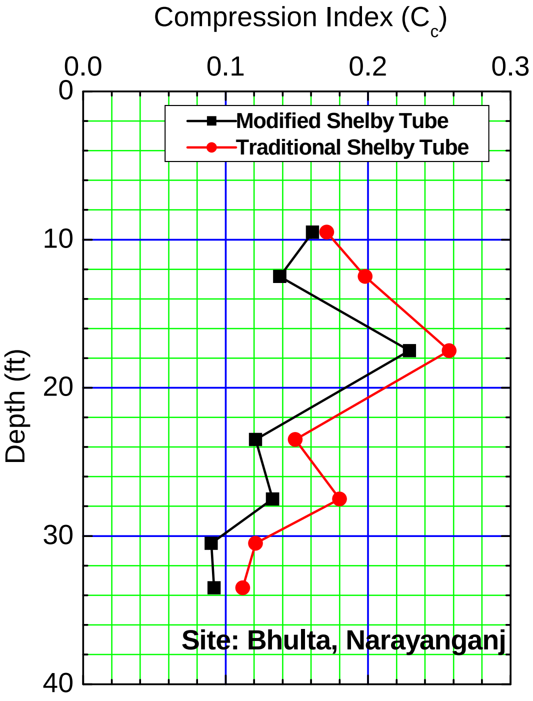


Fig 4.15: Compression index of samples at different depths collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj.

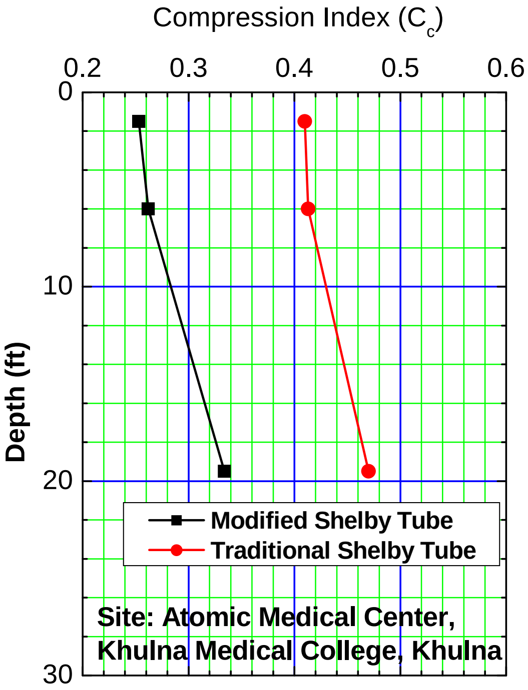


Fig 4.16: Compression index of samples at different depths collected by Modified and Traditional Shelby tube from Atomic Medical center site in Khulna.

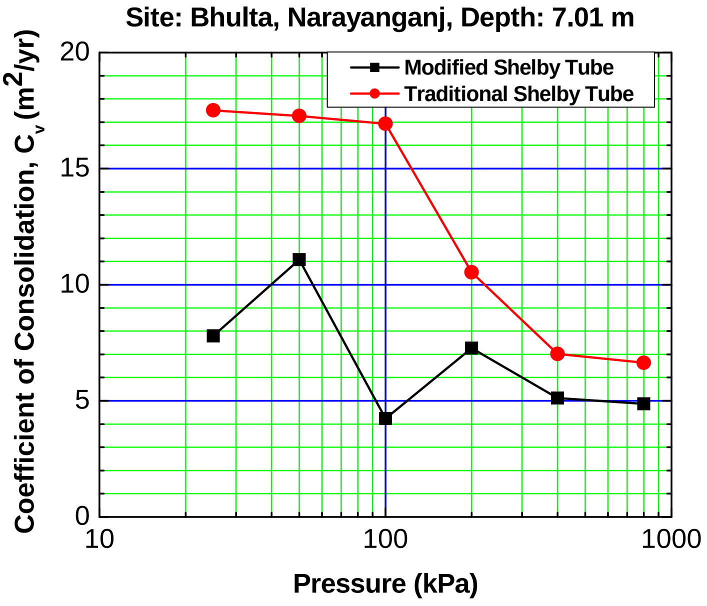


Fig 4.17: Comparison of Coefficient of Consolidation versus pressure curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-15).

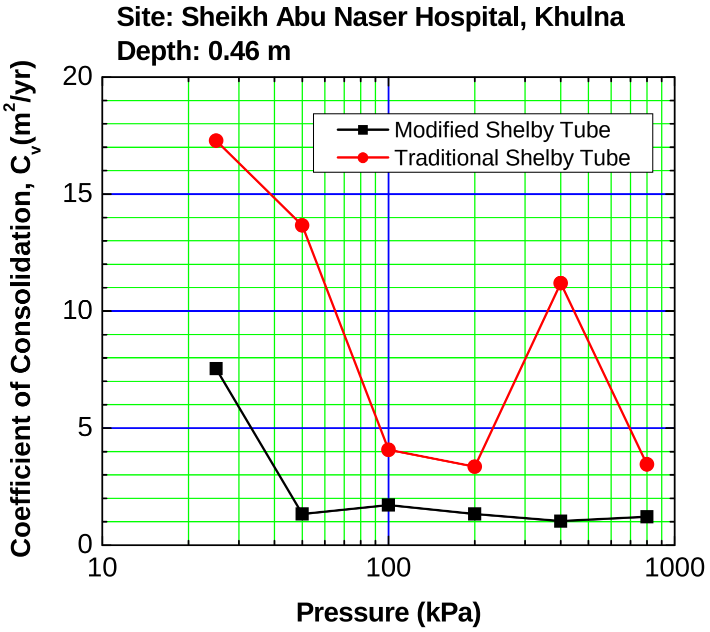


Fig 4.18: Comparison of Coefficient of Consolidation versus pressure curve of samples collected by Modified and Traditional Shelby tube from Abu Naser Hospital site in Khulna (UD-1).

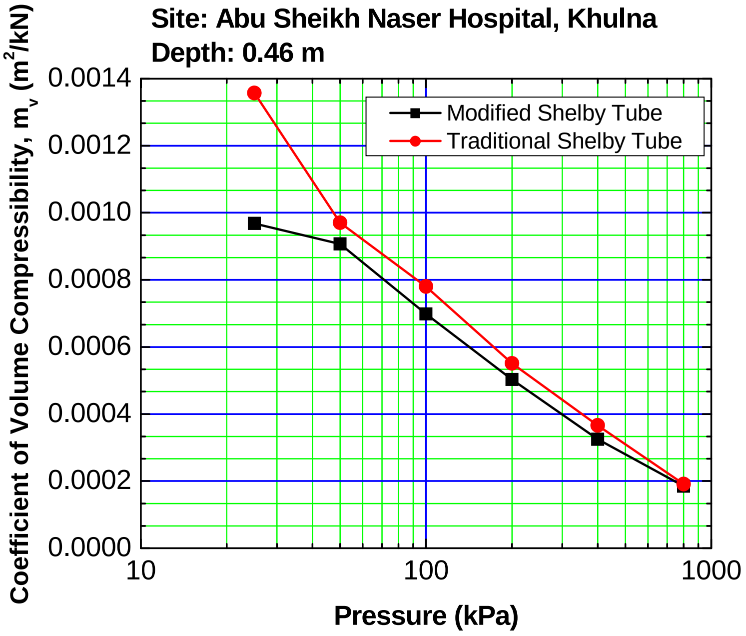


Fig 4.19: Comparison of Coefficient of Volume Compressibility versus pressure curve of samples collected by Modified and Traditional Shelby tube from Abu Naser Hospital (UD-1).

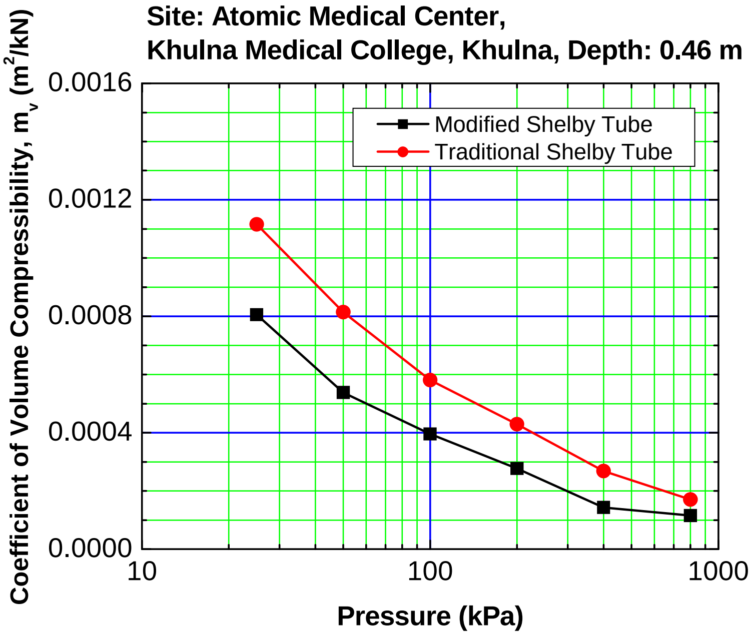


Fig 4.20: Comparison of Coefficient of Volume Compressibility versus pressure curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center (UD-1).

