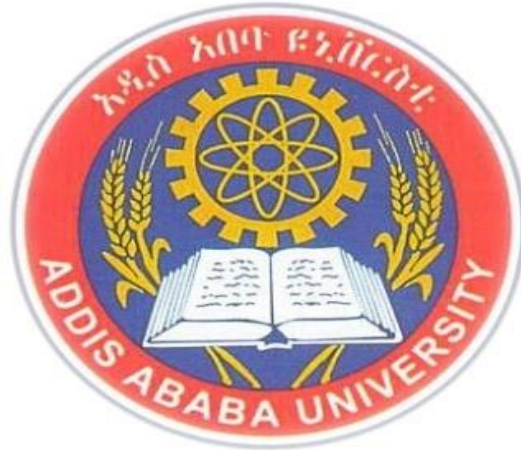


**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**



**ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING**

**Predicting the value of CBR from DCP for Addis
Ababa Red clay**

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November 2014

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**A Thesis Submitted to the School of Graduate Studies of
Addis Ababa University in Partial Fulfillment of the Requirements for
The Degree of
Master of Science in Geotechnical Engineering**

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ABBREVIATIONS, ACRONYMS AND SYMBOLS

ASTM	American Society for Testing of Materials
BS	British Standard
C	Clay Content
CBR	California Bearing Ratio
CH	Inorganic Clay of High Plasticity
c_u	Undrained cohesive resistance
d	depth/diameter
Dcbr	Density at CBR penetration
DCP	Dynamic Cone Penetrometer
DCPI	Dynamic Cone Penetrometer Index
FS	Free Swell
GPS	Global Positioning System
G_s	Specific Gravity
γ	Unit weight of soil
h	Depth of cone tip while recording
kPa	kilo Pascal
LI	Liquidity Index
LL	Liquid Limit
m	meter
mm	Millimetre
NGL	Natural Ground Level
NMC	Natural Moisture Content
N/A	Not Available
ORN	Overseas Road Note
ω	Water Content
PI	Plasticity Index/ Penetration Index
PL	Plastic Limit
R^2	Coefficient of determination
Rd	Density ratio (density at field /MDD)
Rw	water content ratio(water content at field/OMC)
SPSS	Statistical Package for the Social Sciences

TRRL	Transport Road Research Laboratory
UCS	Unconfined Compression Strength
UK	United Kingdom
USAID	United States Agency for International Development
USCS	Unified Soil Classification System

ABSTRACT

The research attempts to introduce the Dynamic cone penetration (DCP) to replace CBR test in preliminary design stage. DCP is a simple test device, portable and easy to operate and a repeated test can be conducted as much as desired to achieve a better and reliable design parameter.

Field DCP test with in situ density test were conducted. Disturbed and undisturbed samples were taken to the laboratory with which natural moisture content, Atterberg limits, grain size analysis, free swell, standard proctor density test and CBR were conducted.

After looking thoroughly the scatter diagrams, it is found out that DCPI is influenced by in situ moisture content and bulk density however it is not influenced by Atterbeg limits. It is also found out that there is good relationship between DCPI and CBR.

Different techniques are used to find an expression that best suits to find the value of CBR from DCP and other parameters. The final accepted one is the expression developed by using two stage residual inclusion estimation using liquidity index as variable The result gives the following equation with N=36 and adjusted coefficient of determination of 0.633.

$$\text{Predicted DCPI} = 0.207 * \text{LI} + 22.571$$

$$\text{CBR} = -0.142 * \text{DCPI} - 0.18(\text{DCPI} - \text{Predicted DCPI}) + 7.701$$

1. INTRODUCTION

1.1 GENERAL

As a millennium development goal, Ethiopia has set different construction programs to enhance the infrastructure of the country.

Before starting the construction, a proper site investigation is mandatory as an input for the subsequent designs (geometric design, pavement design, structural design and etc.)

However if especially the terrain type is classified as escarpment, a high volume of excavation (sometimes it requires an excavation as deep as 10m from the original ground level) is needed for the construction of the road project. Hence the foundation investigation carried out at the design stage will be barely used. This will lead to the need for another subgrade investigation at the final road level.

In doing so, most geotechnical engineers find out that a high amount of money is invested through these stages and proposed to conduct simple and economical tests and find the remaining tests from correlation equations.

Among the tests, DCP can easily be correlated to different kinds of soil parameters. DCP has been used for determination of the soil strength parameter tests including but not limited to CBR, UCS and plate loading test. The DCP is mainly studied and correlated for the application of pavement analysis and hence mainly correlated to CBR.

Since the testing of CBR is relatively expensive, replacing this test with DCP will be ideal and cost effective. Furthermore the repeatability of DCP is more than CBR hence more accurate result can be achieved.

Due to this fact, this thesis will discuss the correlation of DCP and CBR and will derive empirical equation for the particular case of Addis Ababa red clay soils.

1.2 BACK GROUND OF THE PROBLEM

Currently, most geotechnical, material and pavement engineers use DCP to find CBR by using the equation provided by TRL manual and adapted by ERA i.e

$$\text{Log } 10 (\text{CBR}) = 2.48 - 1.057 \text{ Log}_{10} (\text{DN}) \quad (1.1)$$

Where DN= the penetration of the dynamic cone per mm per blow

CBR=the desired Californian bearing ratio

However, the above method has the following problems:-

- The formulated equation by TRL is conducted in the laboratories found in Kenya, Tanzania and South Africa. Considering the erratic behavior of soil, it would be inappropriate to use one formula for every type of soils.
- While conducting CBR for pavement design, the standard procedure requires the soaking of the soil for four days. Furthermore the CBR shall be calculated at MDD. However, the equation given above provides the CBR value at an in situ moisture content and density. Consequently the equation gives a slightly exaggerated figure than the actual one and misinforms the engineer about the capacity of the material.

1.3 OBJECTIVE

1.3.1 General Objective

The main objective of this paper is to develop a correlation formula, which enables the calculation of CBR values from DCPI.

1.3.2 Specific Objective

- To collect soil samples and to carry out the required laboratory tests.
- To check and come up with a correlation between CBR values and DCPI.

1.4 METHODOLOGY

To achieve the objectives of the thesis, the following methodologies have been followed

- Literature review
- Field work and laboratory test

On the field the following tests were conducted

- DCP,
- natural moisture content,
- in-situ density tests.

In the laboratory the following tests were conducted

- Atterberg limits
- Specific gravity
- Grain size analysis
- Free swell
- Compaction
- CBR

After conducting the tests, multiple regressions shall be carried out and an attempt shall be made to develop an empirical equation. The equation shall be evaluated and checked with test data. Finally the findings and results of the work will be presented.

.

1.5 SCOPE OF THE STUDY

The current research work focuses on Northern and Western Addis Ababa where Red clay soils dominates. Samples were taken from ongoing construction sites of Kolfe Police station, Teferi Mekonen School, Asko-Winget road project and Abo church.

Forty samples were taken from those places, of which the thirty six were used for the development of the correlation equation whereas the remaining four were used for validation of the equation.

1.6 ORGANIZATION OF THE THESIS

This thesis contains six chapters and appendices. The first chapter contains introduction, back ground of the problem, objectives scope of the study and methodology. Chapter two covers a literature review containing general description of DCP and CBR, effects of moisture content and density on DCP and previously developed correlation equations. In the third chapter, the laboratory test results are presented. In chapter four the data analysis is presented. In chapter 5 discussions of the results are presented in chapter 6 conclusions and recommendations are given. Reference materials used in the research work are appropriately sited and listed. The thesis ends with appendices which contain detail experimental results of laboratory investigation.

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2. LITERATURE REVIEW

2.1 GENERAL

The Dynamic Cone Penetration has been used for determination of the soil strength parameters. The DCP is mainly studied and correlated for the application of pavement analysis and hence mainly correlated to CBR.

Since the testing of CBR is expensive, replacing this test with DCP will be ideal and cost effective. Furthermore the repeatability of DCP is more than CBR hence more accurate result can be achieved.

DCP and CBR should give a reasonable correlation since both tests use large strain penetration to measure material strength. The difference is the load applied for the DCP is dynamic and the load applied for the CBR is static.

2.2 DYNAMIC CONE PENETRATION

The Dynamic Cone Penetrometer has been increasingly used in many parts of the world in soil (sub grade), granular material, and lightly stabilized soils through its relationship with in-situ California Bearing Ratio (CBR). Throughout the last two decades, sufficient data have been compiled relating DCP index to CBR, making it possible to estimate the in-situ strength of sub grades and pavement layers.

2.2.1 Early Development

Development of the hand-held DCP is credited to Scala of Australia in the mid-1950. Pavement design procedures in Australia then did not specifically require in-situ strength tests of the sub grade soils because of the time and complexity of available test methods. The device Scala developed included a 9.1-kg (20-lb) drop hammer falling a distance of 508 mm (20 inches). A 15.9 mm (5/8 inch) diameter rod calibrated in 50.8 mm (2 inch) increments was used to determine the penetration. The configuration used a 30 degree

included angle cone tip. Scala conducted tests correlating CBR with DCP data and proposed a pavement design procedure based on this correlation. Use of this DCP device was adopted by the Country Roads Board, Victoria, and gained widespread acceptance.

The next generation of DCP equipment was developed by Van Vuuren from South Africa. Basically it was similar to the DCP apparatus developed by Scala except the mass of the drop hammer was changed to 10 kg and the drop height was changed to 383.5 mm (18.1 inches). The shaft diameter measured 16 mm (0.63 inch) while the apex angle remained at 30 degrees. The development was prompted by the need to alleviate problems associated with performing field CBR tests. In the ensuing study, the CBR/DCP correlation resulted in a better correlation when compared to CBR/CPT correlation. Additionally, Van Vuuren concluded that the DCP is suited for use with soils having CBR values of 1 to 50.

The present version of the DCP used in this study was developed by Kleyn of the Transvaal Roads Department, South Africa. Van Vuuren's basic design was utilized in Kleyn's work; however, the hammer mass was reduced to 8 kg and the height of the drop was increased to 576 mm (22.6 inches). Kleyn studied two cone angle configurations of 30 degrees and 60 degrees. The cone angle utilized in this study was based on the 60 degree included angle. Kleyn's work focused on the development of the generalized DCP/CBR correlation for the full range of materials tested.

2.2.2 Operation

A safe working environment should be maintained at all times. Many organizations will have on-site safety procedures which should be followed.

After assembly, the first task is to record the zero reading of the instrument. This is done by standing the DCP on a hard surface, such as concrete, checking that it is vertical and then entering the zero reading in the appropriate place on the plat form (See Figure 2.1).

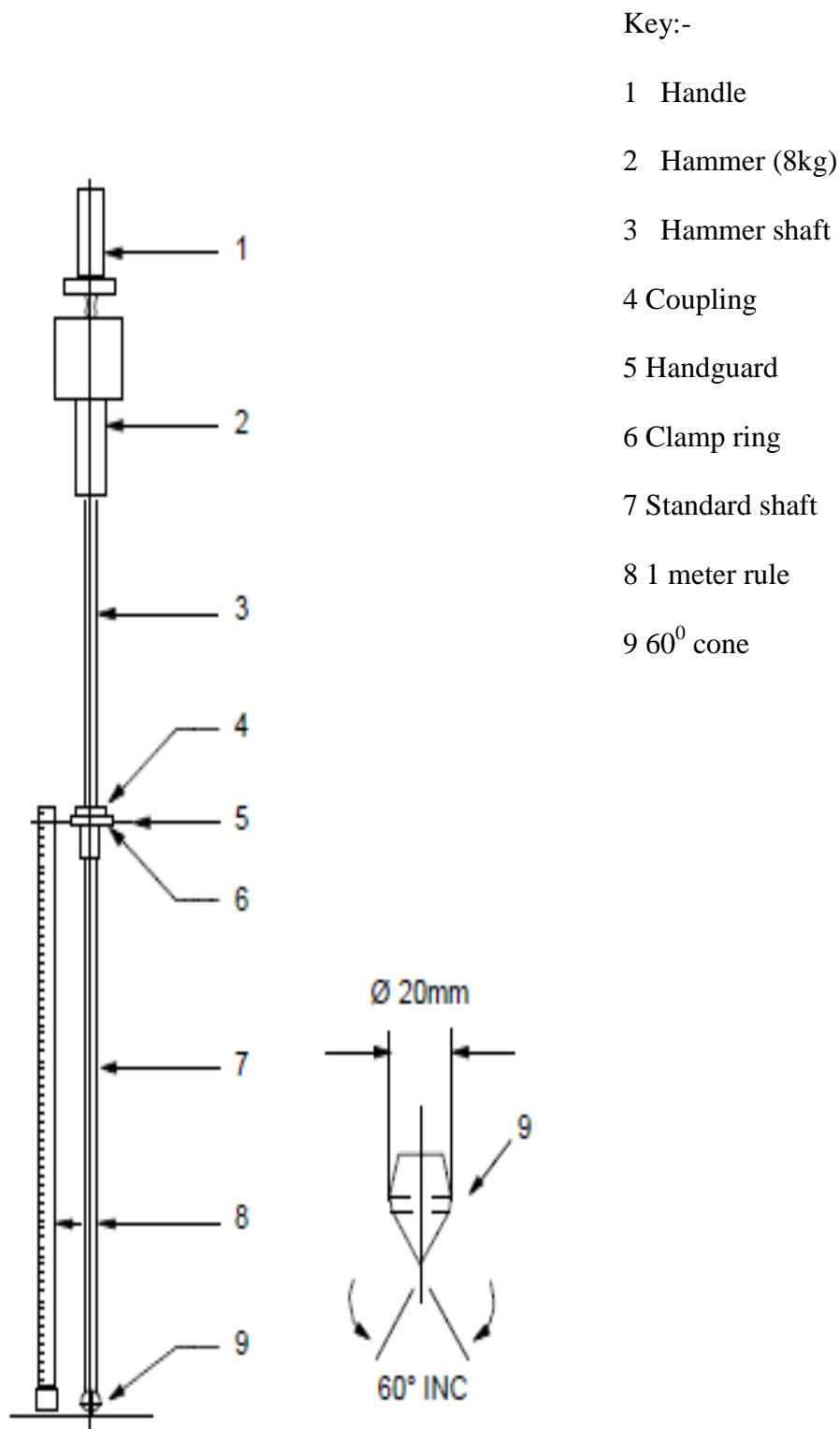


Figure 2-1: The dynamic Cone Penetration Equipment

The DCP needs three operators, one to hold the instrument, one to raise and drop the weight and a technician to record the readings. The instrument is held vertical and the weight raised to the handle. Care should be taken to ensure that the weight is touching the handle, but not lifting the instrument, before it is allowed to drop. The operator must let it fall freely and not partially lower it with his hands.

It is recommended that a reading should be taken at increments of penetration of about 10mm. However it is usually easier to take a reading after a set number of blows. It is therefore necessary to change the number of blows between readings, according to the strength of the layer being penetrated.

For good quality granular bases, readings every 5 or 10 blows are usually satisfactory but for weaker sub-base layers and subgrades readings every 1 or 2 blows may be appropriate. There is no disadvantage in taking too many readings, but if readings are taken too infrequently, weak spots may be missed and it will be more difficult to identify layer boundaries accurately, hence important information will be lost.

When the extended version of the DCP is used the instrument is driven into the pavement to a depth of 400-500mm before the extension shaft can be added. To do this the meter rule is detached from its base plate and the shaft is split to accept the extension shaft. After re-assembly a penetration reading is taken before the test is continued.

After completing the test, the DCP is removed by tapping the weight upwards against the handle. Care should be taken when doing this; if it is done too vigorously the life of the instrument will be reduced. The DCP can be driven through surface dressings but it is recommended that thick bituminous surfacing is cored prior to testing the lower layers. Little difficulty is normally experienced with the penetration of most types of granular or lightly stabilized materials. It is more difficult to penetrate strongly stabilized layers, granular materials with large particles and very dense, high quality crushed stone. The TRL instrument has been designed for strong materials and therefore the operator should persevere with the test.

Penetration rates as low as 0.5mm/blow are acceptable but if there is no measurable penetration after 20 consecutive blows it can be assumed that the DCP will not penetrate

the material. Under these circumstances a hole can be drilled through the layer using an electric or pneumatic drill, or by coring. The lower pavement layer can then be tested in the normal way. If only occasional difficulties are experienced in penetrating granular materials, it is worthwhile repeating any failed tests a short distance away from the original test point.

If, during the test, the DCP leans away from the vertical no attempt should be made to correct it because contact between the shaft and the sides of the hole can give rise to erroneous results. Research (Livneh, 1995) has shown that there can be an overestimate of subgrade strength as a result of friction on the rod caused by either tilted penetration through, or collapse of, any upper granular pavement layers. Where there is a substantial thickness of granular material, and when estimates of the actual subgrade strength are required (rather than relative values) it is recommended that a hole is drilled through the granular layer prior to testing the lower layers.

2.2.3 Presentation of DCP Results

The DCP results, when plotted, describes the number of blows to reach a certain depth affording an instantaneous visual illustration of in-situ material strength (see [Figure 2.2](#)). The slope of the curve at any point expressed in terms of mm/blow is called the dynamic cone penetration index (DCPI) which represents the resistance offered by the material; the lower the DCPI the stiffer the material, and vice versa.

$$PI = \Delta Dp / \Delta BC \quad (2.1)$$

Where

PI = DCP penetration index in units of length divided by blow count;

ΔDp = Penetration depth;

BC = blow counts corresponding to penetration depth ΔDp .

The DCP results, when plotted, describes the number of blows to reach a certain depth

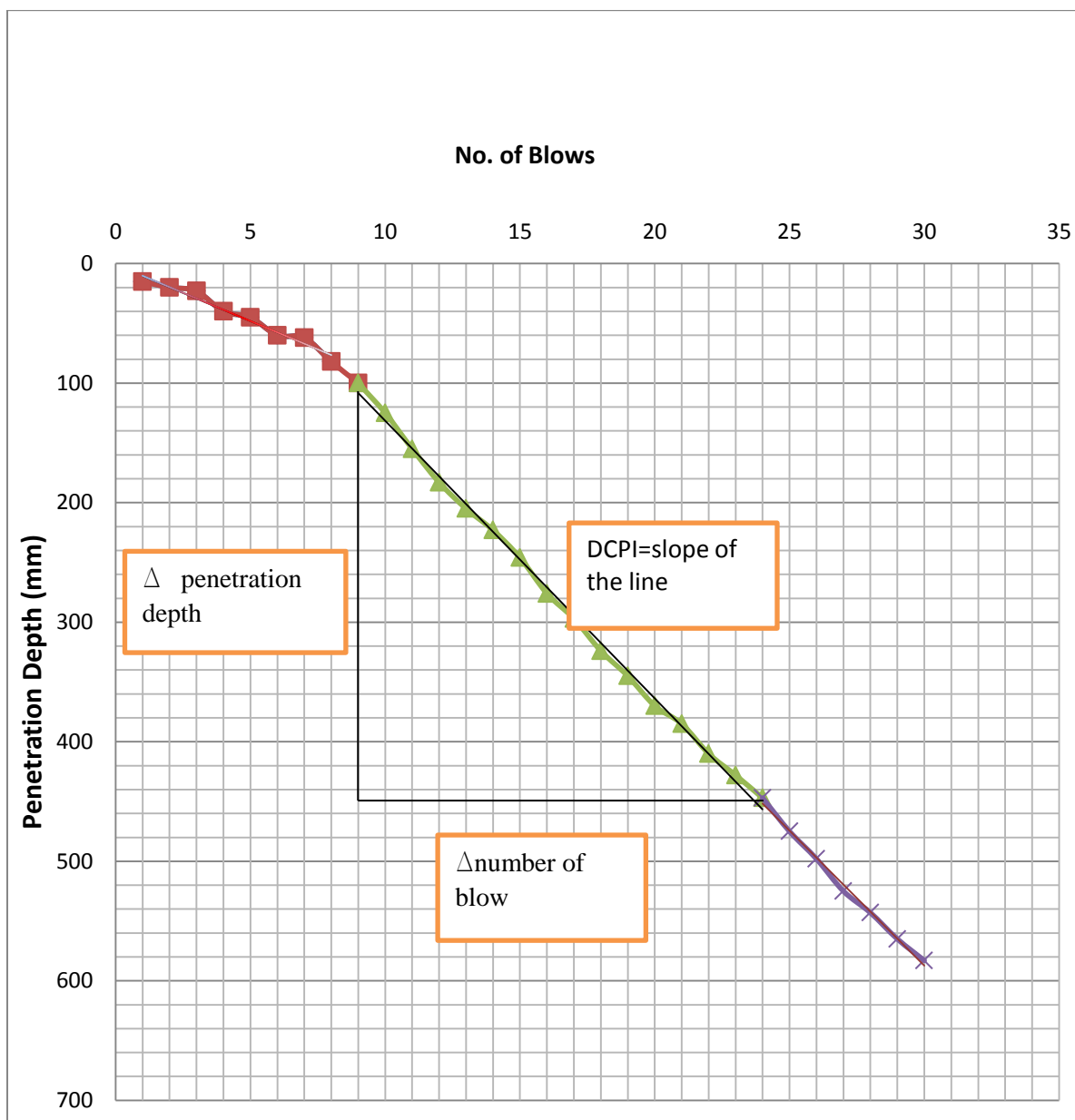


Figure 2-2 Typical presentation of DCP result

2.2.4 Application of DCP

2.2.4.1 DCP for Soil Investigation

The DCP was originally designed and used to determine the strength profile of flexible pavements or the subgrade due to its ability to provide a continuous record of relative soil strength with depth. By plotting a graph of penetration index DCPI, expressed in mm/blow versus depth below the tested surface, one can observe a profile showing layer depths, thicknesses, and strength conditions.

DCP can be conducted during preliminary soil investigation to quickly map out areas of weak materials and to locate potentially collapsible soils. DCP is an ideal tool for monitoring all aspects of the construction of pavement subgrade and verify the level and uniformity of compaction over a project. Yet, another indirect application of DCP is in the characterization of subgrade and base material properties through its relationship with some other soil properties, for example, CBR and Unconfined Compressive Strength (UCS).

2.2.4.2 Pavement Rehabilitation

Significant work has been carried out using the DCP for rehabilitation design of asphalt surfaced roads. Comparisons with various rehabilitation methods including the Asphalt Institute method, Mechanistic methods and standard catalogues have been carried out. A low cost DCP survey can provide sufficient information to design appropriate overlays (or identify areas where overlays are insufficient and additional structural material is required). Rehabilitation should typically follow a multi-analysis approach. [2]

2.2.4.3 Failure investigations and Audits

The DCP is an invaluable tool for failure investigations and technical audits. It can be used prior to any in destructive testing to determine layer thicknesses and condition with respect to the original design specification. This assists with the selection of areas for detailed investigation and allows optimization of the in situ testing to minimize investigation costs.[2]

2.2.4.4 Foundations

The DCP penetration has also been correlated with bearing capacity of soils for founding structure. This provides a general indication and hence can be a useful addition to extend the results of other tests. One such model is

$$q_{ult} = -506.5 \ln(DCPI) + \gamma h + 1891 [26]$$

2.2.4.5 Investigation of moisture effects in roads

The seasonal influence of moisture on the performance of roads and zones of moisture influence within the pavement structure can easily be determined through a regular testing programme. This type of information can be used to determine ideal paved shoulder widths, fill heights, drainage locations, equilibrium moisture contents and strengths, etc.[2]

2.2.5 Factors affecting DCP

From many previous studies it can be inferred that there are a number of factors that affect the values of DCP. Among this are

Material Effects: Hassan [6] reported that DCPI is significantly affected by moisture content , AASHTO soil classification and dry density for fine grained soils. Kleyn [13] concluded that gradation, density, moisture content, and plasticity were important material properties

Side Friction Effect: Because the DCP device is not completely vertical while penetrating through the soil, the penetration resistance would be apparently higher due to side friction. This apparent higher resistance may also be caused when penetrating in a collapsible granular material. This effect is usually small in cohesive soils compared to collapsible granular material [8].

2.3 CALIFORNIAN BEARING RATIO (CBR)

The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road subgrades and basecourses. It was developed by the California Department of Transportation before World War II.

The use of grading and Atterberg limits alone were not sufficient in qualifying materials for road construction use due to the fact that such materials behave differently under different moisture and density conditions. The penetration test was developed in order to establish the materials shear strength whilst the swell test would indicate the materials post compaction behavior.

By definition the CBR can be described as follows “The California bearing ration of a material is the load in Newton, expressed as a percentage of California standard values, required to allow a circular piston of 1935 mm^2 to penetrate the surface of a compacted material at a rate of 1.27mm per minute to a depth of 2.54mm and 5.08 mm. The California standard values for these depths are 13344 N and 20016N respectively”.

Thus, the California Bearing Ratio (CBR) test is a simple strength test that compares the bearing capacity of a material with that of a well-graded crushed stone (hence, a high quality crushed stone material should have a CBR of 100%). It is primarily intended for, but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm (0.75 in.) (AASHTO, 2000[1]). As a result, most agency and commercial geotechnical laboratories are equipped to perform CBR tests.

The basic CBR test involves applying load to a small penetration piston at a rate of 1.3 mm (0.05") per minute and recording the total load at penetrations ranging from 0.64 mm (0.025 in.) up to 7.62 mm (0.300 in.). Figure 2.3 is a sketch of a typical CBR sample.

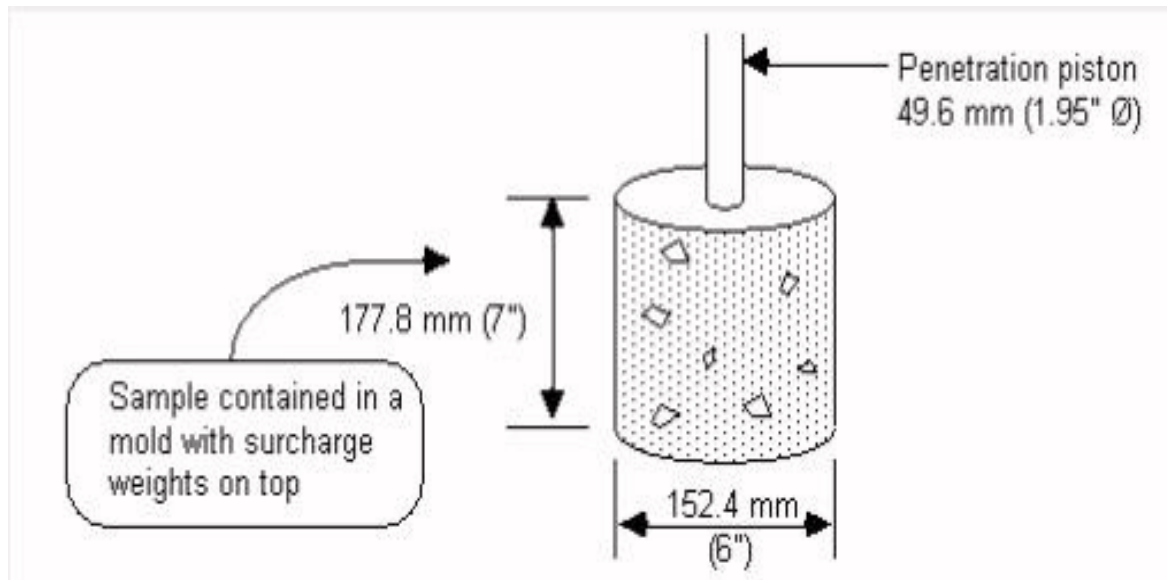


Figure 2-3: A Sketch of a Typical CBR Sample

Equation

Values obtained are inserted in to the following equation to obtain a CBR value

$$\text{CBR}(\%) = 100 * (x/y) \quad (2.2)$$

Where

x= material resistance or the unit load on the piston (pressure) for 2.54 mm (0.1”) or 5.08 mm (2”) of penetration.

y= standard unit load (pressure) for well graded crushed stone

= for 2.54mm penetration = 6.9 Mpa

= for 5.08 mm penetration = 10.3 Mpa

Typical values of CBR are given below:-

Table 2-1 : Typical CBR range of different soil types [3]

General Soil Type	USC Soil Type	CBR Range
<u>Coarse-grained soils</u>	GW	40 – 80
	GP	30 – 60
	GM	20 – 60
	GC	20 – 40
	SW	20 – 40
	SP	10 – 40
	SM	10 – 40
	SC	5 – 20
<u>Fine-grained soils</u>	ML	15 or less
	CL LL < 50%	15 or less
	OL	5 or less
	MH	10 or less
	CH LL > 50%	15 or less
	OH	5 or less

2.3.1 Test Methods

Internationally CBR tests are conducted under the same name. However not all tests utilize the same procedure or test apparatus. Though the tests essentially remain the same, results are interpreted and compared despite differences in test methods. In addition, different compactive efforts are also used e.g proctor or mod AASHTO. CBR can also be conducted on field as well as in the laboratory.

