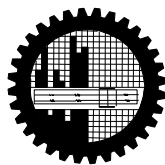# Development of Rod Penetration Test to Measure Shear Strength of Cohesive Soil

by

Shishir Kumar Barman

A project submitted to the Department of Civil Engineering,
Bangladesh University of Engineering and Technology,
Dhaka, in partial fulfillment of the degree of

MASTER OF ENGINEERING (Civil and Geotechnical)
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY,
DHAKA

2013

The project titled **"Development of Rod Penetration Test to Measure Shear Strength of Cohesive Soil"** submitted by Shishir Kumar Barman, Student No: 0409042243 (F), Session: April 2009 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Master of Engineering (Civil and Geotechnical)** on **August 17, 2013**

BOARD OF EXAMINERS

_____

Dr. Md. Jahangir Alam   **Chairman**
Associate Professor   (Supervisor)
Department of Civil Engineering
BUET, Dhaka.

_____

Dr. Sayed Fakhrul Ameen   **Member**
Professor
Department of Civil Engineering
BUET, Dhaka.

_____

Dr. Tahmeed Malik Al-Hussaini   **Member**
Professor
Department of Civil Engineering
BUET, Dhaka.

CANDIDATE'S DECLARATION

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

August, 2013

_____

Shishir Kumar Barman

TABLES OF CONTENTS

List of Figures

List of Tables

Acknowledgements

ABSTRACT

A rod penetrometer was designed and fabricated. In the laboratory the penetration test was performed by this rod penetrometer. From the test results correlations were developed between undrained shear strength and rod penetration for 16 mm and 25 mm diameter rod. In the laboratory, remoulded clay soil samples were prepared at various moisture contents in the range of 20% to 30%. The relation between undrained shear strength and rod penetration is linear for the whole range of water content (20-30%). From 20 to 25% moisture content, the relation is linear with steep slope. From 25 to 30% moisture content, the relation is linear with milder slope. The reason of different slopes before and after at around 25% water content is unkown. Shear strength decreases, in general, with the increase of water content and liquidity index. However, before and after 25% moisture content the slope of the relation is different. The calibration curve which was developed in this study for the portable static rod penetrometer was verified in the field and the verification result was quite satisfactory.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In geotechnical and foundation engineering, in-situ penetration tests have been widely used for site investigation. The standard penetration tests (SPT) (ASTM D1586, 1999), developed around 1927, and is currently the most popular test to obtain subsurface information (Bowels, 1996). Most of the conventional foundation design is made by using the SPT.

But SPT have some limitations since the SPT is performed at some selected points of a site. To overcome these limitations economically, a testing device has been developed that can check the bearing capacity of the clayey soil under each footing before the construction of the footing. A portable static rod penetrometer is such type of device that anyone can perform the test to get undrained shear strength and bearing capacity for shallow foundation on clay soil. Thus, danger of having soft pockets under individual shallow footing may be avoided.

Moreover, for the shallow foundation up to 4 storied residential building in the remote area where the SPT is not available, such a portable testing device can be used easily by local people.

1.2 BACKGROUND OF THE STUDY

There are some penetrometer devices which are used in subsoil investigation in field such as proving ring penetrometer, the hand-held electronic cone penetrometer, swedish weight sounding method, dynamic cone penetrometer etc. The proving ring penetrometer (ASTM D-1558) is a cone type of penetrometer which is used to determine the penetration resistance of soils in shallow exploration work.

The hand-held electronic cone penetrometer (Kees, *G.*, 2005) electronically records the force required to push the probe into the ground and depth reading for computer

down-load and analysis. This penetrometer˝s measurement of soil strength is very sensitive to soil compaction. However, using strength data for definitive interpretations of soil compaction requires correlations to other standard compaction tests or additional knowledge of soil moisture characteristics. The Swedish weight sounding test (Suemasa et al, 2005) is one of the oldest and the most commonly used test to investigate shallow soil strata. There is, however, an inevitable disadvantage on the interpretation of the test results, which is derived from using two different indicators; load and the half turns number. The half turns number is, however, difficult to be related with load, except for using any empirical relationship. The dynamic cone penetrometer (DCP) (Salgado et.al, 2003) which is driven into the soil by dropping a sliding hammer contained on the upper shaft onto the anvil. The underlying soil strength is determined by measuring the penetration of the lower shaft into the soil after each hammer drop. Common errors which may occur during testing include the operator not holding the DCP device plumb, and incorrect reading and recording of the test data. This test is performed for sandy soil. Vane shear testing (Bowels, 1996) is one of the most common in-situ methods for the estimation of the undrained shear strength of the soil. The shear strength of the material is calculated from the torque by dividing by a constant which depends on the dimensions and the shape of the vane. Torque measuring device is not readily available for local people.

In this case, this portable penetrometer can be used widely. Its procedure is very easy. No need of well-trained person to do this. Anyone can find out shear strength of soil without any training and it is also very cheap. So it can be used everywhere to find out the shear of soil easily.

1.3 OBJECTIVE OF THE STUDY

The objectives of the study are as follows:

    i)   To design and fabricate a Rod Penetrometer (RP)

    ii)   To calibrate the Rod Penetrometer (RP) in the laboratory using remolded clay samples of different water contents.

iii)   To verify the calibration of Rod Penetrometer (RP) in any one or two sites.

1.4 METHODOLOGY

The current study was carried out in the following stages:

a) Disturbed cohesive soil samples were collected from different locations and their index properties were determined in the geotechnical laboratory.

b) Remolded soil samples were prepared in a mold at different moisture content on which the penetration test was performed by applying static loads of increasing magnitude. At increasing loads penetration was recorded and penetration per kg load was determined. After penetration test the remolded soil sample of same water content was used for unconfined compression test to get undrained shear strength of soil.

c) A correlation was developed between undrained shear strength and penetration. Thus the Rod Penetrometer was calibrated for 16 mm and 25 mm diameter rod.

d) A construction site with shallow foundation was selected to verify the calibration. After excavation for concrete casting of shallow foundation, penetration test was performed and undisturbed sample was collected. Unconfined compression test was done from the collected undisturbed sample to get the undrained shear strength of soil. These data was used to verify the calibration.

1.5 ORGANIZATION OF THE THESIS

This thesis paper is arranged into five chapters. In Chapter one, background, objectives and methodology of the work is described precisely.

Chapter two contains a brief account of literature review. The basic concepts and past works regarding the study are discussed here.

Chapter three describes the instrumentation and testing procedure of the total experiment.

Chapter four contains the discussion and findings results from the study. The calibration curves of the portable static rod penetrometer and field verification results are shown in this chapter.

Chapter five contains the conclusions and recommendations for further research.

All tables and graphs of penetration test are shown in Appendix A; all tables and figures of unconfined compressive strength are shown in Appendix B.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Many forms of in situ penetration test are in use worldwide. The current research project is related to shear strength of cohesive soil. Shear strength of soil has a vital role in design purpose. Soil bearing capacity is measured from soil strength parameter which is fundamental consideration in design. Shear Strength of soil can be determined by different field and laboratory test. Both the field and Laboratory tests are usually costly and time consuming. In many cases when there is shortage of time, then collecting the soil sample and taking it to the laboratory become a large factor for completion of the project. The use of rod penetrometer in determination of shear strength of soil may make the subsoil investigation easier.

2.2 VARIOUS TYPES OF PENETROMETERS

Penetrometers can be divided into two broad groups. The simplest are dynamic penetrometers. They consist of tubes or solid points driven by repeated blows of a drop weight. „Static" penetrometers are more complex, being pushed hydraulically into the soil. There is no such portable static penetrometer yet for shear strength determination but there are some pentrometers which are a little bit similar to the instrument of the current study. Some of those penetrometers are discussed here.

2.2.1 THE HAND-HELD ELECTRONIC CONE PENETROMETER

The hand-held electronic cone penetrometers can be operated by a single person. Each model electronically records the force required to push the probe into the ground and depth reading for computer down-load and analysis. As the probe is pushed into the ground, the force recorded by the electronic load cell is used to calculate the cone index, a number derived from the frictional forces on the cone"s surface as it is pushed

into the ground. The cone index is a relative indicator of the soil‟s strength, typically recorded in kilopascals or pounds per square inch. The hand-held electronic cone penetrometer is shown in Figure 2.1.

This penetrometer‟s measurement of soil strength is very sensitive to soil compaction. However, using strength data for definitive interpretations of soil compaction requires correlations to other standard compaction tests or additional knowledge of soil moisture and soil characteristics. The hand-held electronic cone penetrometer can help pinpoint compaction problems that might require more extensive soil testing. It‟s also useful for looking at variability or changes in soil strength caused by equipment, vehicles, and foot traffic.

Researchers are evaluating ways to use hand-held electronic cone penetrometers to help predict the likelihood of serious compaction in susceptible areas. Reliable data requires penetrometer operators to insert the probe into the ground at a consistent speed. Certain soil or sampling conditions can greatly alter penetrometer readings and make them much less useful. An operator‟s field notes are helpful when data require editing because of unusual conditions, such as very rocky soils, large roots, hardpans or plowpans, voids such as gopher holes or large root channels, buried organic materials, and very dry conditions. The repetition tests conducted during this evaluation verify the need to probe several locations in a given area to better understand variations in soil conditions and operator inconsistency.

2.2.2 SWEDISH WEIGHT SOUNDING TEST

The Swedish weight sounding test is one of the oldest and the most commonly used test to investigate shallow soil strata. Test apparatus for Swedish weight sounding test are shown in Figure 2.2.

The Swedish weight sounding apparatus consists of a screw point, sounding rods, a rotating handle and 6 pieces of weights making a total of 100 kg. In this test, the screw point jointed by the rods is stepwise loaded until the screw point penetrates into a soil stratum. If the screw point can‟t penetrate under the maximum load of 100 kg, it is rotated by using the handle. Penetration resistance of a soil stratum is estimated by

6

a load required to penetrate, W_{sw}, or the number of half turns at which the screw point was rotated to penetrate to a planned depth. In the present Japanese Industrial Standards, the number of half turns is converted into a value required for 1m penetration as N_{sw}.

The Swedish weight sounding test has advantages of simpler system, faster procedure and better cost efficiency in comparison with any other soundings. There is, however, an inevitable disadvantage on the interpretation of the test results, which is derived from using these two different indicators W_{sw} and N_{sw} in the test. The load W_{sw} with a dimension of force can be easily corresponded to strength or bearing capacity of the penetrated soil layer. The half turns number N_{sw} is, however, difficult to be related with W_{sw} as well as strength of the layer, except for using any empirical relationship.

2.2.3 DYNAMIC CONE PENETROMETER (DCP)

The DCP, was developed in 1956 in South Africa as in situ pavement evaluation technique for evaluating pavement layer strength (Scala, 1956) which also known as the Scala penetrometer. Since then, this device has been extensively used in South Africa, the United Kingdom, the United States, Australia and many other countries, because of its portability, simplicity, cost effectiveness, and the ability to provide rapid measurement of in situ strength of pavement layers and subgrades. Recently DCP is standardized by ASTM (ASTM D 6951-03). The DCP has also been proven to be useful during pavement design and quality control program. The DCP, however, was not a widely accepted technique in the United States in the early 1980s (Ayers, 1990). De Beer (1991), Burnham and Johnson (1993), Tumay (1994); Newcomb et al (1994); Truebe and Evans (1995); Newcomb et al (1995); Parker et el (1998); and White et al (2002) have shown considerable interest in the use of the DCP for several reasons. First, the DCP is adaptable to many types of evaluations. Second, there are no other available rapid evaluation techniques. Third, the DCP testing is economical.

The design specification of the parts has a tremendous impact on the results collected from the tests so various parts of the DCP are very important. The schematic diagram of DCP instrument is shown in Figure 2.3. The instrument is made by Stainless Steel for better efficiency and longer life time.

The Dynamic Cone Penetrometer consists of two 16-mm (5/8 inch) diameter shafts coupled near midpoint. The lower shaft contains an anvil and a pointed tip which is driven into the soil by dropping a sliding hammer contained on the upper shaft onto the anvil. The underlying soil strength is determined by measuring the penetration of the lower shaft into the soil after each hammer drop. This value is recorded in the millimeters (inches) per blow and is known as the DCP penetration index (DPI).The penetration index can be plotted versus depth to identify thickness and strengths of different pavement layers or can be correlated to other soil strength parameters such as the California Bearing Ratio (CBR).

Conducting a DCP test involves raising and dropping the hammer to drive the cone on the lower shaft through the underlying pavement layers. Typically, after each hammer blow, the penetration of the cone is measured and recorded. In stiffer soils, reading may be recorded after several hammer blows. The cone can be driven a total of 0.75 to1m (3-4 feet) at each test location.

Each test takes approximately 5 to 10 minutes, but may take up to 20 or 30 minutes if the bound pavement surface needs to be cored and then patched after testing.

DCP testing can be performed by a crew of one to three people. Common errors which may occur during testing include the operator not holding the DCP device plumb, and incorrect reading and recording of the test data.

2.3 CONCLUDING REMARKS

Until now, there is no research found to find the shear strength of clay using portable rod penetrometer. All the penetrometers found in literature has cone. In this study, only rod with flat bottom is used.
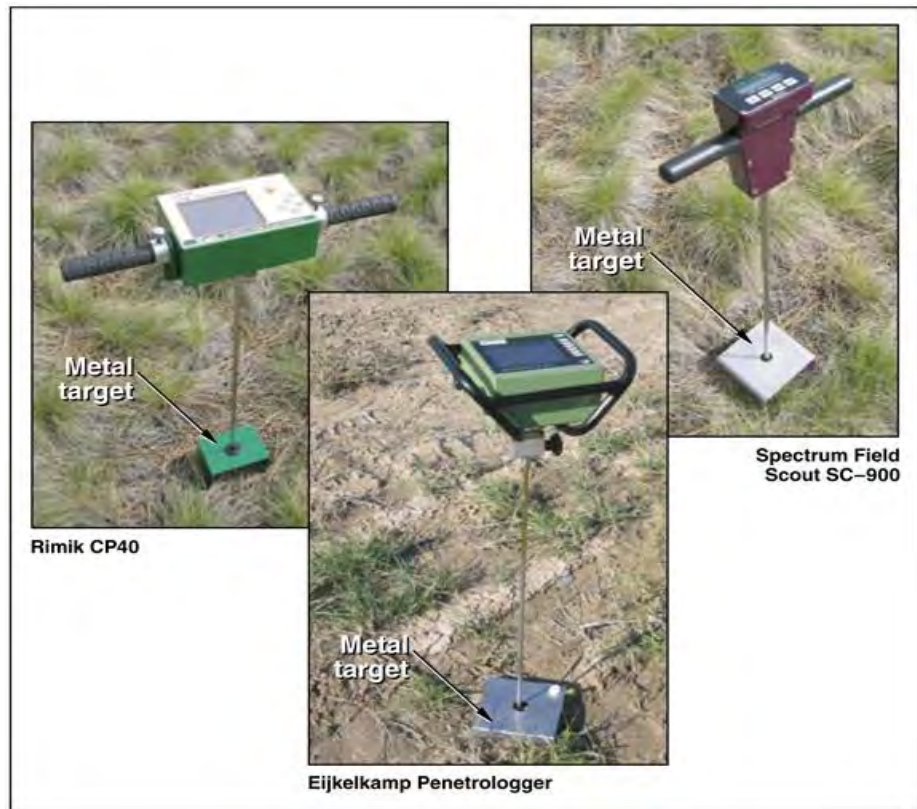
Figure 2.1: Hand held electronic cone penetrometer
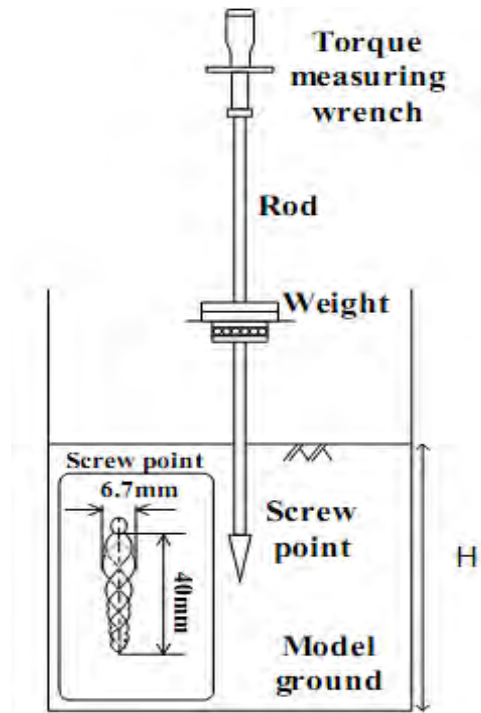
Figure 2.2: Test apparatus for Swedish weight sounding test
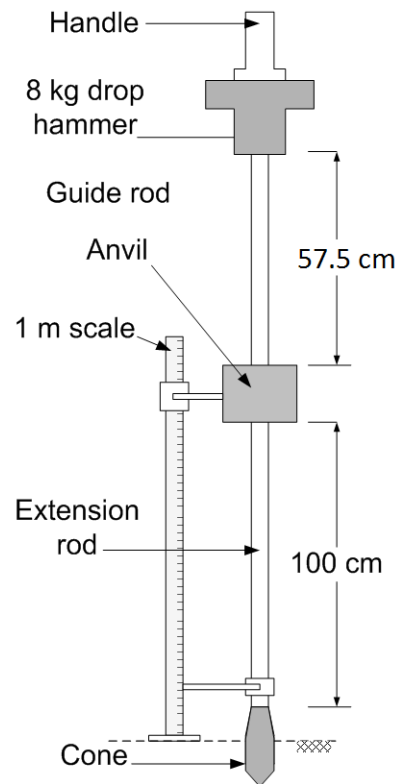
Figure 2.3: Schematic diagram of Dynamic Cone Penetration (DCP) test

CHAPTER 3

INSTRUMENTAION AND TEST PROGRAM

3.1 GENERAL

This chapter describes the overall program including designing and fabricating the portable static rod penetrometer, experimental setup and all the test procedure. To obtain data for analysis, many laboratory tests were performed. It contained physical and index properties for strength properties determination.

3.2 FABRICATION OF ROD PENETROMETER

At first a portable static rod penetrometer was fabricated. The tools of this instrument and experimental setup have been described here.

3.2.1 Instrumentation

The whole instrument is mainly divided in two parts; one is penetrometer and other is the tripod. The schematic diagram and experimental setup of portable static rod penetrometer is shown in Figure 3.1and Figure 3.15.

3.2.1.1 Penetrometer:

Penetrometer is the main part of the Rod penetrometer. It is a portable device. The elements of the penetrometer are:

   i.   16 mm dia rod with extended part
  ii.   25 mm dia rod with extended part
 iii.   Anvil
 iv.   Load plate
  v.   Load Holding bar

First the 16mm or 25mm rod was attached with the anvil & load plate. Then the holding bar was attached to the anvil. Penetrometer should be vertical during loading. Figure 3.3 to Figure 3.6 shows the various parts of penetrometer and its instrumentation.

3.2.1.2 Tripod

Tripod is the supporting part of the Rod penetrometer.It hold the rod vertically.The elements of the Tripod are :

   i. Three legs (three stainless steel rods)
  ii. Base plate
 iii. Balance bubble
 iv. Scale & pointer

The three legs of tripod were attached with the base plate. The labeling of the tripod was checked by balance bubble. If the tripod was not labeled, then the legs of tripod were adjusted. Figure 3.2 shows the tripod and Figure 3.7 to Figure 3.12 shows various parts of apparatus and its instrumentation.

3.3 TEST PROGRAM

3.3.1 General

From different locations disturbed cohesive soil samples were collected and their index properties were determined. Remolded soil samples were prepared in a mold at different moisture content on which the penetration tests were performed. At increasing loads penetration were recorded and penetration per kg load were determined. The remolded soil sample of same water content was used for unconfined compression test to get undrained shear strength of soil after penetration test.