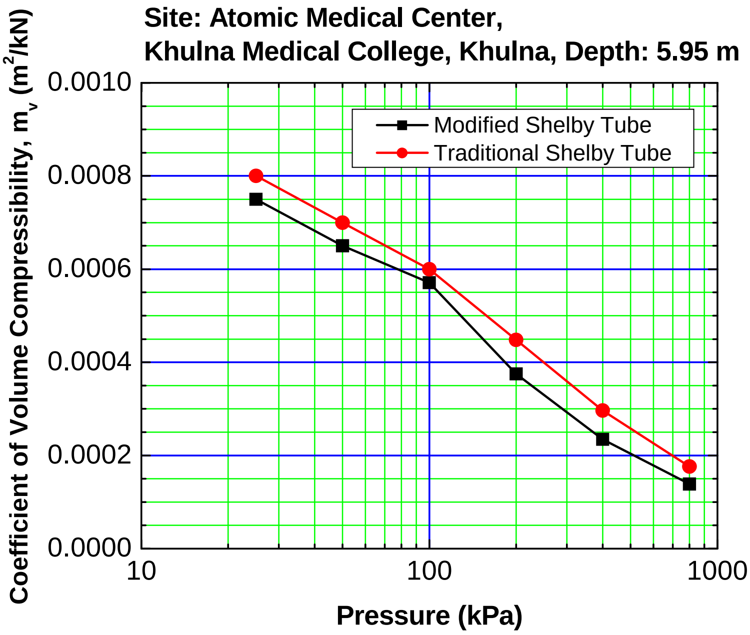


Fig 4.21: Comparison of Coefficient of Volume Compressibility versus pressure curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center (UD-13).

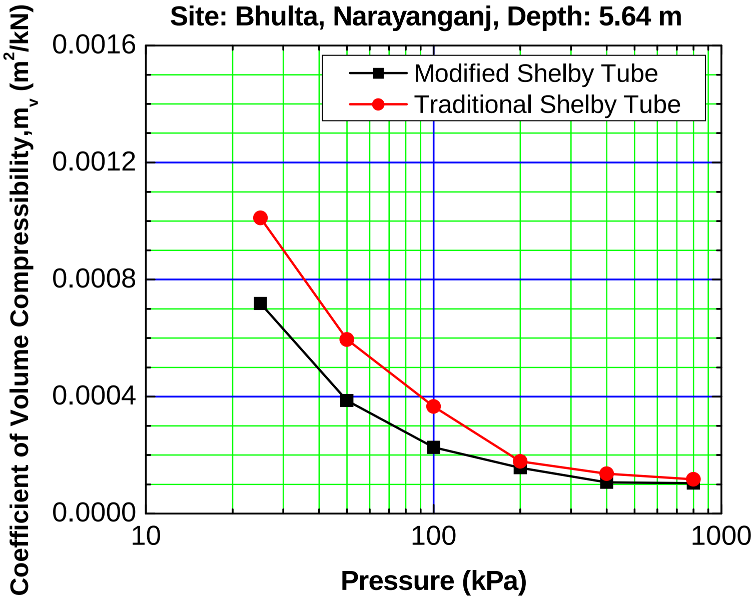


Fig 4.22: Comparison of Coefficient of Volume Compressibility versus pressure curve of samples collected by Modified and Traditional Shelby tube from Bhulta site (UD-12).

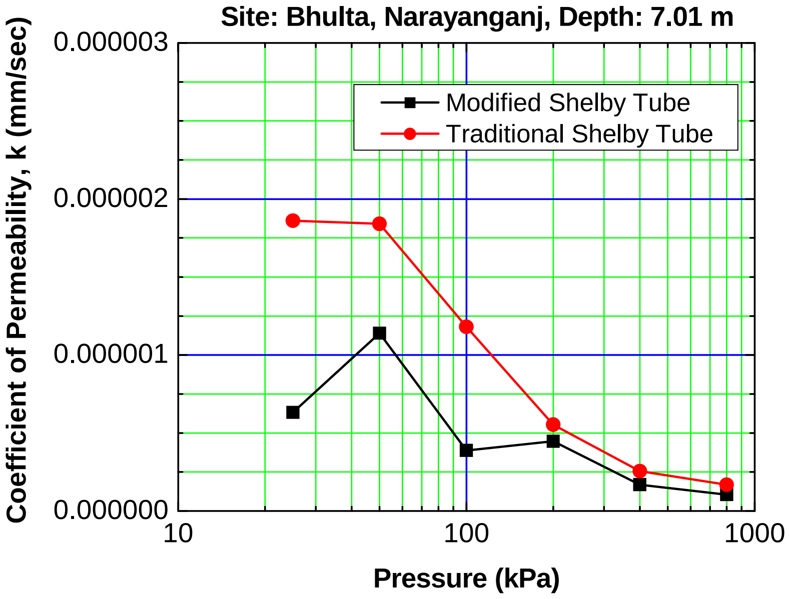


Fig 4.23: Comparison of Coefficient of Permeability versus pressure curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-15).

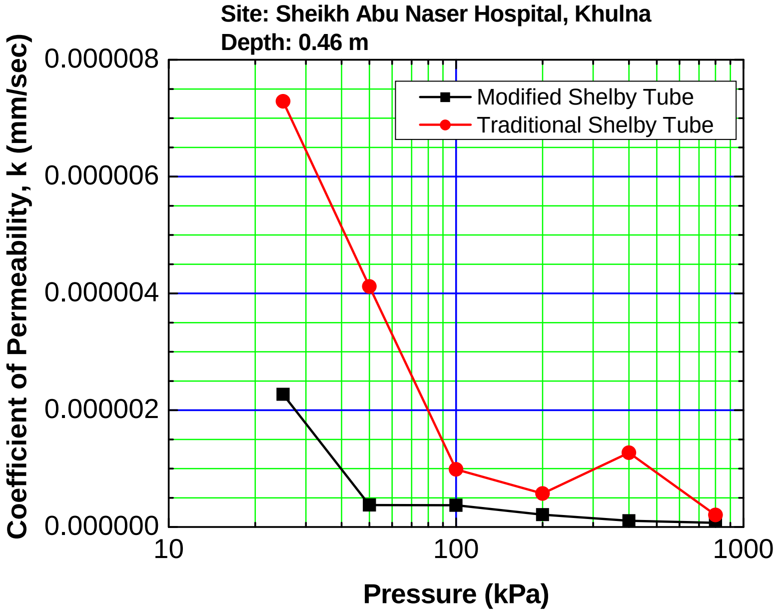


Fig 4.24: Comparison of Coefficient of Permeability versus pressure curve of samples collected by Modified and Traditional Shelby tube from Abu Naser Hospital in Khulna (UD-1).

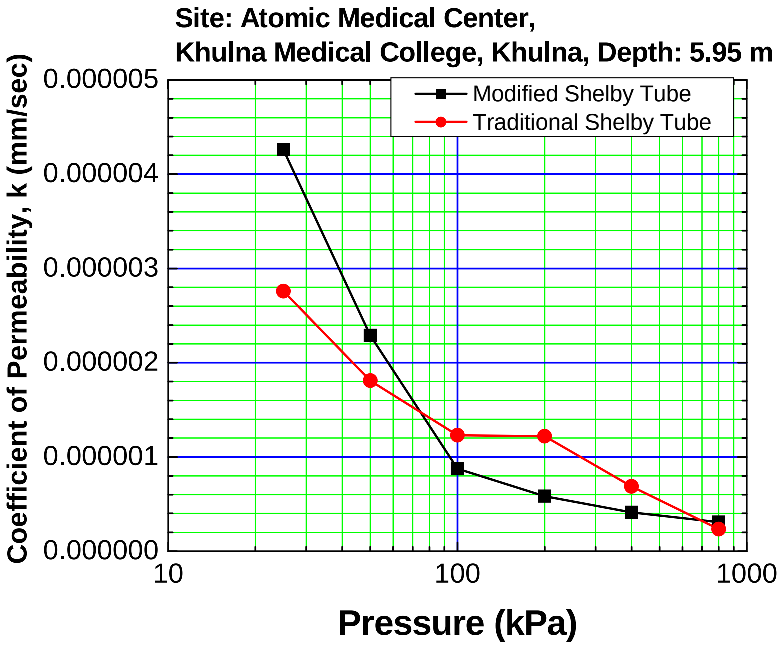


Fig 4.25: Comparison of Coefficient of Permeability versus pressure curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center (UD-13).

CHAPTER 5
CONCLUSIONS

5.1 General

During the past decade or so, our understanding of sampling disturbance and its effects on measured strengths has increased significantly. In this study, the strength properties and consolidation properties of soil collected by using Traditional Shelby Tubes and Modified Shelby Tubes have been compared. The shear strength and compression index from the same depth of soil differed significantly for the two types undisturbed samples. The test results have shown that the disturbance of soil collected by the Modified Shelby tubes is less than the soil collected by the Traditional Shelby Tubes. Those engineers who want to carry out site investigation in an attempt to obtain realistic soil parameters must take cutting-shoe and sampler design into account if they are to obtain suitable samples for advanced laboratory testing.