2.3.2.1 In Situ CBR Test

In Ethiopia in situ CBR test is rarely used. However, this test method is used for the determination of the in place CBR of the soil by comparing the penetration load of the soil that of a standard material. The test is mainly used for the evaluation of the quality sub grade soils but it is also applicable for sub base and some base course materials.

Normally the four days soaked CBR is used to evaluate the strength of the material since it shows the bearing capacity of the material at the worst possible scenario. However if

(a) The degree of saturation (percentage of voids filled with water) is 80 % or greater,

(b) The material is coarse grained and cohesionless so that it is not significantly affected by changes in water content, or

(c) The soil has not been modified by construction activities during the two years preceding the test. In the last-named case, the water content does not actually become constant, but generally fluctuates within a rather narrow range.

The in situ CBR can satisfactorily indicate the average load carrying capacity.

As indicated above, field in-place tests can be used for design under stable condition of water, density, and general characteristics of the material tested.

However, any significant treating, disturbing, handling, compaction, or water change can affect the soil strength and make the prior to test determination inapplicable, leading to the need for retest and reanalysis.

2.3.2.2 Laboratory CBR Test

In the laboratory the load bearing capacity of the material is measured according to ASTM D 1883[20].

2.4 RELATIONSHIP BETWEEN CBR AND DCP

Several authors have investigated relationships between the DCP penetration index PI and California Bearing Ratio (CBR). CBR values are often used in road and pavement design. The following general equation has been considered for the correlation between the PI and CBR. The general equation can be expressed as:[27]

$$\text{Log CBR} = A - B * (\log \text{PI}) \quad (2.3)$$

Where

CBR = California Bearing Ratio;

PI = penetration index obtained from DCP in units of mm/blow or in/blow;

A and B, regression constants for the relationships. Based on statistical analysis of results from the log-log and inverse equations,

Harison [6] concluded that the log-log equation produces more reliable results. Considering the log-log equations, many authors have proposed different values of A, B, and C for use in the above equation. For example, Livneh [12] proposed the following relationships based on field and laboratory tests:

$$\text{Log CBR} = 2.20 - 0.71 * (\log \text{PI}) \quad (2.4)$$

$$\text{Log CBR} = 2.14 - 0.69 * (\log \text{PI}) \quad (2.5)$$

Where

CBR = California Bearing Ratio;

PI = DCP Penetration Index.

Although equation (2.5) was suggested based on equation (2.4), differences in results from equation (2.4) and equation (2.5) are small. After further examination of results by other authors, Livneh [12] proposed the following equation as the best correlation:

$$\text{Log CBR} = 2.46 - 1.12 \cdot (\log \text{PI}) \quad (2.6)$$

In addition to the above equation the following table shows the already developed equations by different authors

Table 2-2 : Existing correlations of DCP and CBR by Various Authors

Cone angle	Reference	Relationship
60°	TRL[18]	$\log_{10}(\text{CBR}) = 2.48 - 1.057 \log_{10}(\text{DN})$
60°	Sampson [28]	
	<i>Plastic materials only</i>	$\log_e(\text{CBR}) = 5.93 - 1.1 \log_e(\text{DN})$
	<i>PI > 6 materials</i>	$\log_e(\text{CBR}) = 6.15 - 1.248 \log_e(\text{DN})$
	<i>PI < 6 materials</i>	$\log_e(\text{CBR}) = 5.70 - 0.82 \log_e(\text{DN})$
	<i>PI = 0 materials</i>	$\log_e(\text{CBR}) = 5.86 - 0.69 \log_e(\text{DN})$
60°	Harison [29]	
	<i>Clayey soils</i>	$\log_{10}(\text{CBR}) = 2.56 - 1.16 \log_{10}(\text{DN})$
	<i>Sand S-W</i>	$\log_{10}(\text{CBR}) = 3.03 - 1.51 \log_{10}(\text{DN})$
	<i>Gravel G-W</i>	$\log_{10}(\text{CBR}) = 2.55 - 0.96 \log_{10}(\text{DN})$
	<i>Combined data</i>	$\log_{10}(\text{CBR}) = 2.81 - 1.32 \log_{10}(\text{DN})$
	<i>Soaked samples</i>	$\log_{10}(\text{CBR}) = 2.76 - 1.28 \log_{10}(\text{DN})$
	<i>Unsoaked samples</i>	$\log_{10}(\text{CBR}) = 2.83 - 1.33 \log_{10}(\text{DN})$
30°	Smith and Pratt[30]	$\text{Log}_{10}(\text{CBR}) = 2.555 - 1.145$ $\text{Log}_{10}(\text{penetration rate})$

2.5 RELATIONSHIP BETWEEN PI AND COMPACTION PROPERTIES

The CBR and DCPI have similar testing mechanisms. Thus, results from the tests may reflect similar mechanical characteristics. Compared to work done for PI-CBR relationships described in the previous section, investigations of the PI – compaction properties relationships were insufficiently performed. This condition may be because the compaction properties, including dry unit weight and moisture content, are affected by a number of different factors. The compacted unit weight itself also depends on the moisture content.

Although limited information concerning these relationships appears in the literature, a typical relationship can be found in Harison [6].

Harison [6] performed a number of laboratory tests including CBR, compaction, and DCP tests for different types of soils. According to Harison [6], values of PI are a function of both moisture content and dry unit weight. Although generalized equations for the relationships were not proposed, certain correlations between the parameters were observed. Figure 2.4 and Figure 2.5 shows the typical trend of PI with respect to values of dry unit weight and moisture content.

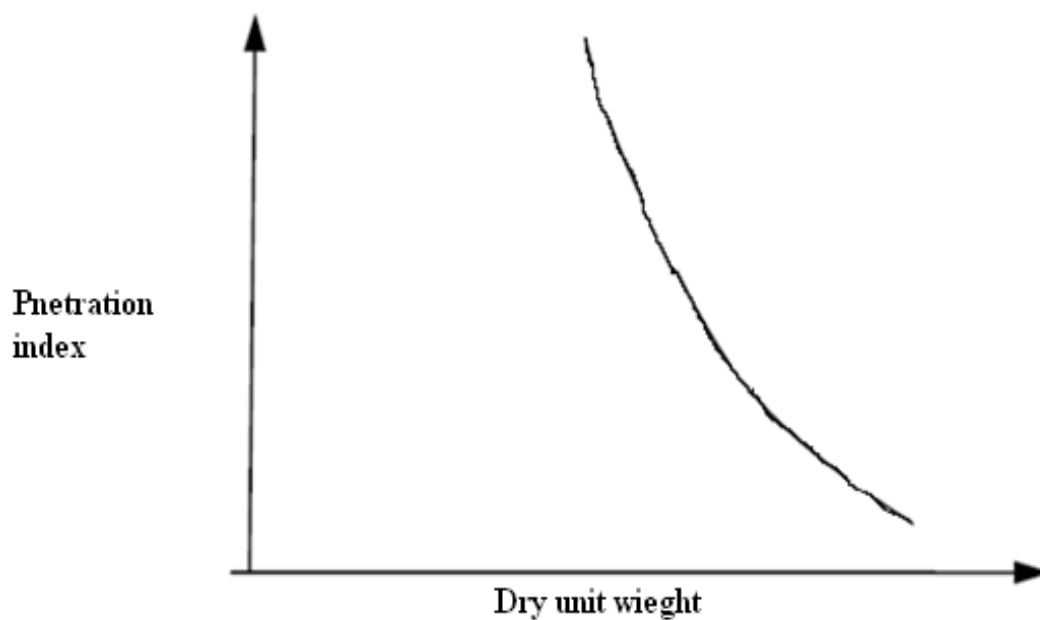


Figure 2-4: A plot of penetration index Vs dry unit weight [31]

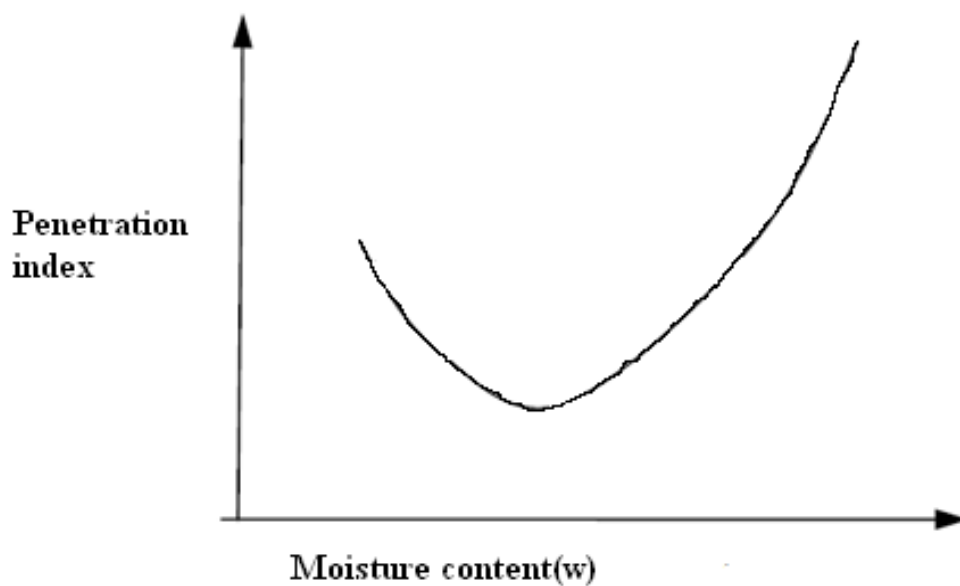


Figure 2-5 : A plot of penetration index Vs moisture content [31]

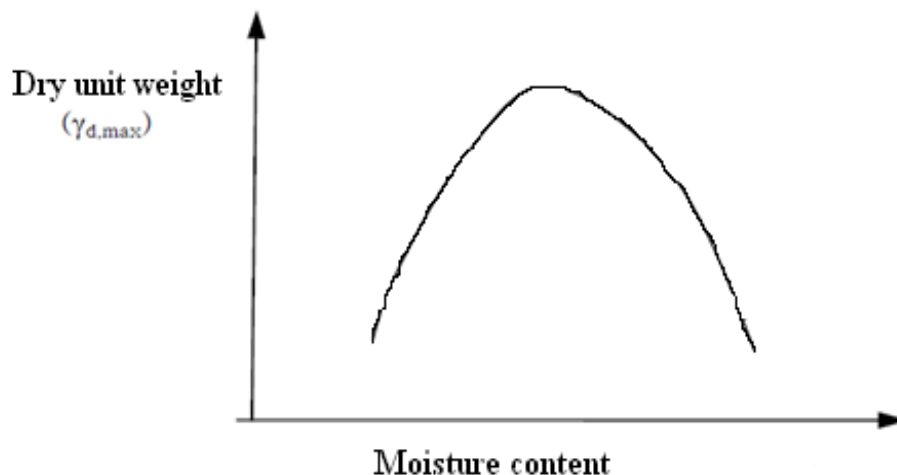


Figure 2-6 A plot of penetration dry unit weight Vs moisture content [31]

From the figure, values of PI decreases as the dry unit weight increases; this result appears to be reasonable since denser soils would result in higher penetration resistance

Figure 2.5 shows a trend of PI values with moisture contents corresponding to the compaction curve. As shown in the figure, the PI value decreases with increasing moisture contents up to the optimum moisture content (OMC) for a given compaction energy. This point corresponds to the maximum dry unit weight for a given compaction energy. After the OMC, PI values increase again with increasing moisture content. It should be noted that the values of PI in figure 2.4 were obtained for the soil states following the compaction curve. Also, although the same dry unit weight was considered, the PI value tends to be higher for higher moisture contents.

3. METHODS, DATA COLLECTION AND RESULT

3.1 GENERAL

All samples are taken from northern and western Addis Ababa where red clay dominates. The specific places are Kolfe police station, Teferi Mekonen school, Asko-Winget road project and Abo church. The location of collected soil samples site is shown with the aid of map in Figure 3.1.



Figure 3-1 Location map

The visual identification of soils was done on the site and both disturbed and undisturbed samples were taken on places where in situ density and DCP tests were conducted. Other tests were conducted in the laboratory.

3.2 FIELD TESTS

At the specific sites where the samples are taken the following tests were performed

- Dynamic cone penetration tests(DCP)
- In situ density

3.3 LABORATORY TESTS

Disturbed and undisturbed samples were taken from the site to perform the following tests.

- Moisture content (ASTM D 2216)
- Specific gravity (ASTM D 854)
- Grain size analysis (ASTM D 854)
- Atterberg limits (ASTM D 4318)
- Free swell tests (According to Gibbs and Holtz, 1956)
- Compaction (ASTM D 698)
- CBR(ASTM D 1883)

For the sake of illustration and easy reference, the typical test results of a soil sample have been demonstrated hereunder

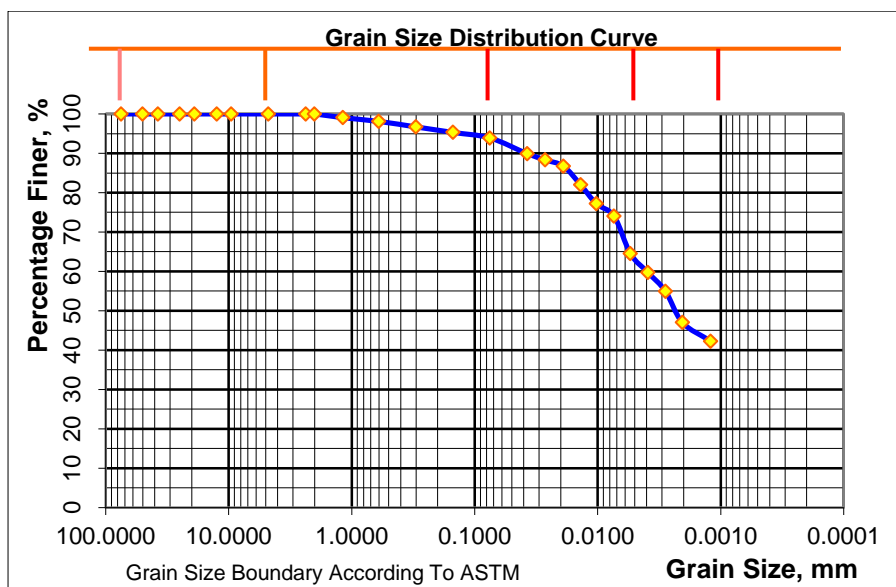


Figure 3-2: Typical Grain Size Analysis Curve

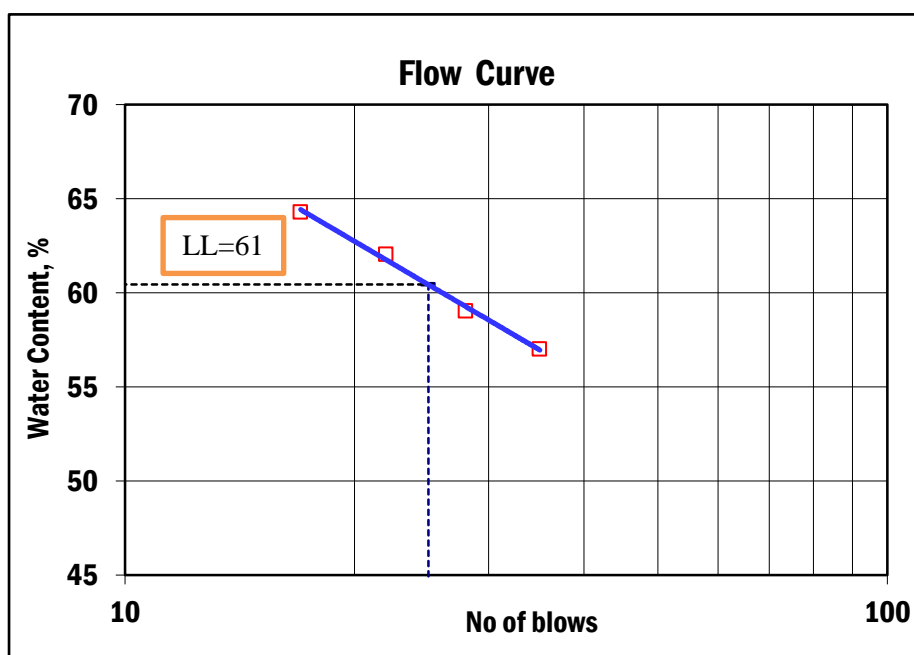


Figure 3-3: Typical Liquid Limit Graph

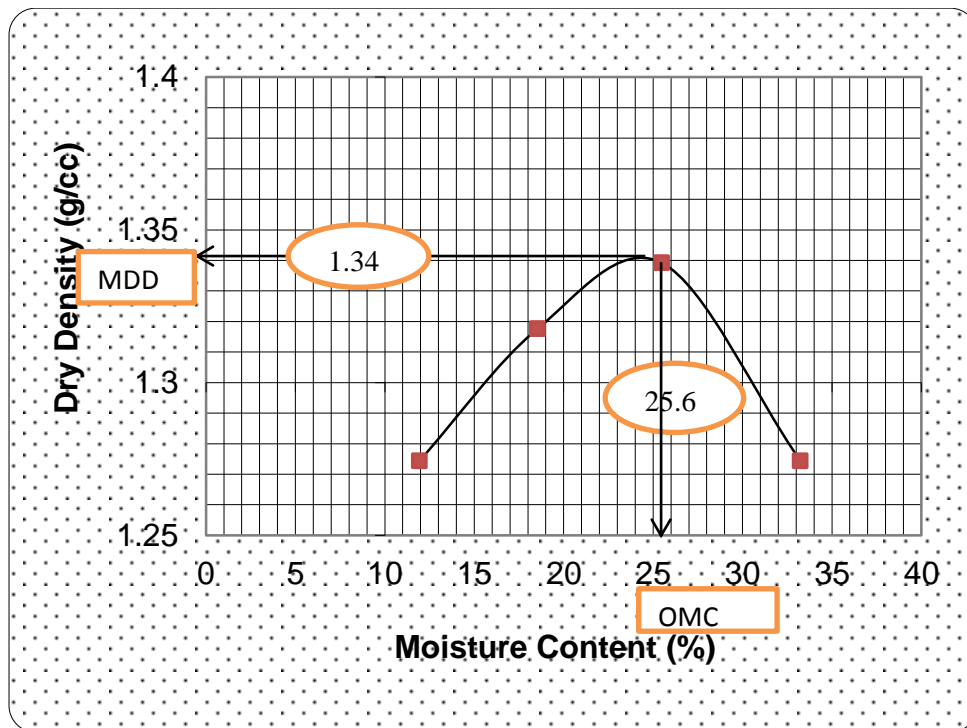


Figure 3-4: Typical Density vs Moisture content relation

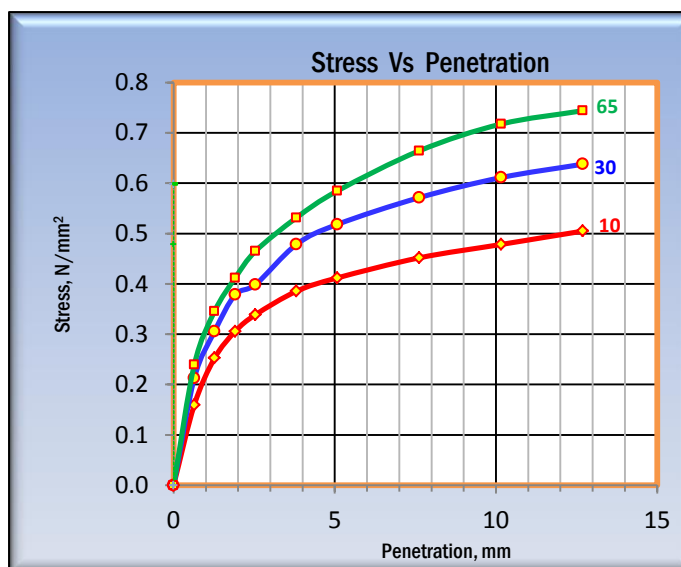


Figure 3-5: Typical Penetration Load vs. Penetration Depth Graph

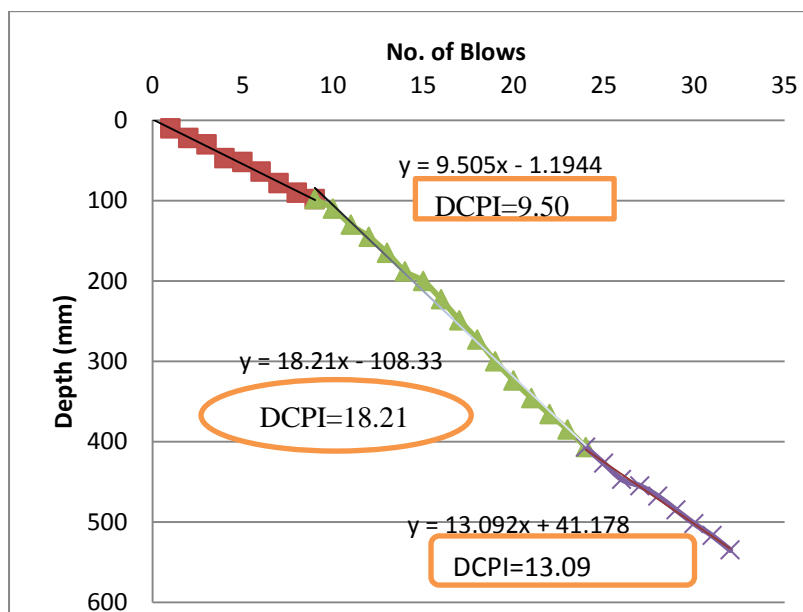


Figure 3-6: Typical DCP graph

3.4 SUMMARY OF TEST RESULTS

In order to analyze the intended correlation, the test results were compiled and summarized in a way that the SPSS Software inputs the data as shown in Table 3.1:

Table 3-1 Summary of test results

Site designation	sample number	Natural Moisture content (%)	Specific gravity	Liquid Limit (%)	Plastic limit (%)	Plasticity index	Free swell (%)	γ_{bulk} (gm/cm ³)	MDD(gm/cm ³)	OMC(%)	DCPI (mm/blow)	CBR	Soil Classification
													AASHTO
Asko-Winget	1	20.88	2.73	62	31	31	50	1.8	1.34	34	14.28	5.7	A-7-5
Asko-Winget	2	27.27	2.74	54	29	25	45	1.72	1.32	26.6	27.23	3.5	A-7-6
Asko-Winget	3	15.26	2.73	59	30	29	35	1.81	1.33	25.6	10.96	6.2	A-7-5
Asko-Winget	4	12.31	2.7	55	26	29	40	1.92	1.34	24.4	6.07	6.9	A-7-6
Asko-Winget	5	14.86	2.68	61	30	31	50	1.86	1.34	24.8	10.85	6.3	A-7-5
Asko-Winget	6	17.66	2.67	60	31	29	30	1.87	1.34	25	9.16	6.9	A-7-5
Abo church	7	16.58	2.67	54	31	23	35	1.86	1.32	24	8.07	6.9	A-7-5
Abo church	8	17.62	2.72	65	32	33	40	1.8	1.33	25	12.37	6	A-7-5
Abo church	9	19.67	2.67	62	35	27	35	1.82	1.33	24.2	8.67	6.9	A-7-5
Abo church	10	13.82	2.67	57	35	22	35	1.81	1.33	25.5	9.45	5.3	A-7-5
Teferi Mekonen	11	31.79	2.7	62	33	29	41	1.8	1.33	25.6	18.21	6.4	A-7-5
Teferi Mekonen	12	18.16	2.73	72	35	37	35	1.8	1.32	25	12.59	6	A-7-5
Teferi Mekonen	13	35.02	2.76	67	33	34	33	1.76	1.33	25.2	17.95	5.6	A-7-5
Teferi Mekonen	14	24.12	2.71	57	32	25	33	1.78	1.31	28.1	16.49	3.7	A-7-5

Site designation	sample number	Natural Moisture content (%)	Specific gravity	Liquid Limit (%)	Plastic limit (%)	Plasticity index	Free swell (%)	γ_{bulk} (gm/cm ³)	MDD(gm/cm ³)	OMC(%)	DCPI (mm/blow)	CBR	Soil Classification
													AASHTO
Kolfe	15	33.33	2.7	61	35	26	32	1.72	1.35	25.8	23.21	5.7	A-7-5
Kolfe	16	32.9	2.7	62	32	30	34	1.72	1.33	25.4	22.85	5.4	A-7-5
Kolfe	17	25.52	2.7	69	33	36	34	1.78	1.28	25.2	17.45	3.8	A-7-5
Kolfe	18	28.89	2.7	63	35	28	35	1.7	1.32	24.5	27.09	5.2	A-7-5
Kolfe	19	31.31	2.7	70	33	37	34	1.76	1.32	26.4	19.39	3.6	A-7-5
Kolfe	20	35.34	2.71	63	29	34	29	1.73	1.33	25	21.37	4.6	A-7-6
Kolfe	21	34.94	2.7	59	33	26	36	1.69	1.32	27.1	27.86	3.2	A-7-5
Kolfe	22	32.01	2.7	66	31	35	31	1.7	1.33	27	27.59	3.3	A-7-5
Kolfe	23	32.86	2.69	59	32	27	32	1.8	1.32	25.5	22.47	4.4	A-7-5
Kolfe	24	26.13	2.71	59	32	27	32	1.85	1.34	25.1	13.51	5.9	A-7-5
Kolfe	25	34.12	2.7	60	32	28	33	1.73	1.33	25.6	22.74	4.4	A-7-5
Kolfe	26	41.57	2.72	61	35	26	35	1.73	1.29	26	30.6	2.8	A-7-5
Kolfe	27	37.54	2.68	71	33	38	37	1.7	1.31	25.7	25.67	3.6	A-7-5
Kolfe	28	26.13	2.72	63	30	33	39	1.81	1.37	25.8	17.35	5.3	A-7-5
Kolfe	29	27.28	2.69	61	32	29	34	1.78	1.33	26.2	18.21	5.2	A-7-5
Kolfe	30	29.13	2.7	59	30	29	33	1.7	1.33	25.8	23.24	3.7	A-7-5

Site designation	sample number	Natural Moisture content (%)	Specific gravity	Liquid Limit (%)	Plastic limit (%)	Plasticity index	Free swell (%)	γ_{bulk} (gm/cm ³)	MDD(gm/cm ³)	OMC(%)	DCPI (mm/blow)	CBR	Soil Classification
													AASHTO
Asko -Winget	31	20.32	2.69	55	32	23	47	1.8	1.33	25.26	15.34	5.6	A-7-5
Asko -Winget	32	34.21	2.71	58	30	28	42	1.77	1.35	26.2	26.81	3.9	A-7-5
Abo church	33	24.64	2.68	62	31	31	38	1.76	1.34	25.46	19.2	6	A-7-5
Teferi Mekonen	34	32.54	2.72	65	35	30	37	1.79	1.35	26.5	22.86	4.1	A-7-5
Kolfe	35	27.6	2.7	66	33	33	35	1.78	1.35	25.59	21.89	5.3	A-7-5
Kolfe	36	33.12	2.71	68	31	37	39	1.77	1.32	27.1	25.2	4	A-7-5

Table 3-2 Summary of grain size analysis

Site Designation	sample no	Sieve Analysis, % passing Sieve			Hydrometer Analysis		
		Grain Size Smaller than (%)			Grain Size Smaller than (%)		
		2	0.475	0.075	0.02	0.002	0.001
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
Asko-Winget	1	94	92.5	89.7	85.89	50.89	47.95
Asko-Winget	2	96	93.7	90.3	79.81	45.18	36.86
Asko-Winget	3	95	94.6	92.7	78.79	43.36	39.11
Asko-Winget	4	97	96.6	93.5	80.53	39.97	35.46
Asko-Winget	5	96	94.9	92.3	89.86	53.98	50.86
Asko-Winget	6	96	94.2	90.4	87.16	61.59	55.2
Abo church	7	96	94.3	91.3	88.89	50.52	44.13
Abo church	8	97	95.3	90.2	84.76	42.07	37.32
Abo church	9	95	94.3	92	81.04	45.87	37.42
Abo church	10	95	93.9	89	79.76	43.73	39.58
Teferi Mekonen	11	98	96.8	93.5	84.03	67.98	47.56
Teferi Mekonen	12	97	96.8	92.9	77.74	44.18	38.59
Teferi Mekonen	13	96	94.4	91.3	79.72	50.65	45.12
Teferi Mekonen	14	93	92.9	91.4	84.95	45.33	43.74
Kolfe	15	100	98.4	96.5	88.31	54.95	50.19
Kolfe	16	100	100	98.2	91.48	58.13	51.78

Site Designation	sample no	Sieve Analysis, % passing Sieve			Hydrometer Analysis		
		Grain Size Smaller than (%)			Grain Size Smaller than (%)		
		2	0.475	0.075	0.02	0.002	0.001
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
Kolfe	17	99	97.7	93.3	88.31	50.19	45.42
Kolfe	18	97	95.6	90.4	85.13	42.25	37.48
Kolfe	19	100	98.9	95.4	91.48	43.84	37.8
Kolfe	20	100	98.1	95.3	88.31	47.01	42.25
Kolfe	21	99	98.3	93.6	85.13	50.19	43.84
Kolfe	22	98	96.2	93.9	88.31	51.78	47.01
Kolfe	23	100	98.6	94.5	85.13	47.01	40.66
Kolfe	24	99	96.4	93.2	88.31	50.19	45.42
Kolfe	25	99	96.2	93.5	84.3	43.32	37.47
Kolfe	26	98	96.5	94.5	87.93	54.72	49.97
Kolfe	27	100	98.2	94.1	89.65	47.22	42.43
Kolfe	28	100	98.5	95.3	91.4	43.96	38.27
Kolfe	29	97	96.4	95.2	81.24	47.06	37.26
Kolfe	30	98	97.3	96.2	89.26	50.82	43.84

Site Designation	sample no	Sieve Analysis, % passing Sieve			Hydrometer Analysis		
		Grain Size Smaller than (%)			Grain Size Smaller than (%)		
		2	0.475	0.075	0.02	0.002	0.001
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
Asko -Winget	31	97	93.8	89.2	83.2	47.9	37.6
Asko -Winget	32	96	91.7	89.8	81.4	50.4	40.4
Abo church	33	96	92.1	88.3	78.86	46.8	38.1
Teferi Mekonen	34	95	91.4	89.2	77.4	52.3	43.23
Kolfe	35	97	94.2	92.4	86.43	54.2	41.4
Kolfe	36	98	96.3	93.3	84.3	49.4	39.3

3.5 DISCUSSION OF TEST RESULT

The primary purpose of this sub-section is to 1) review all the tests results obtained in this research and compare them with previous results in the study area; 2) identify test results with erroneous values and if found necessary exclude them from the correlation

Grain size analysis and index tests were conducted for all the 36 samples and the plot of the representative samples is presented on figure 3-7.