A correlation was developed between undrained shear strength and penetration. Thus the Rod Penetrometer was calibrated for 16 mm and 25 mm diameter rod. Then a construction site with shallow foundation was selected to verify the calibration.

Following are the apparatus those are required to perform the penetration test by this instrument:

  i. Rod penetrometer
  ii. Tripod
  iii. Split mold
  iv. Trimmer
  v. Wire saw
  vi. Knife
  vii. Desiccators
  viii. Balance
  ix. Oven
  x. Stop watch
  xi. Cans
  xii. Scale

3.3.2 Laboratory Tests

All the tests performed at the geotechnical laboratory of BUET were to determine the index properties, grain size distribution and specific gravity (G_s) of the collected disturbed sample from different locations. Index properties tests were performed to classify the soil samples. Besides, natural water content (w_n), unit weight, liquid limit (w_L), plastic limit (w_p), and grain size distributions were determined.

Unconfined compression test was used to determine 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.

3.3.3 Test Procedure of Rod Penetrometer

The tripod was set up and leveling of the tripod was checked by spirit bubble. The legs of tripod were adjusted to make it horizontal. The soil sample was sieved by no. 4 standard sieve and a mold was filled with the soil sample in three layers. Each layer was compacted by 25 blows by standard hammer. The mold was kept under the tripod and the rod was put on it. Loads were given on the soil sample by putting loads on anvil up to 80 kg with an increment of 10 kg each time. The value of penetration was noted by the help of scale and pointer.

From the test data, penetration vs. Load graph was plotted. A best fitted straight was found. From the slope of the line the penetration was found. By this Rod Penetration the shear strength of soil from calibration curve of that penetrated rod was found.

3.3.4 Tests at Field and Verification

A construction site at Kollayanpur in Dhaka with shallow foundation was selected to verify the calibration. After excavation for concrete casting of shallow foundation, penetration test was performed by the Portable Static Rod Penetrometer. Several points on the excavated surface were selected for this purpose. For increasing loads penetration was recorded and penetration per kg load was determined. After that undisturbed sample was collected from each point. Unconfined compression test was done for the collected undisturbed sample to get the undrained shear strength of soil. Knowing the Rod Penetration from Cumulative penetration vs. Load, the shear strength of soil was determined using the calibration curves. Then shear strength from unconfined compression test was used to verify the calibration. Figure 3.13 shows the sealing the undisturbed soil sample collected for laboratory tests.
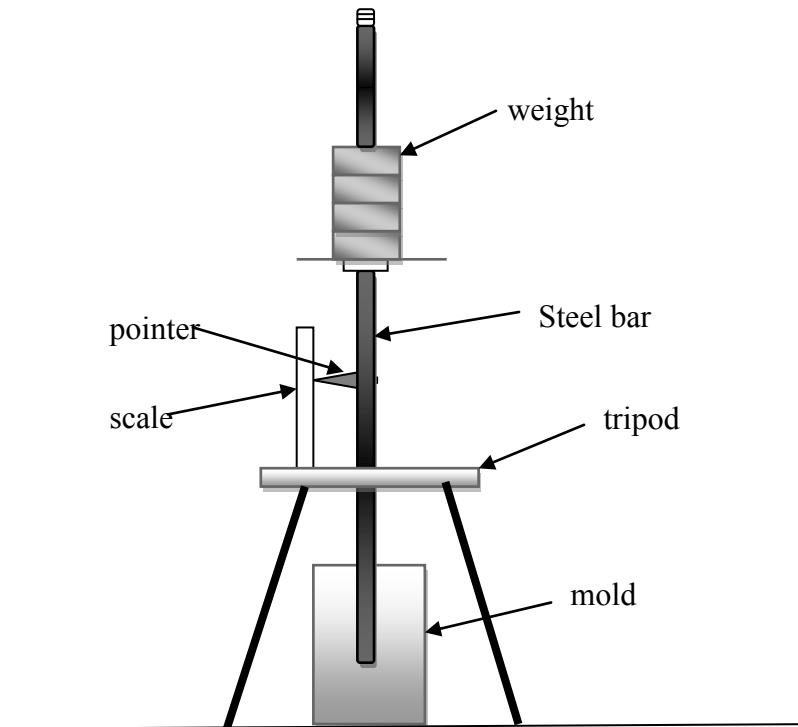
Figure 3.1: Penetrometer

Figure 3.2: Tripod.

Figure 3.3: 25mm dia &16mm dia bar with extended parts

Figure 3.4: Anvil & Load plate

Figure 3.5: Load holding bar attached with anvil

Figure 3.6: Detached Holding bars

Figure 3.7: Elements of Tripod

Figure 3.8: Legs of Tripod.

Figure 3.9: Base plate of tripod

Figure 3.10: Balance bubble.
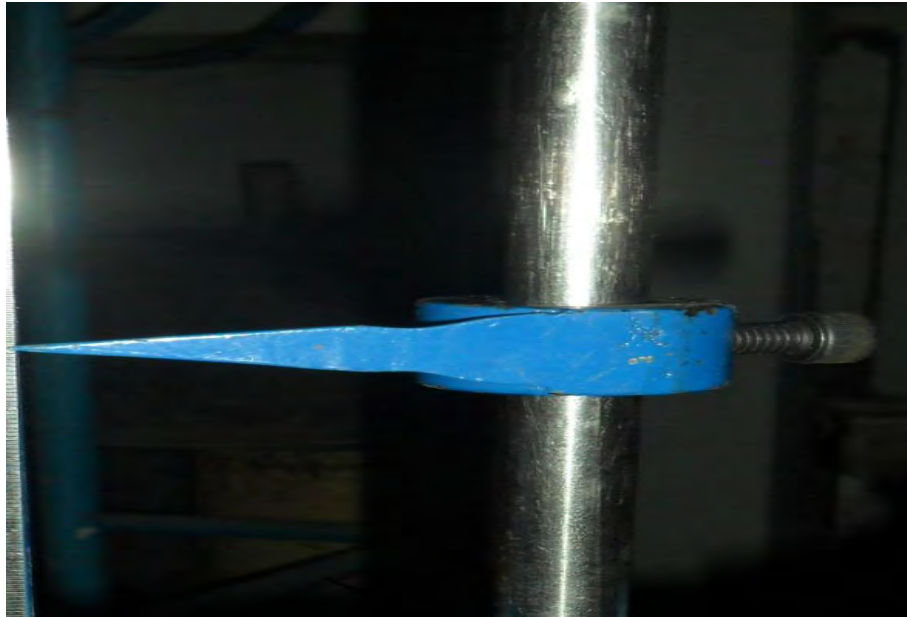
Figure 3.11: Attachment of pointer with rod.
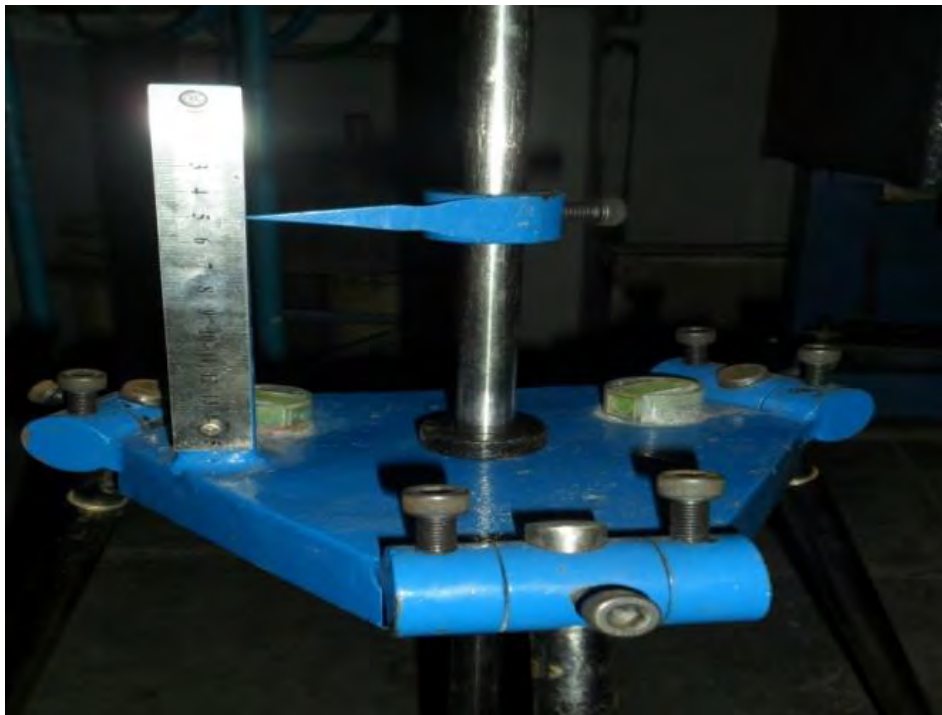
Figure 3.12: Taking penetration reading from scale by pointer.

Figure 3.13: Undisturbed sample collection after field test for unconfined compression test at laboratory.

Figure 3.14: Soil compaction

Figure 3.15: Experimental Setup for Penetration Test

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

The results of the experimental program are presented in this chapter. This chapter provides the calibration results of the Portable Static Rod Penetrometer in the laboratory using remolded clay samples of different water contents. This chapter also provides verification results of Portable Static Rod Penetrometer in the field.

A portable static rod penetration test was developed to determine the in-situ shear strength of cohesive soil. Two steel bars of 25mm and 16mm diameter were used for penetration. The rod was penetrated in a mold that was filled by the compacted soil sample. A static load of 80 kg was applied on the soil in the mold with 10 kg increments. The penetrations were measured. Then the unconfined compression test of the soil samples were done to get the shear strength of each soil sample. Then a correlation graph of shear strength of the soil and penetration was found. These graphs are the calibration curve for those two rods. In-situ shear strength of soil can be determined easily using these calibration curves in the field.

4.2 LABORATORY TEST RESULTS AND DISCUSSIONS

The laboratory test results on soil samples collected from different locations are presented in this section.

4.2.1   Atterberg Limits

ASTM D4318-86 described method of Atterberg Limits Test was performed on undisturbed samples to determine liquid limit, plastic limit, and plasticity index. The liquid limit test was performed using Casagrande''s apparatus. A summary of Atterberg limits and USCS classification of soils are shown in Table 4.1.

4.2.2 Penetration test

Among the two of bar, 16mm bar can be used for stiff clay and 25mm for soft clay. Soil samples were collected from Mohakhali and Kollayanpur sites. Rod Penetration was different for the two bars of the same sample for the difference in load inserted on the soil sample. The penetration due to load increment has been determined and summarized. Typical penetration test results for 16 mm and 25 mm rods are shown in Tables 4.2, Table 4.3, Figure 4.1 and Figure 4.2. The rest of the results are shown in Appendix A.

4.2.3 Shear Strength Characteristics

Unconfined compression test of the soil samples were done to get the undrained shear strength of the soil. ASTM D2166-86 described method was used to determine unconfined compressive strength of cohesive soil samples prepared in the laboratory at various moisture contents. Unconfined compression tests were also performed on undisturbed soil samples collected from Kollayanpur. A typical unconfined compressive stress vs. axial strain curve of soil sample is shown in Figure 4.3. Undrained shear strengths obtained at various moisture contents are shown in Figure 4.4. To generalize this relation, undrained shear strength vs liquidity index graph is shown in Figure 4.5. From these figures, it is seen that shear strength decreases with the increase of moisture content and liquidity index. However the variation is not linear for the whole range. In the both side of 25% moisture content two distinct straight portions exist.

4.3 CALIBRATION CURVES

Undrained shear strength versus rod Rod Penetration graphs are shown separately for the 16 mm and 25 mm rods. Table 4.4 displays the summary of test result in the laboratory for 16 mm and 25 mm rod diameter. Figure 4.6 and Figure 4.7 shows the correlation of shear strength versus rod rod penetration for two rod diameters. From the graph, it was seen that for a certain range the slope line of correlation has mild

slope. Above the 25% moisture content the slope line of correlation has steep slope. These graphs were the calibration curves for those 16 mm and 25 mm rods. Now if anyone knows the Rod Penetration by the portable static rod penetrometer, he will be able to find out the shear strength from these calibration curves.

4.4 VERIFICATION OF CORRELATION FROM FIELD DATA

After establishing correlation between undrained shear strength vs. rod penetration from the test results in laboratory, the correlation was verified by the field test. The Portable Static Rod Penetrometer test was conducted to a construction site at Kollayanpur in Dhaka with shallow foundation to verify the calibration. Penetration was recorded for increasing loads and penetration per kg load was determined. After that undisturbed sample was collected for unconfined compression test to get the undrained shear strength of soil. From the field test the Rod Penetration was found from Penetration vs. Load curve. Then the Rod Penetration was used to determine the shear strength of soil using the calibration curves. Shear strength from calibration curves was compared with undrained shear strength from unconfined compression test to verify the calibration. Two typical field test results for 16 mm and 25 mm rods are shown in Figure 4.8 to 4.9. The verification results are summarized in Tables 4.5 and Table 4.6. It is found that difference between undrained shear strength from unconfined compression test and undrained shear strength from rod penetration test is not significant. Therefore, the portable penetrometer might be used to determine undrained shear strength of cohesive soil.

4.5 CONCLUDING REMARKS

Based on the verification results from Table 4.5 and Table 4.5, it can be said that the calibration curves for the portable static rod penetrometer which were developed at laboratory in this project was quite satisfactory as the shear strength from the calibration curves and undrained shear strength from the unconfined compression test was approximately same.

Table 4.1: Summary of Atterberg Limits of soil samples.

Location of soil samples	Liquid Limit	Plastic Limit	PI	Color	USCS Classification
Mohakhali	56	18	38	Red	Fat Clay
Kollayanpur	51	15	36	Redish Yellow	Fat Clay

Table 4.2: Penetration test with 16mm rod

Location :	Laboratory (soil of Mohakhali)
Penetration No :	For 20% WC
Rod type :	16 mm

Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	6	6
3.792	10	13.792	13.792	7	13
3.792	10	23.792	23.792	11	24
3.792	10	33.792	33.792	10	34
3.792	10	43.792	43.792	13	47
3.792	10	53.792	53.792	18	65
3.792	10	63.792	63.792	19	84
3.792	10	73.792	73.792	14	98
3.792	10	83.792	83.792	16	114

Figure 4.1: Penetration vs. load graph of 16 mm rod at 20% moisture content of soil collected from Mohakhali.

Table 4.3: Penetration test with 25mm rod

Location :   Laboratory (soil of Mohakhali)
Penetration No :   For 20% WC
Rod type :   25 mm

Instrument Weight(kg)	Load(Kg)	Total load, W(kg)	Cumulative load(kg)	Depth, H (mm)	Cumulative Depth(mm)
0	0	0	0	0	0
5.605	5.605	5.605	5.605	3	3
5.605	10	15.605	15.605	2	5
5.605	10	25.605	25.605	3	8
5.605	10	35.605	35.605	4	12
5.605	10	45.605	45.605	5	17
5.605	10	55.605	55.605	5	22
5.605	10	65.605	65.605	3	25
5.605	10	75.605	75.605	4	29
5.605	10	85.605	85.605	4	33