5.2 Conclusions

The following conclusions may be drawn with respect to this experimental study:

i. Modified Shelby Tube sample showed greater undrained shear strength than those of Traditional Shelby Tube samples indicating Modified Shelby Tube samples are less disturbed than Traditional Shelby Tube samples.

ii. Modified Shelby Tube samples had lower compression index, coefficient of consolidation and coefficient of volume of compressibility than those of Traditional Shelby Tube samples indicating Modified Shelby Tube samples are less disturbed than Traditional Shelby Tube samples.

iii. Modified Shelby Tube samples showed greater permeability than those of Traditional Shelby Tube samples indicating that sample disturbance may reduce the permeability of clay.

iv. Finally Traditional Shelby Tube samples are more disturbed than Modified Shelby Tube samples.

5.3 Recommendations for Future Study

From the lessons of the present study, the recommendations for future study may be summarized as follows:

i. In this study, cutting shoe taper angle was considered for fabricating Shelby tubes. However, inside clearance ratio was kept zero. Another similar study can be done by using inside clearance ratio large enough to allow partial swelling and lateral stress reduction but it should not allow excessive soil or loss of the sample when withdrawing from the sampling tube. Thus effect of inside clearance ratio can be studied.

ii. It is recommended to apply static thrust to drive the sampler into the soil during undisturbed sample collection. However in this study impact loading by SPT hammer was used to drive the sampler into soil. Therefore further study can be done to see the effect of sampler driving procedure on sample disturbance.

REFERENCES

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.

Arman, A. and Mc. Manis, K.L. (1976) “Effects of Storage and Extrusion on Sample Properties”, Symposium on Soil Specimen Preparation for Laboratory Testing, ASTM STP 599, pp. 66-87.

ASTM D 1587-00 (2006), “Standard Practice for Thin-walled Tube Sampling of Soils for Geotechnical Purposes”, American Society for Testing and Materials, ASTM International, West Conshohocken, PA 19428-2959, United States.

ASTM D 2487-98 (2006), “Standard practice for Classification of Soils for engineering Purposes (Unified Soil Classification Purposes)”, Designation: D2487-98, Annual Book of ASTM Standards, Vol. 04.08. pp. 220-230.

ASTM D 4318-84 (2006), “Standard Test Method for Liquid Limit, Plastic Limit and plasticity Index of Soils”, Designation: D 4318-84, Annual Book of ASTM Standards, Vol. 04.08. pp. 580-589.

ASTM D 4186-89 (2006), “Standard Test Method for One –Dimensional Consolidation Properties of Soils Using Controlled – Strain Loading”, Designation: D 4186-89 (Reapproved 1998), Annual Book of ASTM Standards, Vol. 04.08.

ASTM D 422-63 (2006), “Standard Test Method for Particle Size Analysis of Soils”, Designation: D 422-63(Reapproved 1998), Annual Book of ASTM Standards, Vol. 04.08. pp. 10-17.

ASTM D 854-98 (2006), “Standard Test Method for Specific Gravity of Soils”, Designation: D 854-98Annual Book of ASTM Standards, Vol. 04.08. pp. 1-4.

ASTM D 2166-98a (2006), “Standard Test Method for Unconfined Compressive Strength of Soils”, Designation: D 2166-98a, Annual Book of ASTM Standards, Vol.

04.08.

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

Bashar, M.A., Siddique, A., and Safiullah, A.M.M., (2000) “Sampling Disturbance Effects in Reconstituted Coastal Soils.” Soils and Foundations, Japanese Geotechnical Society, Vol. 40, no. 5, pp.49-63.

Berre, T., Schjetne, K and Sollie, S. (1969) “Sampling Disturbance of Soft Marine Clays”, Pmc., Specialty Session No. 1 on Soil Sampling, 7th Tnt. Conf Soil Mech. and Found. Engg., Mexico, pp. 21-24.

Bjerrum, L. (1973) “Problems of Soil Mechanics and Construction on Soft Clays and Structurally Unstable Soils (Collapsible, Expansive and Others)”, State-of-the-Art Report, Session IV, Proc., 8th Tnt. Conf Soil Mech. and Found. Engg., Moscow, Vol. 3, pp. 109-159. Reported by Siddique (1990)

Bozozuk, M. (1971) “Effect of Sampling, Size, and Storage on Test Results for Marine Clay”, Symposium on Sampling of Soil and Rock, ASTM STP 483, pp. 121-131.

Bowles, J.E. (1997) “Foundation Analysis and Design,” 5th Ed., McGraw-Hill, New York, pp.15-165.

Chandler, R J., Harwood, A. H., and Skinner, P. J. (1993)” Sample disturbance in London Clay”, Discussion Paper, (Geotechnique 42, No. 4, pp. 577-584.

Clayton, C.RI. (1986) “Sampling Disturbance and BS 5930”, Site Investigation Practice: Assessing BS 5930, Edited by A.W. Hawkins, Geological Society, Engg. Geology Special Publication No. 2, pp. 33-40.

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. and Siddique, A. (1999). “Tube Sampling Disturbance – Forgotten Truths and New Perspectives”, Proceedings of the Institute of Civil Engineers-Geotechnical Engineering Journal, London, Vol. 137, Issue 3, pp. 127-135.

Graham; J., Kwok, C.K. and Ambrosie, R.W. (1987) “Stress Release, Undrained Storage, and Reconsolidation in Simulated Underwater Clay”, Canadian Geotechnical Journal, Vol. 24, No. 2, pp. 279-288.

Hajj, A.R., (1990) “The Simulation of Sampling Disturbance and its Effects on the Deformation Behavior of Clays,” Ph.D. Thesis, University of Sheffield, England. Reported by Hopper, R.J., (1992).

Hight, D.W. and Burland, J.B. (1990) “Review of Soil Sampling and Laboratory Testing for the Science and Engineering research Council”, Summary Report, Science and Engineering Research Council, England.

Holm, G. and Holtz, R.D. (1977) “A Study of Large Diameter Piston Samplers”, Proc., Specialty Session No. 2 on Soil Sampling, 9th Int. Conf. Soil Mech. and Found. Engg., Tokyo, pp. 73-78.

Hvorslev, M.J. (1940) ‘Preliminary Draft Report on the Present Status-of-the-Art of Obtaining Undisturbed Samples of Soils”, Supplement to Proc., Purdue Conf. on Soil Mechanics and its Applications, Purdue University, Lafayette, Indiana, U.S.A.

Hvorslev, M.J. (1949) “Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes”, Waterways Experimental Station, Vicksburg, U.S.A. Repotted by Siddique (1990).

ISSMFE (1965). “Report of the Subcommittee on Problems and Practices of Soil sampling”, Proceedings of the 6th International Conference on Soil Mechanics and Foundation engineering, Montreal, Vol. 3, Appendix II, pp. 64-71.

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.

Jamiolkowski, M., Ladd, C. C., Germaine, J.T. and Lancellotta, R. (1985) “New

Developments in Field and Laboratory Testing of Soils", Proc., 11th Int. Conf. Soil Mech. And Found. Engg., San Francisco, Vol. 1, pp. 57-153. Reported by Hopper (1992).

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

Kirkpatrick, W.M. and Khan, A.J. (1984) "The Reaction of Clays to Sampling Stress Relief', Geotechnique, Vol. 34, No. 1, pp. 29-42.

Kubba. L.M. (1981) "The Effect of sampling Disturbance on the Deformation of Clay", Ph.D. Thesis, University of Wales, U.K. Reported by Siddique (1990).

Rahman, M and Siddique, A. (2009) "Tube Sampling Disturbances in Normally Consolidated and over-Consolidated Dhaka clay", Indian Geotechnical Journal, Vol. 39(2), pp. 153-170.

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

Sarker, J.K. (1994). "An Experimental Investigation of Sampling Disturbance in Dhaka Clay", M. Sc.Engg. Thesis, 1994, BUET, Dhaka.

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. (1998). "Numerical Prediction of Tube Sampling Strains for Realistic Samplers", Proceedings of the 12th Engineering Mechanics Conference, La Jolla, California, USA, pp. 558-561.

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. (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. (2000). “Soil Sampling in South Asia”, Proceedings for International Symposium on Soil Sampling, Yokosuka, Japan.

Siddique, A., Ameen, S. F. and Islam, M. J. (2009). “A Comparative Study on Engineering Properties of Block and Tube Samples of a Soft Clay”, Journal of Civil Engineering, Vol. CE 37, No. 1, pp. 11-30.

Siddique, A., Farooq, S. M. and Clayton, C.R.I. (2000). “Disturbances due to Tube Sampling in Coastal soils”, Journal of the Geotechnical and Geoenvironmental engineering, ASCE, Vol. 126, No. 6, pp. 568-575.

Sone, S., Tsuchiya, H. and Saito, Y. (1971). “The Deformation of a Soil Sample during Extrusion from a Sample Tube”, Proc., Specialty Session on Quality in Soil Sampling, 4th Asian Conf., Int. Society of Soil Mechanics and Foundation Engineering. Bangkok, pp. 3-6.