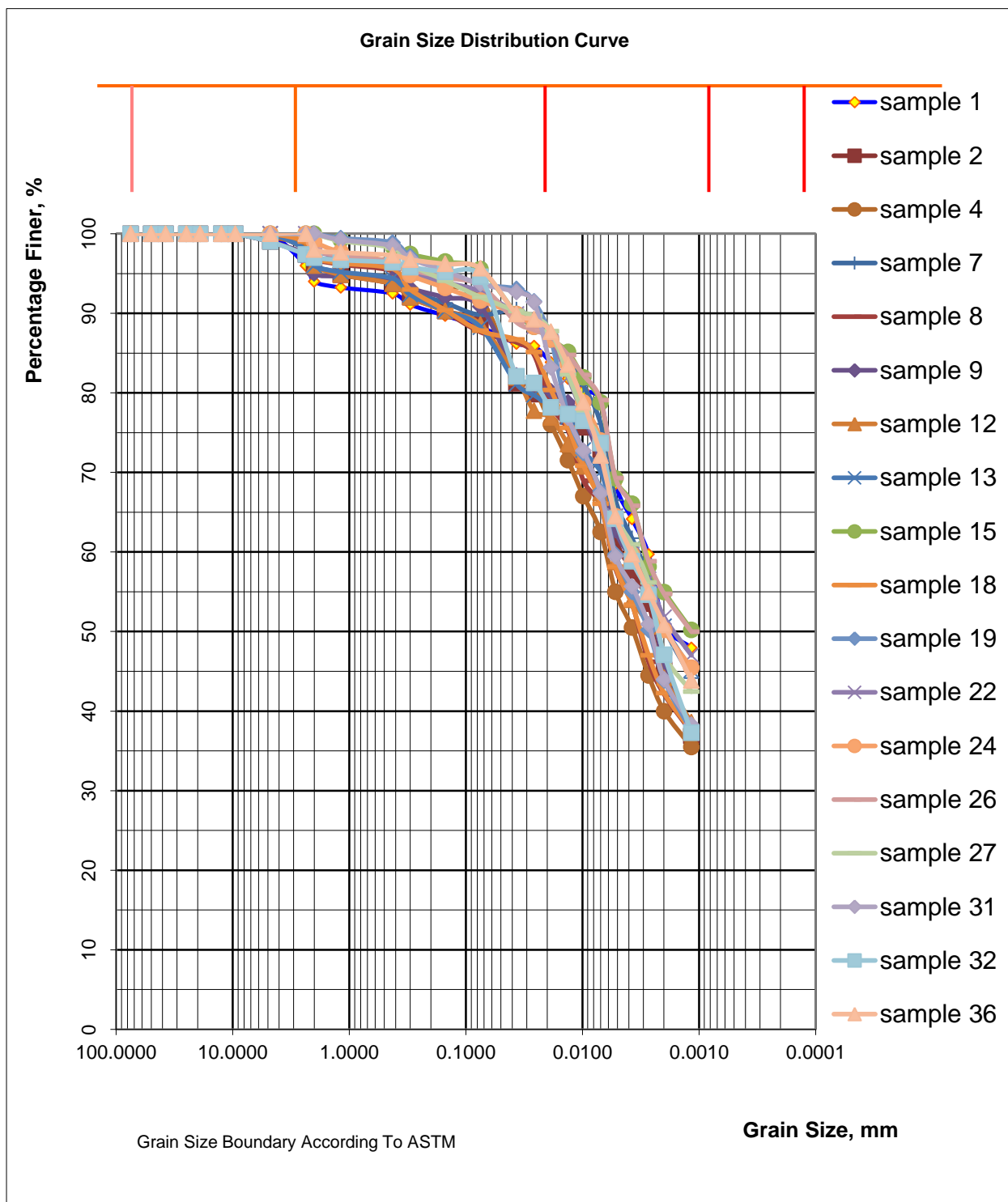


Fig 3-7 plot of soil gradation (representative samples)

3.6 TEST RESULTS FROM LITERATURE

The index properties of Addis Ababa red clay soils as determined from various authors in the past have been compiled in Table 3.3

From Table 3.3 one can observe that the test results of the current research fall almost in the range of the previously conducted researches hence a correlation may be carried out with these data.

Table 3-3 Index properties of Addis Ababa red clay soil from previous researches

Researches	Site	LL (%)	PI (%)	Gs
Samuel Tadesse [22]	Kolfe	61 - 75	15 - 21	2.66 - 2.73
	Semen Gebeya	59 - 72	33 - 47	2.7 - 2.77
Merihun Lukas[23]	Kolfe	61 - 71	34 - 38	2.72 - 2.73
	Addisu Gebeya	63 - 72	35 - 39	2.71
Tesfay Neare [24]	Different places in AA where red clay exists	47.3 - 82	23.5 - 55.5	N/A
Anteneh Getachew[26]	Different places in AA where red clay exists	44 - 66	14 - 30	2.61 - 2.9
Current Research	Different places in AA where red clay exists	54-72	22-38	2.67 - 2.76

4. ANALYSIS

4.1 GENERAL

In statistics to study the relation between two or more variables we use the regression technique. It is also used to test the effect of one or more variables on the other one based on the theoretical forecast that says a variable X affects another variable Y.

The method of regression analysis is used to develop the line or curve which provides the best fit through a set of data points. This basic approach is applicable in situations ranging from single linear regression to more sophisticated nonlinear multiple regressions. The best fit model could be in the form of linear, parabolic or logarithmic trend. A linear relationship is usually practiced in solving different engineering problems because of its simplicity.

4.2 STANDARD ERROR OF THE REGRESSION

The standard error of the regression is used when interpreting the result of the regression. It measures how accurate our estimators are. It is the estimation of the standard deviation of the error term or the unobservable. Usually computer packages give the result of the standard error.

$$\sigma^2 = 1/(n - k - 1) \sum_{i=1}^n u_i^2$$

and the square root of the error variance (σ) is the standard error variance σ .

To calculate the standard error (S_e) of the estimates we use $Se(B_j) = \frac{\sigma}{[SST_j(1-R_j^2)]^{1/2}}$

4.3 COEFFICIENT OF DETERMINATION

The other way of measuring how well the independent variable explains the dependent variable is by looking at the R- squared value of our regression result.

R- Squared is the ratio of the sample variation in the fitted value of Y to the total sample variation in the actual Y.

$SST = \sum_{i=1}^n (y_i - \bar{y})^2$, sample variation in the actual Y

$SSE = \sum_{i=1}^n (y_i - \hat{y}_i)^2$, sample variation in the fitted value of Y

$SSR = \sum_{i=1}^n (u_i)^2$, sample variation in the residuals

$1 = SSE / SST + SSR / SST$

$R^2 = SSE / SST$ $1 = R^2 + SSR / SST$ $R^2 = 1 - SSR / SST$

R^2 is “the ratio of the explained variation compared to the total variation.” It shows how well the regression line fits our data. Its value is always between 0 and 1. When the value is near or equal to 1 our regression line fits the data well or our independent variable X explains the variation in Y very well and if the value is near to zero shows that our regression line doesn't fit the data very well. When interpreting the result of R-squared value we usually multiply it with 100 and express it in percent.

4.4 SCATTER DIAGRAM

While developing correlations, the first step is creating a scatter plot of the data, to visually assess the strength and form of the relationship. In the figures below (Figure 4-1 to 4-11) the scatter plot of CBR and DCPI with maximum dry density, bulk density, NMC, and OMC are presented.