Figure 4.2: Penetration vs. Load graph of 25 mm rod at 20% moisture content of soil collected from Mohakhali.
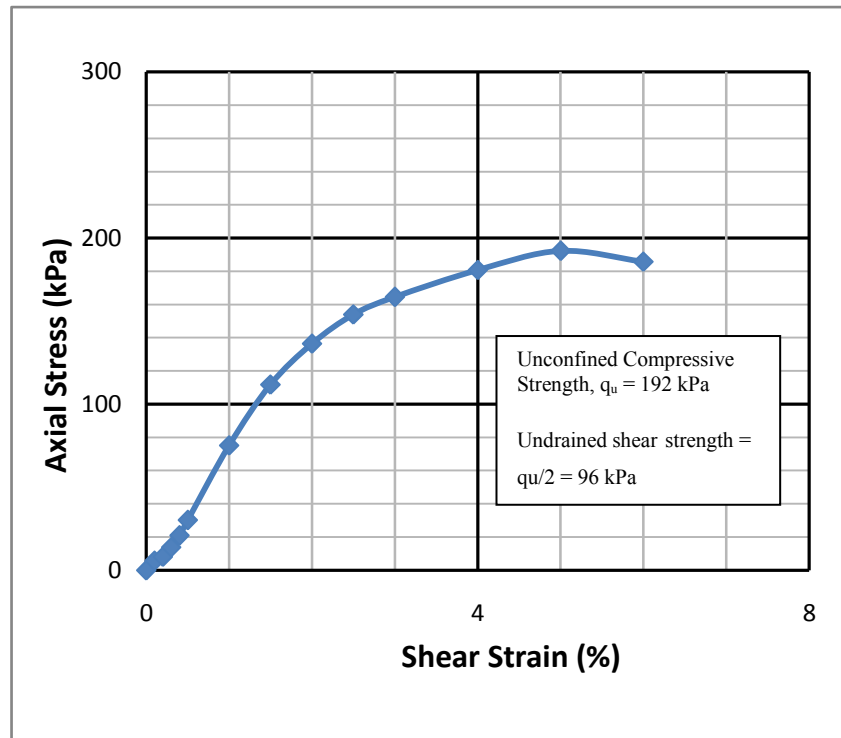
Figure 4.3: Axial stress vs. Shear Strain (%) curve of compacted specimen at 20% moisture content of soil collected from Mohakhali.
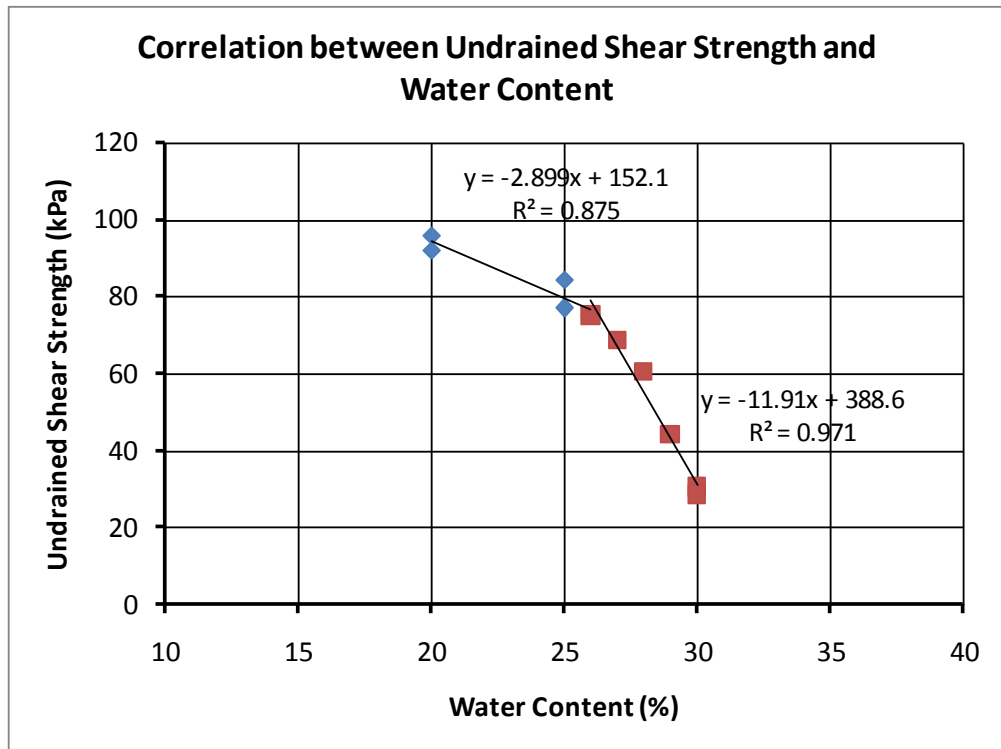
Figure 4.4: Undrained shear strength vs. water content.
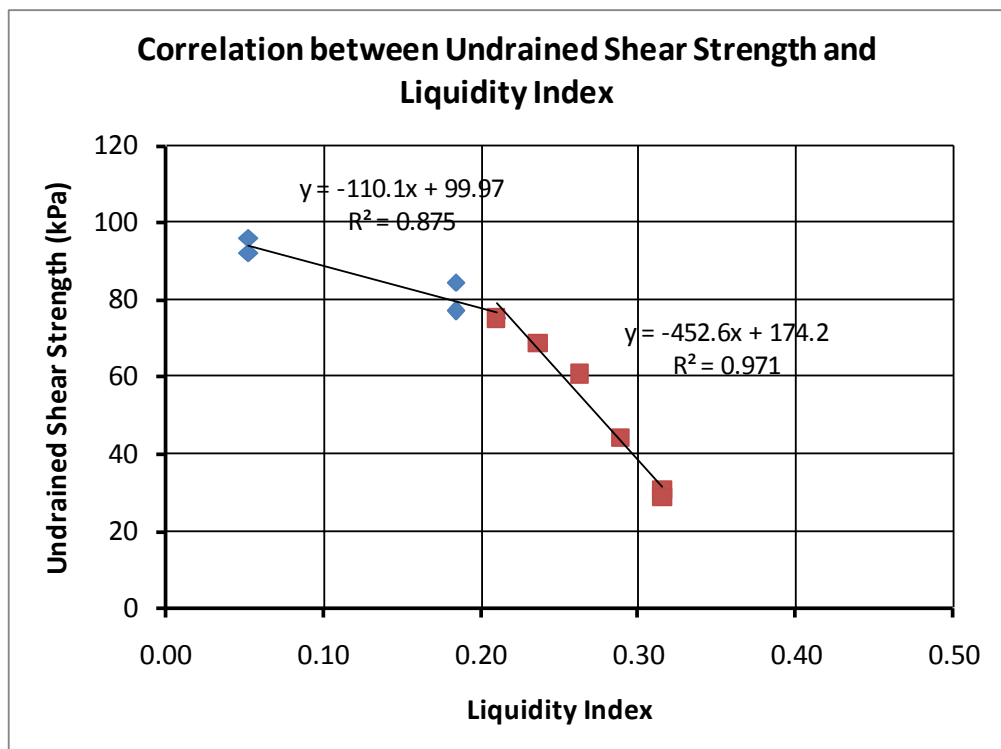
Figure 4.5: Undrained shear strength vs. Liquidity Index.
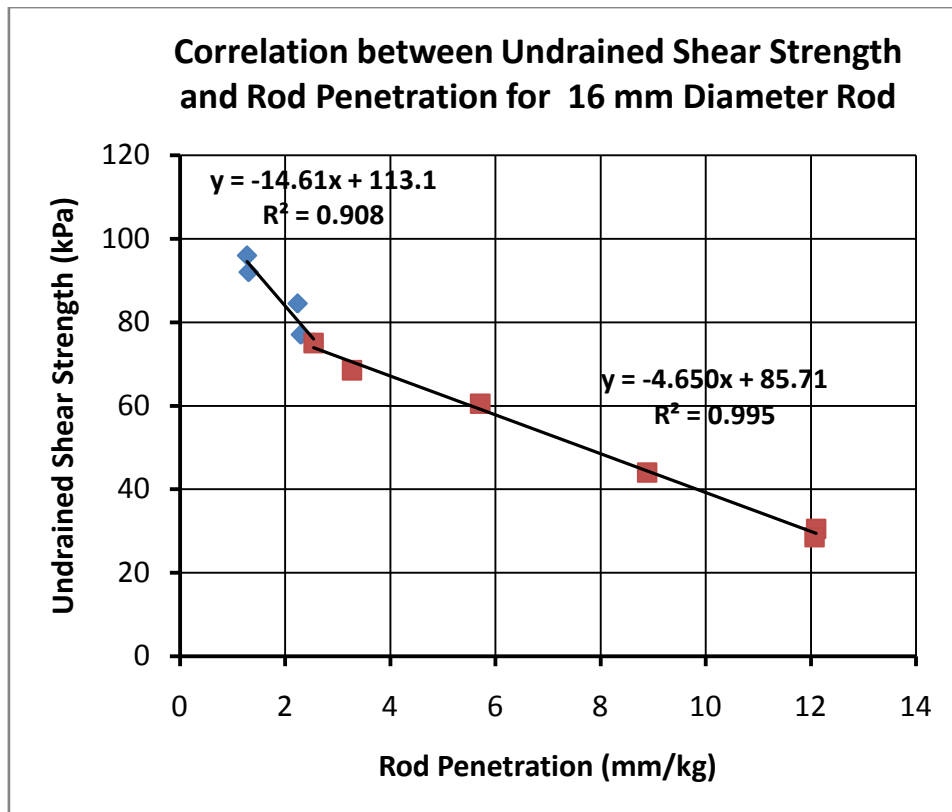
Figure 4.6: Calibration Curve for 16 mm diameter rod penetrometer.
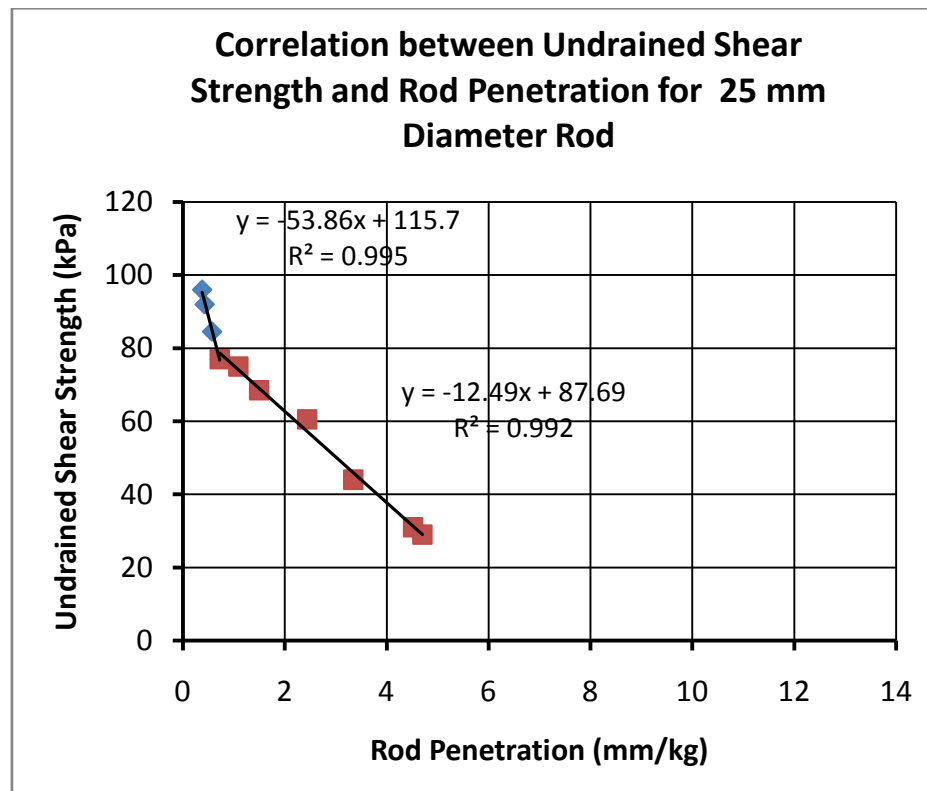
Figure 4.7: Calibration Curve for 25 mm diameter rod penetrometer.

Table 4.4: Summary of penetration test results in laboratory.

Moisture Content (%)	Rod diameter (mm)	Rod penetration (mm/kg)	Undrained shear strength (kPa)
20	25	0.379	96
25	25	0.575	85
21	25	0.429	92
26	25	0.724	77
30	25	4.520	31
25	25	0.724	77
30	25	4.703	29
27	25	1.497	69
29	25	3.343	44
26	25	1.091	75
28	25	2.439	61
20	16	1.270	96
25	16	2.240	85
21	16	1.310	92
26	16	2.300	77
26	16	2.540	75
30	16	12.100	30
30	16	12.070	29
27	16	3.270	29
29	16	8.890	44
26	16	2.540	75
28	16	5.710	61
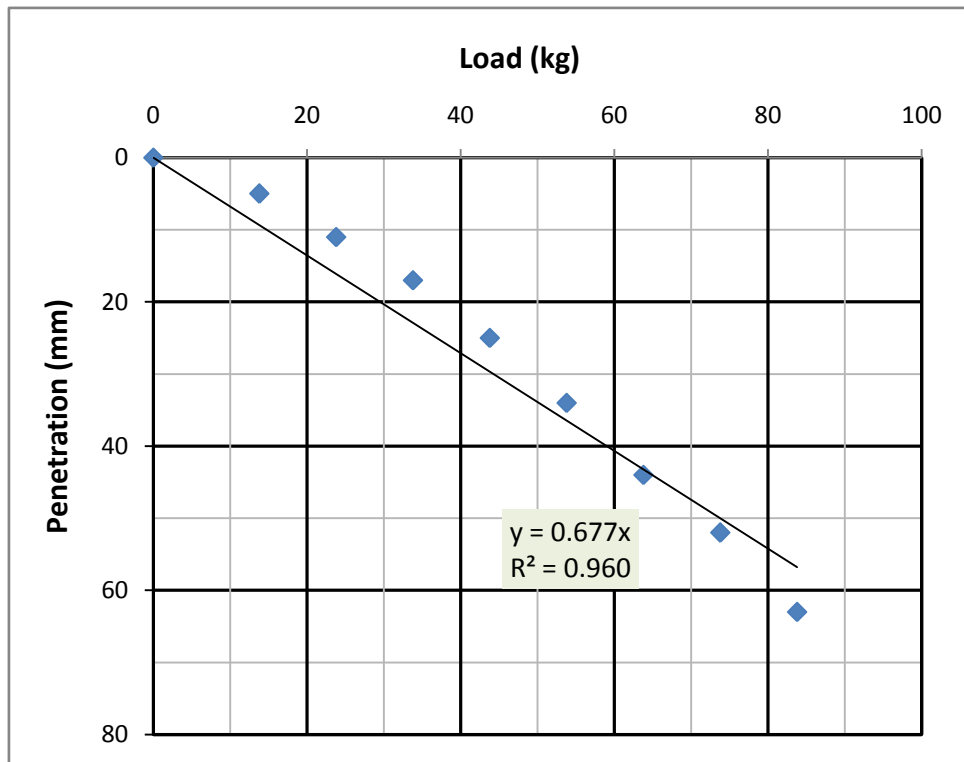
Figure 4.8: Penetration vs. load graph of 16 mm rod during field verification at Kollayanpur.
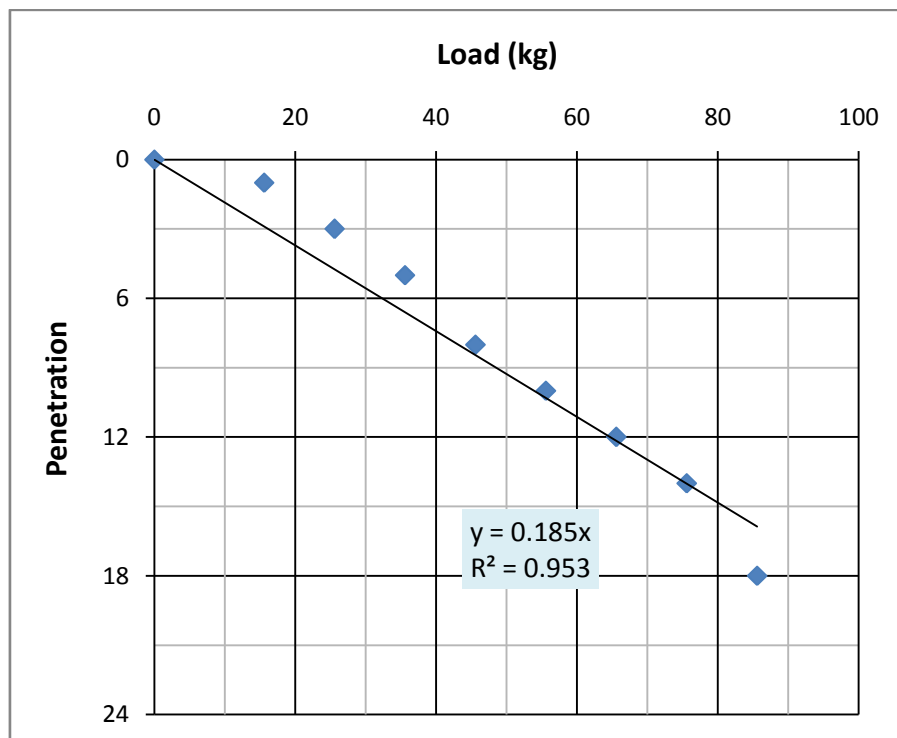
Figure 4.9: Penetration vs. load graph of 25 mm rod during field verification at Kollayanpur.

33

Table 4.5: Verification of correlation from field data for 16 mm rod.

Rod Penetration (mm/kg)	Average Rod Penetration (mm/kg)	Shear strength from Calibration curve (kPa)	Undrained shear strength from Unconfined Compression test (kPa)	Average Undrained shear strength from Unconfined Compression test (kPa)
0.677			102	
0.659	0.670	103	104	101
0.636			98	
0.706			99	

Table 4.6: Verification of correlation from field data for 25 mm rod.

Rod Penetration (mm/kg)	Average Rod Penetration (mm/kg)	Shear strength from Calibration curve (kPa)	Undrained shear strength from Unconfined Compression test (kPa)	Average Undrained shear strength from Unconfined Compression test (kPa)
0.185			98	
0.192	0.188	105	100	99
0.187			99	

Table 4.7: Degree of saturation of remolded laboratory specimens and field soil.

Moisture Content	Location	Degree of Saturation (%)
20	laboratory	95
25	laboratory	91
27	laboratory	96
28	laboratory	97
29	laboratory	95
30	laboratory	99
21	field	96

CHAPTER 5

CONCLUSION

5.1 GENERAL

In this study a rod penetrometer was designed and fabricated successfully. In the laboratory the penetration test was performed by this rod penetrometer. From the test results a correlation was established between undrained shear strength versus rod penetration. The correlation was verified by doing penetration test in a construction site.

5.2 CONCLUSIONS

Following conclusions may be drawn from the experimental results of this study.

i.   A correlation between shear strength and rod penetration of the portable rod penetrometer was developed. The relation between undrained shear strength and rod penetration is not linear for the whole range of water content (20-30%). From 20 to 25% moisture content, the relation is linear with steep slope. From 25 to 30% moisture content, the relation is linear with milder slope. The reason of different slopes before and after at around 25% water content is unkown.

ii. Shear strength decreases, in general, with the increase of water content and liquidity index. However, before and after 25% moisture content the slope of the relation is different. However the reason is not known until now.

iii. The calibration curve which was developed in this study for the portable static rod penetrometer was verified in the field and the verification result was quite satisfactory.

5.3 LIMITATIONS

- In the laboratory the remolded clay soil was used to develop the correlation. However in the field the soil is undisturbed. Calibration curves were made only by test results at laboratory. Results from more field test should be included in developing calibration curves.
- Field verification was conducted at one site only. More field verifications were necessary for more accurate result.
- Calibration curves were made only for fat clay soil (LL=56, PI=38). For other soil the calibration curves may not give the accurate result.
- Water content of clay was varied from 20 to 30%. So, the calibration curve is valid only for moisture content 20 to 30% for fat clay.

5.4 RECOMMENDATIONS FOR FUTURE STUDY

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

- ❖ Calibration curves were formed only for two steel bar 25 mm and 16 mm. These calibration curves may be formed for more steel bar diameters.
- ❖ Calibration curve was done based on the test results of soil samples from two locations only; therefore more experiment may be done for more soil sample including lean clay, fat clay, elastic silt, silty clay, clayey silt etc. So the calibration curve would be generalized.
- ❖ As cost of stainless steel bar is much higher than deformed bar and deformed bar is readily available in every construction site, calibration curve may be developed for deformed bar.
- ❖ More experiments can be conducted at field to make these calibration curves reliable.

REFERENCES

Aoki, N., Esquivel, E.R., Neves, L.F.S., and Cintra J.C.A. (2007) *"The impact efficiency obtained from static load test performed on the SPT sampler,"* Soils and Foundations, Japanese Geotechnical Society, Vol. 4, No. 6, 1045-1052.

ASTM D 1586-99 (1999), *"Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils"*. American Society for Testing and Materials.

ASTM D-1558-99, *"Proving Ring Penetrometer, for Determining Penetration Resistance of Soil Layers"* American Society for Testing and Materials.

Baligh, M.M., A.S. Azzouz, A.Z.E. Wissa, R.T. Martin, and M.J. Morrison, "The Piezocone Penetrometer," *Cone Penetration Testing and Experience* (Proc. ASCE National Convention, St. Louis, Mo.), 1981, pp. 247–263.

Begemann, H.K., "The Friction Jacket Cone as an Aide in Determining the Soil Profile," *Proceedings, 6th International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, Montreal, QC, Canada, 1965, pp. 17–20.

Bowles, J. E. (1996),*"Foundation Analysis and Design"*, McGraw- Hill, New York, pp.135-189.

Broms, B.B. and N. Flodin, "History of Soil Penetration Testing," *Proceedings of the First International Symposium on Penetration Testing*, Vol. 1, Orlando, Fla. (*Penetration Testing 1988*), Balkema, Rotterdam, The Netherlands, Mar. 20–24, 1988, pp. 157–220.

deRuiter, J., "Electric Penetrometer for Site Investigations," *Journal of the Soil Mechanics and Foundations Division*, Vol. 97, No. SM2, 1971, pp. 457–472.

Jamiolkowski, M., "Opening Address: CPT'95," *Proceedings, International Symposium on Cone Penetration Testing*, Vol. 1, Swedish Geotechnical Society Report 3:95, Oct. 4–5, 1995, Linköping, Sweden, pp. 7–15.

Kees, G. (2005), *"Hand-Held Electronic Cone Penetrometers for Measuring Soil Strength"*,Tech. Rep. 0524–2837–MTDC. Missoula, MT: U.S. Department of Agriculture (USDA).

Lunne, T., "In-Situ Testing in Offshore Geotechnical Investigations," *Proceedings, International Conference on In-Situ Measurement of Soil Properties and Case Histories*, Bali, Indonesia, 2001, pp. 61–81.

Senneset, K., "Penetration Testing in Norway," *Proceedings of the European Symposium on Penetration Testing*, Vol. 1, Swedish Geotechnical Society, Stockholm, Sweden, June 5–7, 1974, pp. 85–95.

Suemasa, N., Shinkai, K. and Suzawa, T. (2005), *"A Plasticity Model for Swedish Weight Sounding Test"*, Proc. of 5th Workshop on Safety and Stability of Infrastructures against Environmental Impacts.

Van De Graaf, H.C. and J.W.A. Jekel, "New Guidelines for the Use of Inclinometer with the CPT," *Penetration Testing*, Vol. 2 (Proc. ESOPT-1, Amsterdam, The Netherlands), Balkema, Rotterdam, The Netherlands, 1982, pp. 581–584.

Vlasblom, A., *The Electrical Penetrometer: A Historical Account of Its Development*, LGM Mededelingen Report No. 92, Delft Soil Mechanics Laboratory, The Netherlands, Dec. 1985, pp. 51.

APPENDIX A

TEST RESULTS OF ROD PENETRATION TEST

Table A.1: Summary of Atterberg Limits of soil samples.