Appendix A:

UNCONFINED COMPRESSION TEST & CONSOLIDATION TEST RESULTS

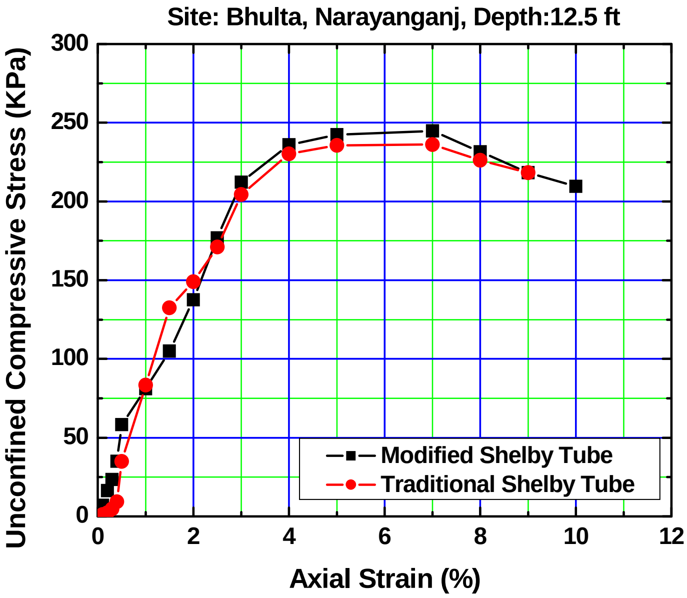


Fig. A.1: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-8)

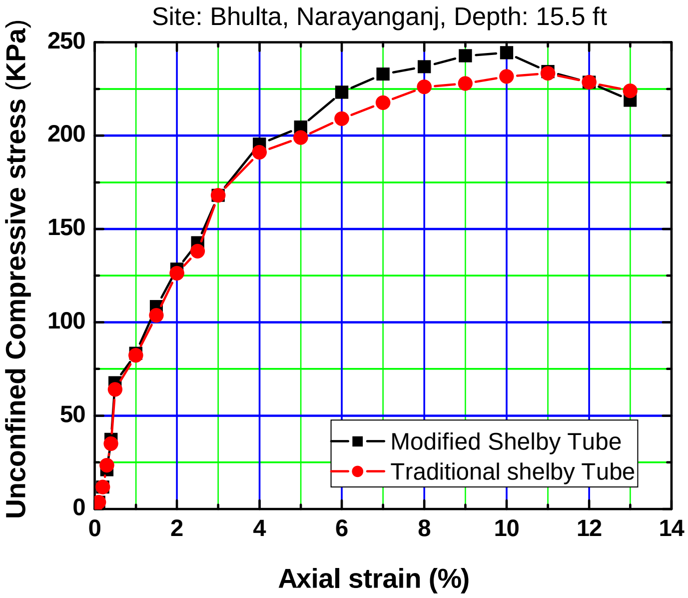


Fig. A.2: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-10)

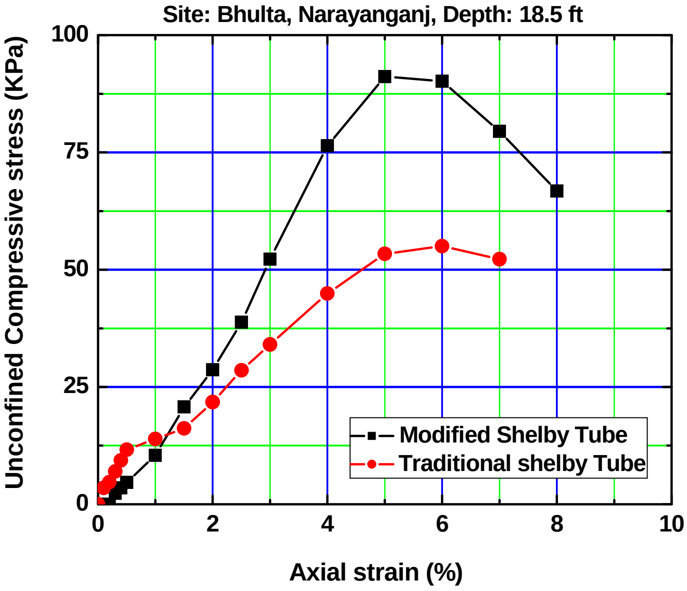


Fig. A.3: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-12)

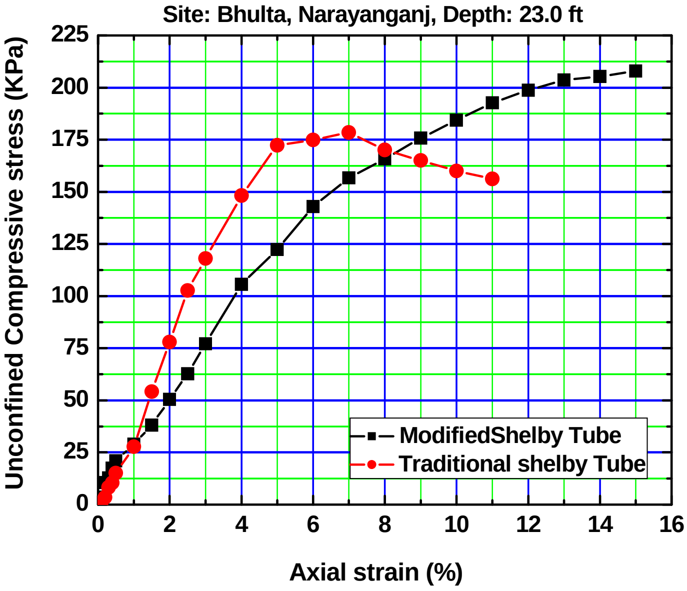


Fig. A.4: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-15)

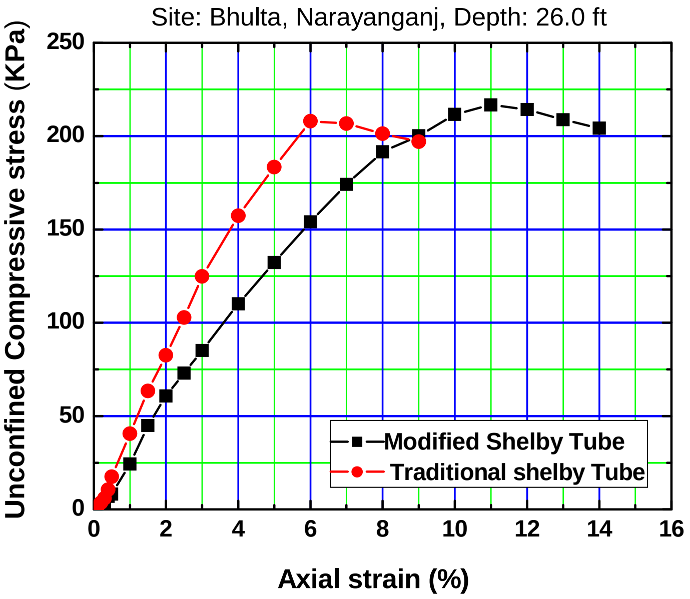


Fig. A.5: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-17)

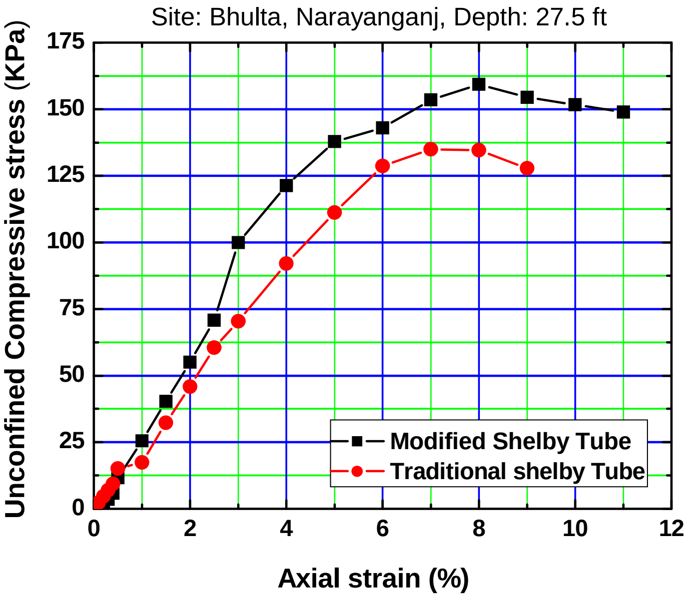


Fig. A.6: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-19)

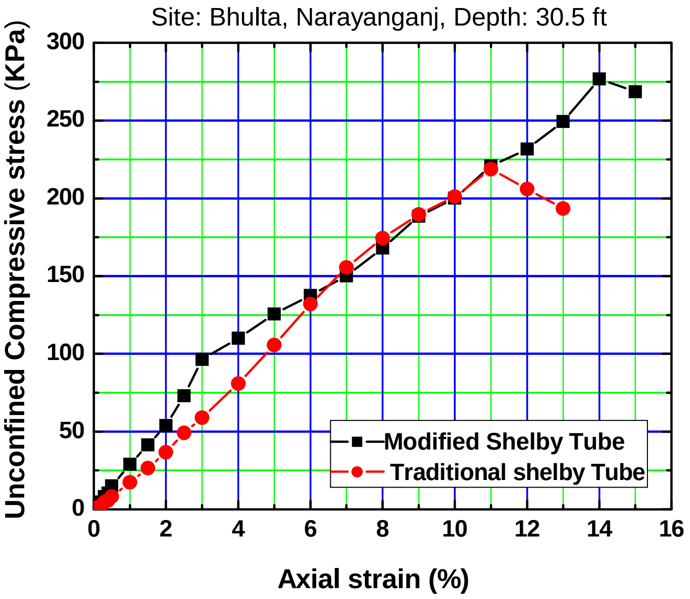


Fig. A.7: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-20)