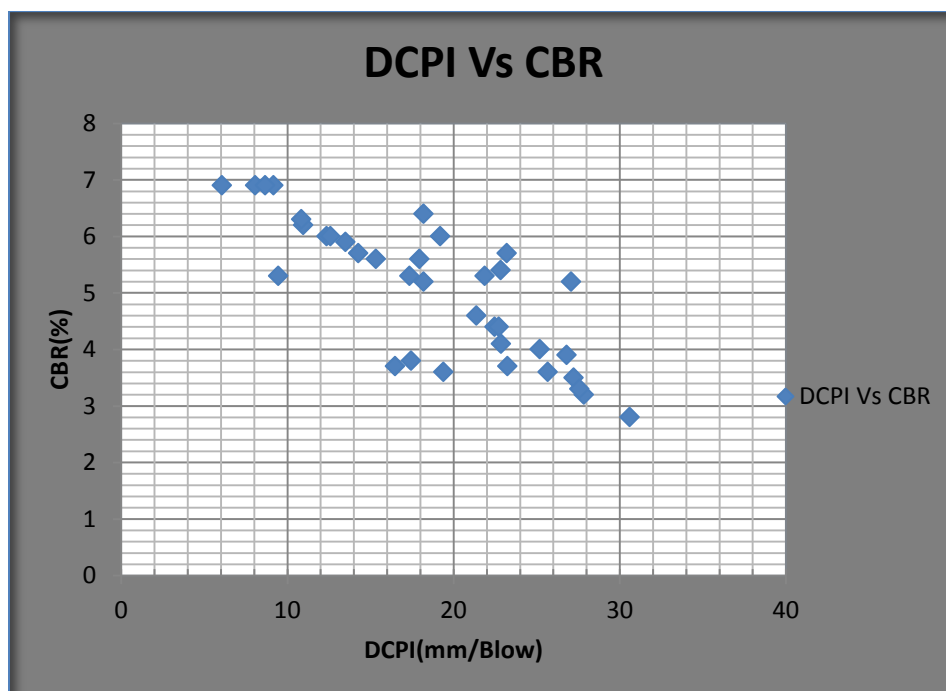


Figure 4-1 Scatter plot for DCPI and CBR

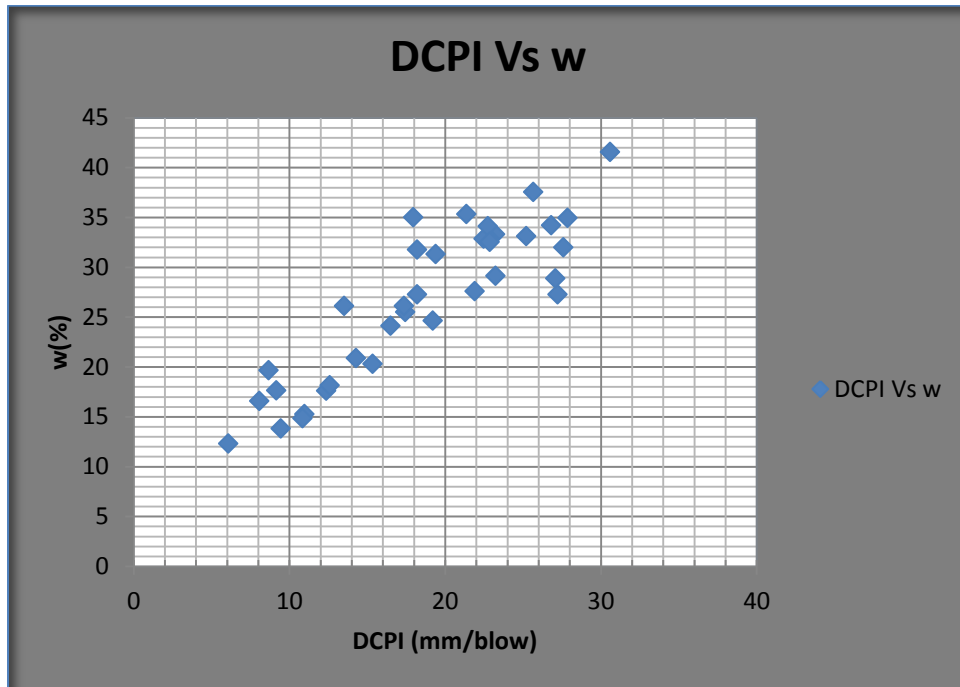


Figure 4-2 Scatter diagram for DCPI and Natural moisture content

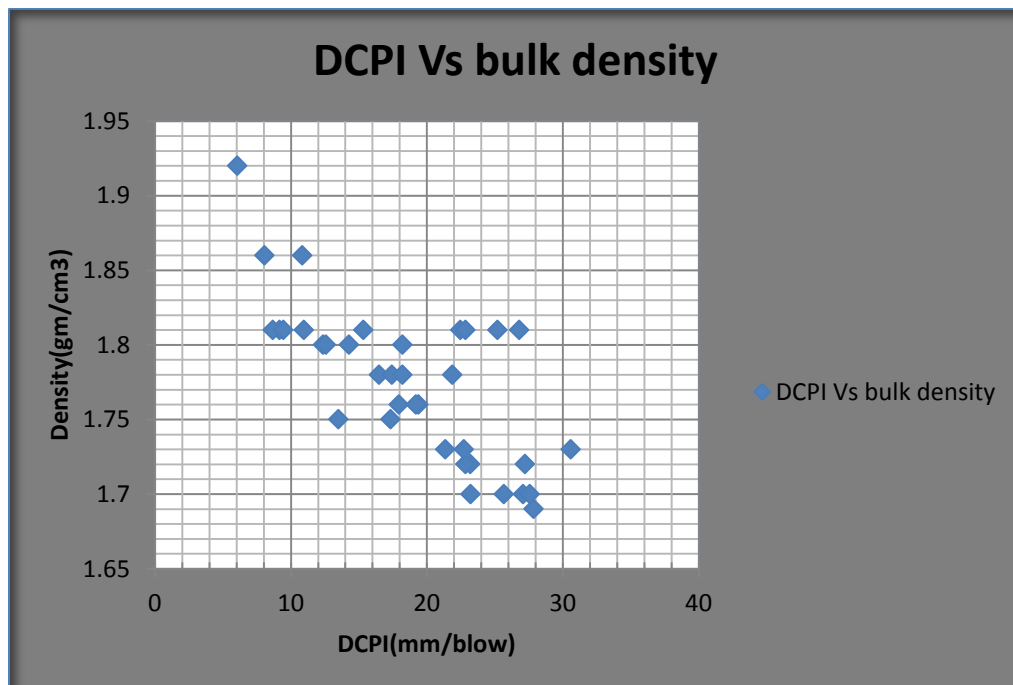


Figure 4-3 Scatter diagram for DCPI and bulk density

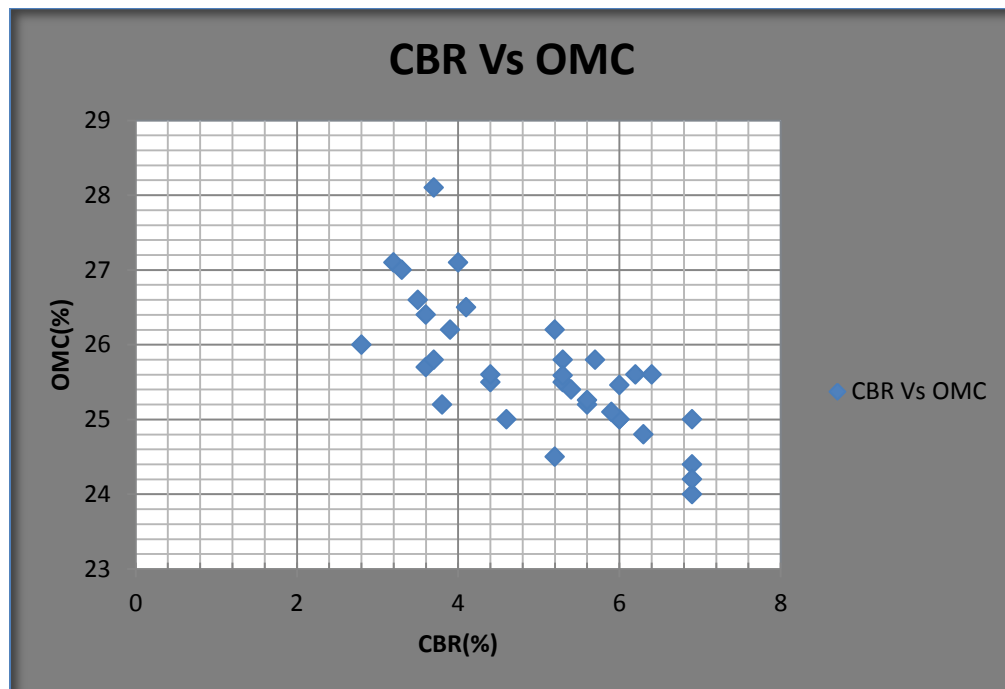


Figure 4-4 Scatter diagram for CBR and OMC

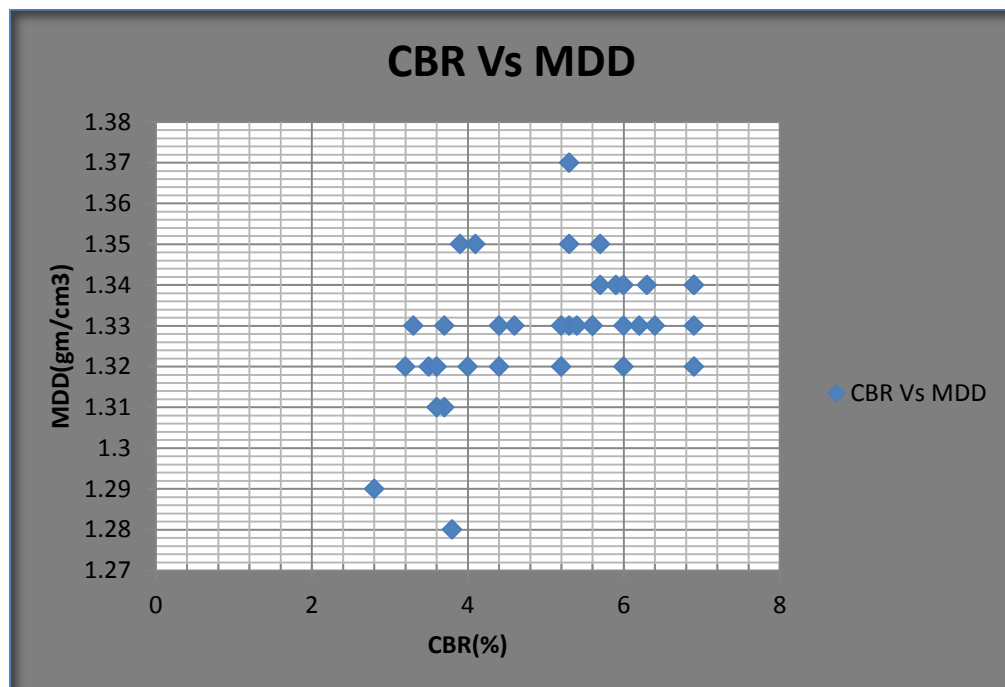


Figure 4-5 Scatter diagram for CBR and MDD

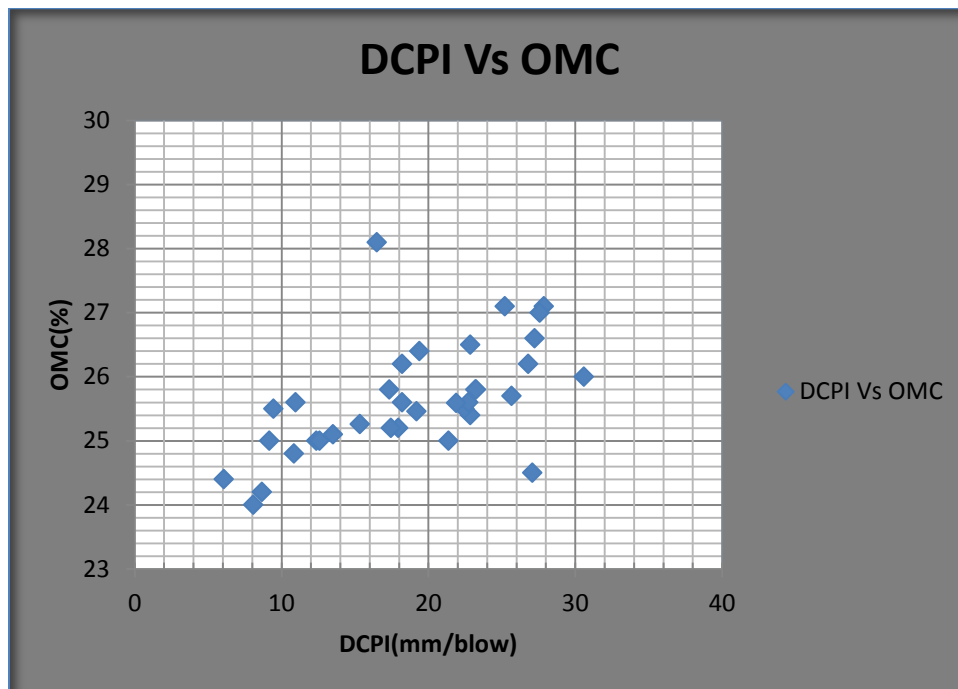


Figure 4-6 Scatter diagram for DCPI and OMC

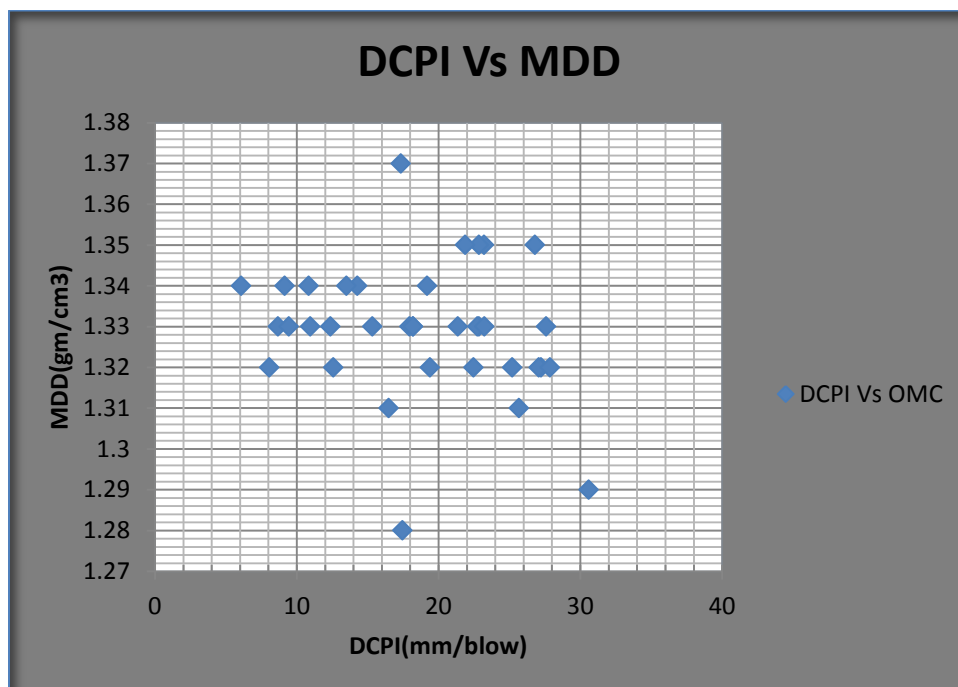


Figure 4-7 Scatter diagram for DCPI and MDD

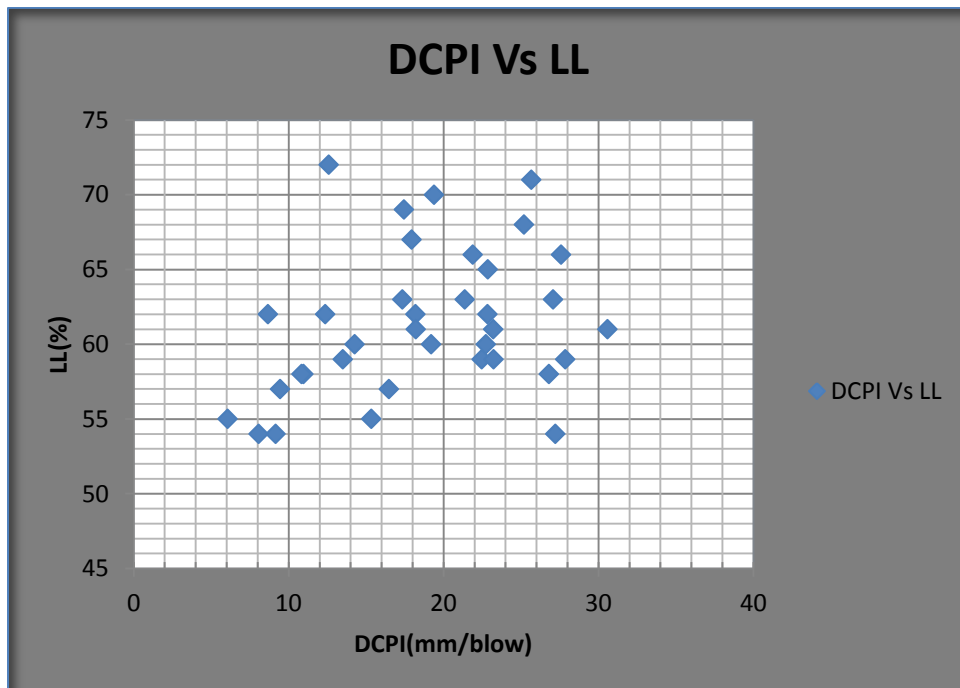


Figure 4-8 Scatter diagram for DCPI and Liquid limit

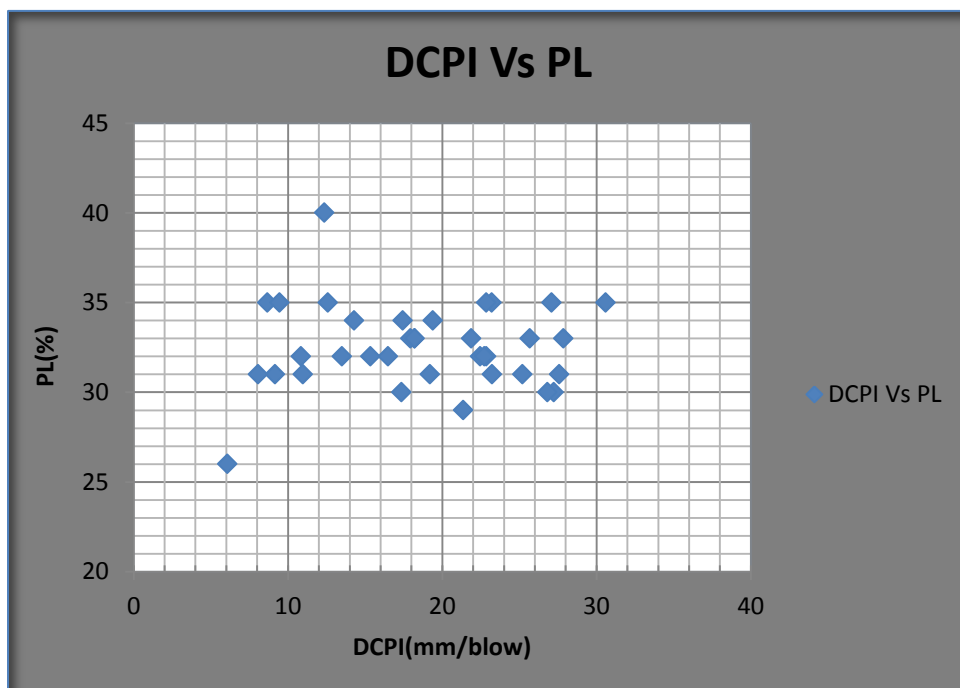


Figure 4-9 Scatter diagram for DCPI and plastic limit

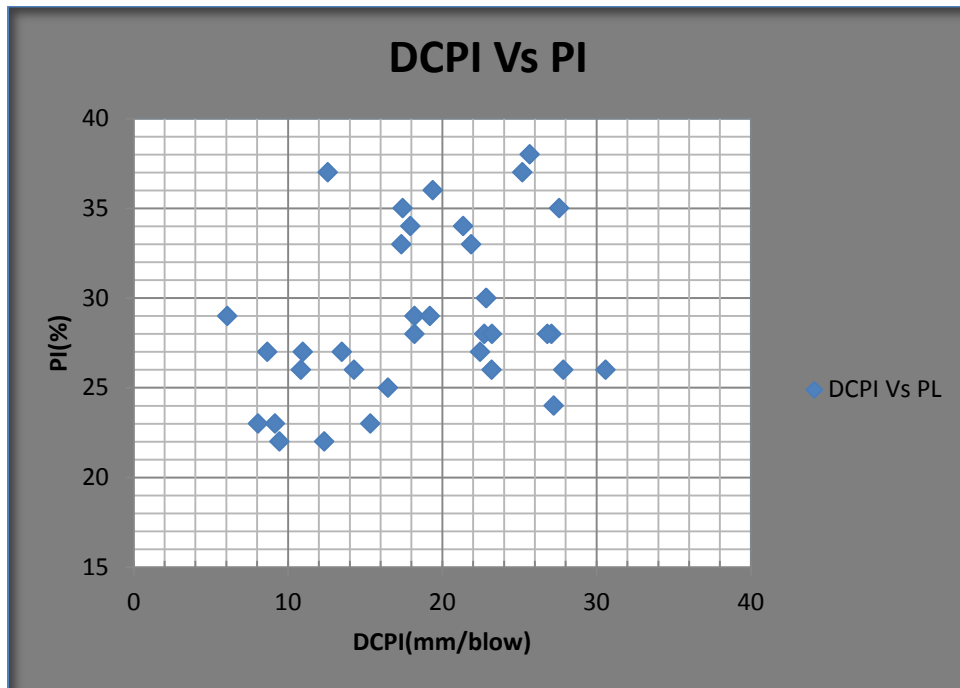


Figure 4-10 Scatter diagram for DCPI and PI

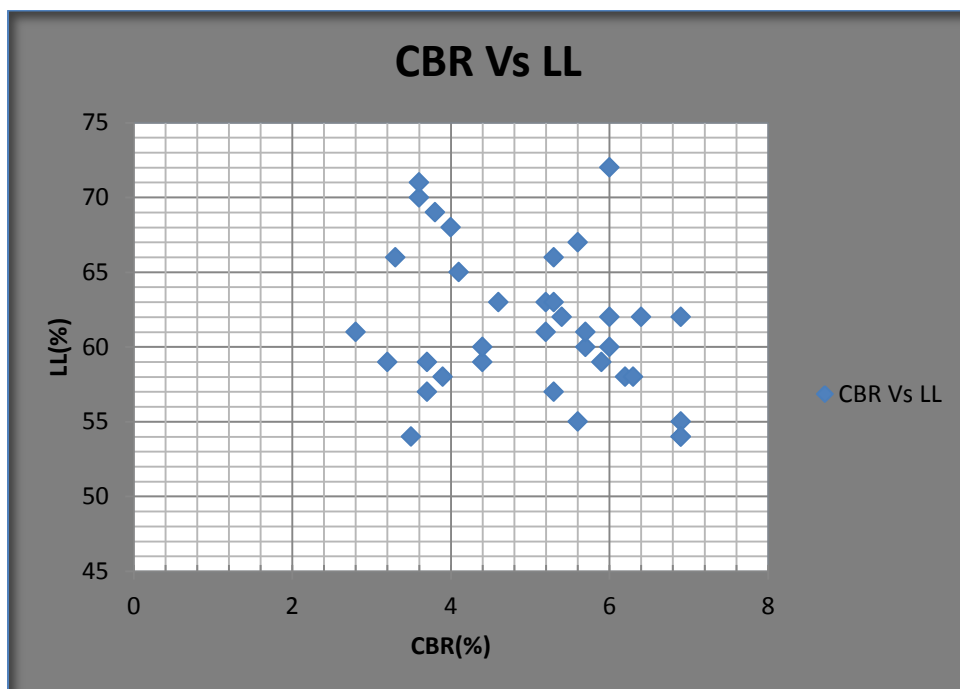


Figure 4-11 Scatter diagram for CBR and LL

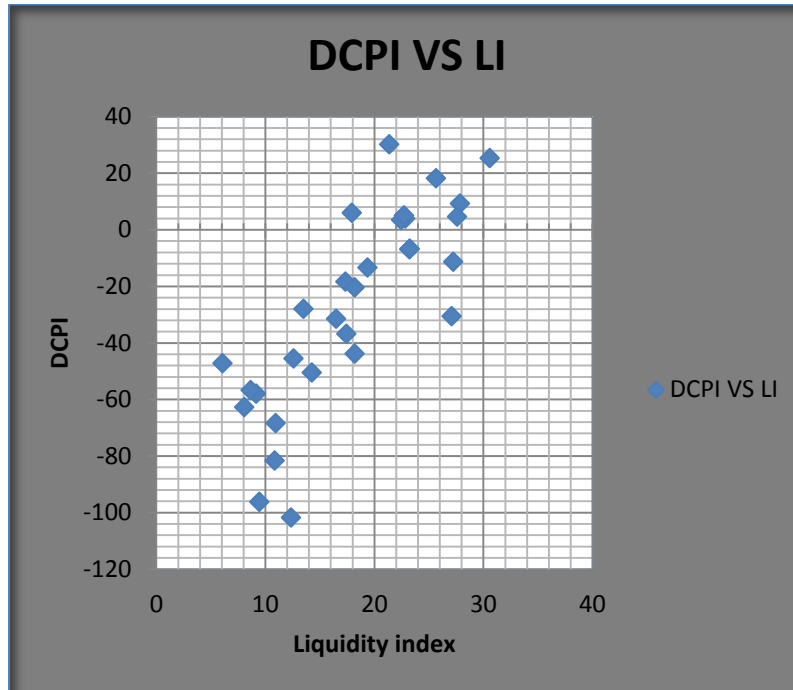


Figure 4-12 Scatter diagram for DCPI and LI

In the above scatter diagrams, it can be seen that there is a reasonable indication that the points lie scattered randomly around a straight line for the relation between CBR with DCPI and for the relation between DCPI with bulk density and natural moisture content. While for the remaining parameters the points are scattered spatially and most of their data outliers away from the possible straight line. Relatively the above scatter plot shows a linear response and hence, a linear regression model expresses the association between the subject parameters.

4.5 REGRESSION

In this research work, an attempt is made to apply single linear regression model and multiple linear regression models to find CBR from DCPI and other soil parameters using a statistical approach. The general representation of a probabilistic single and multiple linear regression models are presented in the following forms:

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{4.1}$$

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \dots + \alpha_n X_n + \varepsilon \tag{4.2}$$

Where, the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients $\alpha_0, \alpha_1, \alpha_2$ and α_n are termed multiple regression coefficients. The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model) plus the random error term, ϵ [33]. The basic assumption to estimate the regression coefficients of the single and multiple regression models is based on the least square method.

To identify the influence of one variable on the other, a stepwise linear regression has been analyzed and as a result, the respective correlation coefficients and level of significance is determined. Hereunder, the Pearson correlation coefficient matrix is shown in Table 4.1

Table 4-1 Correlation Matrix of Pearson Correlation Coefficient

Pearson Correlation (R)	CBR	NMC	Bulk density	MDD	OMC	DCPI
CBR	1.00	-0.70	0.60	0.44	-0.31	-0.81
NMC	-0.70	1.00	-0.69	-0.19	0.13	0.88
Bulk density	0.60	-0.69	1.00	0.18	-0.12	-0.74
MDD	0.44	-0.19	0.18	1.00	0.04	-0.20
OMC	-0.31	0.13	-0.12	0.04	1.00	0.20
DCPI	-0.81	0.88	-0.74	-0.20	0.20	1.00

4.5.1 Single regression

The summary of the equations developed are presented in table 4.2

Table 4-2 Summary of correlation equation

Equation	R²	sample size
CBR=-0.147*DCPI+7.794	0.652	36
CBR=32.093*MDD-37.621	0.190	36
CBR=-0.226*OMC+10.885	0.094	36
DCPI=-104.048* γ_{bulk} +203.646	0.738	36
DCPI=0.207*LI+22.571	0.726	36
DCPI=0.764* ω -1.793	0.782	36

4.5.2 Multiple regression

4.5.2.1 Ordinary least square method

After going through a number of alternative combinations of predictors, only variables which have a direct influence on the dependent variables are taken for analysis. The result of the analysis gave equation 4.3 with N=36 and adjusted $R^2=0.715$

$$\text{CBR} = -0.137 * \text{DCPI} + 21.162 * \text{MDD} - 20.529 \quad (4.3)$$

4.5.2.2 Two stage least square method

Two stage least square method provides consistent estimates for linear regression models with some explanatory variables correlated with instrumental variables. The name two stage least square method comes from the two regressions in the estimation process. In the first stage, an ordinary least square prediction of the explanatory term is obtained from regressing it on the instrumental variable. In stage two, the coefficient of interest are estimated using ordinary least square after substituting the instrumental variable by its prediction/or inclusion of residual from stage one. [33]

4.5.2.2.1 Two stage predictor substitution

While developing equation (4.3) only emphasis is given for independent variables which have a direct influence on the dependent variable (CBR). However, variables like Natural moisture content and bulk density have great influence on DCPI even though they don't have on CBR. In this scenario it is a must to incorporate these instrumental variables (bulk density and natural moisture content) to predict the explanatory variable (DCPI) in the first of the two stages of the regression. The result of the analysis, after two stages of regression, gave equation 4.5 with N=36 and adjusted $R^2=0.614$

$$\text{Predicted DCPI} = -54.311 * \gamma_{\text{bulk}} + 0.474 \text{NMC} + 102.539 \quad (4.4)$$

$$\text{CBR} = -0.135 * (\text{predicted DCPI}) + 19.751 * \text{MDD} - 18.694 \quad (4.5)$$

4.5.2.2.2 Two stage residual inclusion estimation

In the above method, the value of DCPI obtained from the field is replaced by the predictor value obtained from equation 4.5. Hence the value of DCPI obtained from field is barely used. But since this thesis intends to find the value of CBR from DCPI, another regression method known as two stage residual inclusion estimation is used.

The two stage residual inclusion estimation system is similar as the predictor substitution except that in the second regression stage the endogenous variables are not replaced by the predictor, instead first stage residuals are included as additional regressor.[33]

The result of the analysis after two stages of regression gave, equation 4.7 with N=36 and adjusted $R^2=0.708$

$$\text{Predicted DCPI} = -54.311 * \gamma_{\text{bulk}} + 0.474 \text{ NMC} + 102.539 \quad (4.6)$$

$$\text{CBR} = -0.133 * (\text{DCPI}) + 21.731 * \text{MDD} + 0.025(\text{DCPI} - \text{predicted DCPI}) - 21.351 \quad (4.7)$$

4.5.2.2.3 Two stage residual inclusion estimation (considering liquidity index as variable)

In the above method, maximum dry density and bulk density are used as variables. However for fine grain materials, these parameters are barely used to identify the engineering properties of the material since the state of consistency best explains the engineering property of fine grain material than their density. Hence the density of the material is left out of the equation and liquidity index is introduced in the equation.

The result of the analysis after two stages of regression gave, equation 4.9 with N=36 and adjusted $R^2=0.633$

$$\text{Predicted DCPI} = 0.207 * \text{LI} + 22.571 \quad (4.8)$$

$$\text{CBR} = -0.142 * \text{DCPI} - 0.18(\text{DCPI} - \text{Predicted DCPI}) + 7.701 \quad (4.9)$$

5. DISCUSSION

5.1 SINGLE REGRESSION

After examining the scatter plot and after finding different equation using different mathematical model, one can see that the dynamic cone penetration index is highly influenced by the in situ water content, density and liquidity index. The coefficients of determination are 78.2%, 74.1% and 72.6 % respectively.

This study also reveals that the correlation of OMC and MDD with CBR for Addis Ababa red clay is poor.

5.2 MULTIPLE REGRESSION

5.2.1 Ordinary least square method

Since the purpose of this thesis is to find the value of CBR from DCPI and other known soil parameters, a multiple regression was carried out by taking DCPI and MDD as independent and CBR as a dependent. The result has revealed that CBR has a good correlation with the aforementioned parameters by achieving adjusted coefficient of determination of 0.715.

5.2.2 Two stage least square method (predictor substitution)

In the ordinary least square method, since the effect of natural moisture content and bulk density is not significant on CBR, both parameters were overlooked during the development of equation 4.3. However since both parameters have a huge impact on DCPI a two stage regression, with predictor substituted, was carried out. The result shows that CBR has a fair correlation with the predicted DCPI, MDD, natural moisture content and bulk density by achieving adjusted coefficient of determination of 0.614.

5.2.3 Two stage least square method (residual inclusion estimation)

A two stage least square residual inclusion estimation was carried out and the result revealed that CBR has a good relation with DCPI, MDD, Bulk density and natural moisture content by achieving a coefficient of determination of 0.708 with 36 samples.

5.2.4 Two stage least square method (residual inclusion estimation using LI as variable)

A two stage least square residual inclusion estimation was carried out and the result revealed that CBR has a good relation with DCPI, and LI by achieving a coefficient of determination of 0.633 with 36 samples.

5.3 VALIDATION OF DEVELOPED EQUATION

Many previous researchers had developed plenty of equation that correlates DCPI with insitue CBR. However, since the equations developed in this work relates four days soaked CBR with DCPI, MDD, bulk density and natural moisture content, the researcher could not evaluate this work with the previous equations.

However, to validate the equation four additional samples were taken from the sites.

Like the other thirty six test samples, field tests and laboratory tests were performed. With these values in hand, the CBR obtained with the equation and the CBR values obtained from the laboratory were compared.

Table 5-1 Validation of the developed equations

sample number	Natural Moisture content (%)	γ_{bulk} (gm/cm ³)	MDD(gm/cm ³)	OMC(%)	DCPI (mm/blow)	predicted CBR	laboratory CBR	variation(%)
37	26.54	1.75	1.30	25.55	20.91	4.2	4.7	11.57%
38	18.6	1.78	1.29	25.42	16.21	4.7	5.4	13.84%
39	29.43	1.81	1.34	25.68	22.34	4.6	4.1	-13.09%
40	31.53	1.81	1.33	25.78	23.56	4.3	3.6	-19.06%

6. CONCLUSION AND RECOMENDATION

6.1 CONCLUSION

The major objective of this thesis is to introduce DCP to replace CBR test at the preliminary design stage since DCP is cheap, portable and very easy to operate and it is easy to conduct as many test as possible in a single spot to achieve a better result.

In the study the following conclusions are **drawn**

- Results of single regression analysis shows that the relationship developed between DCPI, bulk density and natural moisture content have a good determination of coefficient (R^2) of 0.741 and 0.782 respectively. In addition, the single regression analysis shows that CBR has a good relationship with DCPI.
- DCPI is also influenced by liquidity index.
- CBR can be fairly estimated from DCP hence CBR test can be replaced by DCP for preliminary design.

RECOMMENDATION

- Further study with additional sample shall be carried out to check the applicability of the equations.

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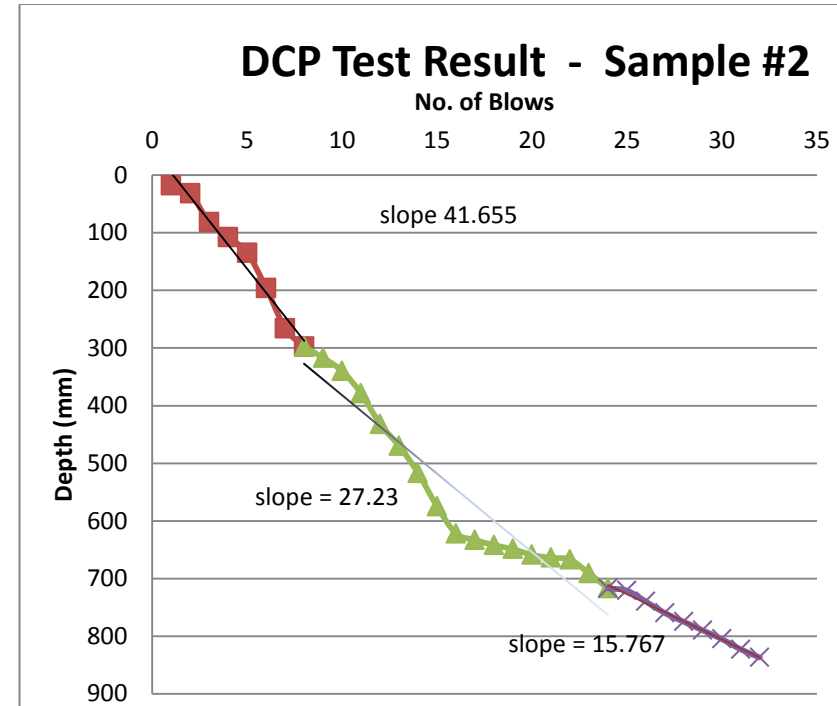
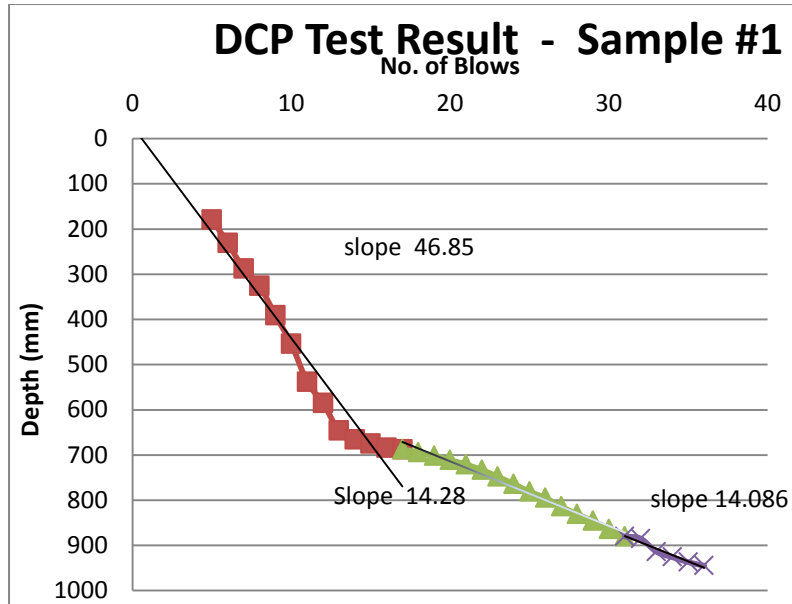
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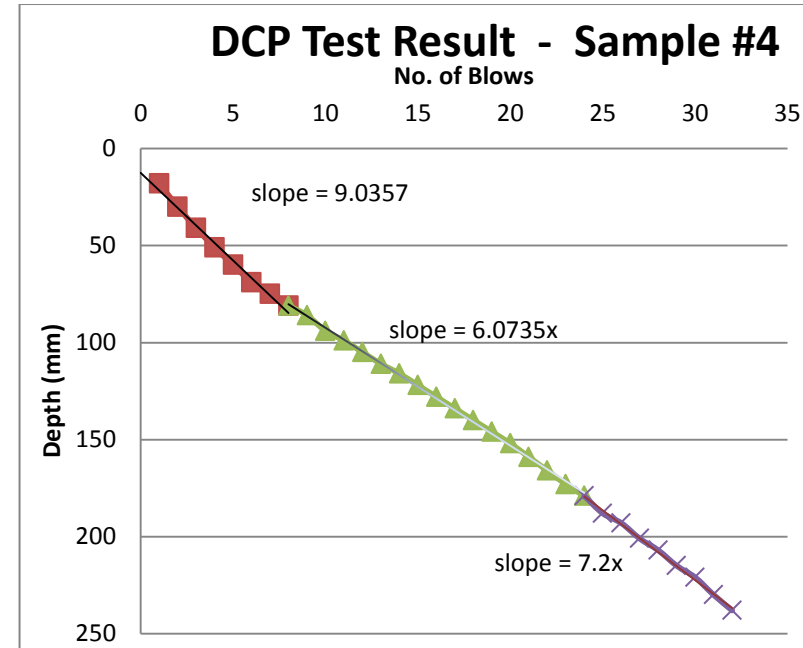
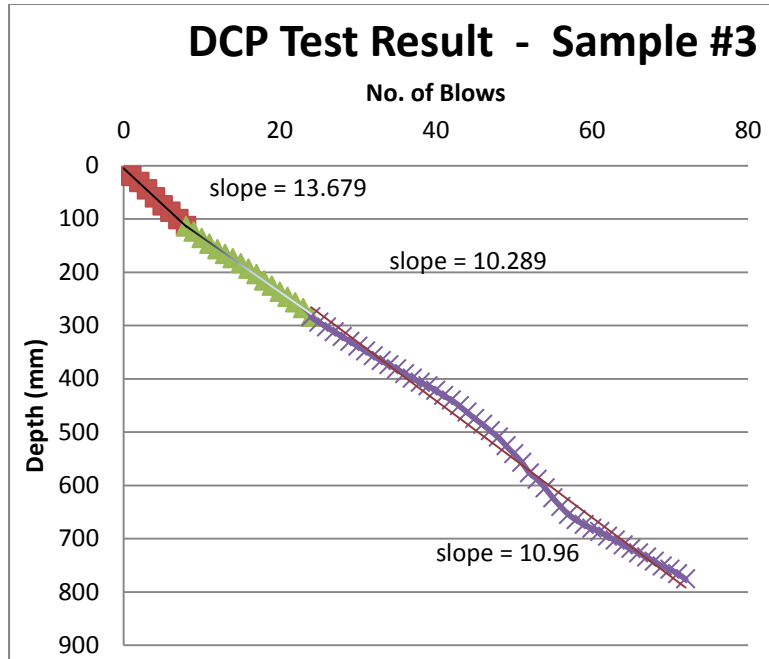
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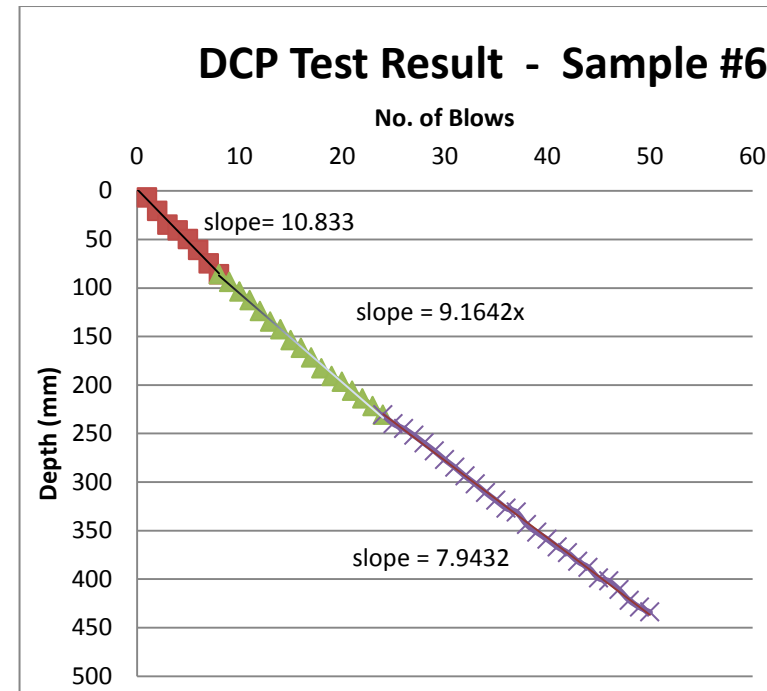
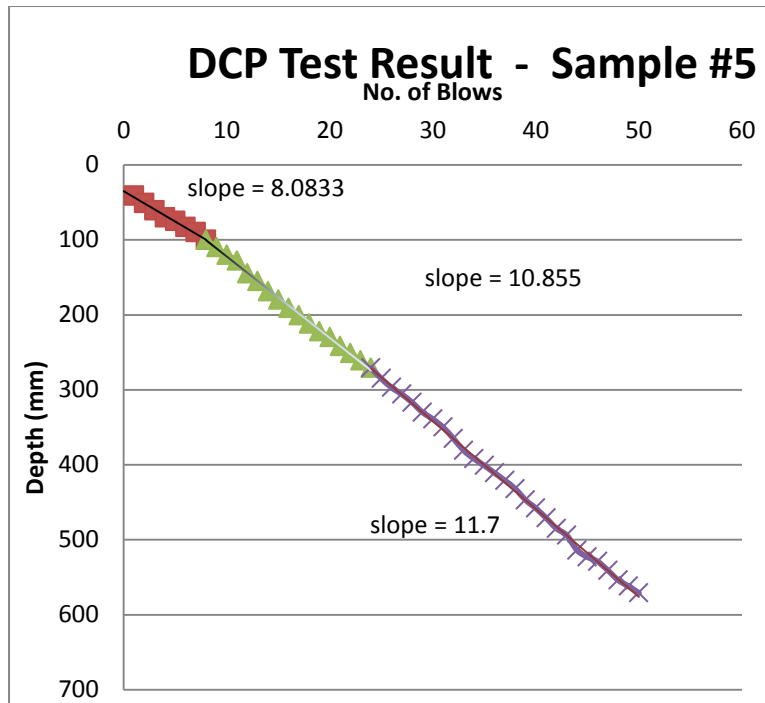
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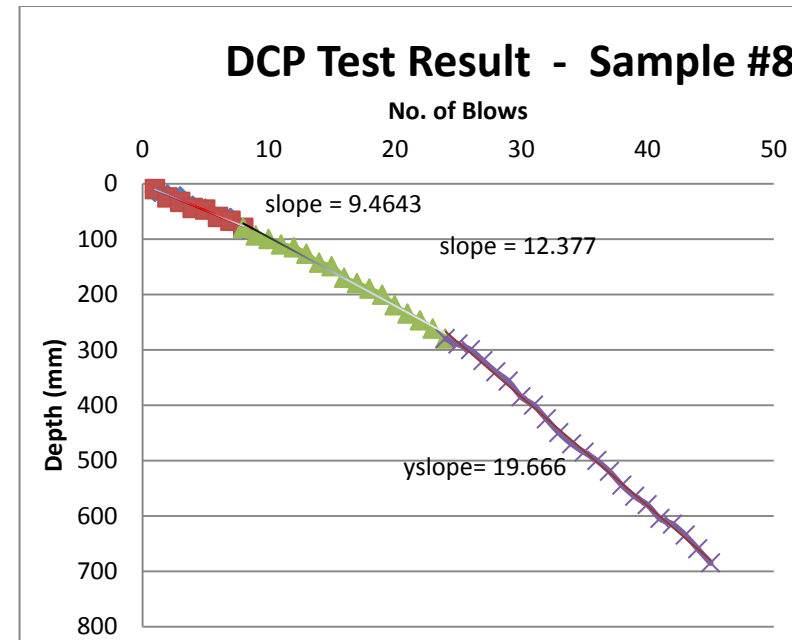
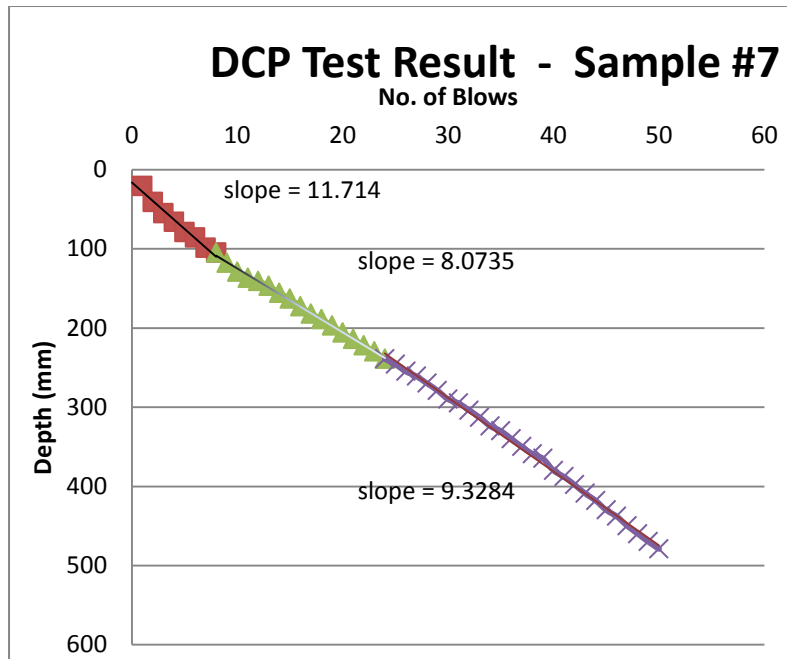
APPENDIXES