Location of soil samples	Liquid Limit	Plastic Limit	PI	Color	USCS Classification
Mohakhali	56	18	38	Red	Fat Clay
Kollayanpur	51	15	36	Redish Yellow	Fat Clay

Table A.2: Penetration test for sample at 20% moisture content

Location :	Laboratory (Mohakhali soil)
Penetration No :	1 (For 20% WC)
Rod type :	16 mm

Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	6	6
3.792	10	13.792	13.792	7	13
3.792	10	23.792	23.792	11	24
3.792	10	33.792	33.792	10	34
3.792	10	43.792	43.792	13	47
3.792	10	53.792	53.792	18	65
3.792	10	63.792	63.792	19	84
3.792	10	73.792	73.792	14	98
3.792	10	83.792	83.792	16	114

Figure A.1: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 20% moisture content of soil collected from Mohakhali.

Table A.3: Penetration test for sample at 25% moisture content
Location :   Laboratory (Mohakhali soil)
Penetration No :   2(For 20% WC)
Rod type :   25 mm

Instrument Weight(kg)	Load(Kg)	Total load, W(kg)	Cumulative load(kg)	Depth, H (mm)	Cumulative Depth(mm)
0	0	0	0	0	0
5.605	5.605	5.605	5.605	3	3
5.605	10	15.605	15.605	2	5
5.605	10	25.605	25.605	3	8
5.605	10	35.605	35.605	4	12
5.605	10	45.605	45.605	5	17
5.605	10	55.605	55.605	5	22
5.605	10	65.605	65.605	3	25
5.605	10	75.605	75.605	4	29
5.605	10	85.605	85.605	4	33

Figure A.2: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 20% moisture content of soil collected from Mohakhali.

Table A.4: Penetration test for sample at 25% moisture content

Location : Laboratory (Mohakhali soil)
Penetration No : 1 (For 25% WC)
Rod type : 16 mm

Instrument Weight(kg)	Load increment (Kg)	Total load, W(kg)	Cumulative load(kg)	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	9	9
3.792	10	13.792	13.792	10	19
3.792	10	23.792	23.792	14	33
3.792	10	33.792	33.792	27	60
3.792	10	43.792	43.792	26	86
3.792	10	53.792	53.792	28	114
3.792	10	63.792	63.792	34	148
3.792	10	73.792	73.792	40	188
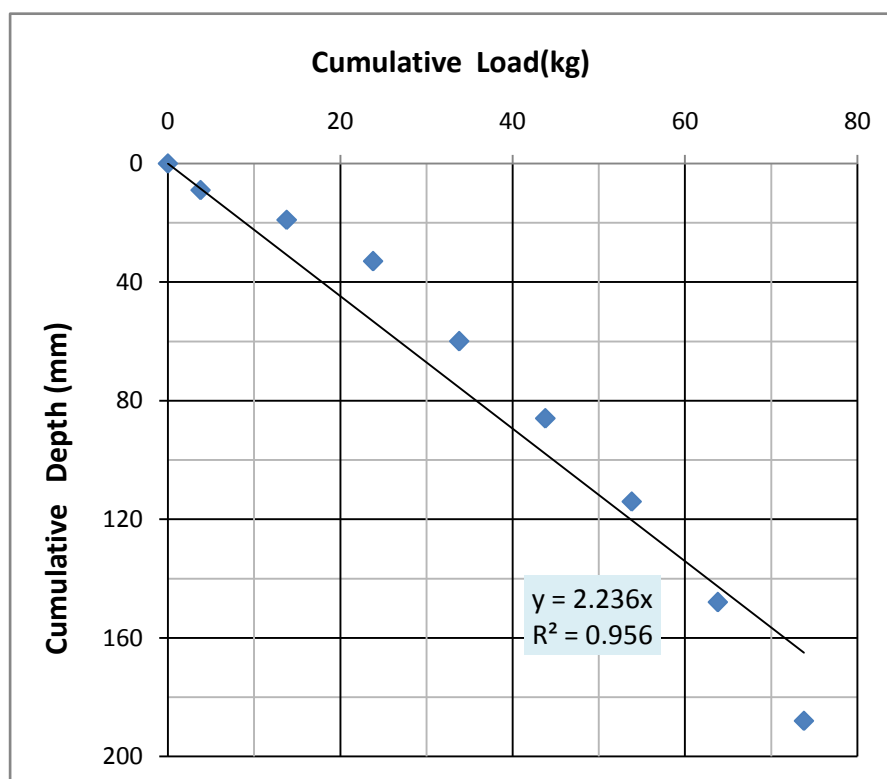
Figure A.3: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 25% moisture content of soil collected from Mohakhali.

Table A.5: Penetration test for sample at 25% moisture content

Location : Laboratory (Mohakhali soil)
Penetration No : 2(For 25% WC)
Rod type : 25 mm

Instrument Weight(kg)	Load(Kg)	Total load, W(kg)	Cumulative load(kg)	Depth, H (mm)	Cumulative Depth(mm)
0	0	0	0	0	0
5.605	5.605	5.605	5.605	5	5
5.605	10	15.605	15.605	4	9
5.605	10	25.605	25.605	6	15
5.605	10	35.605	35.605	5	20
5.605	10	45.605	45.605	4	24
5.605	10	55.605	55.605	6	30
5.605	10	65.605	65.605	7	37
5.605	10	75.605	75.605	8	45
5.605	10	85.605	85.605	6	51
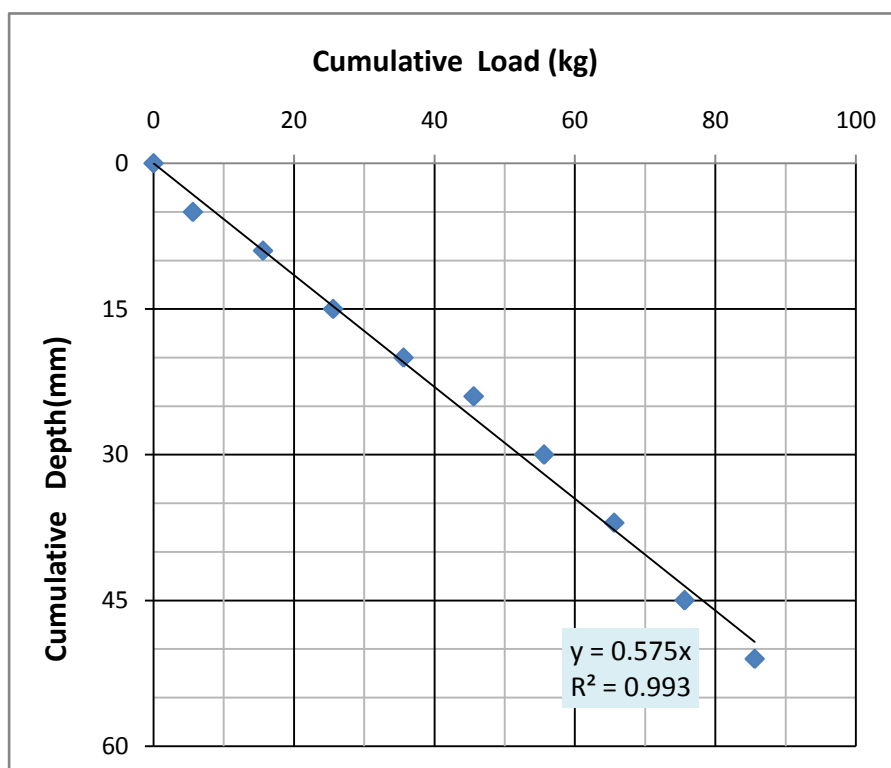
Figure A.4: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 25% moisture content of soil collected from Mohakhali.

Table A.6: Penetration test for sample at 30% moisture content

Location :   Laboratory (Mohakhali soil)
Penetration No :   1 (For 30% WC)
Rod type :   16 mm

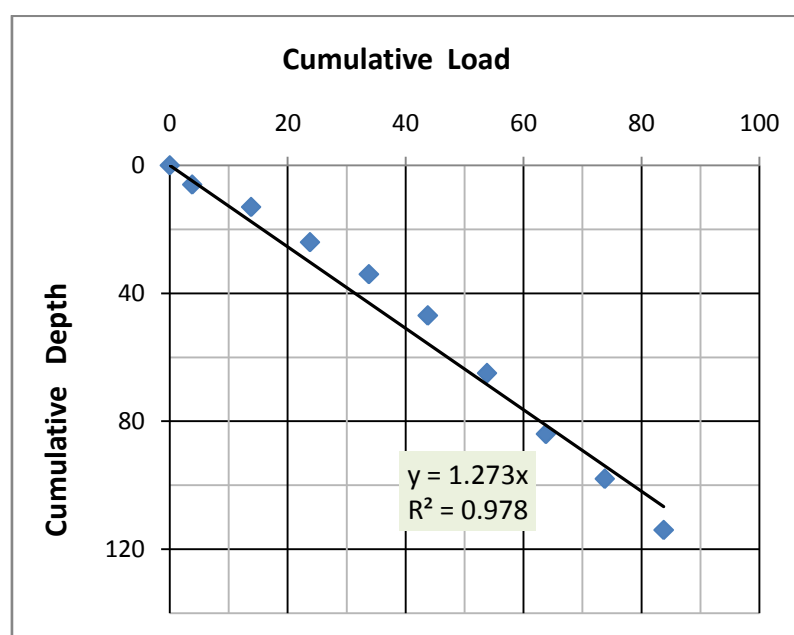| Instrument Weight(kg)	Load increment (Kg)	Total load, W(kg)	Cumulative load(kg)	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	60	60
3.792	10	13.792	13.792	103	163

Figure A.5: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 30% moisture content of soil collected from Mohakhali.

Table A.7: Penetration test for sample at 30% moisture content

Location :   Laboratory (Mohakhali soil)
Penetration No :   2(For 30% WC)
Rod type :   25 mm

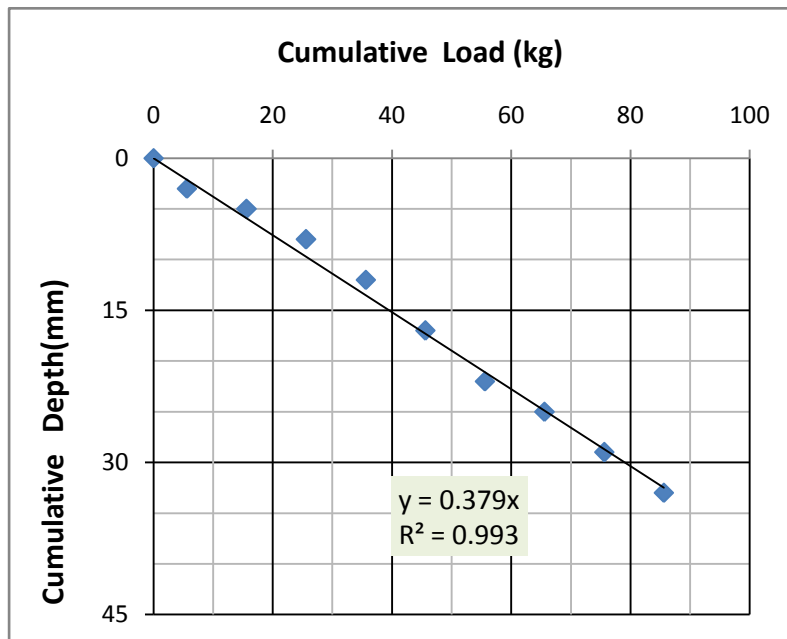| Instrument Weight(kg)	Load(Kg)	Total load, W(kg)	Cumulative load(kg)	Depth, H (mm)	Cumulative Depth(mm)
0	0	0	0	0	0
5.605	5.605	5.605	5.605	21	21
5.605	10	15.605	15.605	45	66
5.605	10	25.605	25.605	52	118
5.605	10	35.605	35.605	44	162

Figure A.6: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 30% moisture content of soil collected from Mohakhali.

Table A.8: Penetration test for sample at 20% moisture content

Location : Laboratory(Kollayanpur)
Penetration No : 1 (For 20% WC)
Rod type : 16 mm

| Instrument Weight(kg)	Load increment (Kg)	Total load, W(kg)	Cumulative load(kg)	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	7	7
3.792	10	13.792	13.792	6	13
3.792	10	23.792	23.792	11	24
3.792	10	33.792	33.792	12	36
3.792	10	43.792	43.792	14	50
3.792	10	53.792	53.792	14	64
3.792	10	63.792	63.792	18	82
3.792	10	73.792	73.792	20	102
3.792	10	83.792	83.792	17	119

Figure A.7: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 20% moisture content of soil collected from Kollayanpur.

Table A.9: Penetration test for sample at 20% moisture content

Location : Laboratory(Kollayanpur)
Penetration No : 2(For 20% WC)
Rod type : 25 mm

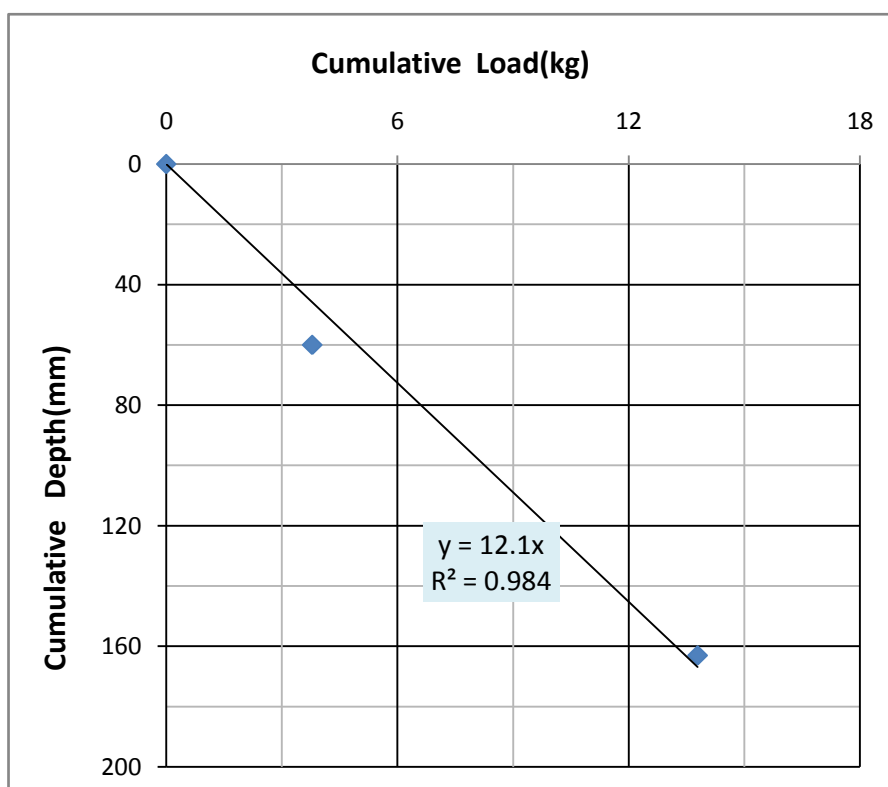| Instrument Weight(kg)	Load(Kg)	Total load, W(kg)	Cumulative load(kg)	Depth, H (mm)	Cumulative Depth(mm)
0	0	0	0	0	0
5.605	5.605	5.605	5.605	3	3
5.605	10	15.605	15.605	3	6
5.605	10	25.605	25.605	5	11
5.605	10	35.605	35.605	4	15
5.605	10	45.605	45.605	4	19
5.605	10	55.605	55.605	5	24
5.605	10	65.605	65.605	4	28
5.605	10	75.605	75.605	5	33
5.605	10	85.605	85.605	4	37

Figure A.8: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 20% moisture content of soil collected from Kollayanpur.

Table A.10: Penetration test for sample at 25% moisture content

Location :　　　　　　Laboratory(Kollayanpur)
Penetration No :　　　1 (For 25% WC)
Rod type :　　　　　　16 mm

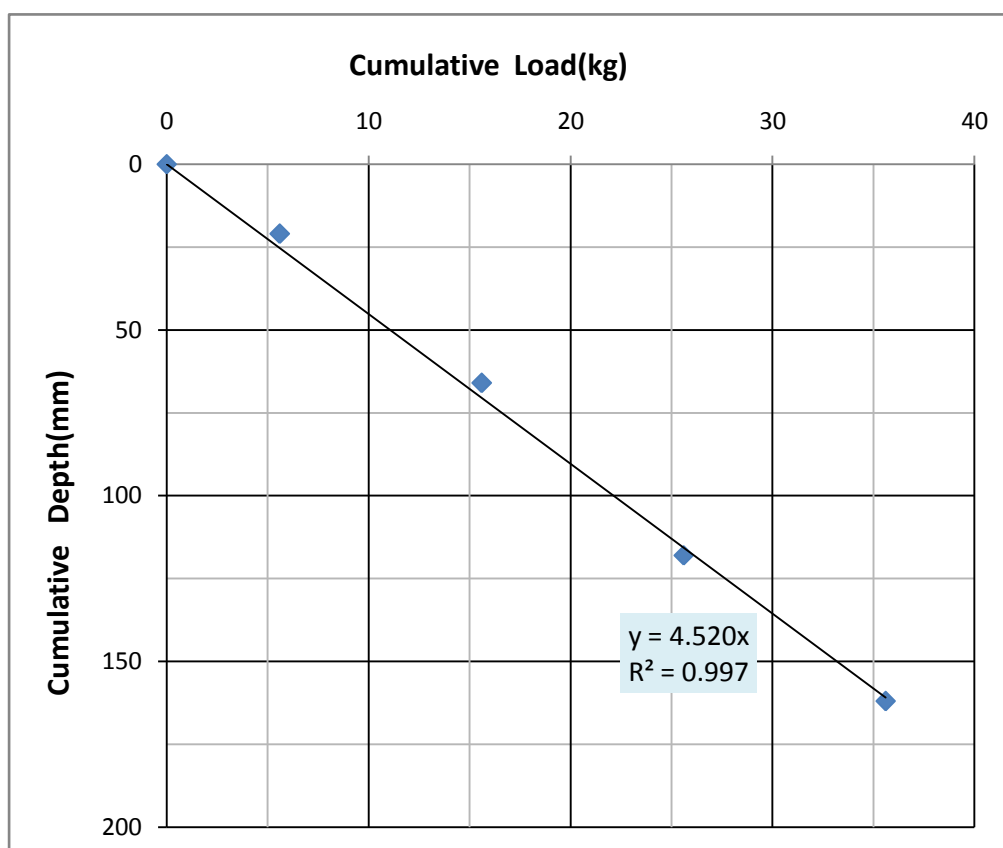| Instrument Weight(kg)	Load increment (Kg)	Total load, W(kg)	Cumulative load(kg)	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	10	10
3.792	10	13.792	13.792	12	22
3.792	10	23.792	23.792	15	37
3.792	10	33.792	33.792	26	63
3.792	10	43.792	43.792	32	95
3.792	10	53.792	53.792	34	129
3.792	10	63.792	63.792	33	162
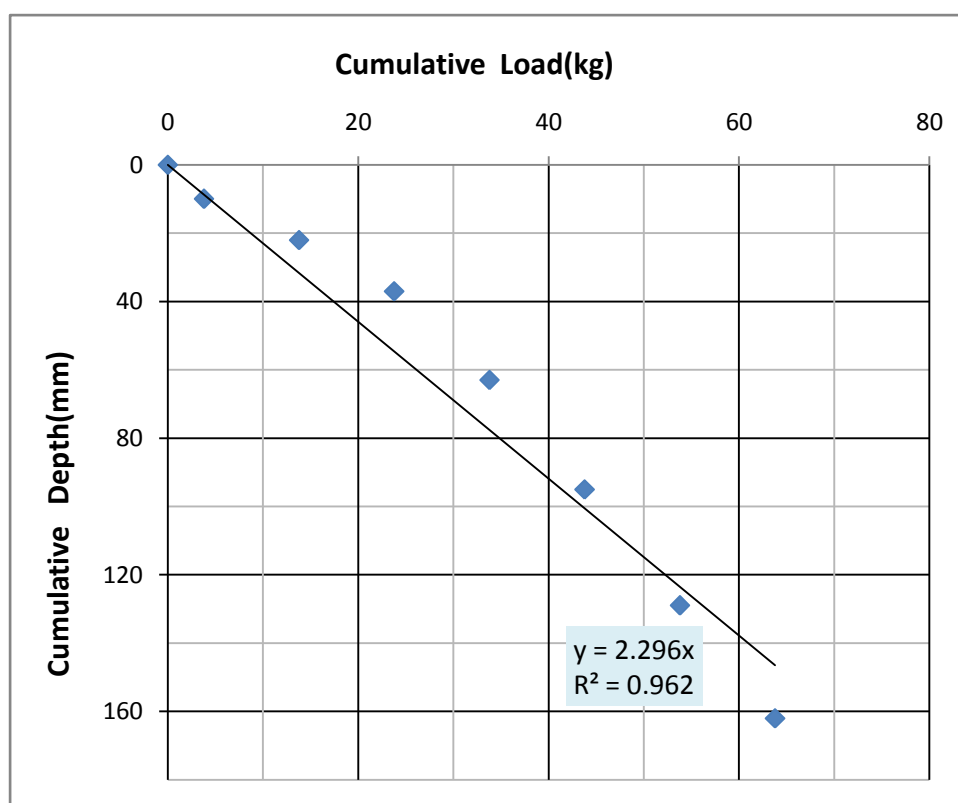
Figure A.9: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 25% moisture content of soil collected from Kollayanpur.