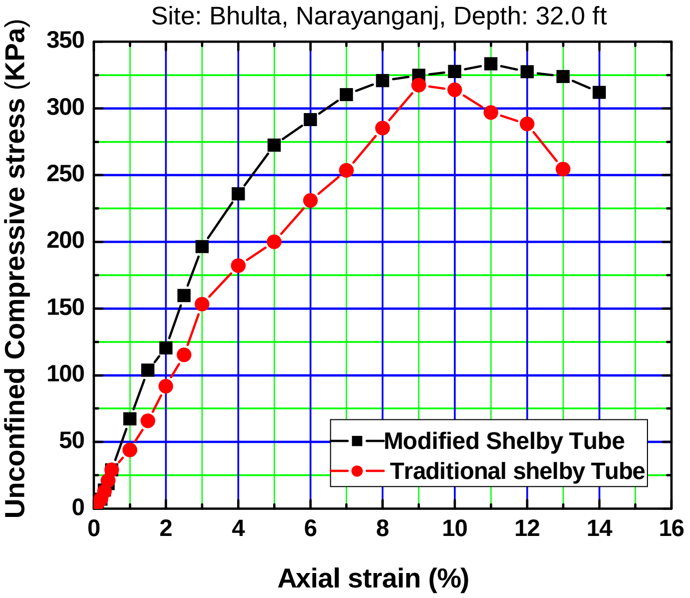


Fig. A.8: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-21)

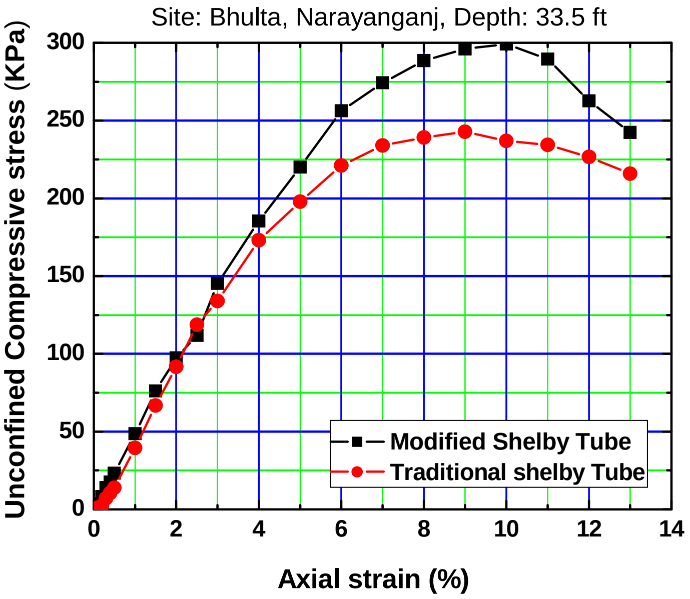


Fig. A.9: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-22)

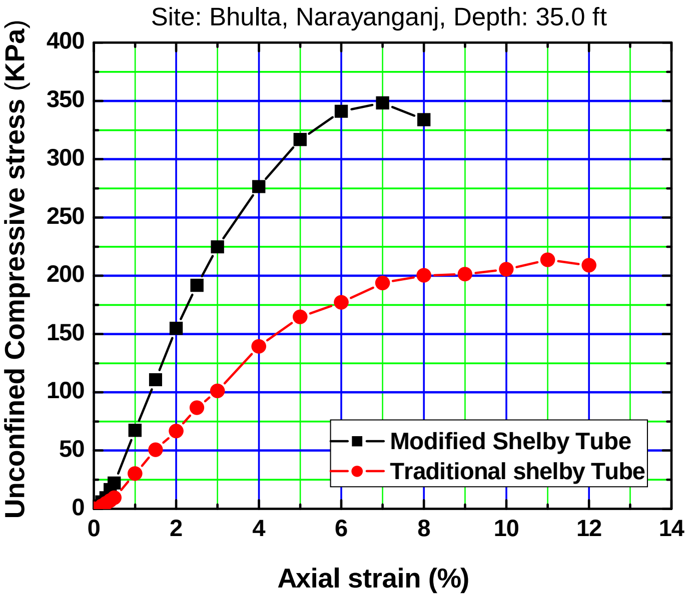


Fig. A.10: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-23)

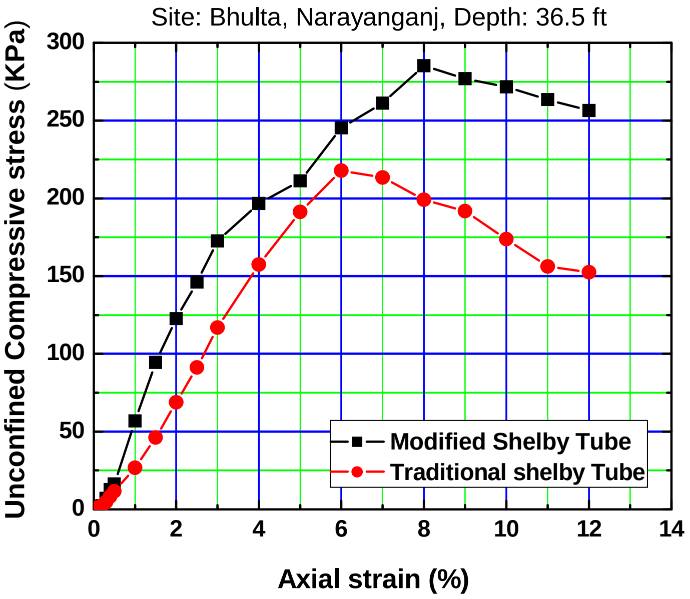


Fig. A.11: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-24)

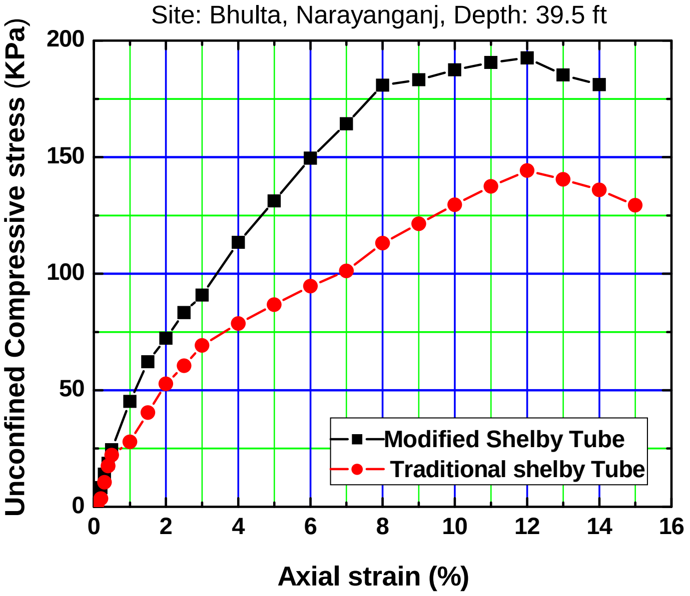


Fig. A.12: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-26)

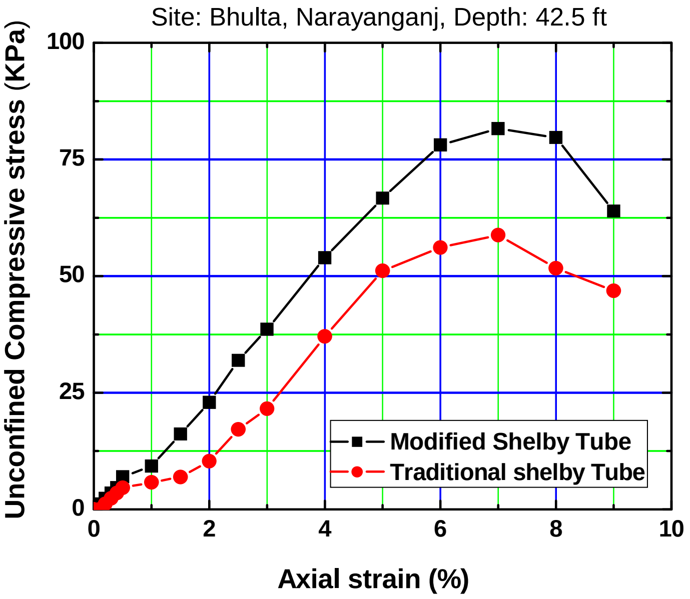


Fig. A.13: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-28)