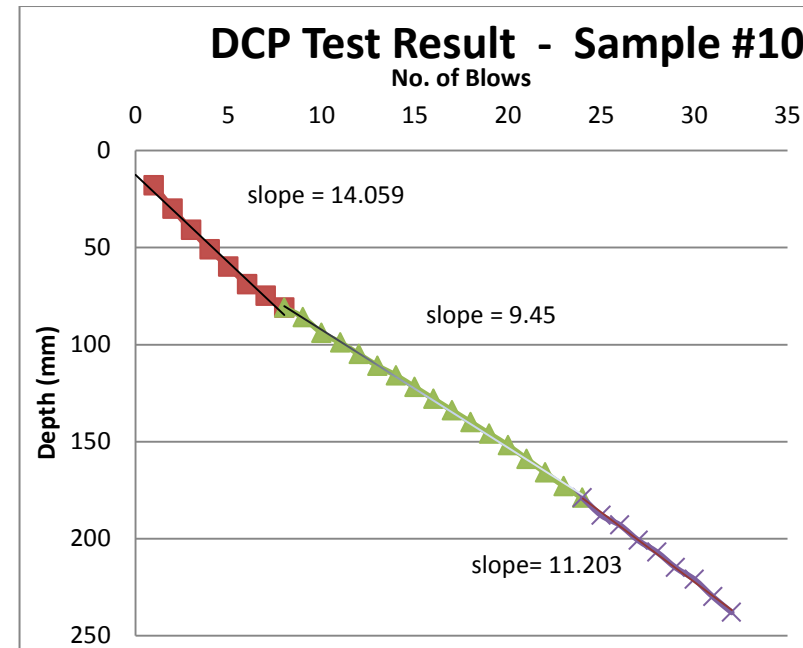
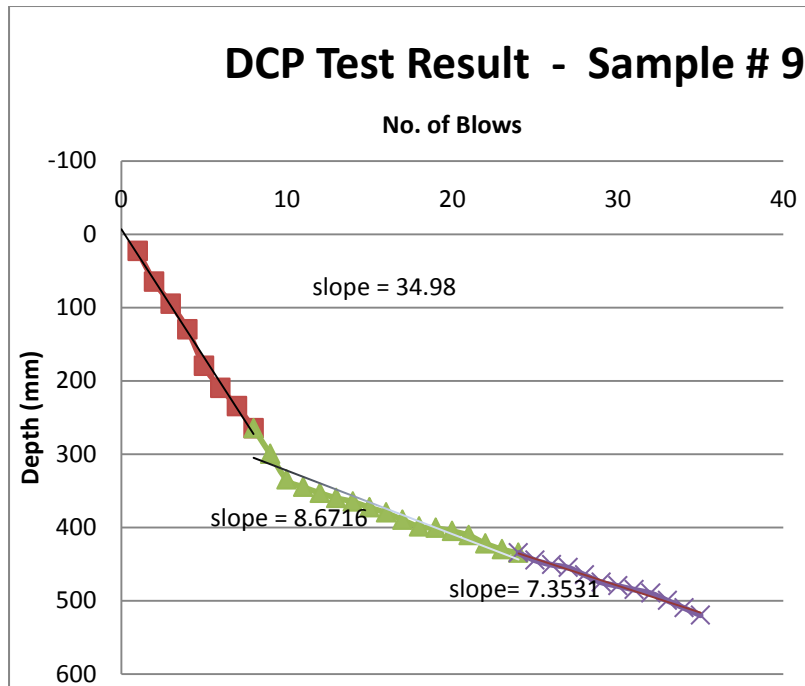
APPENDIX A – DCP RESULTS

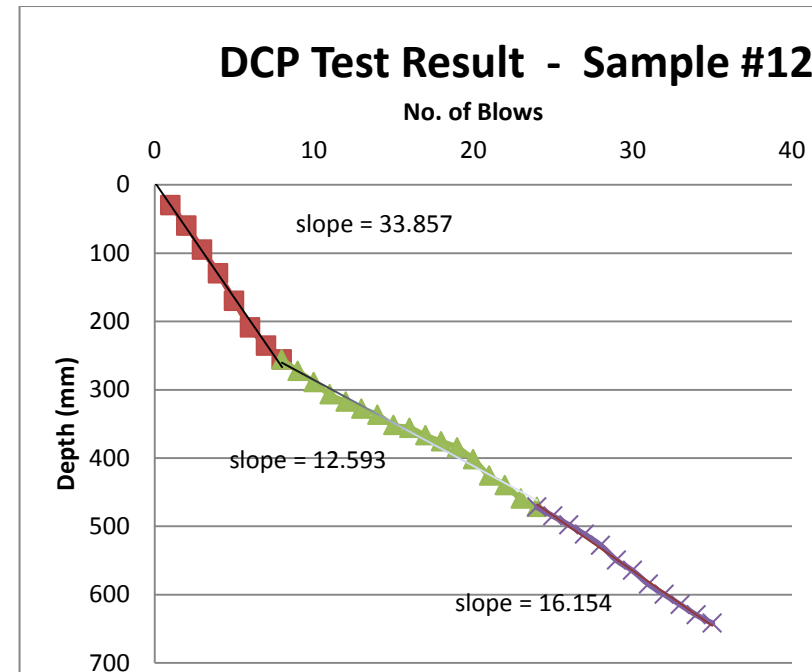
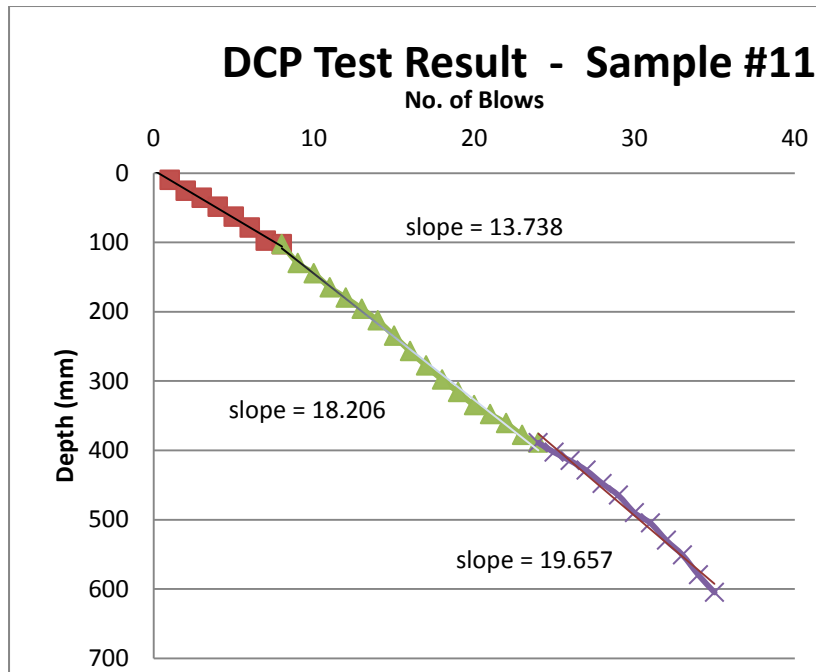


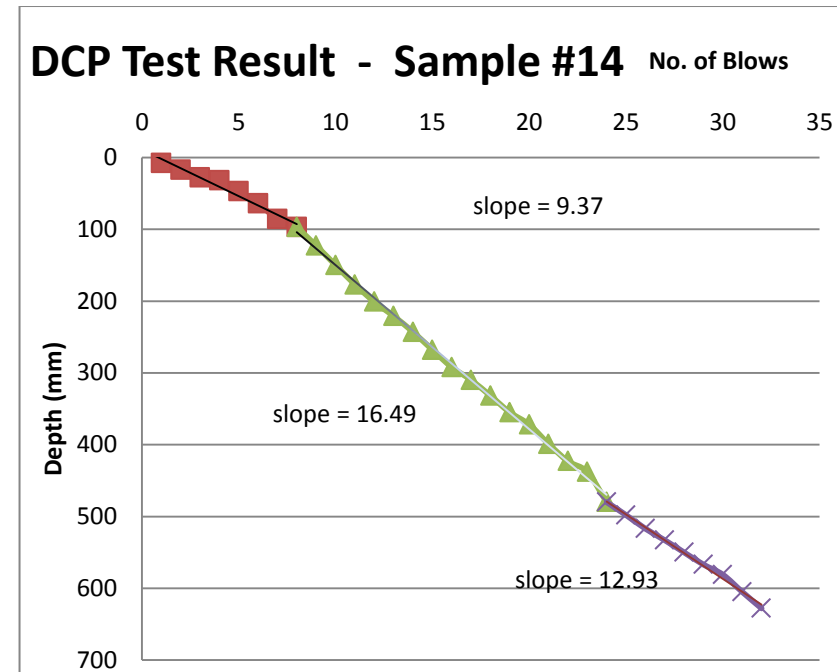
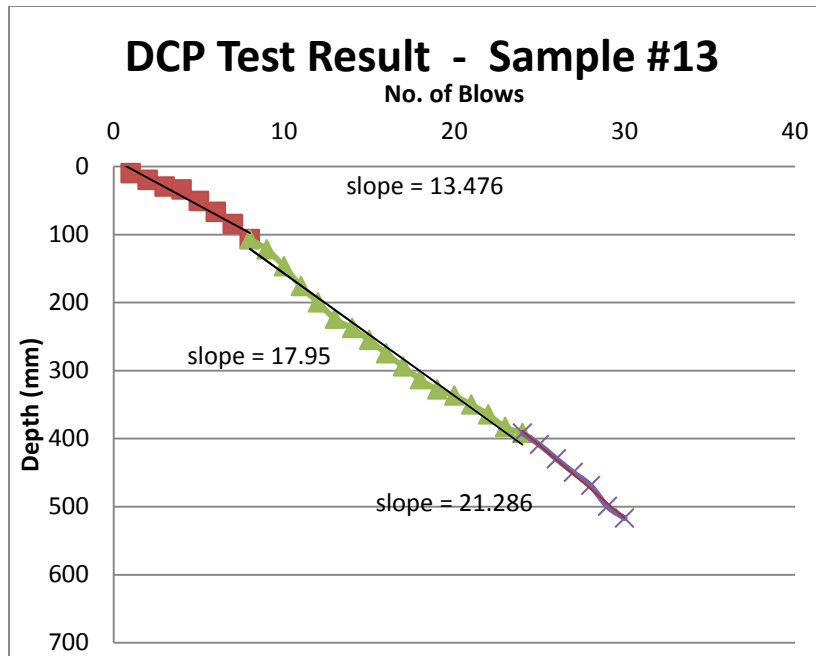


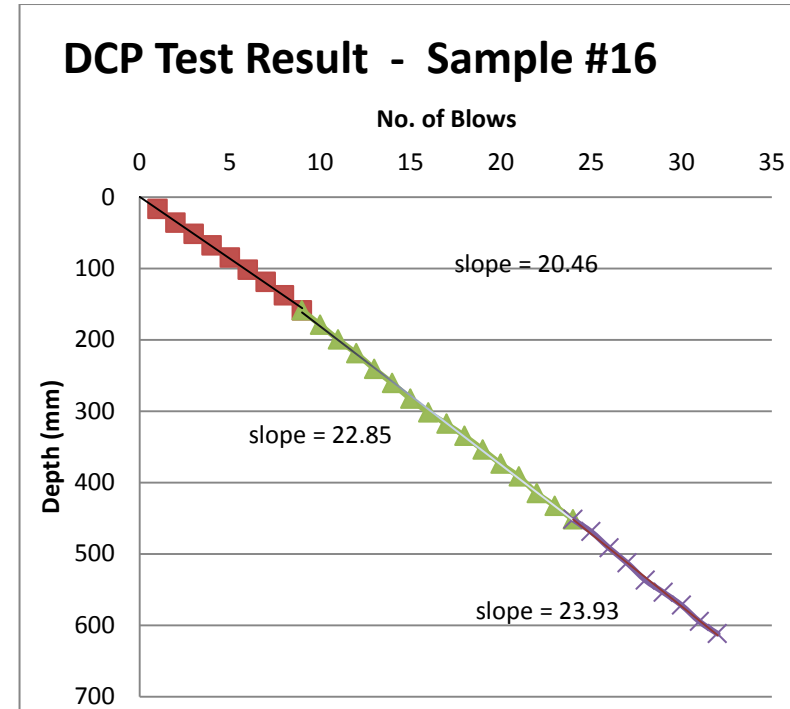
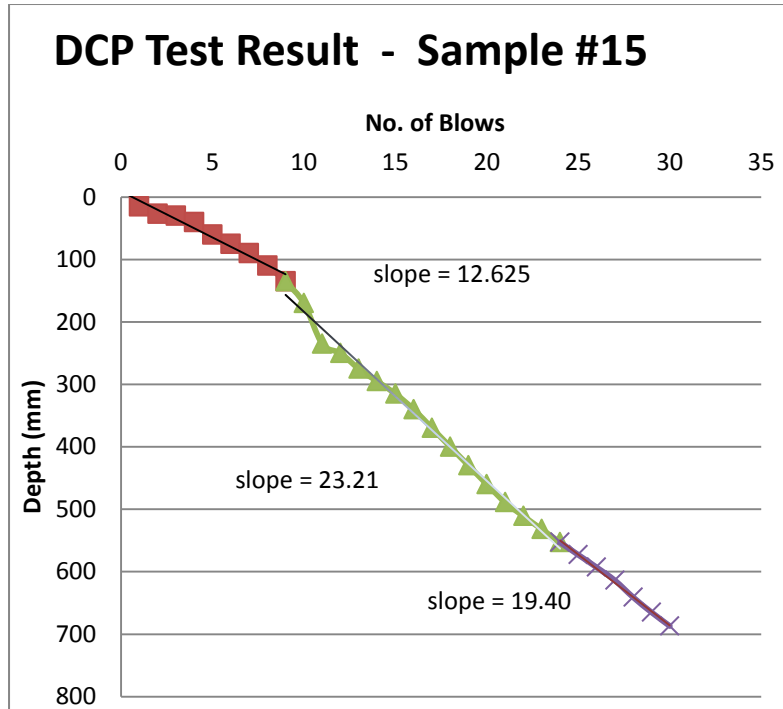


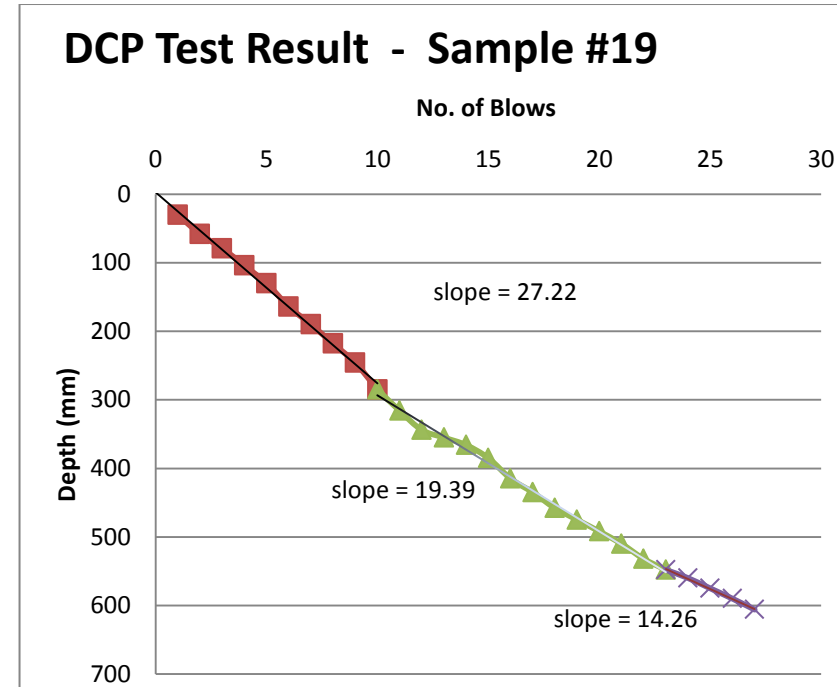
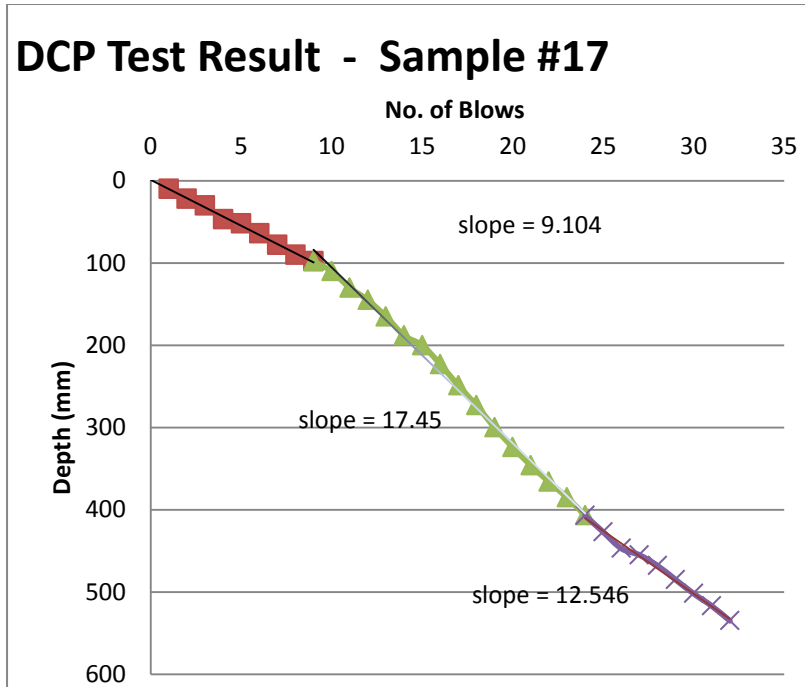


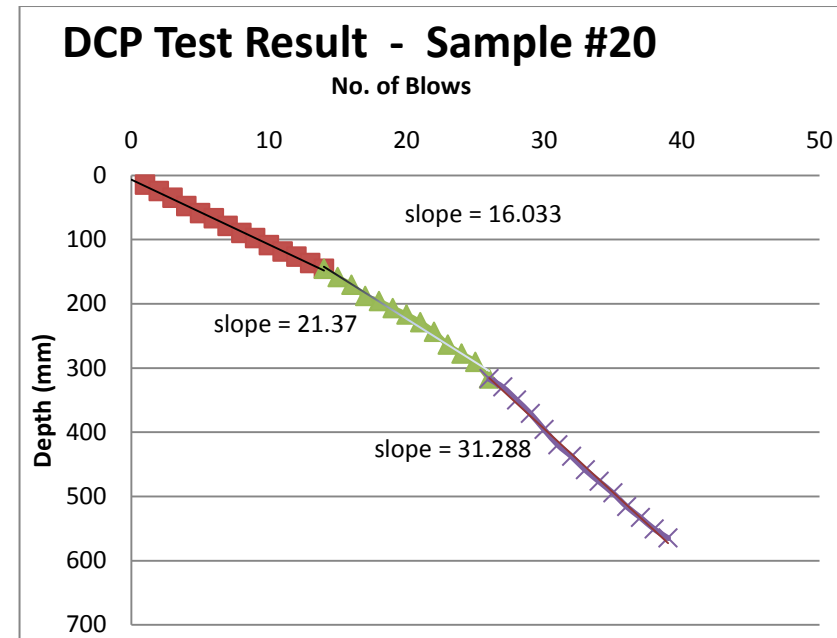
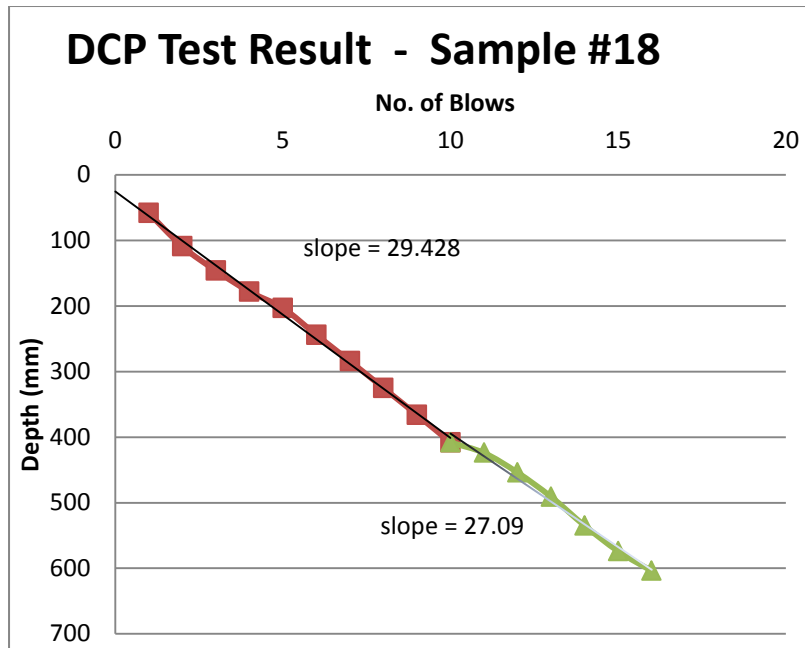


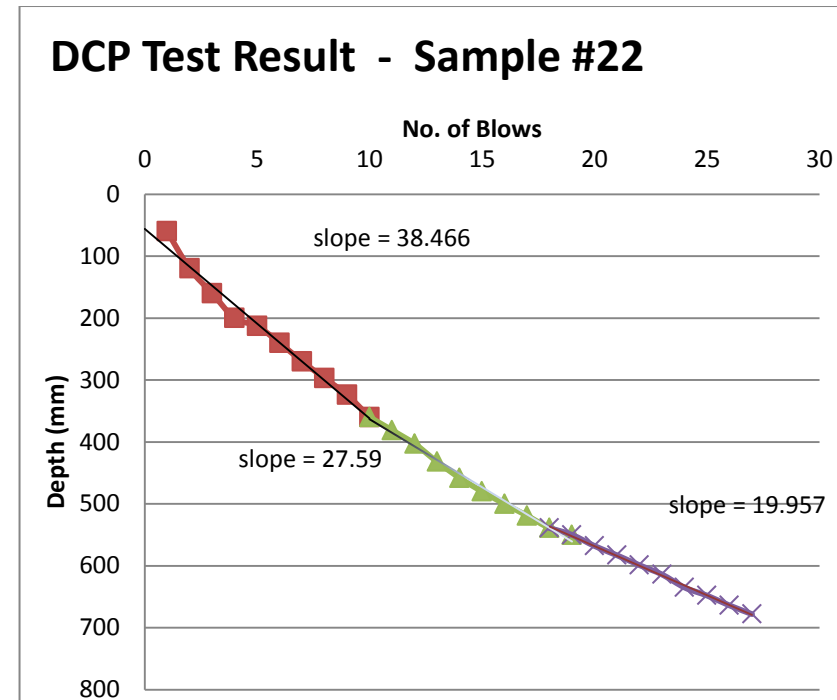
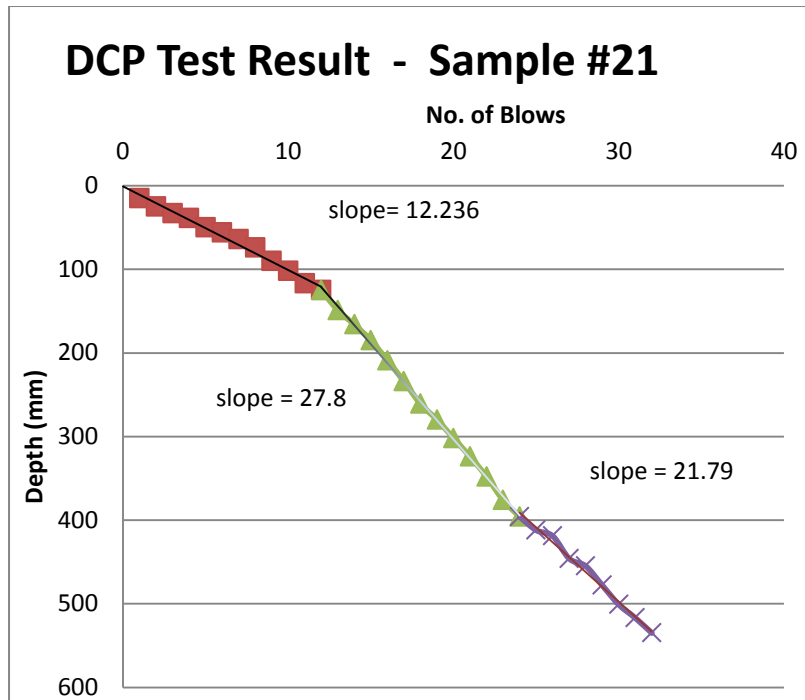