Table A.11: Penetration test for sample at 25% moisture content

Location : Laboratory(Kollayanpur)
Penetration No : 2(For 25% WC)
Rod type : 25 mm

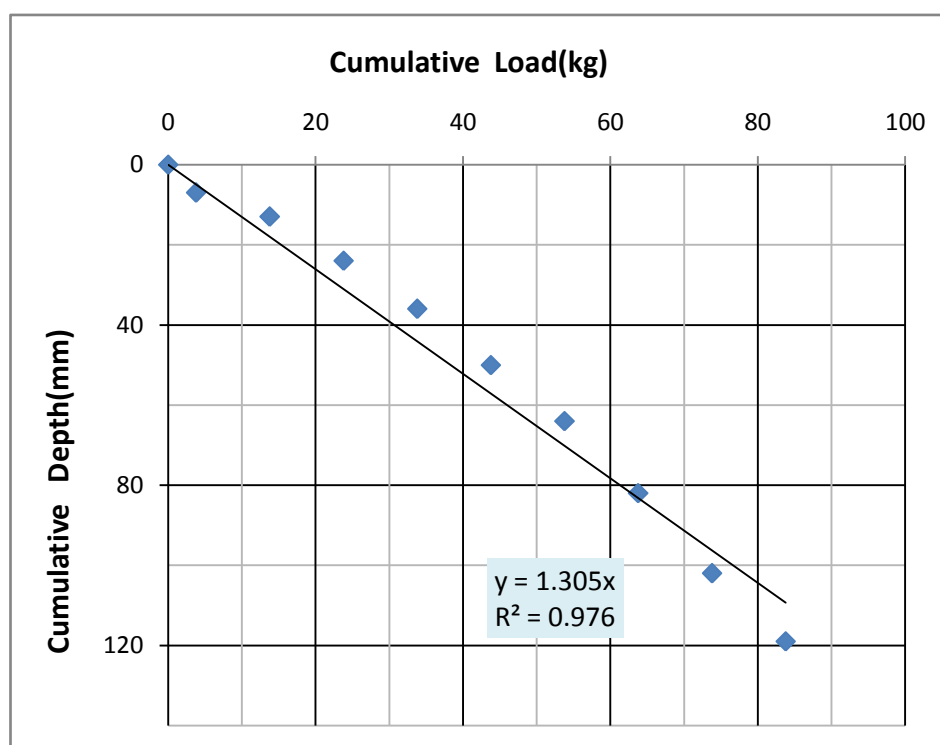| Instrument Weight(kg)	Load(Kg)	Total load, W(kg)	Cumulative load(kg)	Depth, H (mm)	Cumulative Depth(mm)
0	0	0	0	0	0
5.605	5.605	5.605	5.605	6	6
5.605	10	15.605	15.605	6	12
5.605	10	25.605	25.605	7	19
5.605	10	35.605	35.605	8	27
5.605	10	45.605	45.605	6	33
5.605	10	55.605	55.605	6	39
5.605	10	65.605	65.605	7	46
5.605	10	75.605	75.605	9	55
5.605	10	85.605	85.605	8	63

Figure A.10: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 25% moisture content of soil collected from Kollayanpur.

Table A.12: Penetration test for sample at 30% moisture content

Location : Laboratory(Kollayanpur)
Penetration No : 1 (For 30% WC)
Rod type : 16 mm

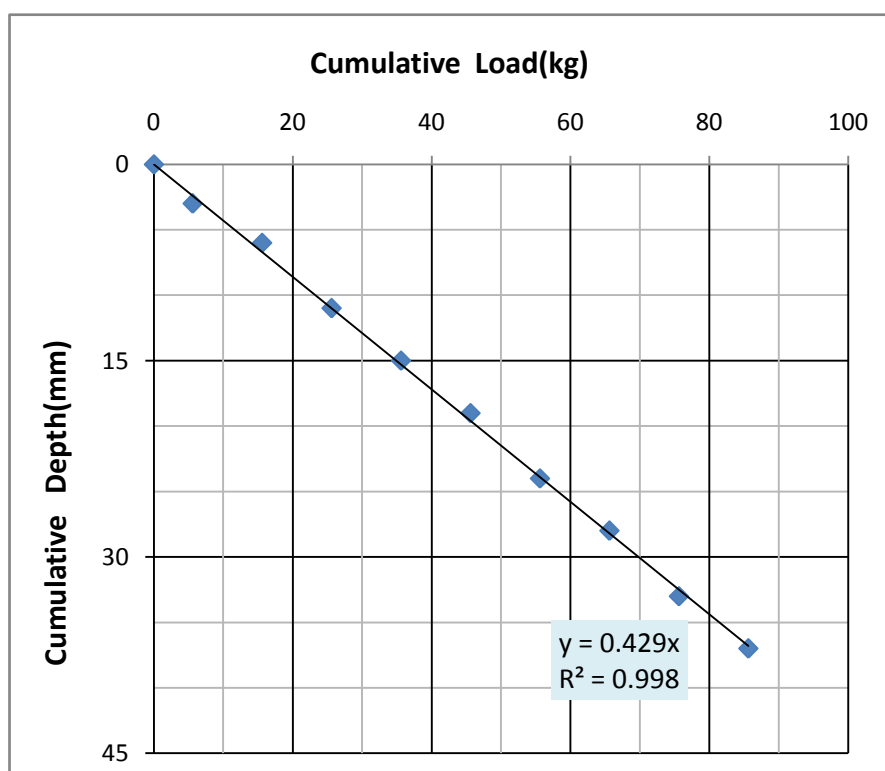| Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	62	62
3.792	10	13.792	13.792	100	162

Figure A.11: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 30% moisture content of soil collected from Kollayanpur.

Table A.13: Penetration test for sample at 30% moisture content

Location : Laboratory(Kollayanpur)
Penetration No : 2(For 30% WC)
Rod type : 25 mm

Instrument Weight(kg)	Load(Kg)	Total load, W	Cumulative load	Depth, H (mm)	Cumulative Depth
0	0	0	0	0	0
5.605	5.605	5.605	5.605	23	23
5.605	10	15.605	15.605	51	74
5.605	10	25.605	25.605	53	127
5.605	10	35.605	35.605	36	163

Figure A.12: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 30% moisture content of soil collected from Kollayanpur.

Graph values: $y = 4.703x$, $R^2 = 0.996$

Table A.14: Penetration test for sample at 27% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   1 (For 27 % WC)
Rod type :   16 mm

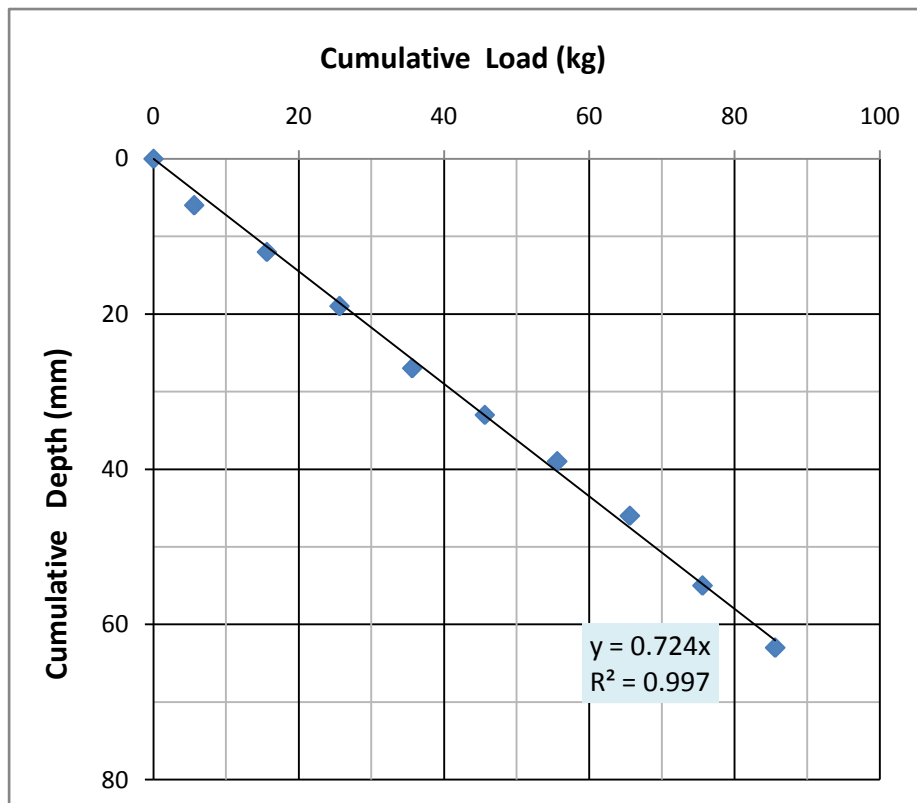| Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	12.3	12.3
3.792	10	13.792	13.792	32	44.3
3.792	10	23.792	23.792	34	78.3
3.792	10	33.792	33.792	35	113.3

Figure A.13: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 27% moisture content of soil collected from Kollayanpur.

Table A.15: Penetration test for sample at 27% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   2(For 27 % WC)
Rod type :   25 mm

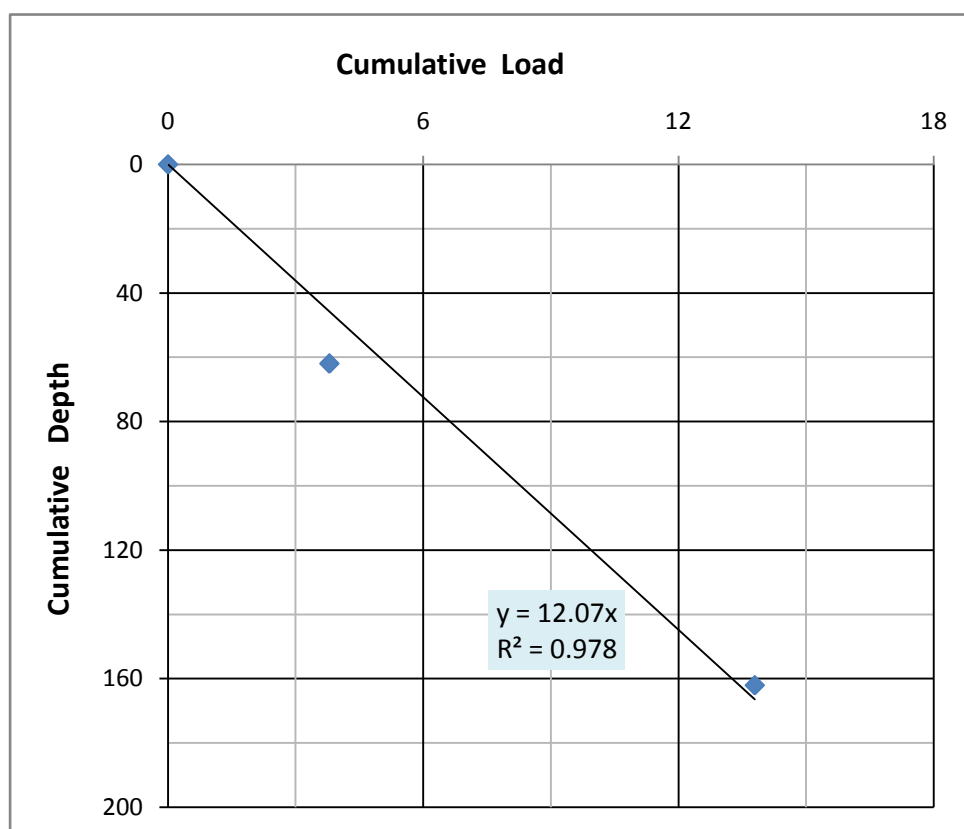| Instrument Weight(kg)	Load(Kg)	Total load, W	Cumulative load	Depth, H (mm)	Cumulative Depth
0	0	0	0	0	0
5.605	5.605	5.605	5.605	10.5	10.5
5.605	10	15.605	15.605	13	23.5
5.605	10	25.605	25.605	15	38.5
5.605	10	35.605	35.605	14	52.5
5.605	10	45.605	45.605	19	71.5
5.605	10	55.605	55.605	14	85.5
5.605	10	65.605	65.605	12	97.5
5.605	10	75.605	75.605	13	110.5

Figure A.14: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 27% moisture content of soil collected from Kollayanpur.

Table A.16: Penetration test for sample at 29% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   1 (For 29 % WC)
Rod type :   16 mm

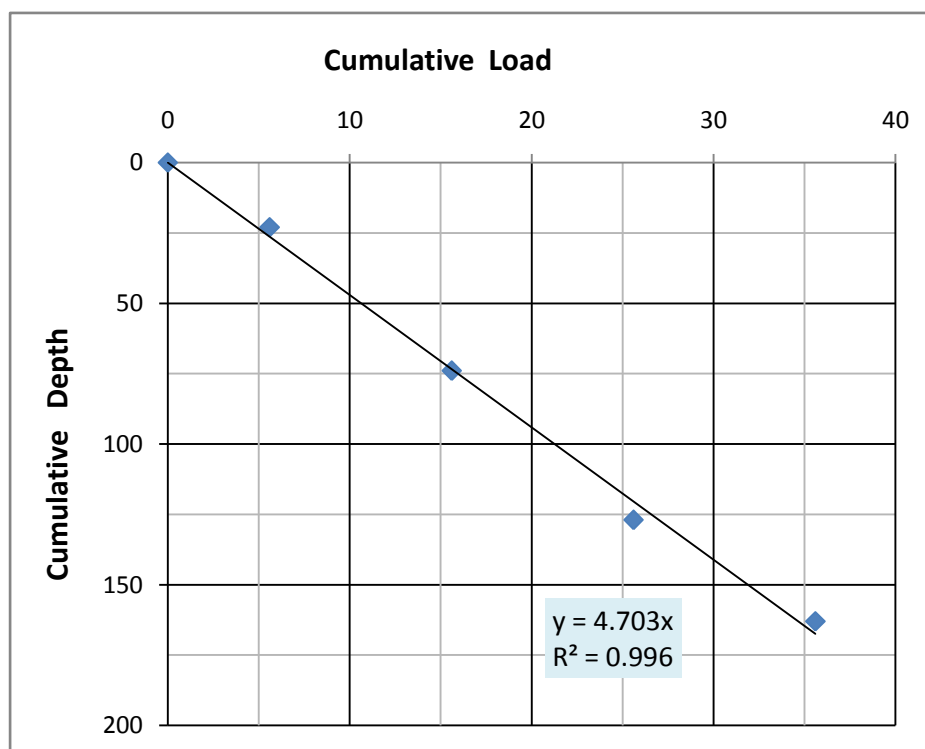| Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	43	43
3.792	10	13.792	13.792	77	120

Figure A.15: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 29% moisture content of soil collected from Kollayanpur.

Table A.17: Penetration test for sample at 29% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   2(For 29 % WC)
Rod type :   25 mm

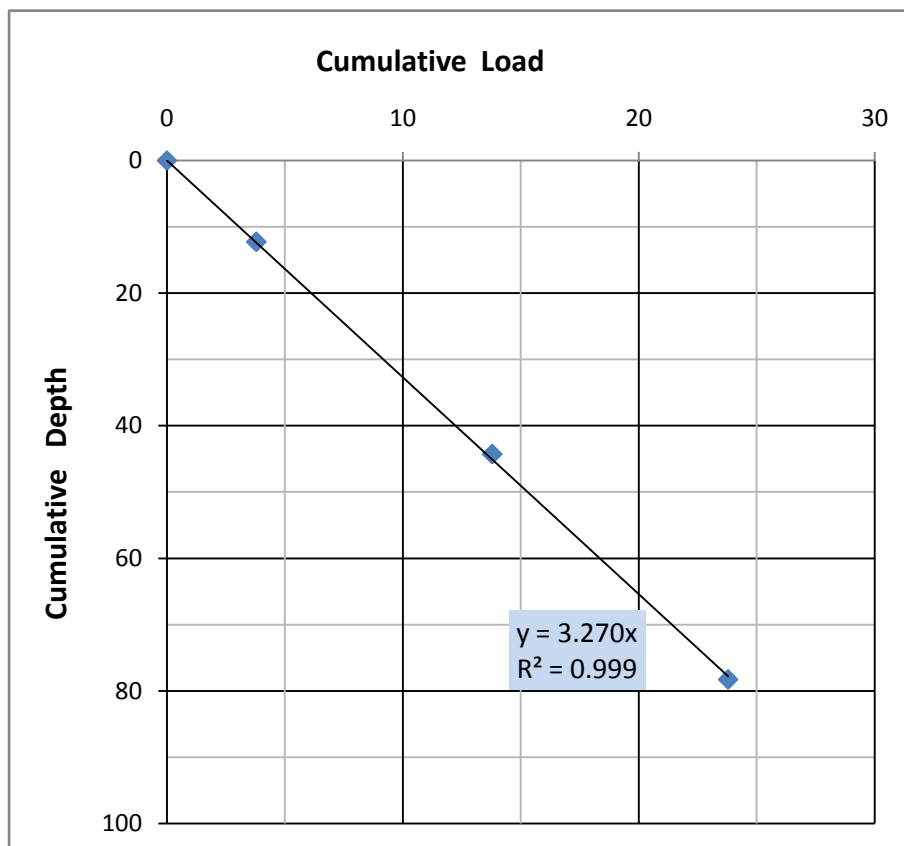| Instrument Weight(kg)	Load(Kg)	Total load, W	Cumulative load	Depth, H (mm)	Cumulative Depth
0	0	0	0	0	0
5.605	5.605	5.605	5.605	17	17
5.605	10	15.605	15.605	33	50
5.605	10	25.605	25.605	36	86
5.605	10	35.605	35.605	34	120

Figure A.16: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 29% moisture content of soil collected from Kollayanpur.