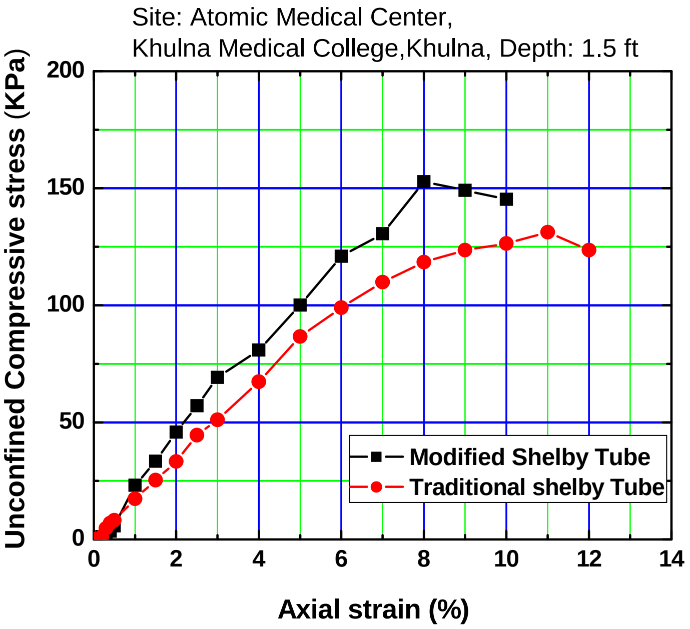


Fig. A.14: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-1)

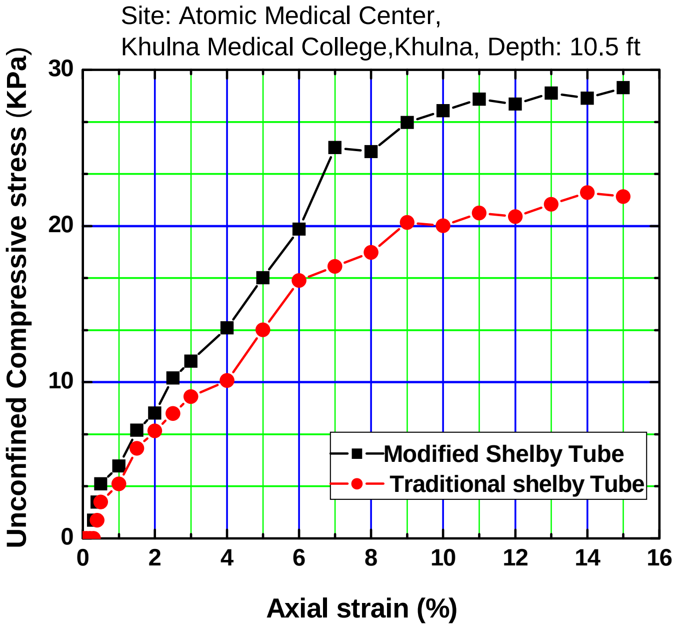


Fig. A.15: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-7)

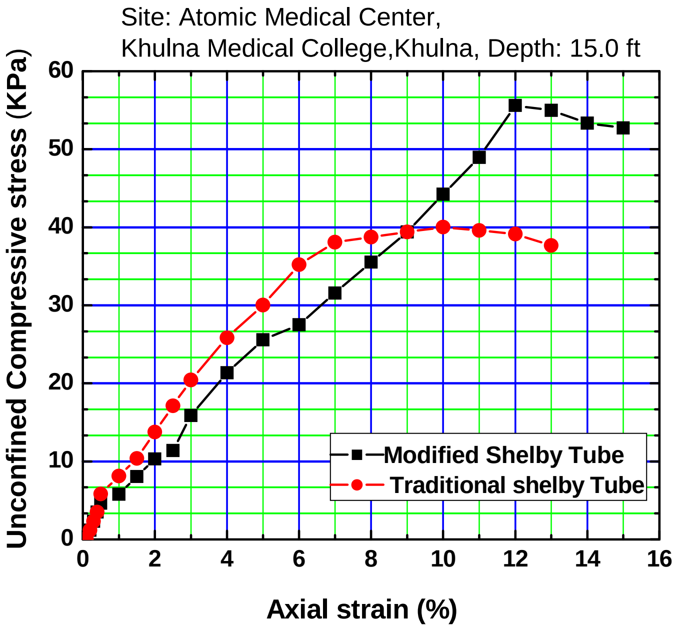


Fig. A.16: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-10)

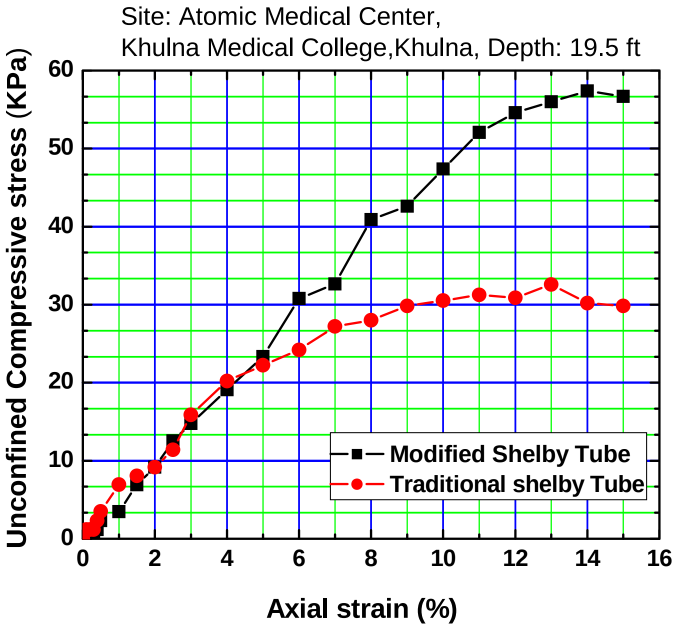


Fig. A.17: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-13)

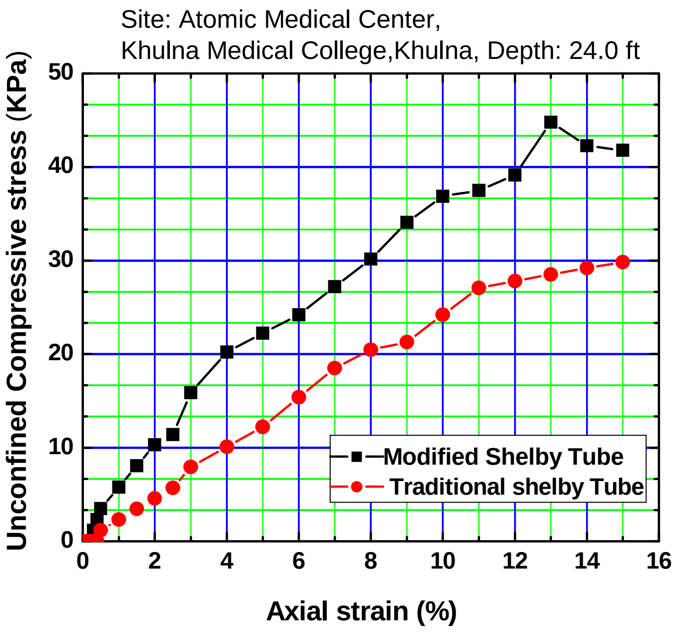


Fig. A.18: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-16)

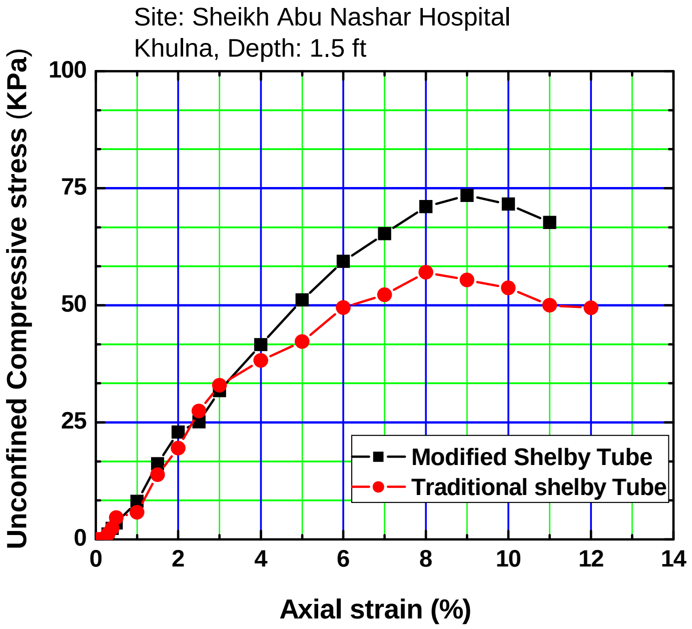


Fig. A.19: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna (UD-1)

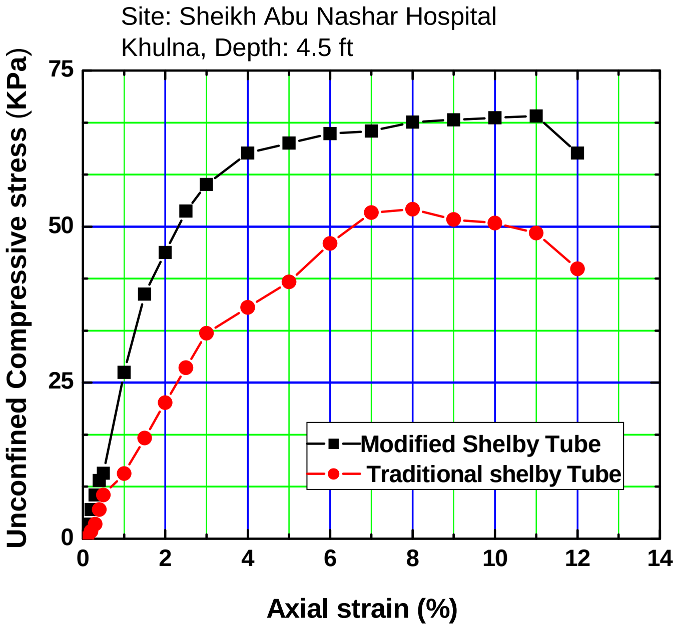


Fig. A.20: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna (UD-3)