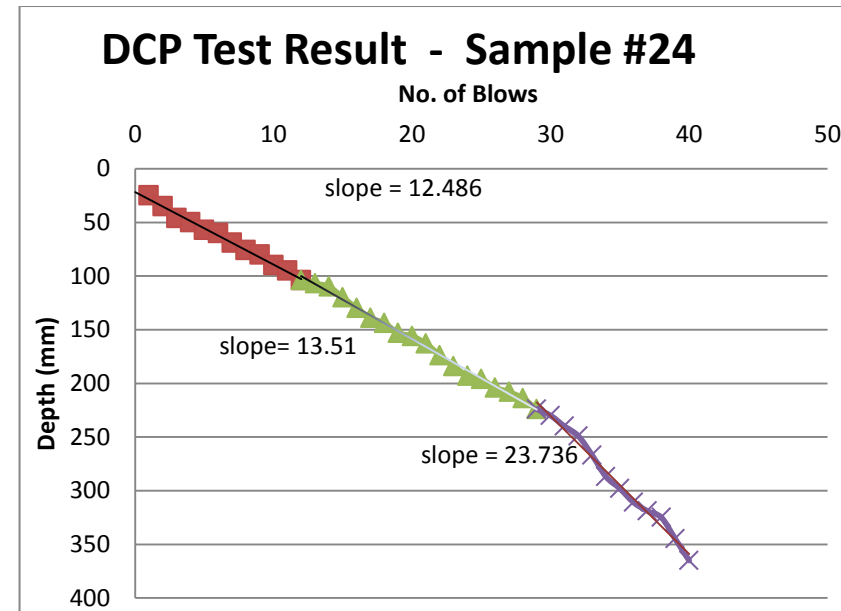
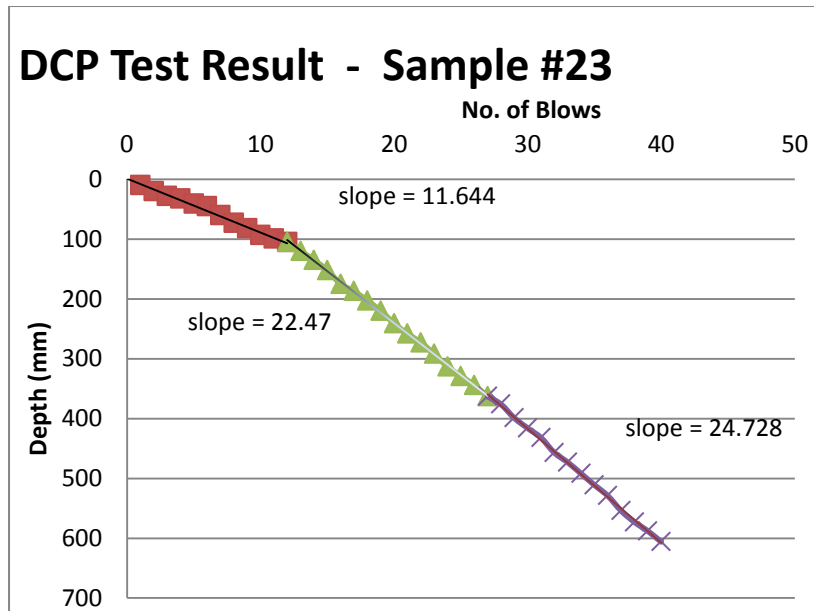


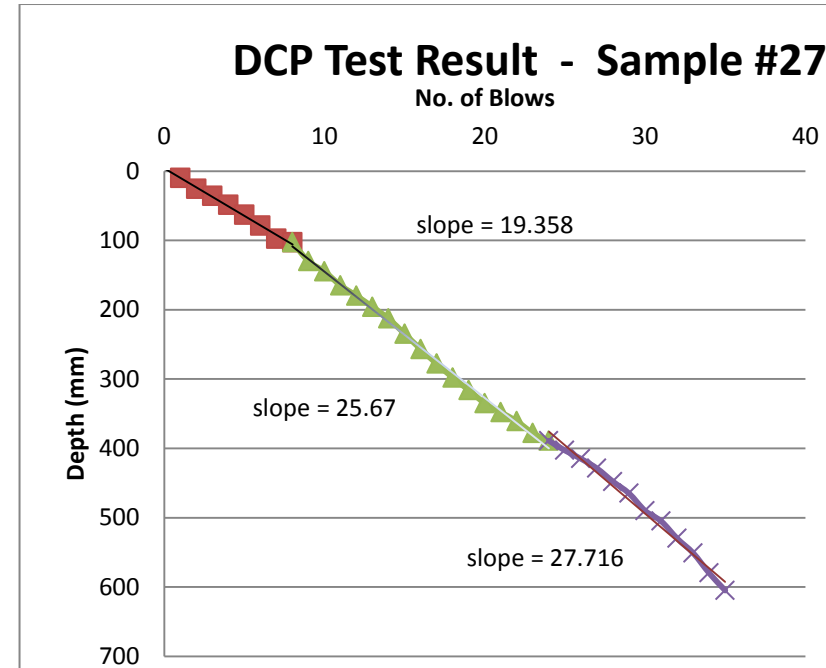
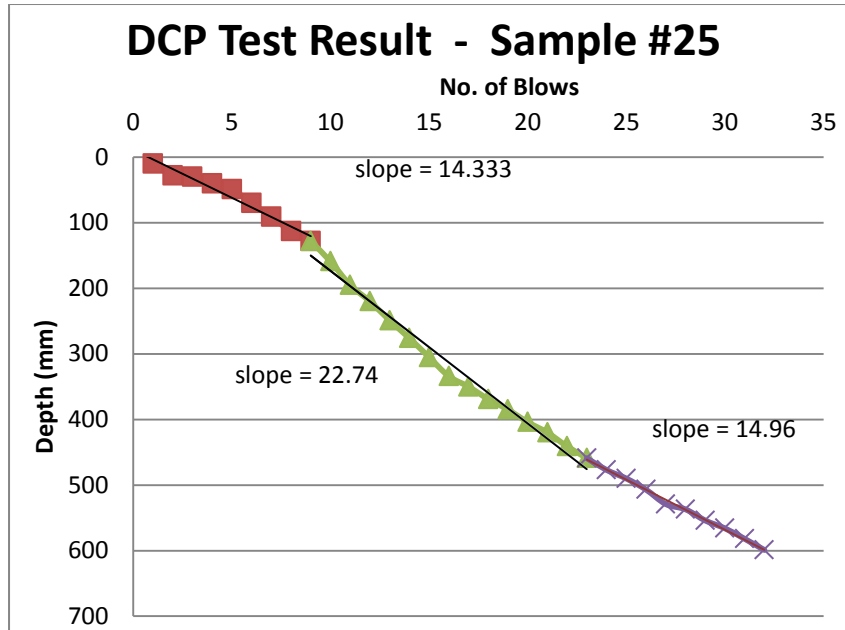


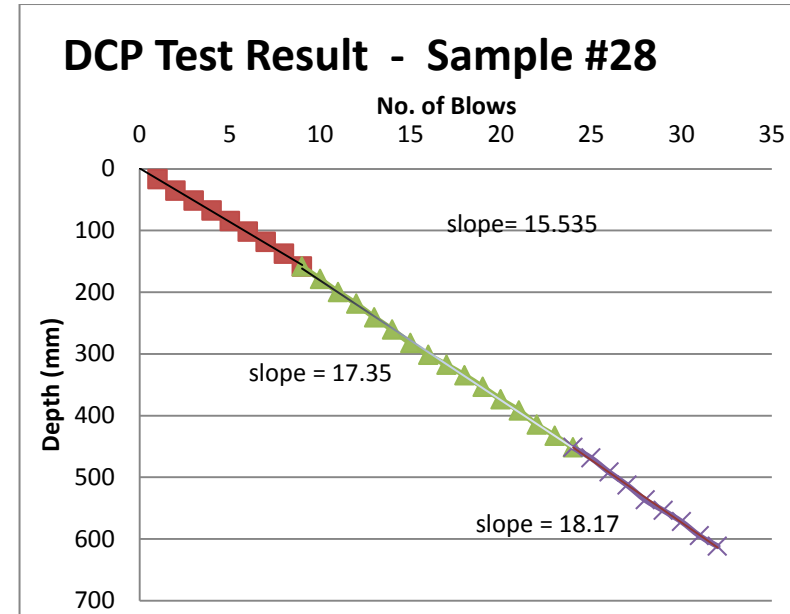
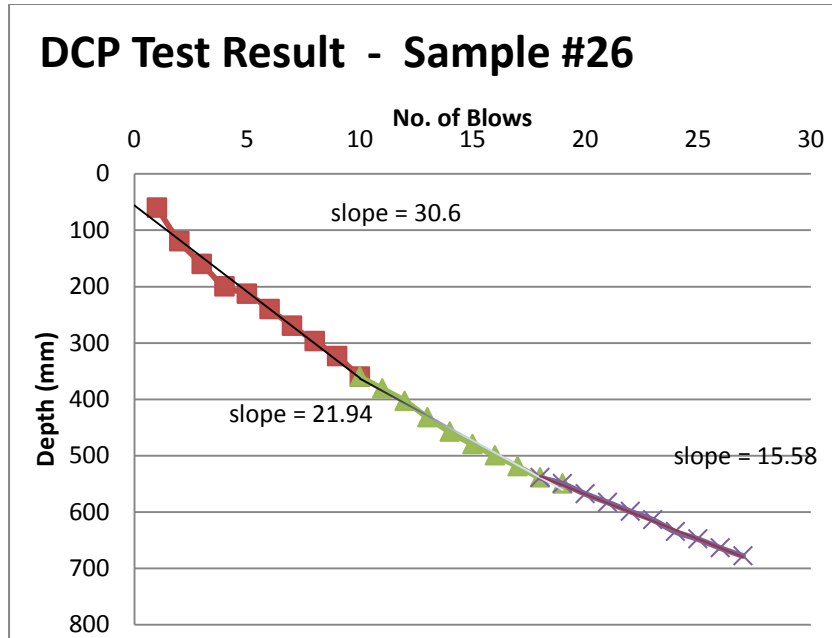


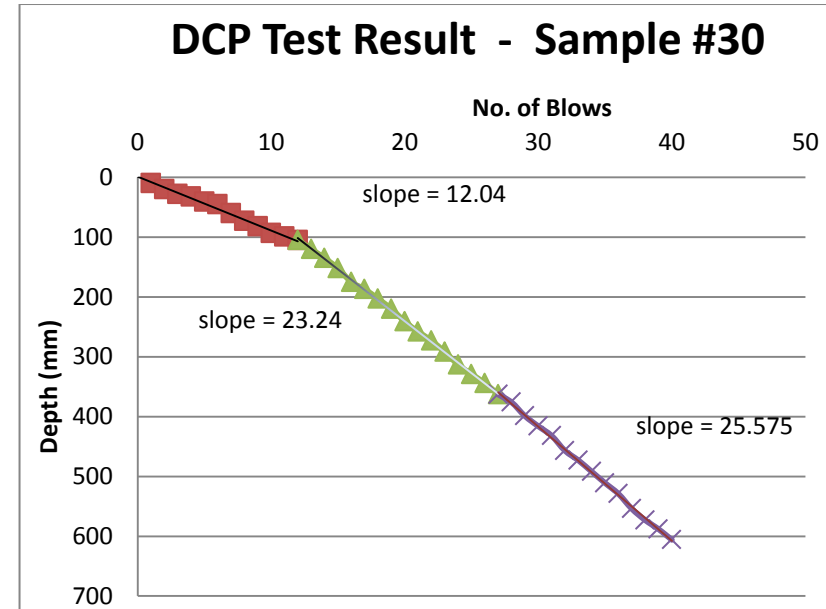
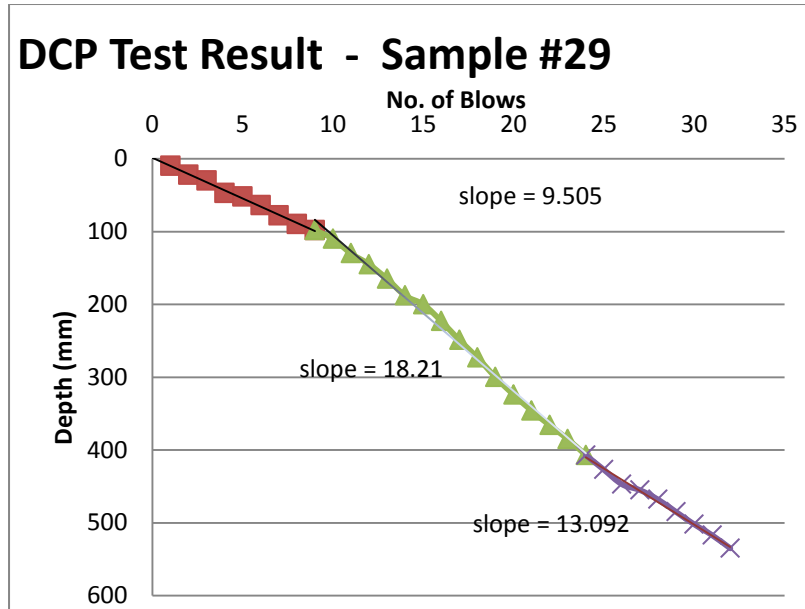


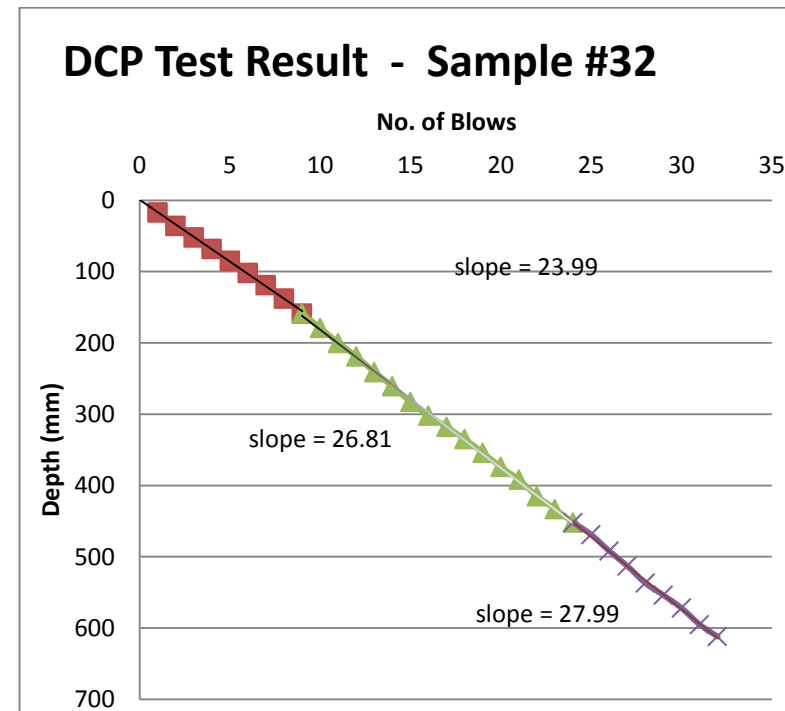
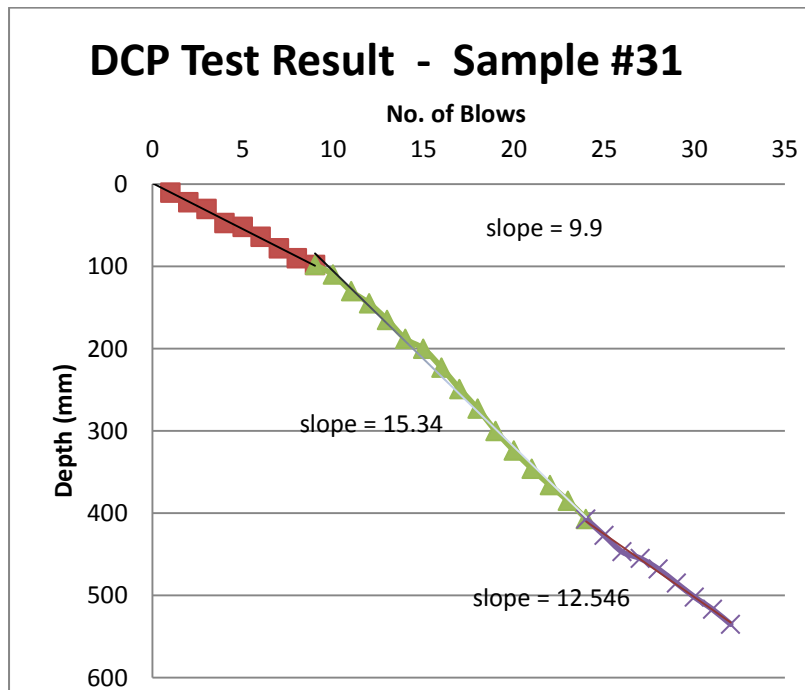


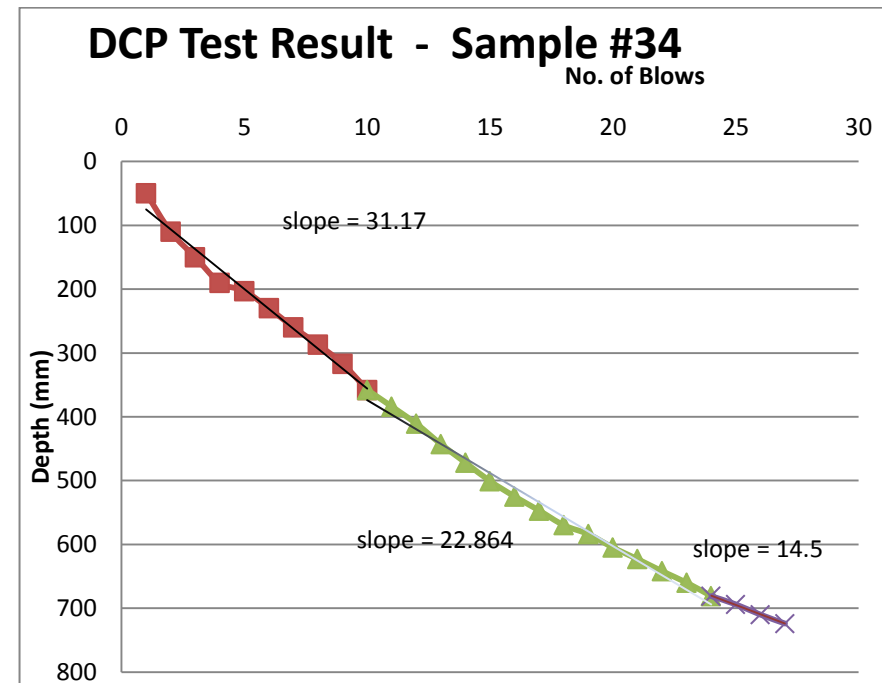
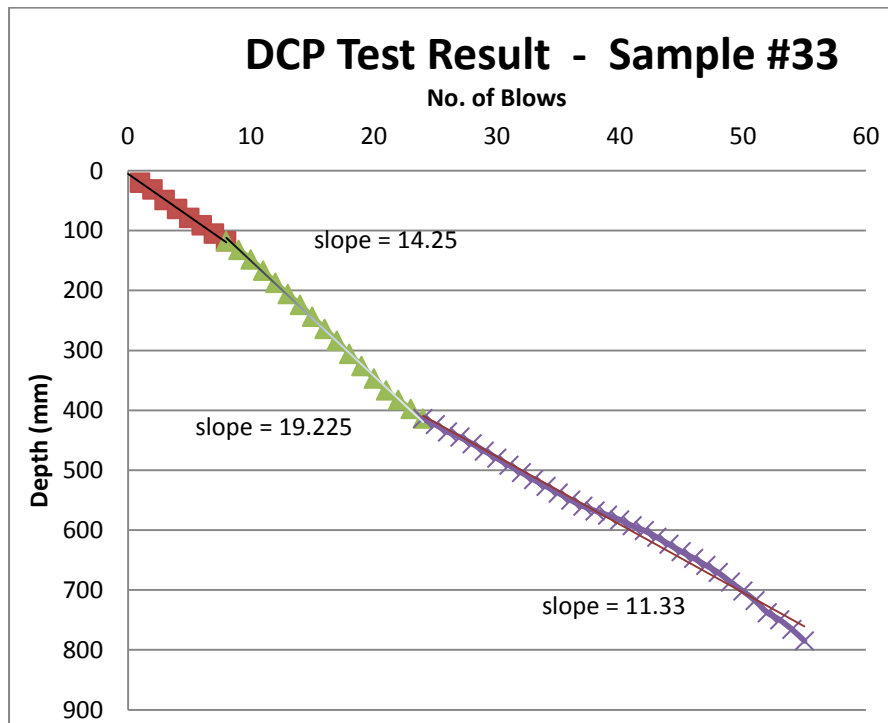


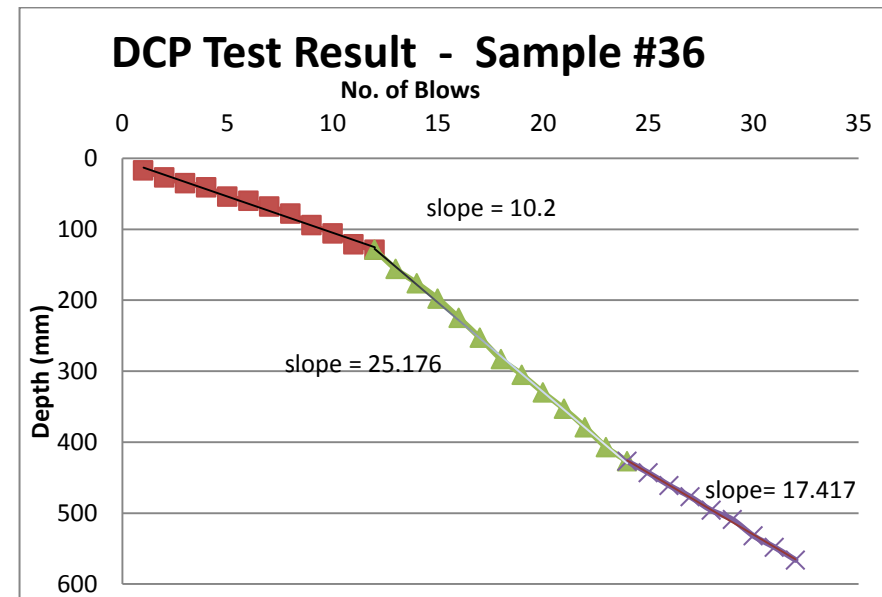
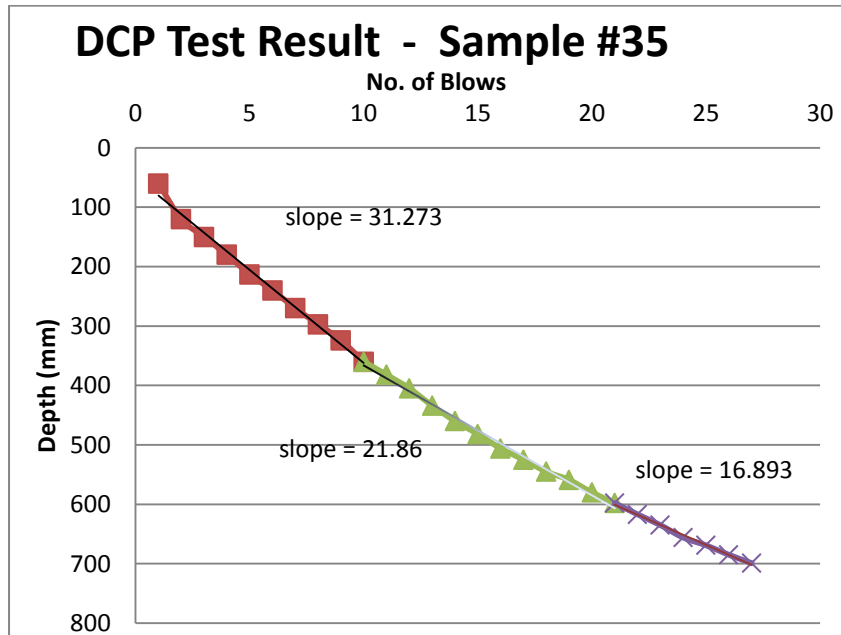












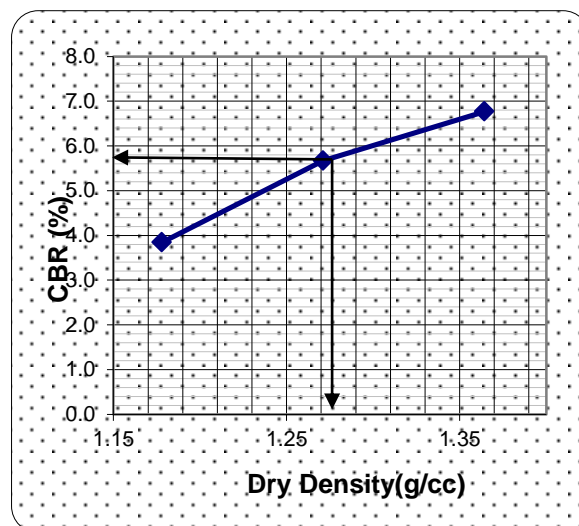
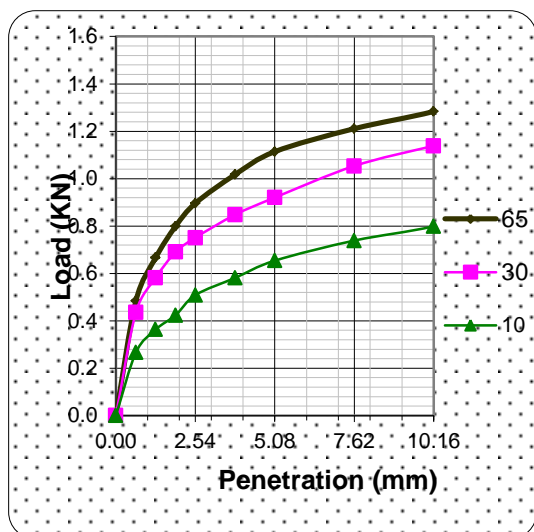
APPENDIX B – CBR RESULTS

Sample no 1

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	1	1	1	0.0	0.0	0.00
0.64	11	18	20	0.3	0.4	0.5
1.27	15	24	27.5	0.4	0.6	0.7
1.91	17.5	28.5	33	0.4	0.7	0.8
2.54	21	31	37	0.5	0.8	0.9
3.81	24	35	42	0.6	0.8	1.0
5.08	27	38	46	0.7	0.9	1.1
7.62	30.5	43.5	50	0.7	1.1	1.2
10.16	33	47	53	0.8	1.1	1.3
12.7	37	50	57	0.9	1.2	1.4

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.18	3.8	3.3	3.8
30	1.27	5.7	4.6	5.7
56	1.36	6.8	5.6	6.8

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	98	175	0.66
30	16	290	2.35
65	105	512	3.49



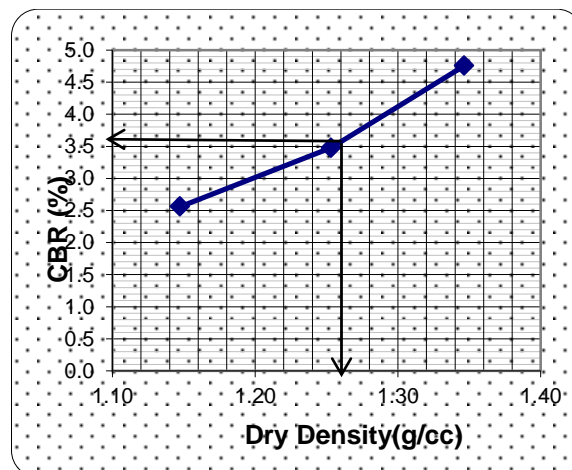
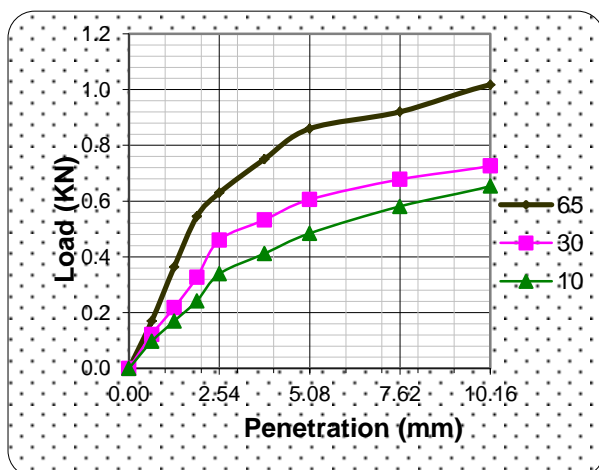
CBR at 95% MDD= 5.7

Sample no 2

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0	0	0	0.0	0.0	0.00
0.64	4	5	7	0.1	0.1	0.2
1.27	7	9	15	0.2	0.2	0.4
1.91	10	13.5	22.5	0.2	0.3	0.5
2.54	14	19	26	0.3	0.5	0.6
3.81	17	22	31	0.4	0.5	0.8
5.08	20	25	35.5	0.5	0.6	0.9
7.62	24	28	38	0.6	0.7	0.9
10.16	27	30	42	0.7	0.7	1.0
12.7	31	33	44	0.8	0.8	1.1

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.15	2.6	2.4	2.6
30	1.25	3.5	3.0	3.5
56	1.35	4.8	4.3	4.8

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	762	950	1.61
30	504	720	1.85
65	378	650	2.33