Table A.18: Penetration test for sample at 26% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   1 (For 26% WC)
Rod type :   16 mm

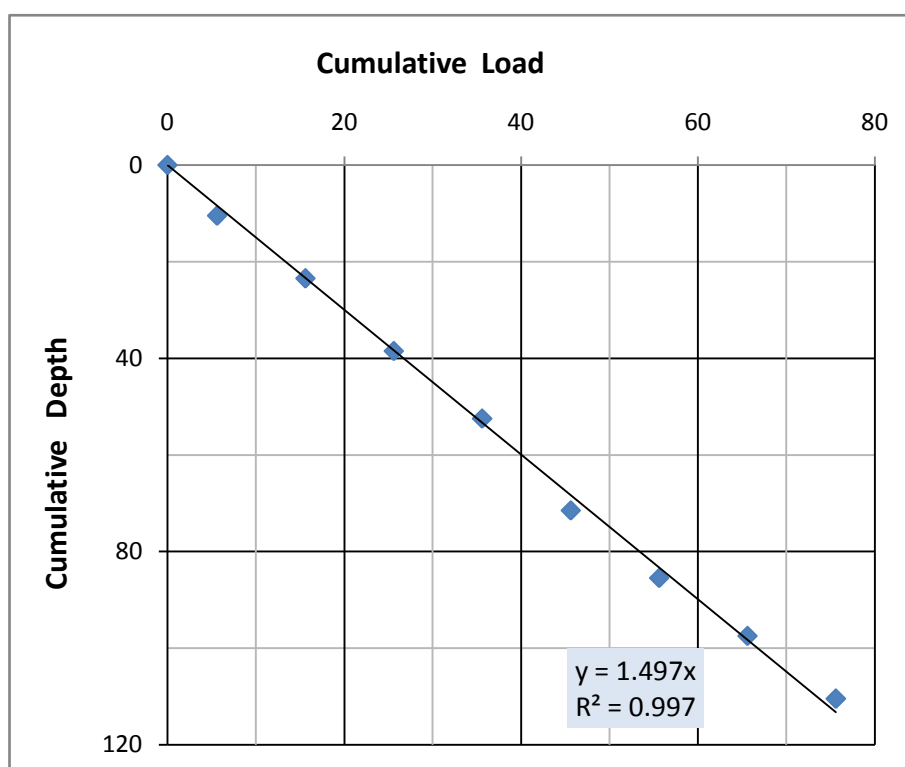| Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	12	12
3.792	10	13.792	13.792	18	30
3.792	10	23.792	23.792	25	55
3.792	10	33.792	33.792	27	82
3.792	10	43.792	43.792	30	112
3.792	10	53.792	53.792	30	142
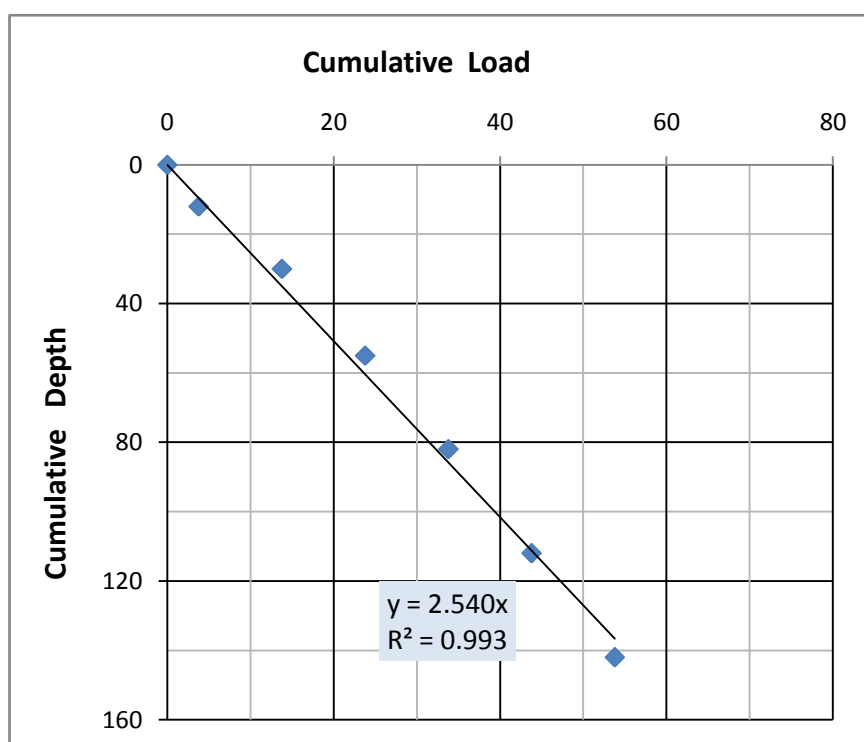
Figure A.17: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 26% moisture content of soil collected from Kollayanpur.

Table A.19: Penetration test for sample at 26% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   2(For 26% WC)
Rod type :   25 mm

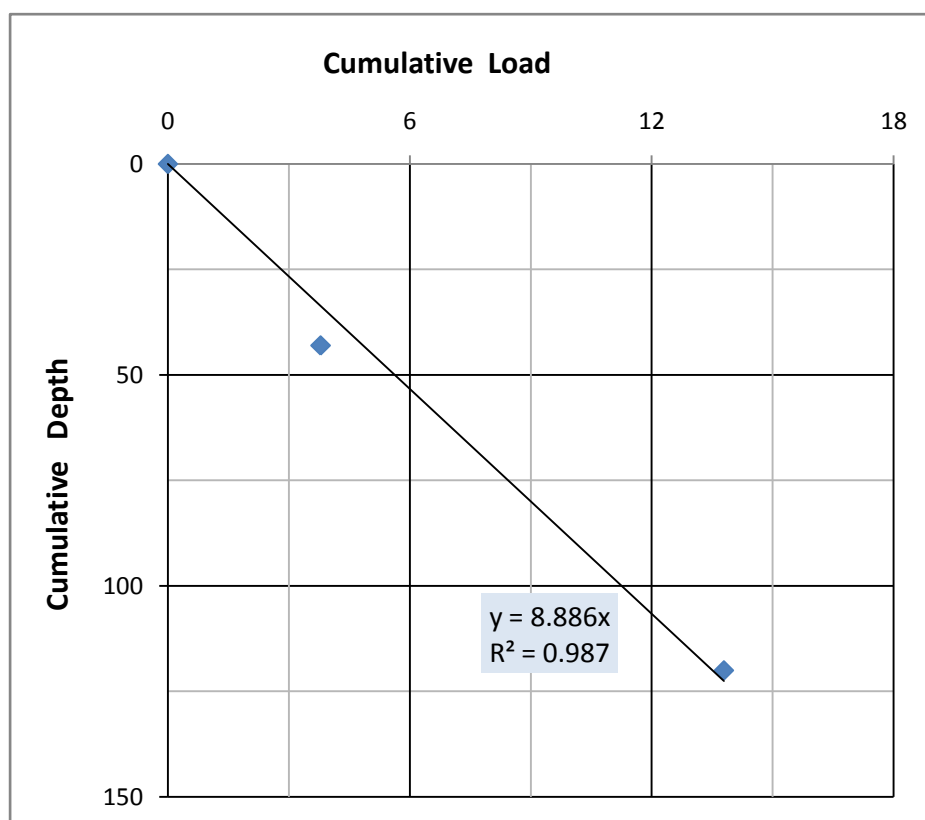| Instrument Weight(kg)	Load(Kg)	Total load, W	Cumulative load	Depth, H (mm)	Cumulative Depth
0	0	0	0	0	0
5.605	5.605	5.605	5.605	8	8
5.605	10	15.605	15.605	9	17
5.605	10	25.605	25.605	11	28
5.605	10	35.605	35.605	11	39
5.605	10	45.605	45.605	13	52
5.605	10	55.605	55.605	10	62
5.605	10	65.605	65.605	9	71
5.605	10	75.605	75.605	11	82
5.605	10	85.605	85.605	10	92
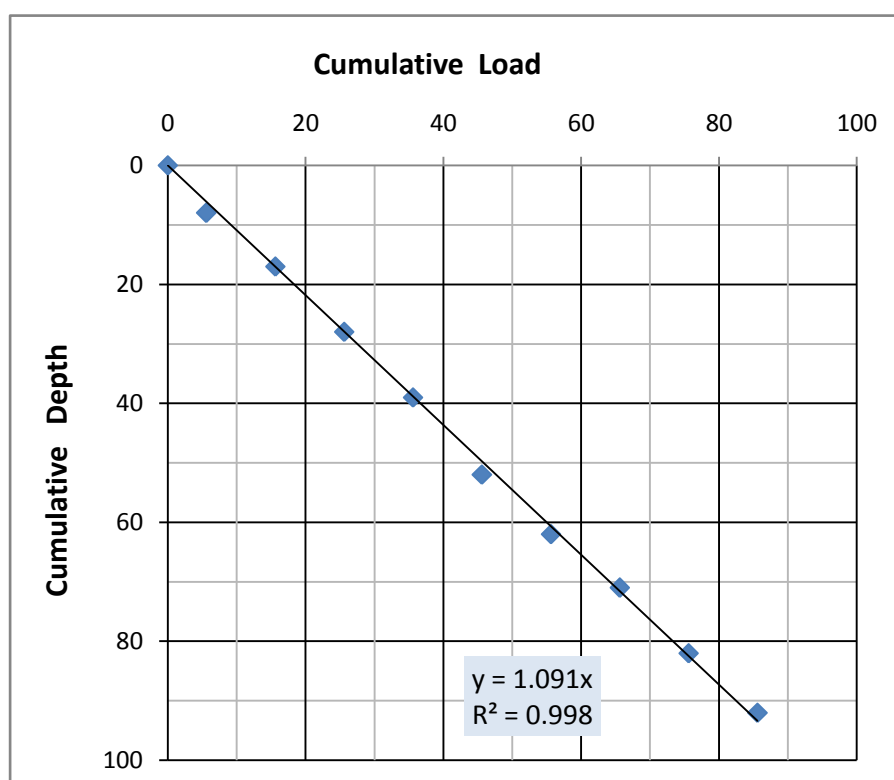
Figure A.18: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod
at 26% moisture content of soil collected from Kollayanpur.

Table A.20: Penetration test for sample at 28% moisture content

Location :   Laboratory(Kollayanpur)
Penetration No :   1 (For 28 % WC)
Rod type :   16 mm

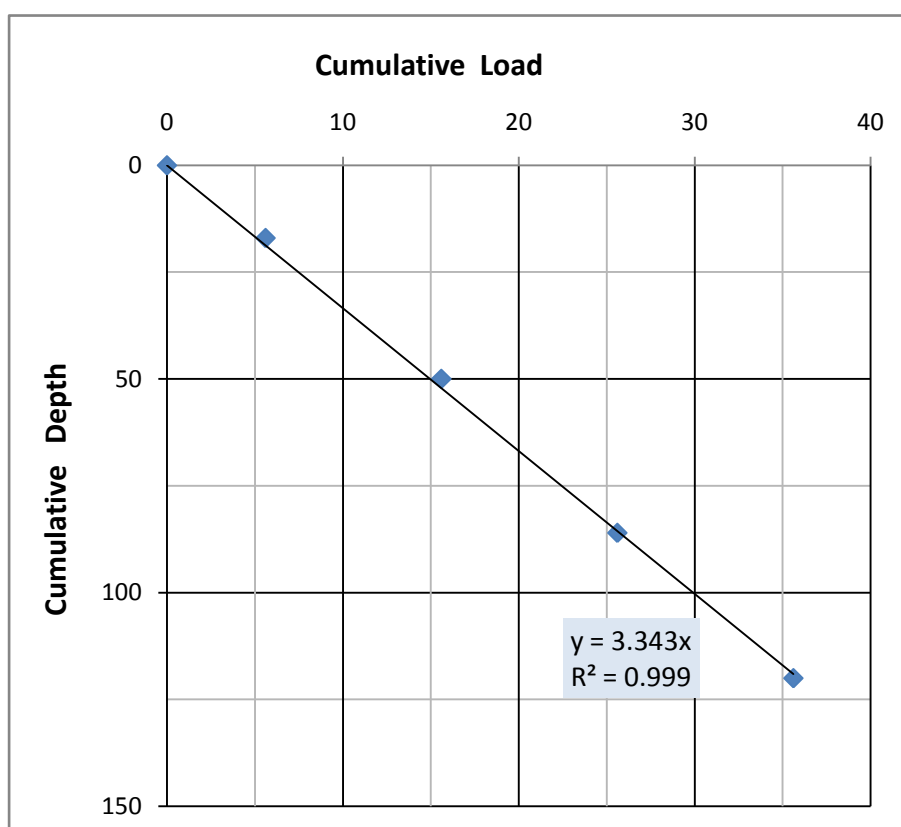| Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cumulative load	Penetration (mm)	Cumulative Depth (mm)
0	0	0	0	0	0
3.792	3.792	3.792	3.792	28	28
3.792	10	13.792	13.792	54	82
3.792	10	23.792	23.792	51	133
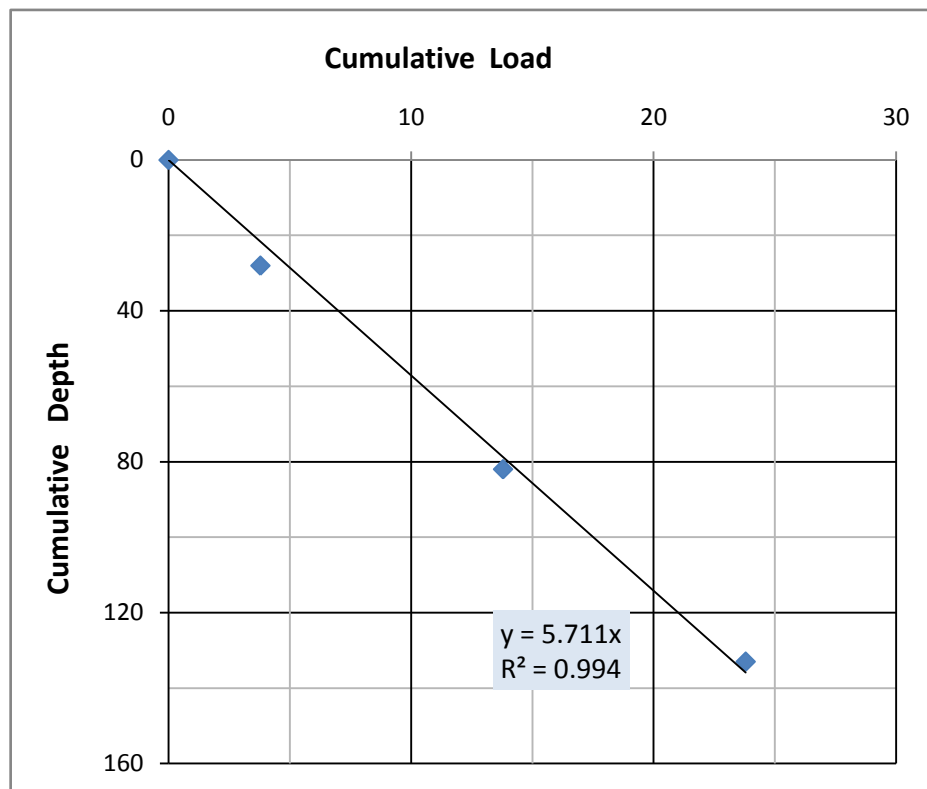
Figure A.19: Cumulative penetration depth vs. Cumulative load graph of 16 mm rod at 28% moisture content of soil collected from Kollayanpur.

Table A.21: Penetration test for sample at 28% moisture content

Location : Laboratory(Kollayanpur)
Penetration No : 2(For 28 % WC)
Rod type : 25 mm

| Instrument Weight(kg)	Load(Kg)	Total load, W	Cumulative load	Depth, H (mm)	Cumulative Depth
0	0	0	0	0	0
5.605	5.605	5.605	5.605	13	13
5.605	10	15.605	15.605	23	36
5.605	10	25.605	25.605	25	61
5.605	10	35.605	35.605	24	85
5.605	10	45.605	45.605	26	111
5.605	10	55.605	55.605	25	136
5.605	10	65.605	65.605	26	162
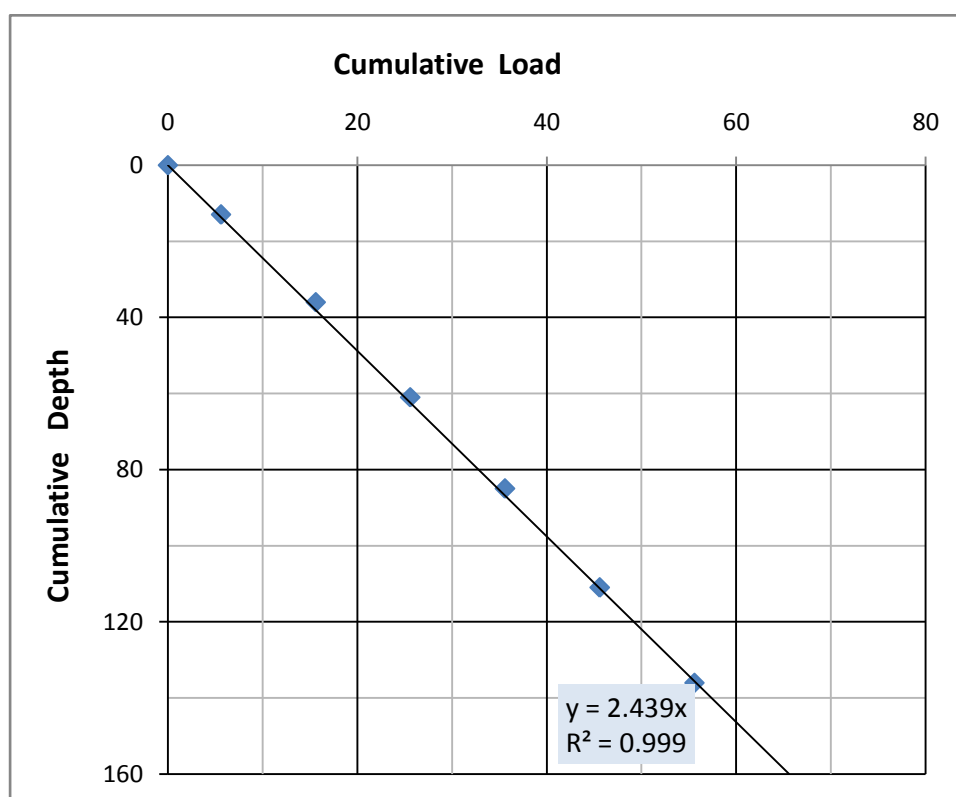
Figure A.20: Cumulative penetration depth vs. Cumulative load graph of 25 mm rod at 28% moisture content of soil collected from Kollayanpur.

60

Table A.22: Penetration test at field with 16 mm rod

Location :   Field (Kollayanpur)
Rod type :   16 mm

Instrument Weight(kg)	Load increment (Kg)	Total load, W	Cummulative load	Penetration (mm)	Cummulative Depth (mm)
0	0	0	0	0	0
3.792	13.792	13.792	13.792	5	5
3.792	10	23.792	23.792	6	11
3.792	10	33.792	33.792	6	17
3.792	10	43.792	43.792	8	25
3.792	10	53.792	53.792	9	34
3.792	10	63.792	63.792	10	44
3.792	10	73.792	73.792	8	52
3.792	10	83.792	83.792	11	63

Figure A.21: Penetration vs. Load graph of 16 mm rod of field test at Kollayanpur.