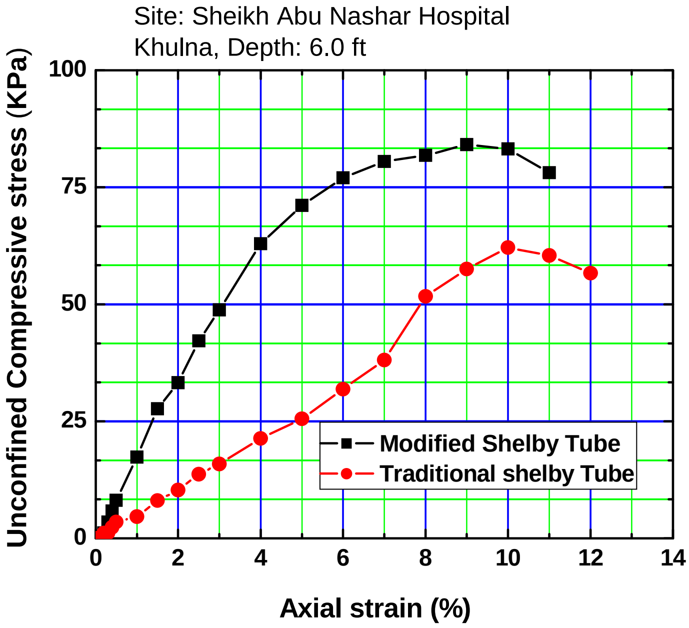


Fig. A.21: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna (UD-4)

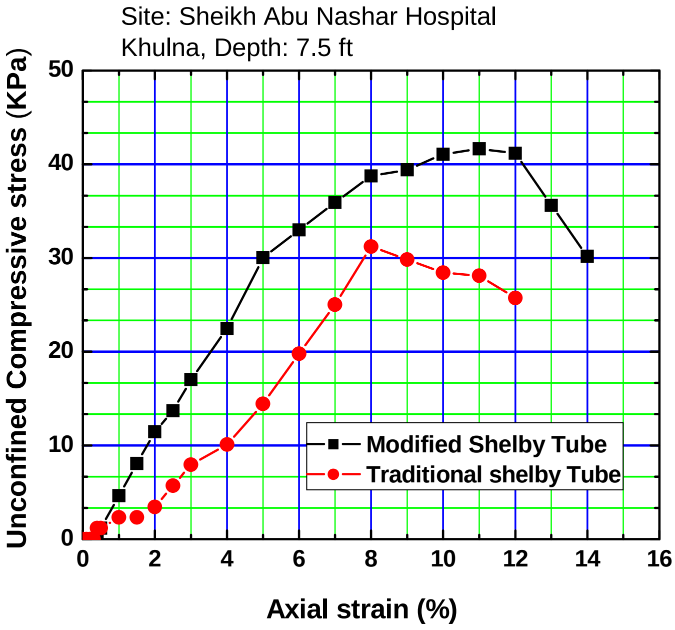

Site: Sheikh Abu Nashar Hospital
Khulna, Depth: 7.5 ft

Fig. A.22: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna (UD-5)

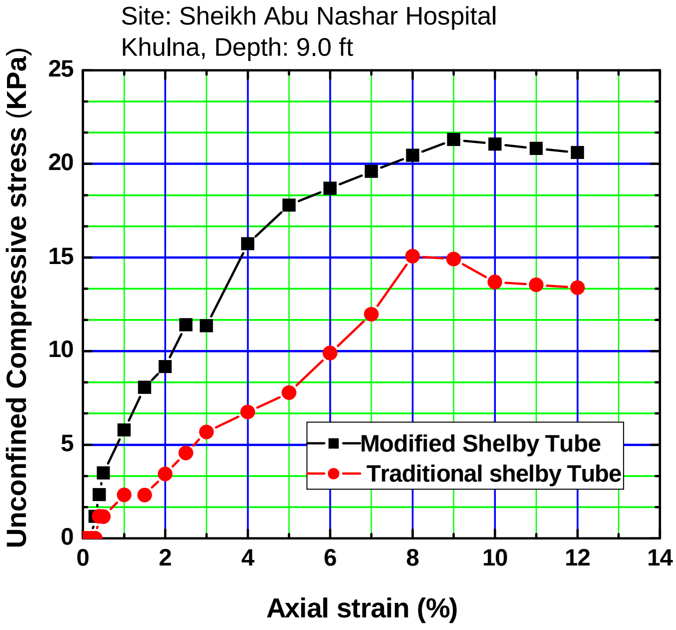

Site: Sheikh Abu Nashar Hospital
Khulna, Depth: 9.0 ft

Fig. A.23: Typical stress strain curve of samples collected by Modified and Traditional Shelby tube from Sheikh Abu Nashar Hospital site in Khulna (UD-6).

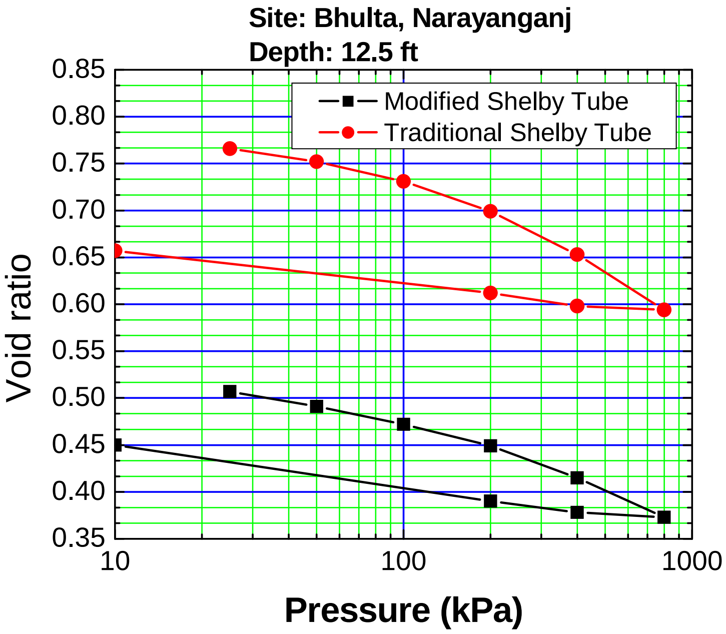


Fig. A.24: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-8).

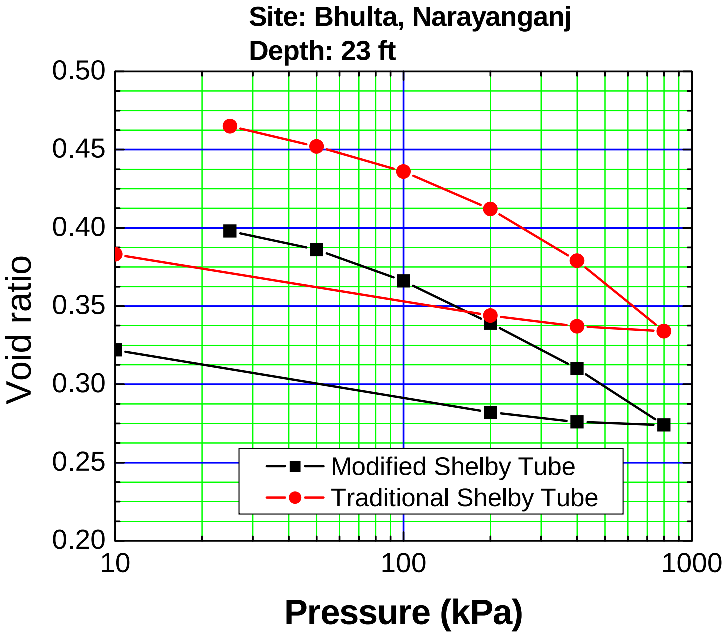


Fig. A.25: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-15).

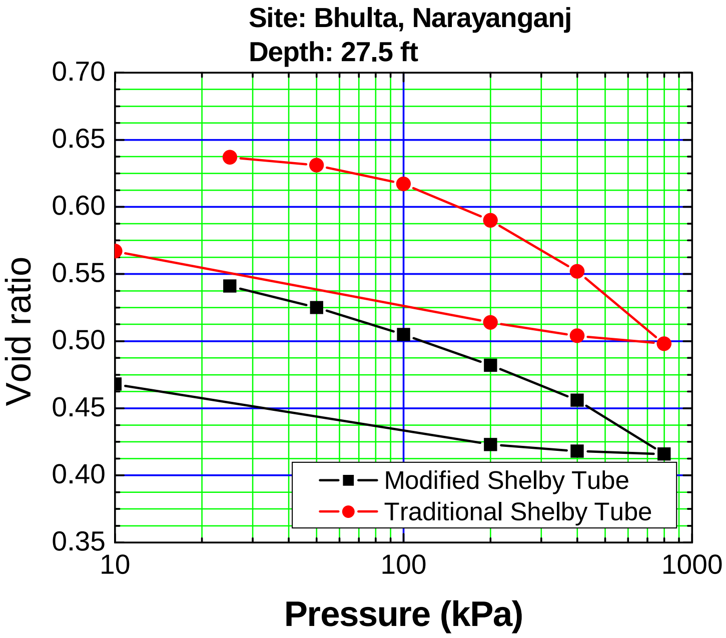


Fig. A.26: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-17).