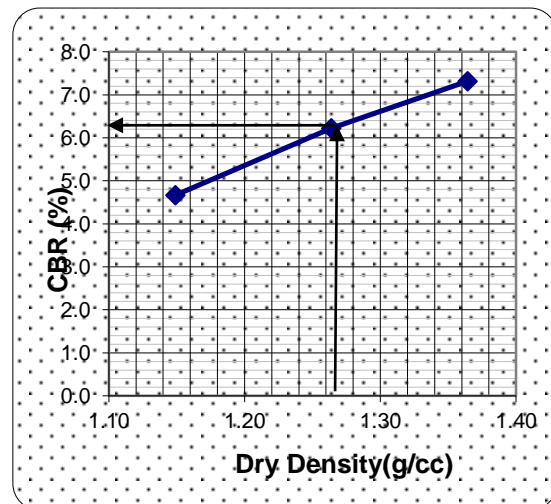
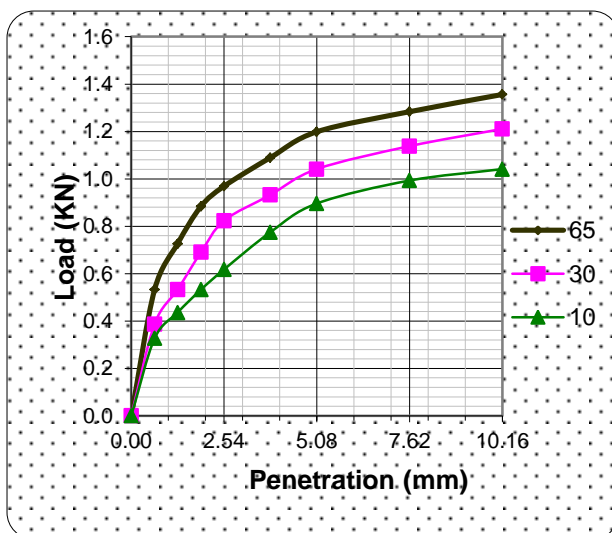
CBR at 95% MDD= 3.5

Sample no 3

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0	0	0	0.0	0.0	0.00
0.64	13.5	16	22	0.3	0.4	0.5
1.27	18	22	30	0.4	0.5	0.7
1.91	22	28.5	36.5	0.5	0.7	0.9
2.54	25.5	34	40	0.6	0.8	1.0
3.81	32	38.5	45	0.8	0.9	1.1
5.08	37	43	49.5	0.9	1.0	1.2
7.62	41	47	53	1.0	1.1	1.3
10.16	43	50	56	1.0	1.2	1.4
12.7	45	53	59	1.1	1.3	1.4

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.15	4.7	4.5	4.7
30	1.26	6.2	5.2	6.2
56	1.36	7.3	6.0	7.3

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	52	93	0.35
30	344	538	1.66
65	99	354	2.19



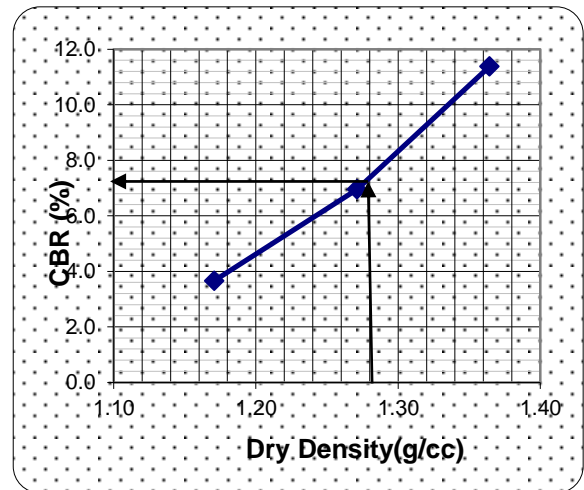
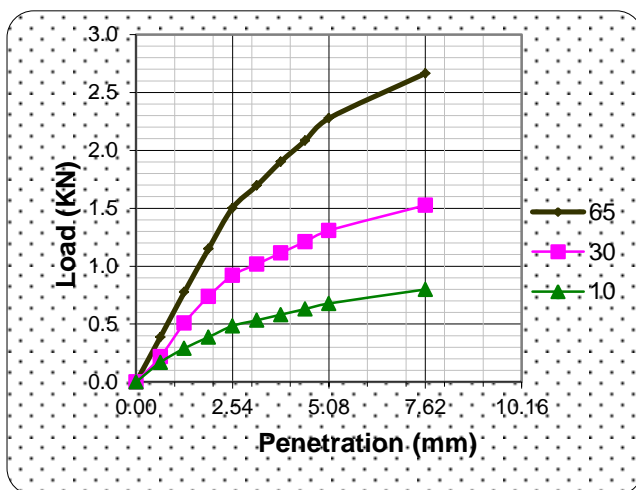
CBR at 95% MDD= 6.2

Sample no 4

PENETRATION DATA						
Ring Factor (KN/DIV)					0.024217	
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0	0	0	0.0	0.0	0.00
0.64	7	9	16	0.2	0.2	0.4
1.27	12	21	32	0.3	0.5	0.8
1.91	16	30.5	47.5	0.4	0.7	1.2
2.54	20	38	62	0.5	0.9	1.5
3.18	22	42	70	0.5	1.0	1.7
3.81	24	46	78.5	0.6	1.1	1.9
4.45	26	50	86	0.6	1.2	2.1
5.08	28	54	94	0.7	1.3	2.3
7.62	33	63	110	0.8	1.5	2.7
10.16	38	72	126	0.9	1.7	3.1

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.17	3.7	3.4	3.7
30	1.27	7.0	6.5	7.0
56	1.36	11.3	11.4	11.4

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	52	93	0.35
30	344	538	1.66
65	99	354	2.19



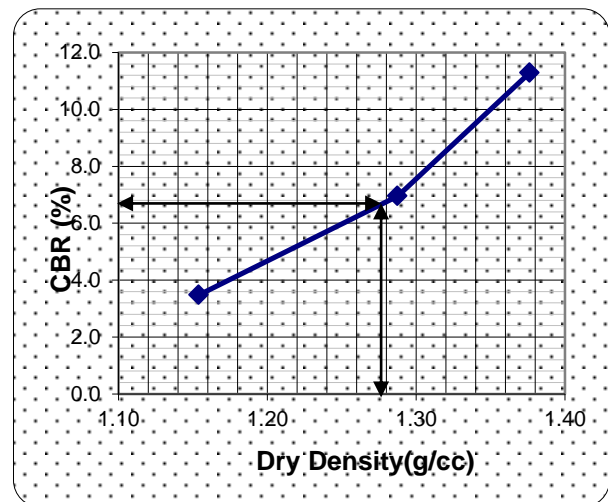
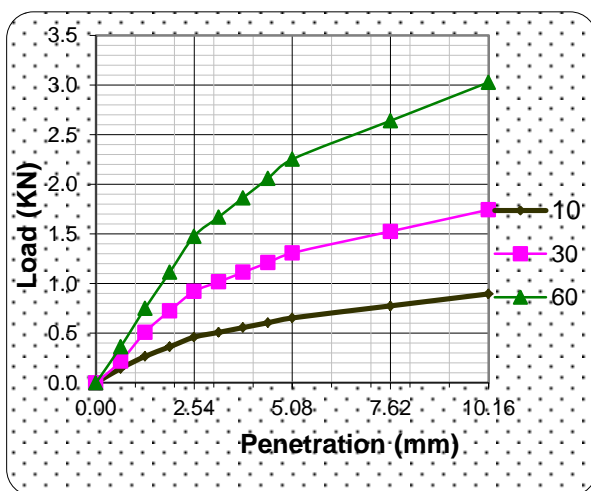
CBR at 95% MDD= 6.9

Sample no 5

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	6.0	9.0	15.0	0.1	0.2	0.4
1.27	11.0	21.0	31.0	0.3	0.5	0.8
1.91	15.0	30.0	46.0	0.4	0.7	1.1
2.54	19.0	38.0	61.0	0.5	0.9	1.5
3.18	21.0	42.0	69.0	0.5	1.0	1.7
3.81	23.0	46.0	77.0	0.6	1.1	1.9
4.45	25.0	50.0	85.0	0.6	1.2	2.1
5.08	27.0	54.0	93.0	0.7	1.3	2.3
7.62	32.0	63.0	109.0	0.8	1.5	2.6
10.16	37.0	72.0	125.0	0.9	1.7	3.0

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.15	3.5	3.3	3.5
30	1.29	7.0	6.6	7.0
56	1.38	11.2	11.3	11.3

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	585	692	0.92
30	44	240	1.68
65	39	321	2.42



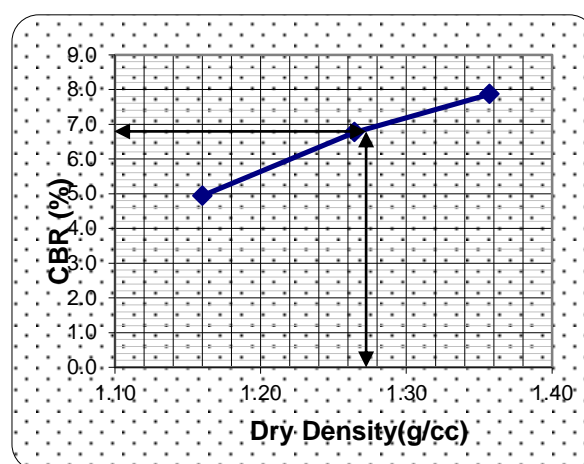
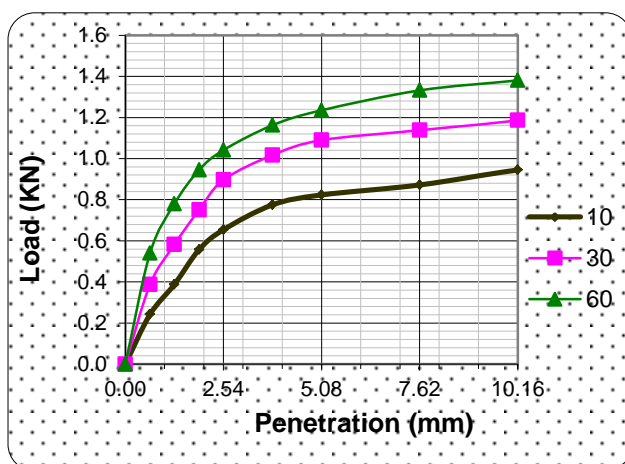
CBR at 95% MDD= 6.3

Sample no 6

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	10.0	16.0	22.3	0.2	0.4	0.5
1.27	16.0	24.0	32.2	0.4	0.6	0.8
1.91	23.0	31.0	39.0	0.6	0.8	0.9
2.54	27.0	37.0	43.0	0.7	0.9	1.0
3.81	32.0	42.0	48.0	0.8	1.0	1.2
5.08	34.0	45.0	51.0	0.8	1.1	1.2
7.62	36.0	47.0	55.0	0.9	1.1	1.3
10.16	39.0	49.0	57.0	0.9	1.2	1.4
12.7	41.0	52.0	59.0	1.0	1.3	1.4

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.16	4.9	4.1	4.9
30	1.26	6.8	5.5	6.8
56	1.36	7.9	6.2	7.9

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	315	560	2.1
30	145	325	1.54
65	265	327	0.53



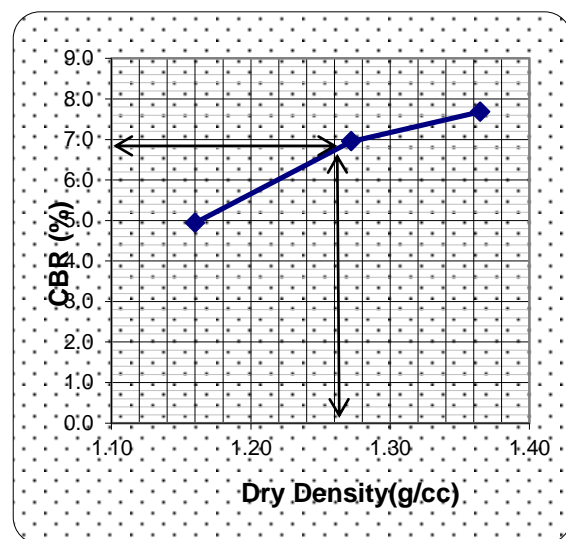
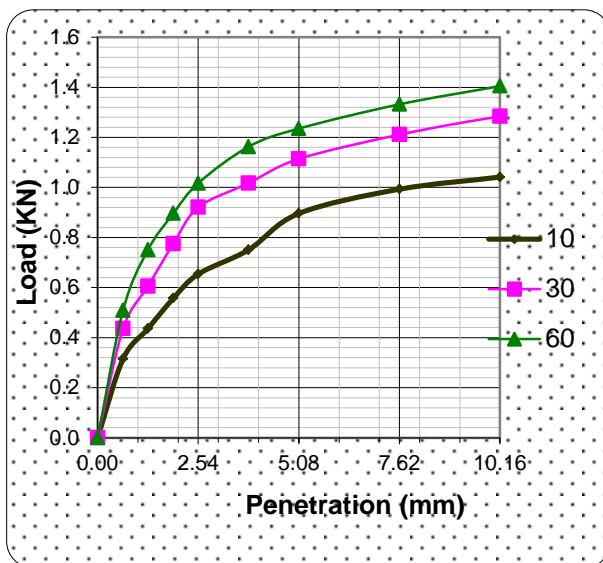
CBR at 95% MDD= 6.9

Sample no 7

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	13.0	18.0	21.0	0.3	0.4	0.5
1.27	18.0	25.0	31.0	0.4	0.6	0.8
1.91	23.0	32.0	37.0	0.6	0.8	0.9
2.54	27.0	38.0	42.0	0.7	0.9	1.0
3.81	31.0	42.0	48.0	0.8	1.0	1.2
5.08	37.0	46.0	51.0	0.9	1.1	1.2
7.62	41.0	50.0	55.0	1.0	1.2	1.3
10.16	43.0	53.0	58.0	1.0	1.3	1.4
12.7	45.0	55.0	61.0	1.1	1.3	1.5

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.16	4.9	4.5	4.9
30	1.27	7.0	5.6	7.0
56	1.36	7.7	6.2	7.7

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	456	625	1.45
30	562	782	1.89
65	652	895	2.08



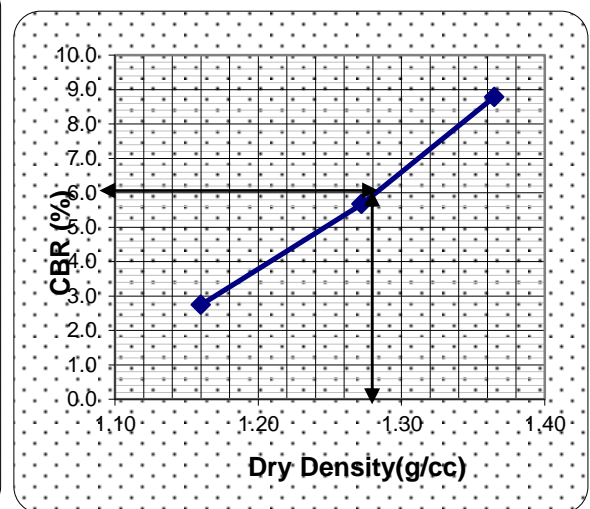
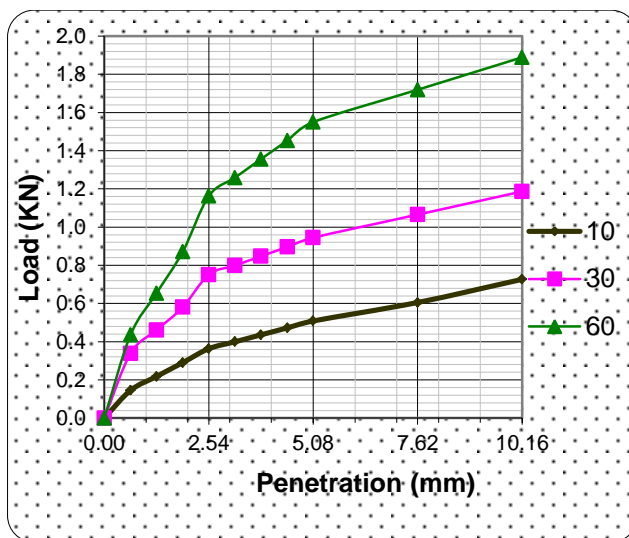
CBR at 95% MDD= 6.9

Sample no 8

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	6.0	14.0	18.0	0.1	0.3	0.4
1.27	9.0	19.0	27.0	0.2	0.5	0.7
1.91	12.0	24.0	36.0	0.3	0.6	0.9
2.54	15.0	31.0	48.0	0.4	0.8	1.2
3.18	16.5	33.0	52.0	0.4	0.8	1.3
3.81	18.0	35.0	56.0	0.4	0.8	1.4
4.45	19.5	37.0	60.0	0.5	0.9	1.5
5.08	21.0	39.0	64.0	0.5	0.9	1.5
7.62	25.0	44.0	71.0	0.6	1.1	1.7
10.16	30.0	49.0	78.0	0.7	1.2	1.9

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.16	2.7	2.2	2.7
30	1.27	5.7	4.2	5.7
56	1.36	8.8	6.8	8.8

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.19	1.65	0.4
30	0.4	1.24	0.72
65	0.55	1.47	0.79



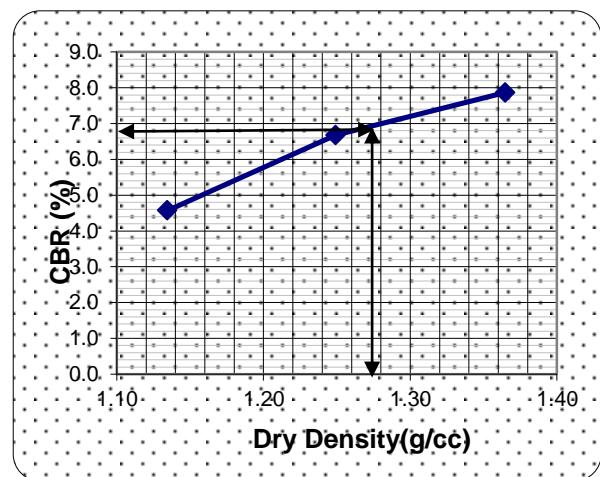
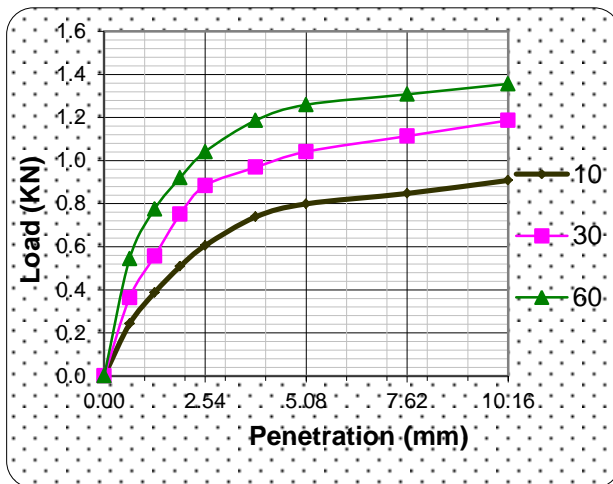
CBR at 95% MDD= 6

Sample no 9

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	10.0	15.0	22.5	0.2	0.4	0.5
1.27	16.0	23.0	32.0	0.4	0.6	0.8
1.91	21.0	31.0	38.0	0.5	0.8	0.9
2.54	25.0	36.5	43.0	0.6	0.9	1.0
3.81	30.5	40.0	49.0	0.7	1.0	1.2
5.08	33.0	43.0	52.0	0.8	1.0	1.3
7.62	35.0	46.0	54.0	0.8	1.1	1.3
10.16	37.5	49.0	56.0	0.9	1.2	1.4
12.7	40.0	52.0	58.0	1.0	1.3	1.4

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	4.6	4.0	4.6
30	1.25	6.7	5.2	6.7
56	1.36	7.9	6.3	7.9

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	585	698	0.97
30	145	312	1.43
65	456	756	2.57



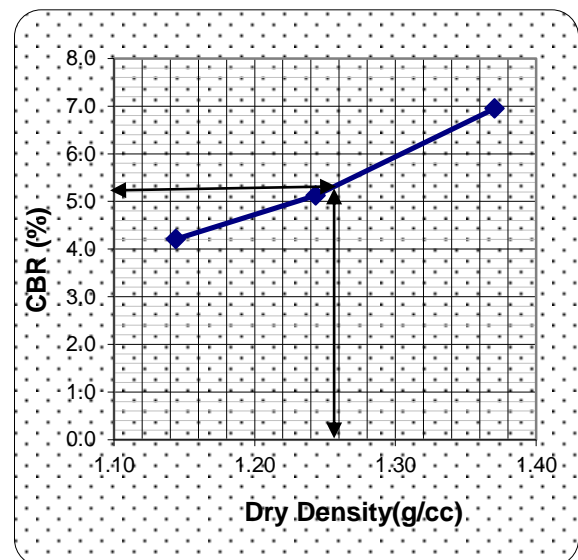
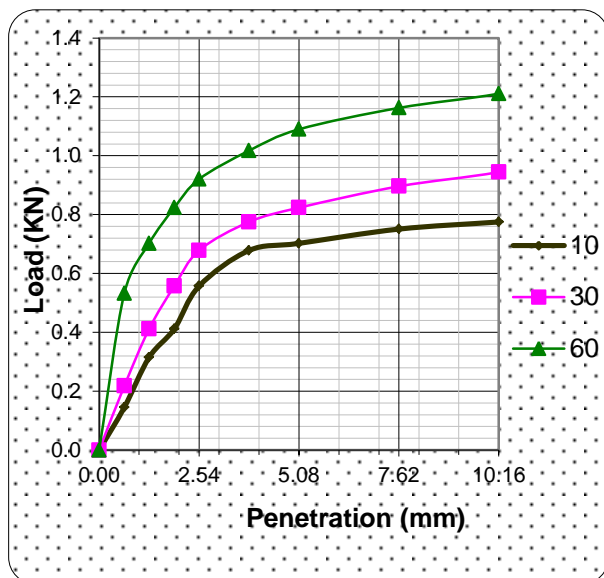
CBR at 95% MDD= 6.9

Sample no 10

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	6.0	9.0	22.0	0.1	0.2	0.5
1.27	13.0	17.0	29.0	0.3	0.4	0.7
1.91	17.0	23.0	34.0	0.4	0.6	0.8
2.54	23.0	28.0	38.0	0.6	0.7	0.9
3.81	28.0	32.0	42.0	0.7	0.8	1.0
5.08	29.0	34.0	45.0	0.7	0.8	1.1
7.62	31.0	37.0	48.0	0.8	0.9	1.2
10.16	32.0	39.0	50.0	0.8	0.9	1.2
12.7	33.0	42.0	53.0	0.8	1.0	1.3

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.14	4.2	3.5	4.2
30	1.24	5.1	4.1	5.1
56	1.37	7.0	5.5	7.0

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	762	950	1.61
30	504	720	1.85
65	378	650	2.33



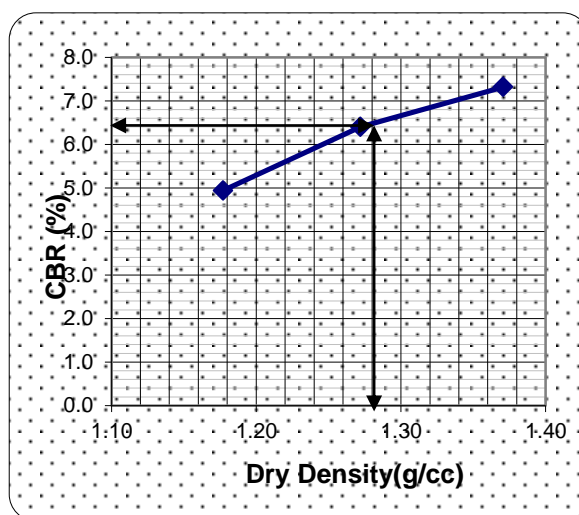
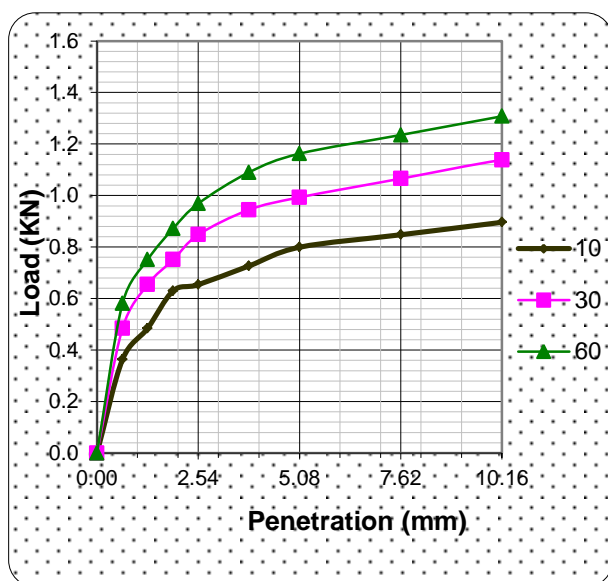
CBR at 95% MDD= 5.3

Sample no 11

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	15.0	20.0	24.0	0.4	0.5	0.6
1.27	20.0	27.0	31.0	0.5	0.7	0.8
1.91	26.0	31.0	36.0	0.6	0.8	0.9
2.54	27.0	35.0	40.0	0.7	0.8	1.0
3.81	30.0	39.0	45.0	0.7	0.9	1.1
5.08	33.0	41.0	48.0	0.8	1.0	1.2
7.62	35.0	44.0	51.0	0.8	1.1	1.2
10.16	37.0	47.0	54.0	0.9	1.1	1.3
12.7	39.0	49.0	57.0	0.9	1.2	1.4

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.18	4.9	4.0	4.9
30	1.27	6.4	5.0	6.4
56	1.37	7.3	5.8	7.3

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	110	202	0.79
30	340	670	2.83
65	250	601	3.01



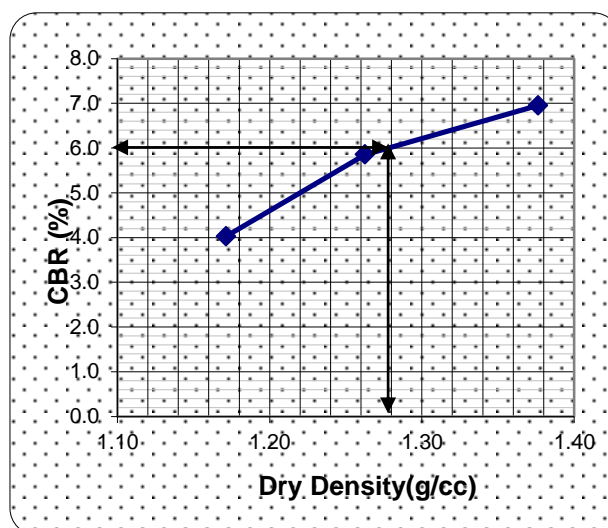
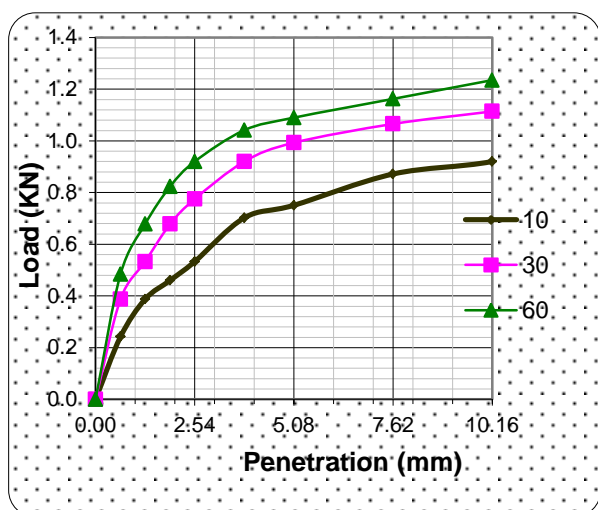
CBR at 95% MDD= 6.4

Sample no 12

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	10.0	16.0	20.0	0.2	0.4	0.5
1.27	16.0	22.0	28.0	0.4	0.5	0.7
1.91	19.0	28.0	34.0	0.5	0.7	0.8
2.54	22.0	32.0	38.0	0.5	0.8	0.9
3.81	29.0	38.0	43.0	0.7	0.9	1.0
5.08	31.0	41.0	45.0	0.8	1.0	1.1
7.62	36.0	44.0	48.0	0.9	1.1	1.2
10.16	38.0	46.0	51.0	0.9	1.1	1.2
12.7	42.0	48.0	54.0	1.0	1.2	1.3

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.17	4.0	3.8	4.0
30	1.26	5.9	5.0	5.9
56	1.38	7.0	5.5	7.0

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	50	129	0.68
30	508	670	1.39
65	95	350	2.19