Table A.23: Penetration test at field with 16 mm rod

Location :   Field(Kollayanpur)
Penetration No :   3
Rod type :   16 mm

Instrument Weight(kg)	Load(Kg)	Total load, W	Cummulative load	Depth, H (mm)	Cummulative Depth
0	0	0	0	0	0
3.792	13.792	13.792	13.792	4	4
3.792	10	23.792	23.792	5	9
3.792	10	33.792	33.792	7	16
3.792	10	43.792	43.792	6	22
3.792	10	53.792	53.792	9	31
3.792	10	63.792	63.792	10	41
3.792	10	73.792	73.792	12	53
3.792	10	83.792	83.792	11	64

Figure A.22: Penetration vs. Load graph of 16 mm rod of field test at Kollayanpur

Table A.24: Penetration test at field with 16 mm rod

Location :	Field(Kollayanpur)
Penetration No :	4
Rod type :	16 mm

Instrument Weight(kg)	Load(Kg)	Total load, W	Cummulative load	Depth, H (mm)	Cummulative Depth
0	0	0	0	0	0
3.792	13.792	13.792	13.792	6	6
3.792	10	23.792	23.792	4	10
3.792	10	33.792	33.792	5	15
3.792	10	43.792	43.792	7	22
3.792	10	53.792	53.792	10	32
3.792	10	63.792	63.792	8	40
3.792	10	73.792	73.792	9	49
3.792	10	83.792	83.792	12	61

Figure A.23: Penetration vs. Load graph of 16 mm rod of field test at Kollayanpur

Table A.25: Penetration test at field with 16 mm rod

Location : Field(Kollayanpur)
Penetration No : 6
Rod type : 16 mm

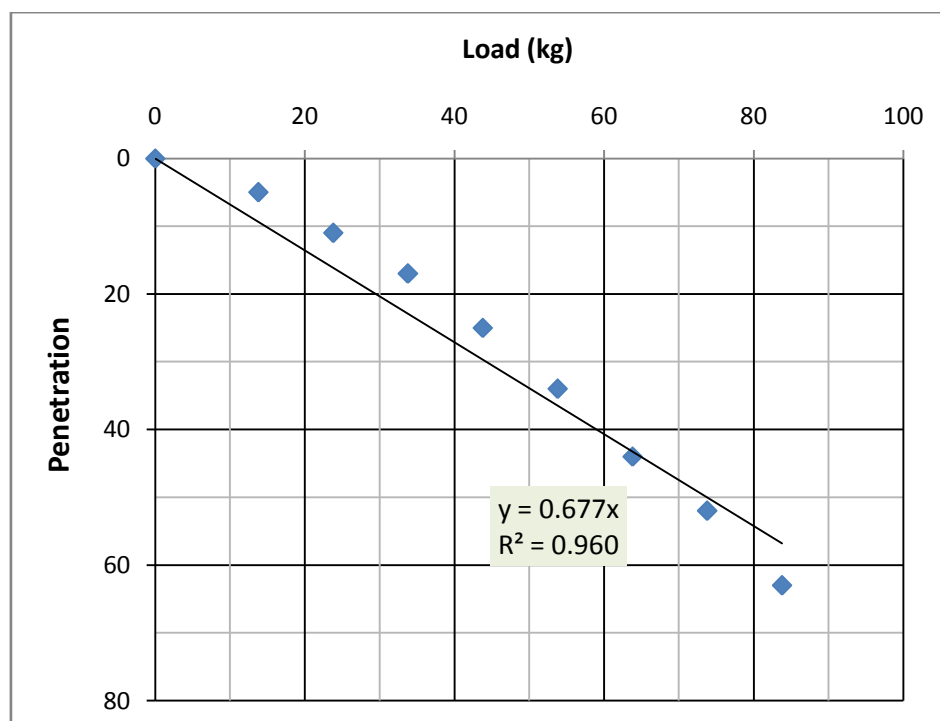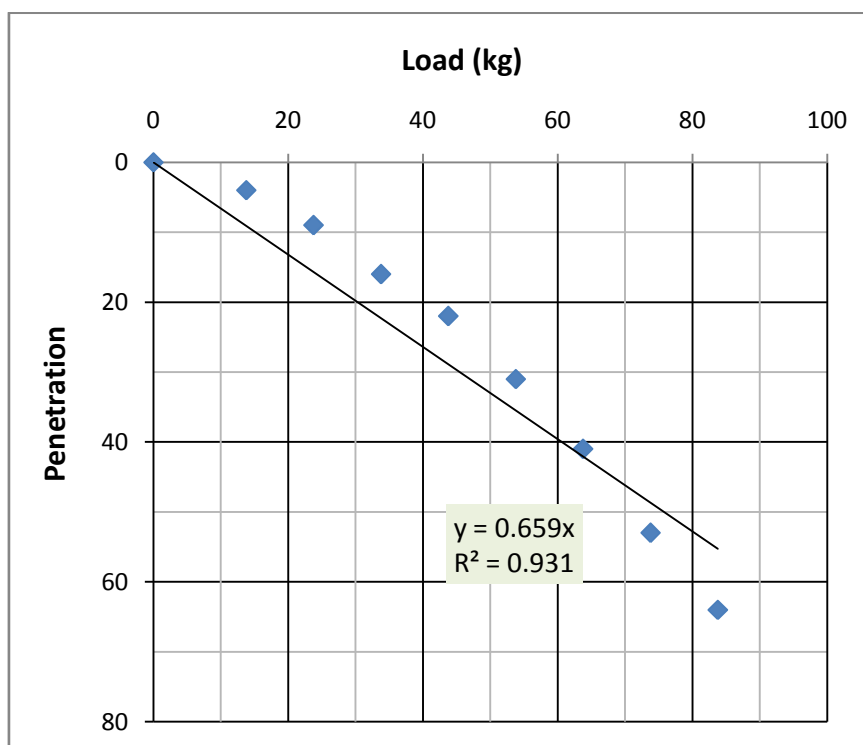| Instrument Weight(kg)	Load(Kg)	Total load, W	Cummulative load	Depth, H (mm)	Cummulative Depth
0	0	0	0	0	0
3.792	13.792	13.792	13.792	6	6
3.792	10	23.792	23.792	2	8
3.792	10	33.792	33.792	8	16
3.792	10	43.792	43.792	3	19
3.792	10	53.792	53.792	15	34
3.792	10	63.792	63.792	14	48
3.792	10	73.792	73.792	10	58
3.792	10	83.792	83.792	9	67

Figure A.24: Penetration vs. Load graph of 16 mm rod of field test at Kollayanpur

Table A.26: Penetration test at field with 25 mm rod

Location :   Field(Kollayanpur)
Penetration No :   4
Rod type :   25 mm

Instrument Weight(kg)	Load(Kg)	Total load, W	Cummulative load	Depth, H (mm)	Cummulative Depth
0	0	0	0	0	0
5.605	15.605	15.605	15.605	1	1
5.605	10	25.605	25.605	2	3
5.605	10	35.605	35.605	2	5
5.605	10	45.605	45.605	3	8
5.605	10	55.605	55.605	2	10
5.605	10	65.605	65.605	2	12
5.605	10	75.605	75.605	2	14
5.605	10	85.605	85.605	4	18

Figure A.25: Penetration vs. Load graph of 25 mm rod of field test at Kollayanpur.

$y = 0.185x$
$R^2 = 0.953$

Table A.27: Penetration test at field with 25 mm rod

Location :	Field(Kollayanpur)	
Penetration No :	5	
Rod type :	25 mm	

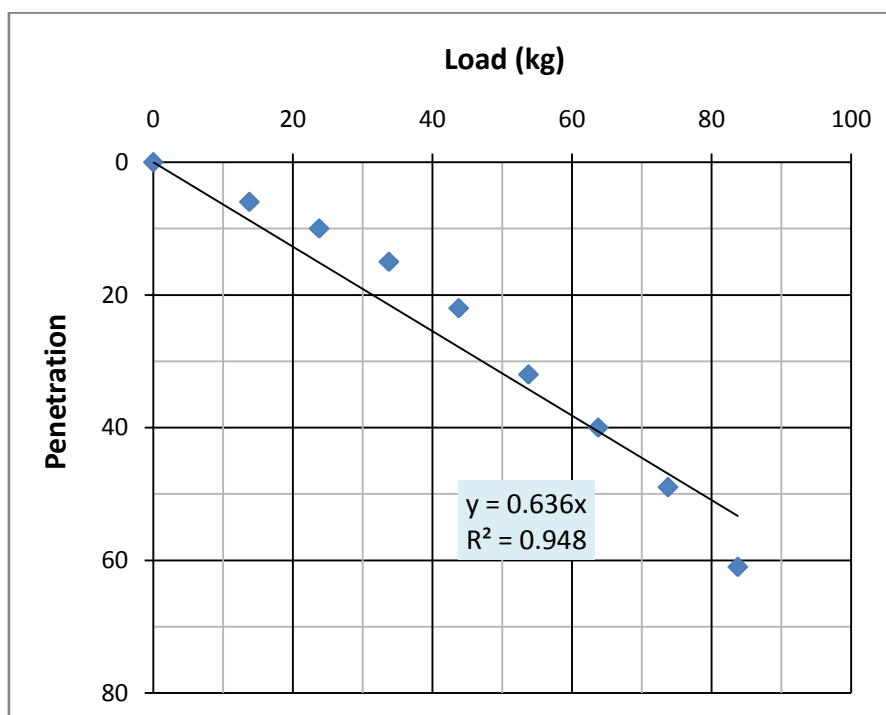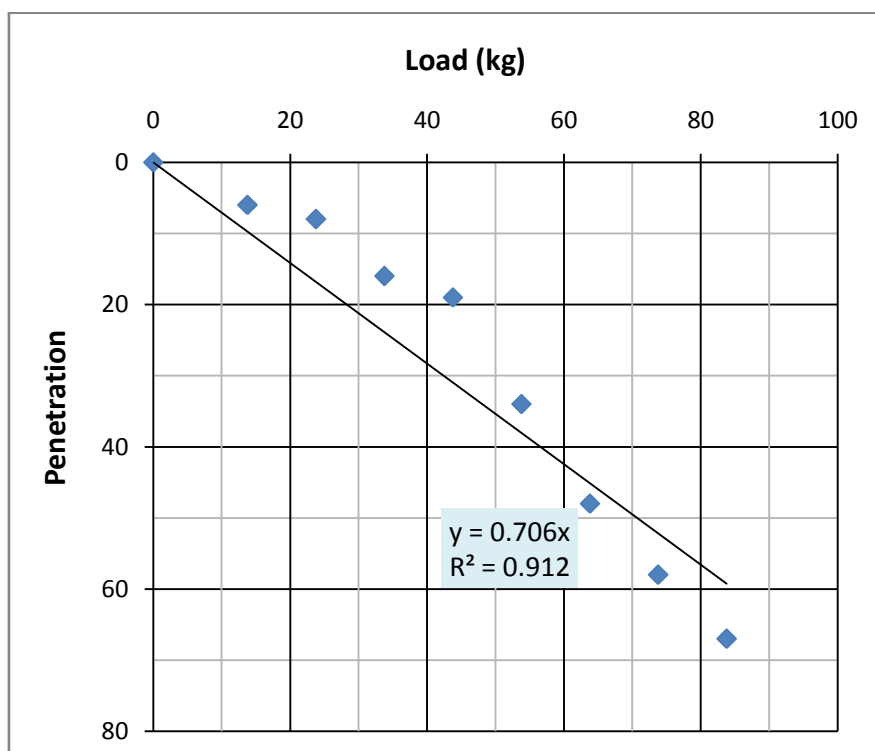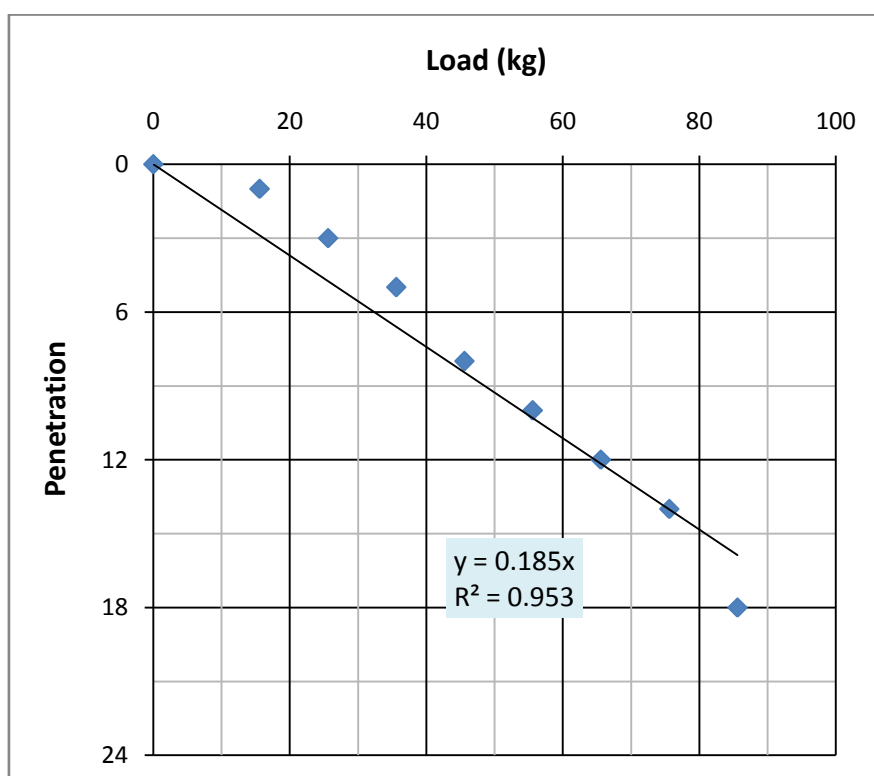| Instrument Weight(kg)	Load(Kg)	Total load, W	Cummulative load	Depth, H (mm)	Cummulative Depth
0	0	0	0	0	0
5.605	15.605	15.605	15.605	1	1
5.605	10	25.605	25.605	2	3
5.605	10	35.605	35.605	3	6
5.605	10	45.605	45.605	2	8
5.605	10	55.605	55.605	2	10
5.605	10	65.605	65.605	3	13
5.605	10	75.605	75.605	2	15
5.605	10	85.605	85.605	3	18
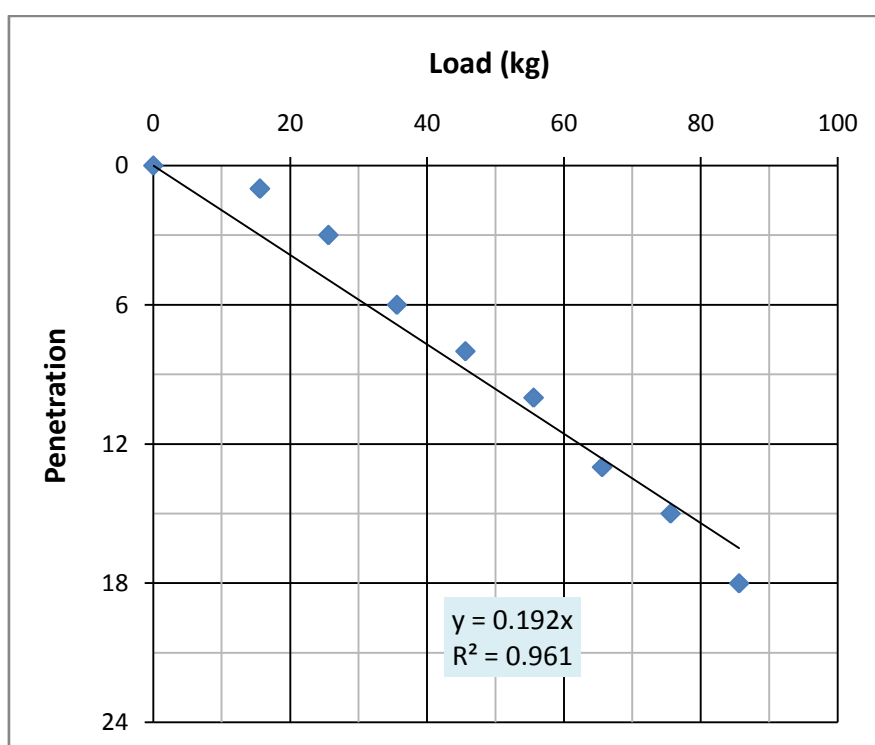
Figure A.26: Penetration vs. Load graph of 25 mm rod of field test at Kollayanpur

Table A.28: Penetration test at field with 25 mm rod

Location :   Field (Kollayanpur)
Penetration No :   6
Rod type :   25 mm

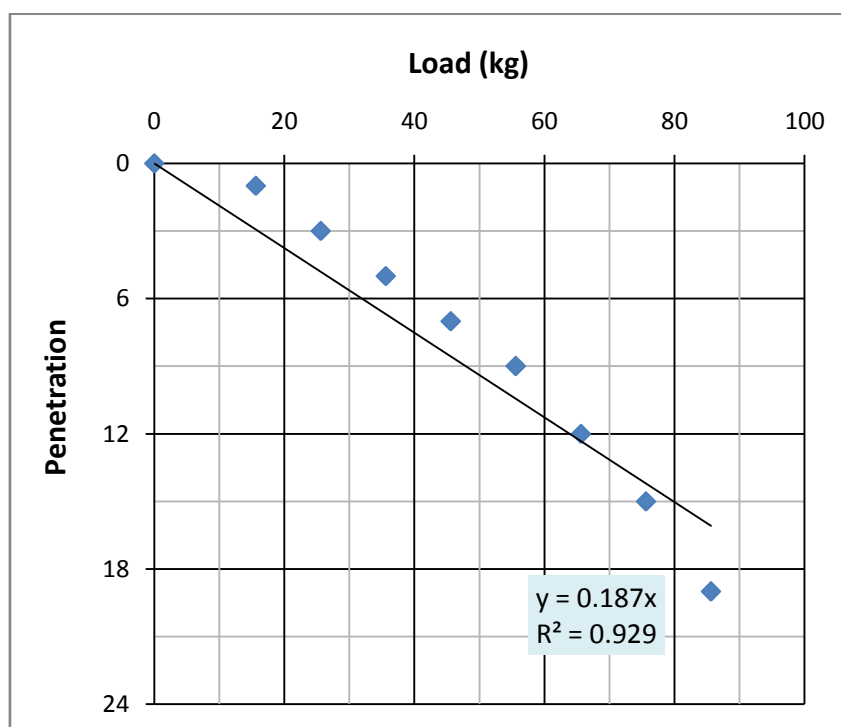| Instrument Weight(kg)	Load(Kg)	Total load, W	Cummulative load	Depth, H (mm)	Cummulative Depth
0	0	0	0	0	0
5.605	15.605	15.605	15.605	1	1
5.605	10	25.605	25.605	2	3
5.605	10	35.605	35.605	2	5
5.605	10	45.605	45.605	2	7
5.605	10	55.605	55.605	2	9
5.605	10	65.605	65.605	3	12
5.605	10	75.605	75.605	3	15
5.605	10	85.605	85.605	4	19

Figure A.27: Penetration vs. Load graph of 25 mm rod of field test at Kollayanpur

APPENDIX B

UNCONFINED COMPRESSION TEST RESULTS

Table B.1: Unconfined compression test for sample 1(a,b)