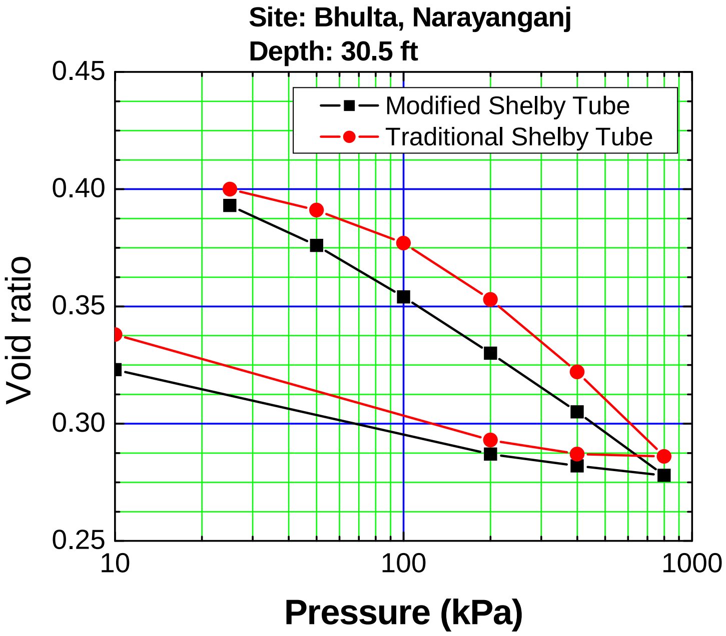


Fig. A.27: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-20).

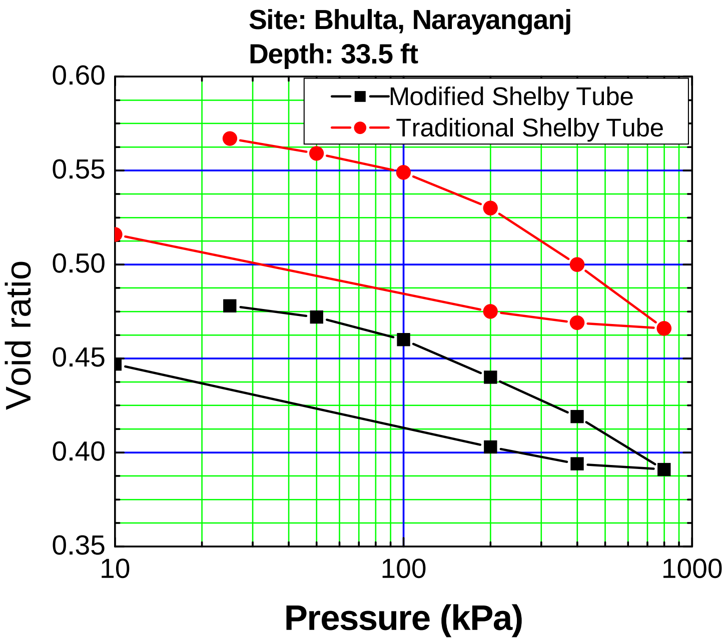


Fig. A.28: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Bhulta site in Narayanganj (UD-22).

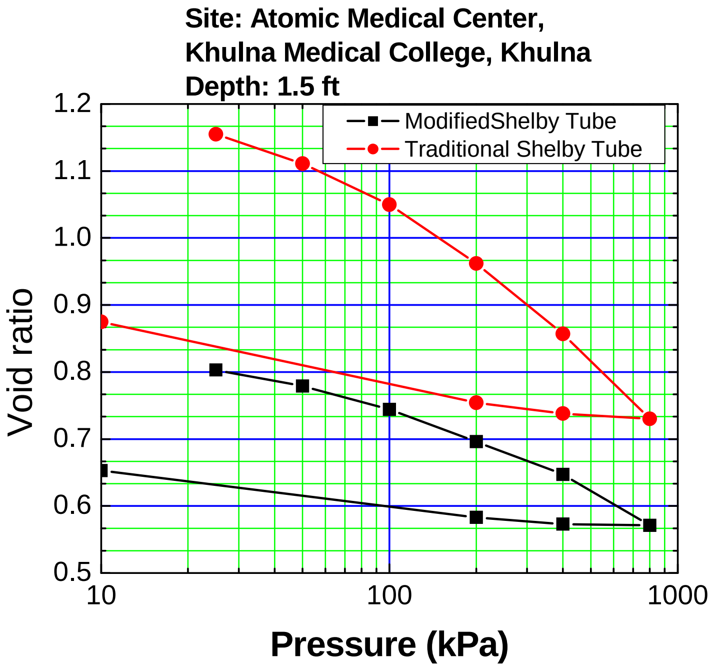


Fig. A.29: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-1).

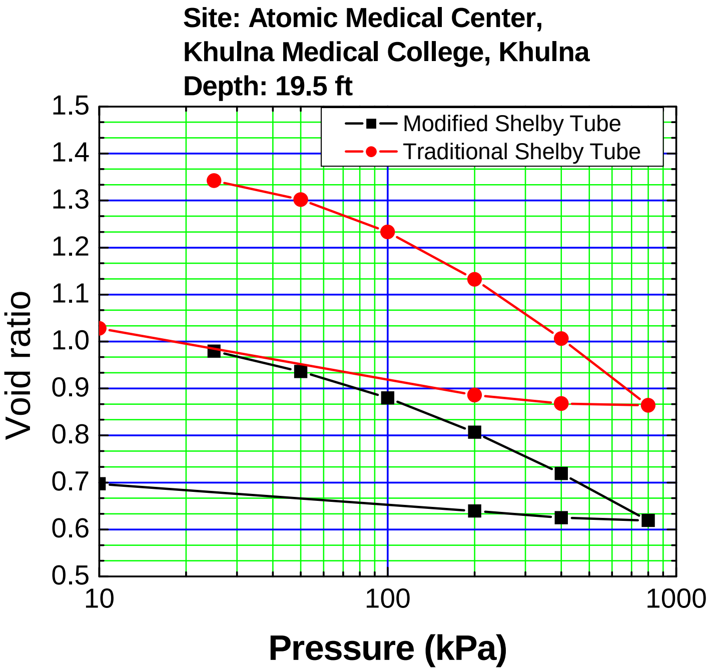


Fig. A.30: Typical e-logp curve of samples collected by Modified and Traditional Shelby tube from Atomic Medical Center site in Khulna (UD-13).

Table A.1: Summary of Specific Gravity of soils Bhulta (Narayanganj)

Location	Sample Depth	Soil Sample	Soil Type		Specific Gravity, Gs	
			BH-2 (Modified Shelby Tube)	BH-3 (Traditional Shelby Tube)	BH-2 (Modified Shelby Tube)	BH-3 (Traditional Shelby Tube)
Bhulta (Narayanganj)	9.5	UD-6	CL	CH	2.59	2.51
	12.5	UD-8	CH	CH	2.62	2.50
	15.5	UD-10	CH	CH	2.66	2.53
	17.0	UD-11	CH	CH	2.55	2.58
	18.5	UD-12	CL	CL	2.56	2.62
	21.5	UD-14	CL	CL	2.59	2.69
	23.0	UD-15	CL	CL	2.51	2.51
	24.5	UD-16	CL	CL	2.56	2.58
	26.0	UD-17	CL	CL	2.56	2.62
	27.5	UD-18	CL	CL	2.59	2.55
	30.5	UD-20	CL	CL	2.69	2.66
	32.0	UD-21	CL	CL	2.66	2.58
	33.5	UD-22	CL	CL	2.65	2.6
	35.0	UD-23	CL	CL	2.58	2.59
	36.5	UD-24	CL	CL	2.56	2.56
	38.0	UD-25	CL	CL	2.63	2.62
	39.5	UD-26	CL	CL	2.53	2.54

Table A.2: Summary of Specific Gravity of Soils of Khulna Area.

Location	Sample Depth	Soil Sample	Soil Type		Specific Gravity, Gs	
			BH-1 (Modified Shelby Tube)	BH-2 (Traditional Shelby Tube)	BH-1 (Modified Shelby Tube)	BH-2 (Traditional Shelby Tube)
Atomic Medical Center (Khulna)	1.5	UD-1	CH	CH	2.60	2.60
	6.5	UD-4	MH	MH	2.66	2.72
	10.5	UD-7	ML	ML	2.66	2.67
	15.0	UD-10	OH	OH	2.55	2.46
	19.5	UD-13	MH	MH	2.63	2.70
	24.0	UD-16	ML	ML	2.60	2.60
Sheikh abu Naser Hospital (Khulna)	1.5	UD-1	MH	MH	2.66	2.59
	3.0	UD-2	CH	CH	2.69	2.68
	4.5	UD-3	ML	ML	2.66	2.62
	6.0	UD-4	ML	ML	2.59	2.62
	7.5	UD-5	ML	ML	2.69	2.66
	9.0	UD-6	OH	OH	2.52	2.44