Initial diameter = 1.5 in.　　　　　　　　Wt of can + wet sample = 48.1 g

Initial area = 1.767 in.^{2}　　　　　　　　Wt of can + dry sample = 44.9g

Initial height = 3.0 in.　　　　　　　　　Wt of can = 28.7 g

Initial Volume = 5.301 in.^{3}　　　　　　Water content = 19.753 %

Calibration factor = 0.3 lb/div

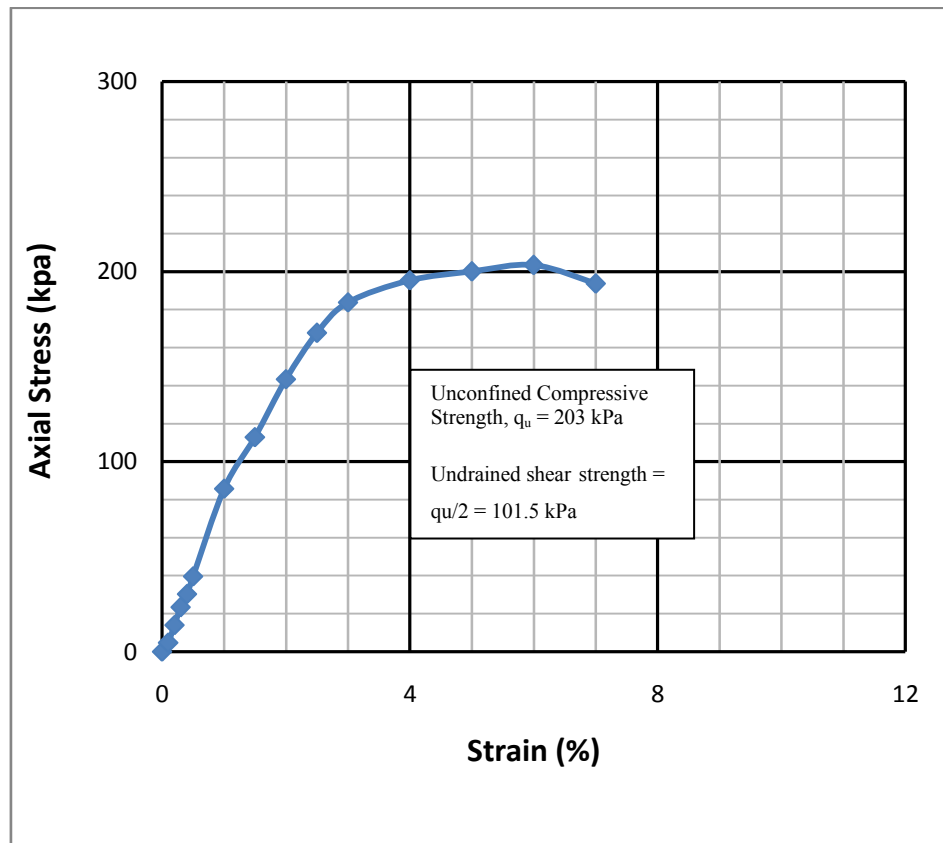| Load dial in 0.0001	Axial Load P(lb)	Displacement Dial in 0.001	Total displacement(inches)	Unit Strain, $\varepsilon=(\Delta H/H_\circ)$	Strain (%)	Corrected Area, $A=A_o/(1-\varepsilon)$ (inch^2)	Stress (psi)	Stress (kPa)
0	0	0	0	0	0	1.767	0	0
4	1.2	3	0.003	0.001	0.1	1.769	0.678	5
12	3.6	6	0.006	0.002	0.2	1.771	2.033	14
20	6	9	0.009	0.003	0.3	1.772	3.386	23
26	7.8	12	0.012	0.004	0.4	1.774	4.397	30
34	10.2	15	0.015	0.005	0.5	1.776	5.743	40
74	22.2	30	0.03	0.01	1	1.785	12.437	86
98	29.4	45	0.045	0.015	1.5	1.794	16.388	113
125	37.5	60	0.06	0.02	2	1.803	20.799	143
147	44.1	75	0.075	0.025	2.5	1.812	24.338	168
162	48.6	90	0.09	0.03	3	1.822	26.674	184
174	52.2	120	0.12	0.04	4	1.841	28.354	195
180	54	150	0.15	0.05	5	1.86	29.032	200
185	55.5	180	0.18	0.06	6	1.88	29.521	203
178	53.4	210	0.21	0.07	7	1.9	28.105	194

Figure B .1: Axial stress vs. Strain (%) curve at 20% moisture content of soil collected from Mohakhali.

Table B.3: Unconfined compression test for sample 3(a,b)

Initial diameter = 1.5 in.   Wt of can + wet sample = 60.9 g

Initial area = 1.767 in.^{2} Wt of can + dry sample = 56 g

Initial height = 3.0 in.   Wt of can = 29 g

Initial Volume = 5.301 in.^{3} Water content = 18.148 %

Calibration factor = 0.3 lb/div

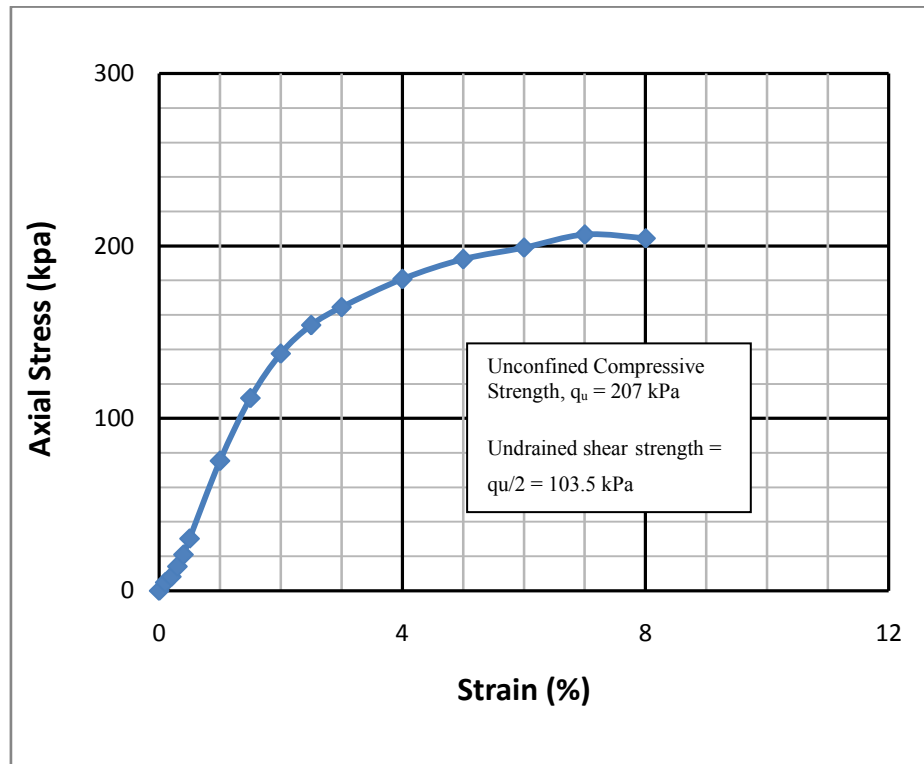| Load dial in 0.0001	Axial Load P(lb)	Displacement Dial in 0.001	Total displacement (inches)	Unit Strain, $\varepsilon=(\Delta H/H_\circ)$	Strain(%)	Corrected Area, $A=Ao/(1-\varepsilon)$ (inch^2)	Stress (psi)	Stress (kPa)
0	0	0	0	0	0	1.767	0	0
4	1.2	3	0.003	0.001	0.1	1.769	0.678	5
7	2.1	6	0.006	0.002	0.2	1.771	1.186	8
12	3.6	9	0.009	0.003	0.3	1.772	2.032	14
18	5.4	12	0.012	0.004	0.4	1.774	3.044	21
26	7.8	15	0.015	0.005	0.5	1.776	4.392	30
65	19.5	30	0.03	0.01	1	1.785	10.924	75
97	29.1	45	0.045	0.015	1.5	1.794	16.221	112
120	36	60	0.060	0.02	2	1.803	19.967	138
135	40.5	75	0.075	0.025	2.5	1.812	22.351	154
145	43.5	90	0.090	0.03	3	1.822	23.875	165
161	48.3	120	0.120	0.04	4	1.841	26.236	181
173	51.9	150	0.150	0.05	5	1.86	27.903	192
181	54.3	180	0.180	0.06	6	1.88	28.883	199
190	57	210	0.210	0.07	7	1.9	30	207
190	57	240	0.240	0.08	8	1.921	29.672	204

Figure B.3: Typical stress strain curve

Table B.4: Unconfined compression test for sample 4(a,b)

Initial diameter = 1.5 in.   Wt of can + wet sample = 67.4 g

Initial area = 1.767 in.^{2} Wt of can + dry sample = 63.3 g

Initial height = 3.0 in.   Wt of can = 42.3 g

Initial Volume = 5.301 in.^{3} Water content = 19.524 %

Calibration factor = 0.3 lb/div

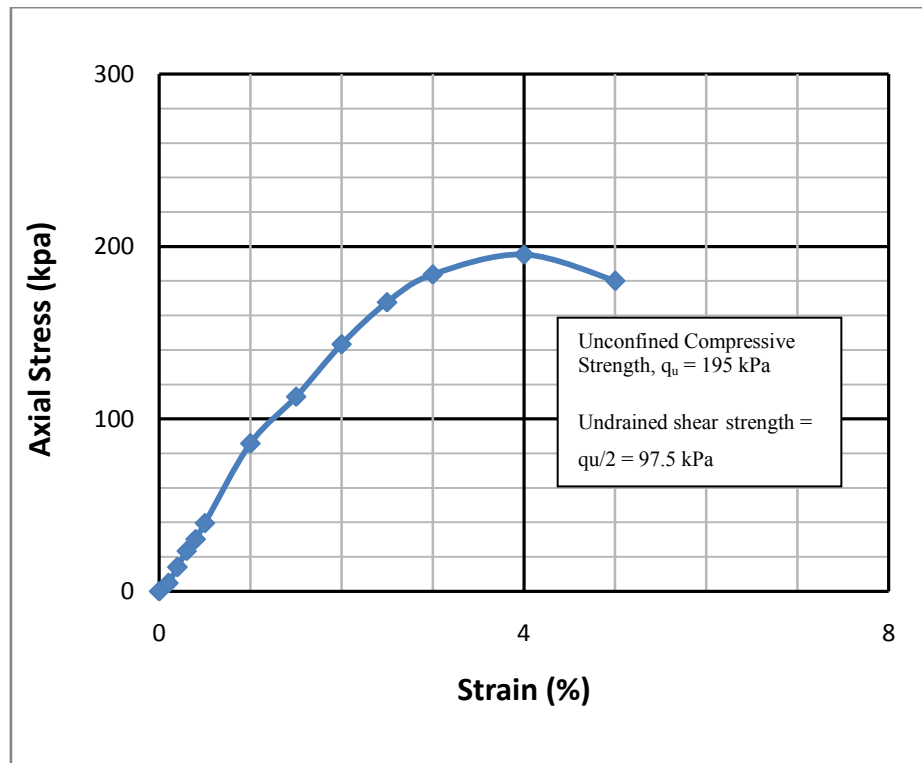| Load dial in 0.0001	Axial Load P(lb)	Displacement Dial in 0.001	Total displacement(inches)	Unit Strain, $\mathcal{E}=(\Delta H/H_\circ)$	Strain(%)	Corrected Area, A=Ao/(1 - $\mathcal{E}$) (inch^2)	Stress (psi)	Stress (kPa)
0	0	0	0	0	0	1.767	0	0
4	1.2	3	0.003	0.001	0.1	1.769	0.678	5
12	3.6	6	0.006	0.002	0.2	1.771	2.033	14
20	6	9	0.009	0.003	0.3	1.772	3.386	23
26	7.8	12	0.012	0.004	0.4	1.774	4.397	30
34	10.2	15	0.015	0.005	0.5	1.776	5.743	40
74	22.2	30	0.03	0.01	1	1.785	12.437	86
98	29.4	45	0.045	0.015	1.5	1.794	16.388	113
125	37.5	60	0.06	0.02	2	1.803	20.799	143
147	44.1	75	0.075	0.025	2.5	1.812	24.338	168
162	48.6	90	0.09	0.03	3	1.822	26.674	184
174	52.2	120	0.12	0.04	4	1.841	28.354	195
162	48.6	150	0.15	0.05	5	1.86	26.129	180

Figure . B.4: Typical stress strain curve

Table B.5: Unconfined compression test for sample 5(a,b)

Initial diameter = 1.5 in.   Wt of can + wet sample = 68.1 g

Initial area = 1.767 in.^{2} Wt of can + dry sample = 63.9 g

Initial height = 3.0 in.   Wt of can = 42.2 g

Initial Volume = 5.301 in.^{3} Water content = 19.355 %

Calibration factor = 0.3 lb/div

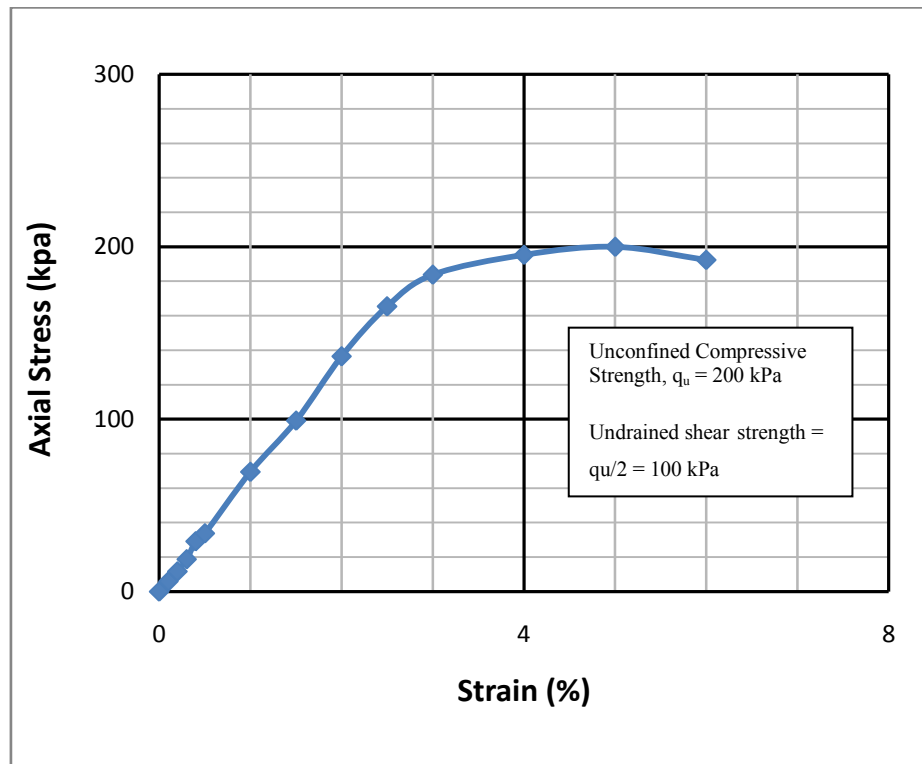| Load dial in 0.0001	Axial Load P(lb)	Displacement Dial in 0.001	Total displacement(inches)	Unit Strain, $\varepsilon=(\Delta H/H_\circ)$	Strain(%)	Corrected Area, $A=A_o/(1-\varepsilon)$ (inch^2)	Stress (psi)	Stress (kPa)
0	0	0	0	0	0	1.767	0	0
5	1.5	3	0.003	0.001	0.1	1.769	0.848	6
10	3	6	0.006	0.002	0.2	1.771	1.694	12
16	4.8	9	0.009	0.003	0.3	1.772	2.709	19
25	7.5	12	0.012	0.004	0.4	1.774	4.228	29
29	8.7	15	0.015	0.005	0.5	1.776	4.899	34
60	18	30	0.03	0.01	1	1.785	10.084	69
86	25.8	45	0.045	0.015	1.5	1.794	14.381	99
119	35.7	60	0.06	0.02	2	1.803	19.8	136
145	43.5	75	0.075	0.025	2.5	1.812	24.007	165
162	48.6	90	0.09	0.03	3	1.822	26.674	184
174	52.2	120	0.12	0.04	4	1.841	28.354	195
180	54	150	0.15	0.05	5	1.86	29.032	200
175	52.5	180	0.18	0.06	6	1.88	27.926	192

Figure . B.5: Typical stress strain curve

Table B.6: Unconfined compression test for sample 6(a,b)

Initial diameter = 1.5 in. Wt of can + wet sample = 99.5 g

Initial area = 1.767 in.^{2} Wt of can + dry sample = 91.4 g

Initial height = 3.0 in. Wt of can = 47.1 g

Initial Volume = 5.301 in.^{3} Water content = 18.284 %

Calibration factor = 0.3 lb/div

| Load dial in 0.0001	Axial Load P(lb)	Displacement Dial in 0.001	Total displacement (inches)	Unit Strain, $\varepsilon=(\Delta H/H_\circ)$	Strain (%)	Corrected Area, $A=A_o/(1-\varepsilon)$ (inch^2)	Stress (psi)	Stress (kPa)
0	0	0	0	0	0	1.767	0	0
8	2.4	3	0.003	0.001	0.1	1.769	1.357	9
15	4.5	6	0.006	0.002	0.2	1.771	2.541	18
24	7.2	9	0.009	0.003	0.3	1.772	4.063	28
31	9.3	12	0.012	0.004	0.4	1.774	5.242	36
38	11.4	15	0.015	0.005	0.5	1.776	6.419	44
75	22.5	30	0.03	0.01	1	1.785	12.605	87
99	29.7	45	0.045	0.015	1.5	1.794	16.555	114
128	38.4	60	0.06	0.02	2	1.803	21.298	147
151	45.3	75	0.075	0.025	2.5	1.812	25	172
164	49.2	90	0.09	0.03	3	1.822	27.003	186
173	51.9	120	0.12	0.04	4	1.841	28.191	194
178	53.4	150	0.15	0.05	5	1.86	28.71	198
172	51.6	180	0.18	0.06	6	1.88	27.447	189
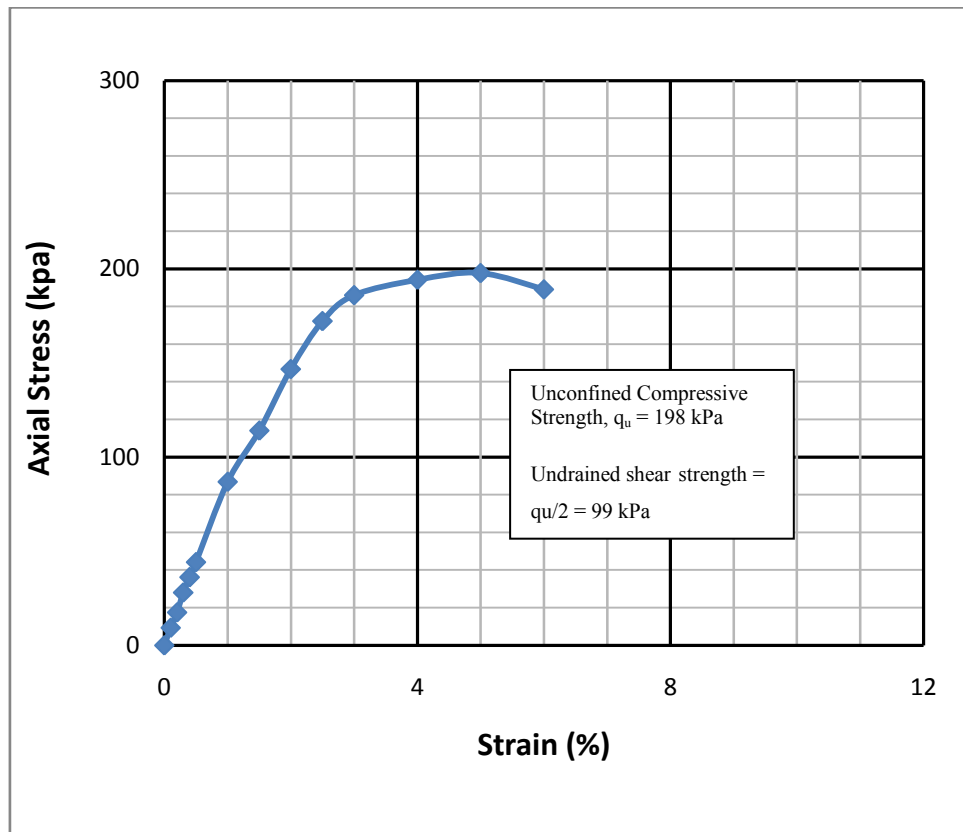
Figure B.6: Typical stress strain curve