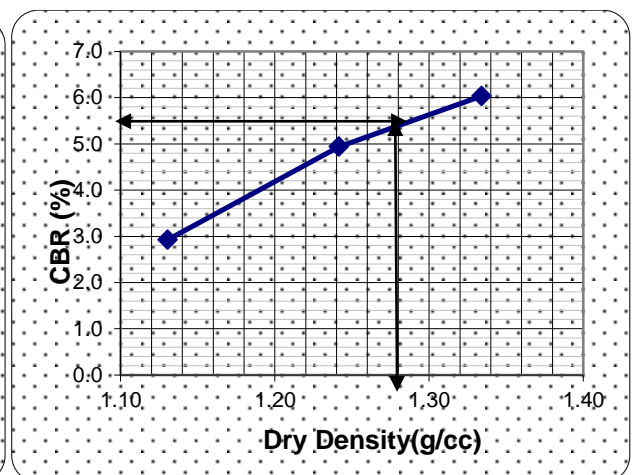
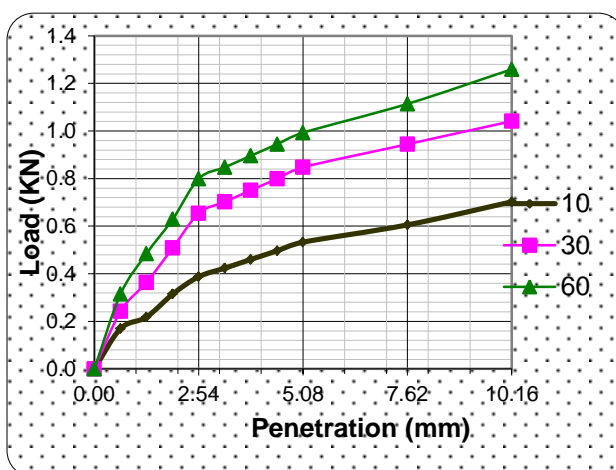
CBR at 95% MDD= 6

Sample no 13

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	7.0	10.0	13.0	0.2	0.2	0.3
1.27	9.0	15.0	20.0	0.2	0.4	0.5
1.91	13.0	21.0	26.0	0.3	0.5	0.6
2.54	16.0	27.0	33.0	0.4	0.7	0.8
3.18	17.5	29.0	35.0	0.4	0.7	0.8
3.81	19.0	31.0	37.0	0.5	0.8	0.9
4.45	20.5	33.0	39.0	0.5	0.8	0.9
5.08	22.0	35.0	41.0	0.5	0.8	1.0
7.62	25.0	39.0	46.0	0.6	0.9	1.1
10.16	29.0	43.0	52.0	0.7	1.0	1.3

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	2.9	2.7	2.9
30	1.24	4.9	4.2	4.9
56	1.33	6.0	5.0	6.0

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	0.8	2.97	1.86
30	3	5.06	1.77
65	1.75	3.55	1.55



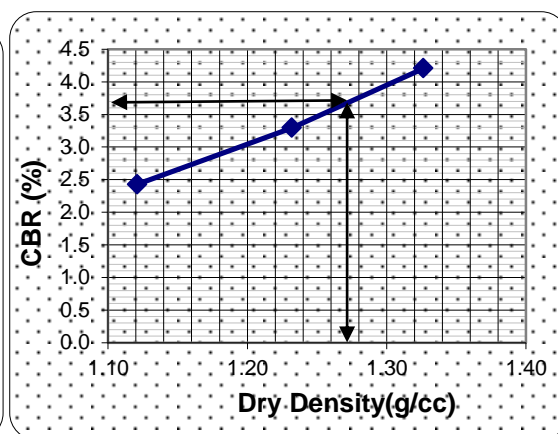
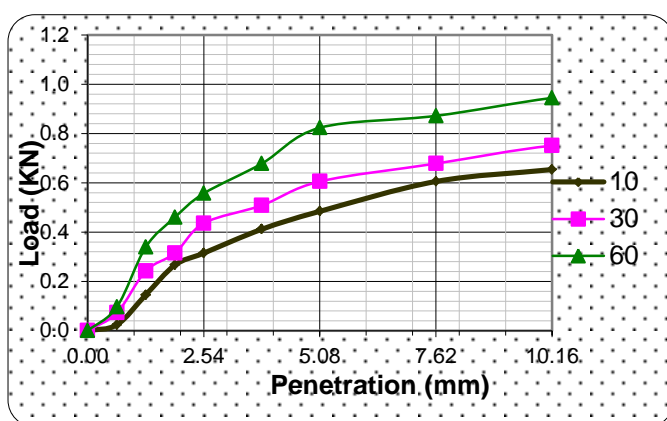
CBR at 95% MDD= 5.6

Sample no 14

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	1.0	3.0	4.0	0.0	0.1	0.1
1.27	6.0	10.0	14.0	0.1	0.2	0.3
1.91	11.0	13.0	19.0	0.3	0.3	0.5
2.54	13.0	18.0	23.0	0.3	0.4	0.6
3.81	17.0	21.0	28.0	0.4	0.5	0.7
5.08	20.0	25.0	34.0	0.5	0.6	0.8
7.62	25.0	28.0	36.0	0.6	0.7	0.9
10.16	27.0	31.0	39.0	0.7	0.8	0.9
12.7	29.0	32.0	41.0	0.7	0.8	1.0

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.12	2.4	2.4	2.4
30	1.23	3.3	3.0	3.3
56	1.33	4.2	4.1	4.2

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	587	756	1.45
30	658	895	2.03
65	745	987	2.07



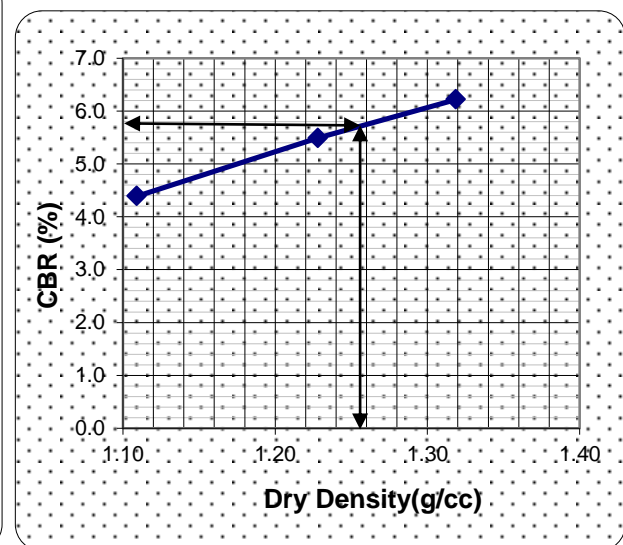
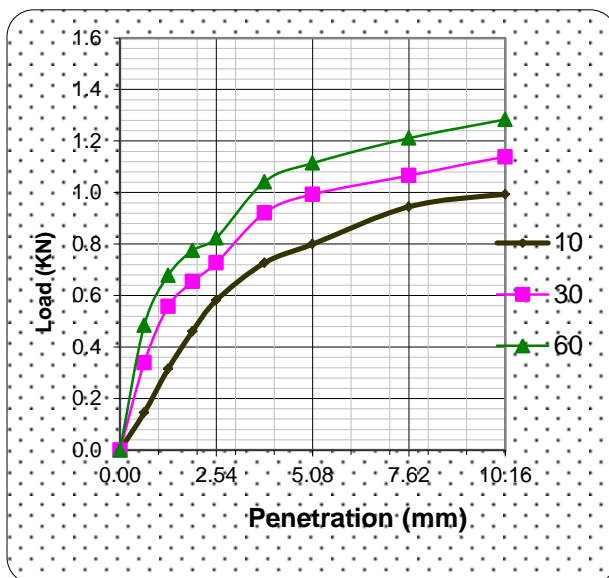
CBR at 95% MDD= 3.7

Sample no 15

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	6.0	14.0	20.0	0.1	0.3	0.5
1.27	13.0	23.0	28.0	0.3	0.6	0.7
1.91	19.0	27.0	32.0	0.5	0.7	0.8
2.54	24.0	30.0	34.0	0.6	0.7	0.8
3.81	30.0	38.0	43.0	0.7	0.9	1.0
5.08	33.0	41.0	46.0	0.8	1.0	1.1
7.62	39.0	44.0	50.0	0.9	1.1	1.2
10.16	41.0	47.0	53.0	1.0	1.1	1.3
12.7	42.0	49.0	56.0	1.0	1.2	1.4

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.11	4.4	4.0	4.4
30	1.23	5.5	5.0	5.5
56	1.32	6.2	5.6	6.2

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	98	175	0.66
30	16	290	2.35
65	105	512	3.49



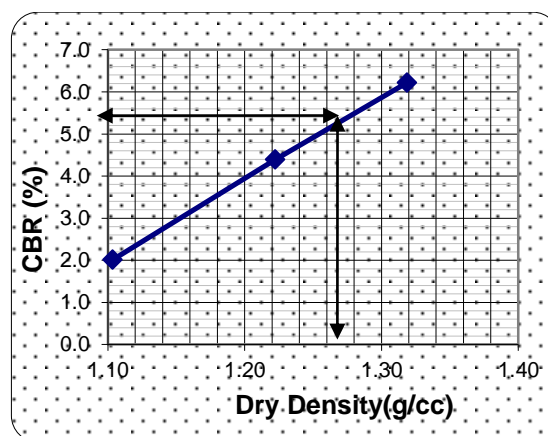
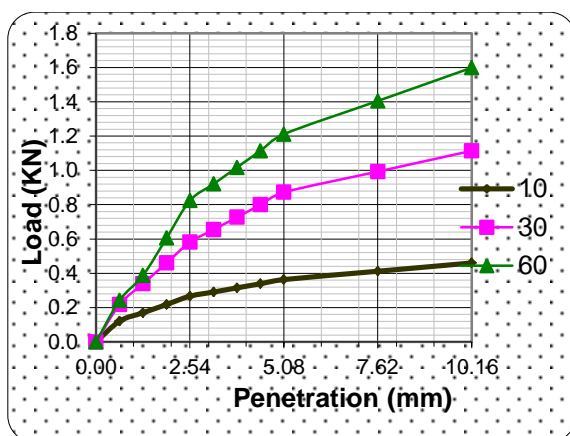
CBR at 95% MDD= 5.7

Sample no 16

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	5.0	9.0	10.0	0.1	0.2	0.2
1.27	7.0	14.0	16.0	0.2	0.3	0.4
1.91	9.0	19.0	25.0	0.2	0.5	0.6
2.54	11.0	24.0	34.0	0.3	0.6	0.8
3.18	12.0	27.0	38.0	0.3	0.7	0.9
3.81	13.0	30.0	42.0	0.3	0.7	1.0
4.45	14.0	33.0	46.0	0.3	0.8	1.1
5.08	15.0	36.0	50.0	0.4	0.9	1.2
7.62	17.0	41.0	58.0	0.4	1.0	1.4
10.16	19.0	46.0	66.0	0.5	1.1	1.6

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.10	2.0	1.6	2.0
30	1.22	4.4	3.6	4.4
56	1.32	6.2	5.1	6.2

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	0.61	2.25	1.41
30	0.5	2.12	1.39
65	1.3	2.89	1.37



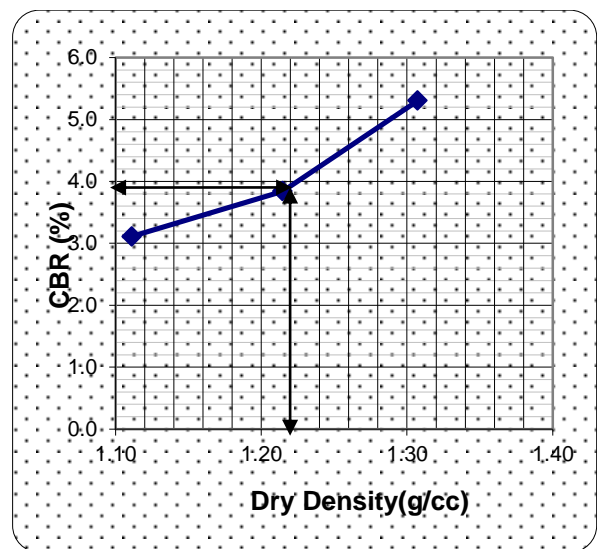
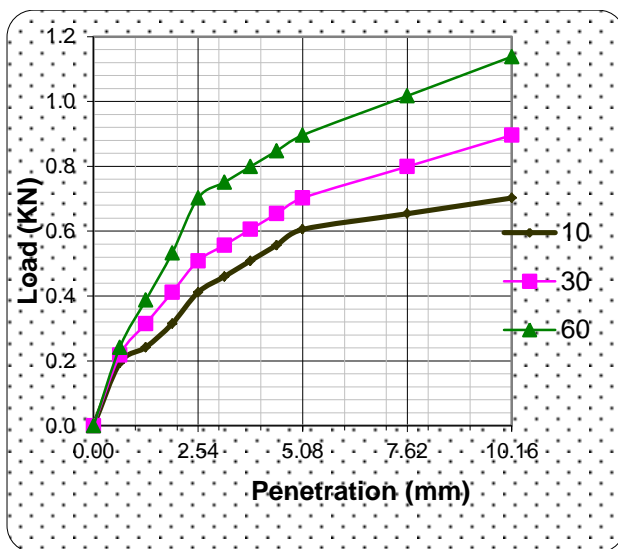
CBR at 95% MDD= 5.4

Sample no 17

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	8.0	9.0	10.0	0.2	0.2	0.2
1.27	10.0	13.0	16.0	0.2	0.3	0.4
1.91	13.0	17.0	22.0	0.3	0.4	0.5
2.54	17.0	21.0	29.0	0.4	0.5	0.7
3.18	19.0	23.0	31.0	0.5	0.6	0.8
3.81	21.0	25.0	33.0	0.5	0.6	0.8
4.45	23.0	27.0	35.0	0.6	0.7	0.8
5.08	25.0	29.0	37.0	0.6	0.7	0.9
7.62	27.0	33.0	42.0	0.7	0.8	1.0
10.16	29.0	37.0	47.0	0.7	0.9	1.1

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.11	3.1	2.5	3.1
30	1.21	3.8	3.0	3.8
56	1.31	5.3	4.0	5.3

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	0.64	2.93	1.97
30	1.13	3.16	1.74
65	0.98	2.87	1.62



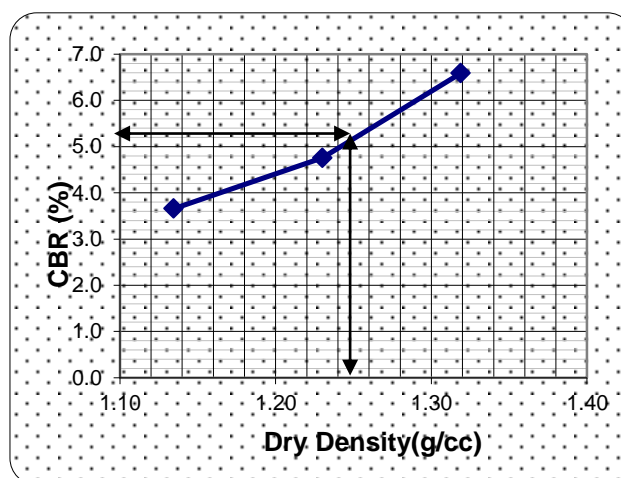
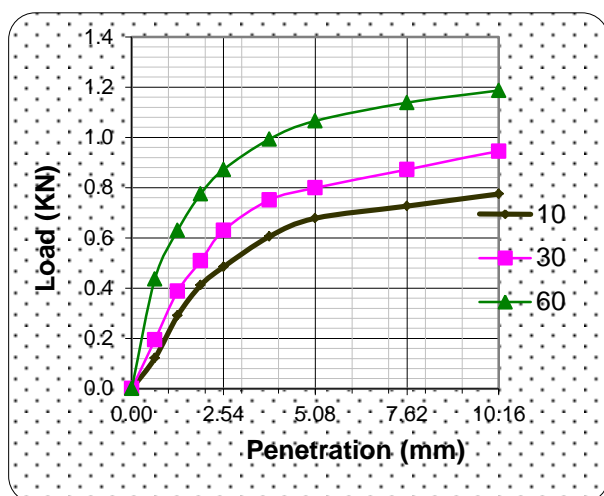
CBR at 95%MDD =3.8

Sample no 18

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	5.0	8.0	18.0	0.1	0.2	0.4
1.27	12.0	16.0	26.0	0.3	0.4	0.6
1.91	17.0	21.0	32.0	0.4	0.5	0.8
2.54	20.0	26.0	36.0	0.5	0.6	0.9
3.81	25.0	31.0	41.0	0.6	0.8	1.0
5.08	28.0	33.0	44.0	0.7	0.8	1.1
7.62	30.0	36.0	47.0	0.7	0.9	1.1
10.16	32.0	39.0	49.0	0.8	0.9	1.2
12.7	34.0	41.0	51.0	0.8	1.0	1.2

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	3.7	3.4	3.7
30	1.23	4.8	4.0	4.8
56	1.32	6.6	5.3	6.6

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	780	970	1.63
30	560	690	1.11
65	487	652	1.41



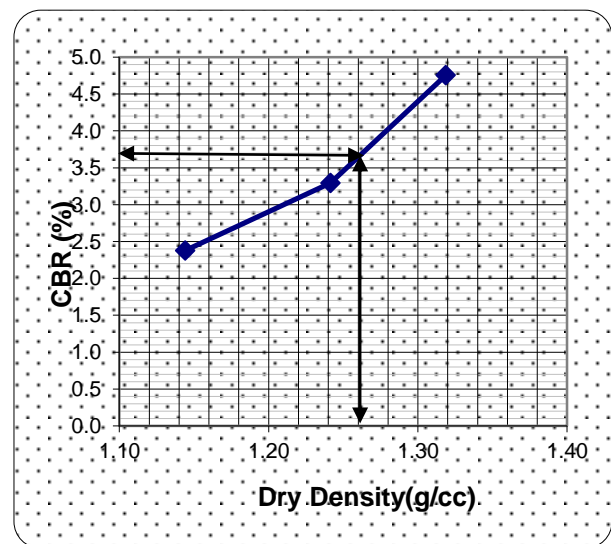
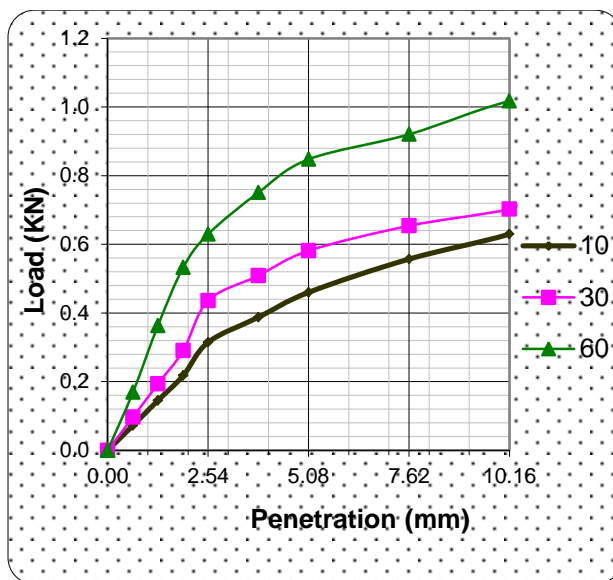
CBR at 95%MDD =5.2

Sample no19

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	3.0	4.0	7.0	0.1	0.1	0.2
1.27	6.0	8.0	15.0	0.1	0.2	0.4
1.91	9.0	12.0	22.0	0.2	0.3	0.5
2.54	13.0	18.0	26.0	0.3	0.4	0.6
3.81	16.0	21.0	31.0	0.4	0.5	0.8
5.08	19.0	24.0	35.0	0.5	0.6	0.8
7.62	23.0	27.0	38.0	0.6	0.7	0.9
10.16	26.0	29.0	42.0	0.6	0.7	1.0
12.7	30.0	32.0	44.0	0.7	0.8	1.1

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.14	2.4	2.3	2.4
30	1.24	3.3	2.9	3.3
56	1.32	4.8	4.2	4.8

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	762	950	1.61
30	504	720	1.85
65	378	650	2.33



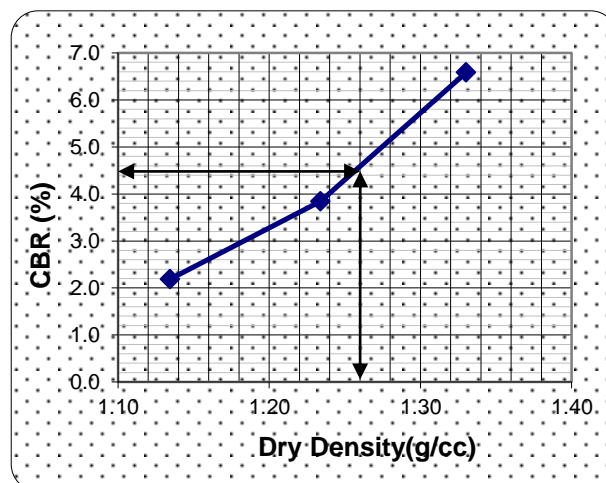
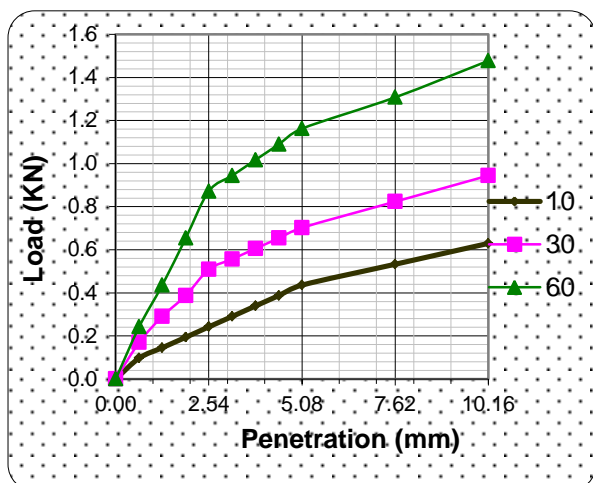
CBR at 95%MDD = 3.6

Sample no 20

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	7.0	10.0	0.1	0.2	0.2
1.27	6.0	12.0	18.0	0.1	0.3	0.4
1.91	8.0	16.0	27.0	0.2	0.4	0.7
2.54	10.0	21.0	36.0	0.2	0.5	0.9
3.18	12.0	23.0	39.0	0.3	0.6	0.9
3.81	14.0	25.0	42.0	0.3	0.6	1.0
4.45	16.0	27.0	45.0	0.4	0.7	1.1
5.08	18.0	29.0	48.0	0.4	0.7	1.2
7.62	22.0	34.0	54.0	0.5	0.8	1.3
10.16	26.0	39.0	61.0	0.6	0.9	1.5

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	1.8	2.2	2.2
30	1.23	3.8	3.5	3.8
56	1.33	6.6	5.8	6.6

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	762	950	1.61
30	504	720	1.85
65	378	650	2.33



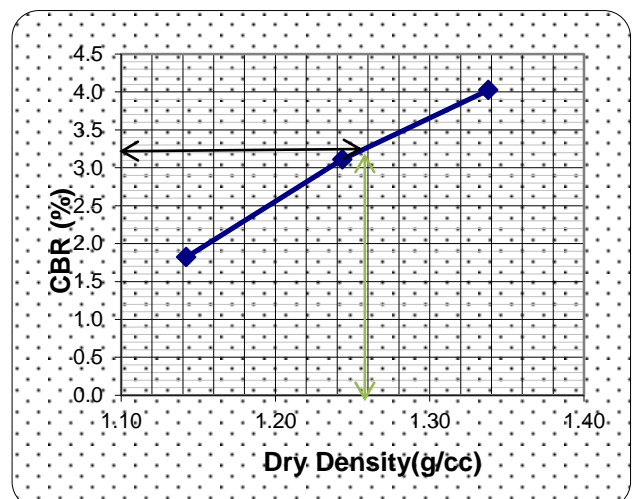
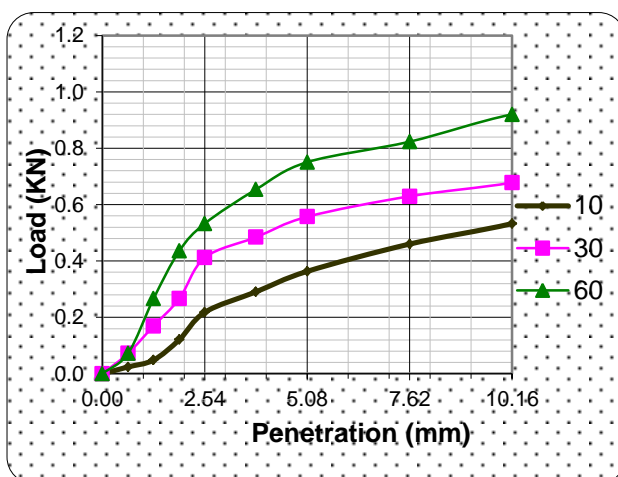
CBR at 95%MDD = 4.6

Sample no 21

PENETRATION DATA						
	Ring Factor (KN/DIV)					0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	1.0	3.0	3.0	0.0	0.1	0.1
1.27	2.0	7.0	11.0	0.0	0.2	0.3
1.91	5.0	11.0	18.0	0.1	0.3	0.4
2.54	9.0	17.0	22.0	0.2	0.4	0.5
3.81	12.0	20.0	27.0	0.3	0.5	0.7
5.08	15.0	23.0	31.0	0.4	0.6	0.8
7.62	19.0	26.0	34.0	0.5	0.6	0.8
10.16	22.0	28.0	38.0	0.5	0.7	0.9
12.7	26.0	31.0	40.0	0.6	0.8	1.0

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.14	1.6	1.8	1.8
30	1.24	3.1	2.8	3.1
56	1.34	4.0	3.8	4.0

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	767	948	1.55
30	508	722	1.83
65	377	652	2.36



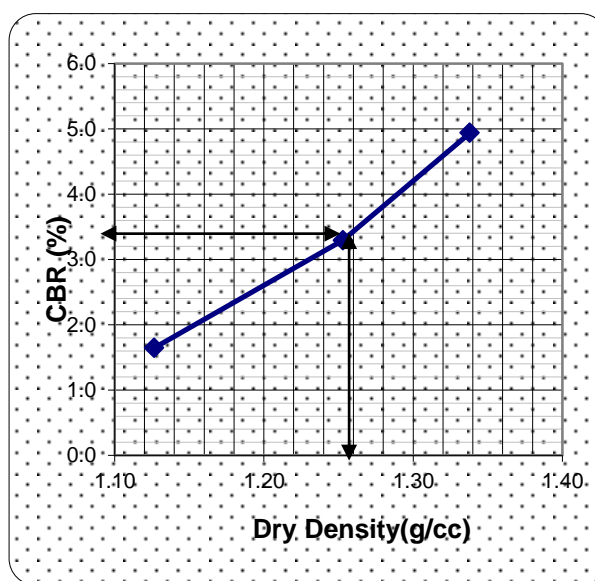
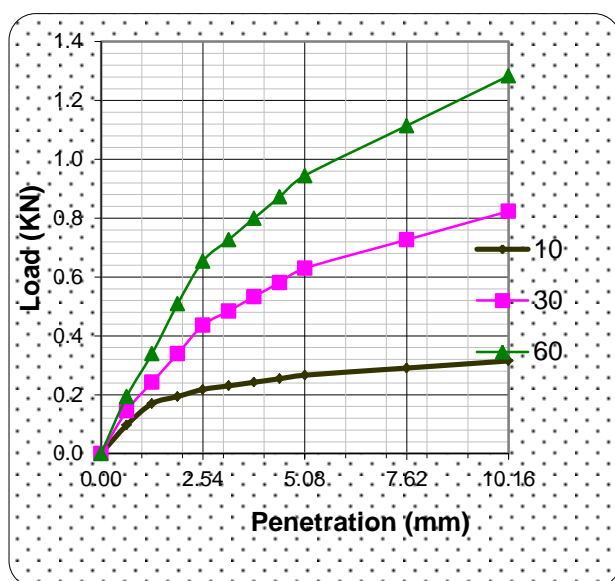
CBR at 95%MDD = 3.2

Sample no 22

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	6.0	8.0	0.1	0.1	0.2
1.27	7.0	10.0	14.0	0.2	0.2	0.3
1.91	8.0	14.0	21.0	0.2	0.3	0.5
2.54	9.0	18.0	27.0	0.2	0.4	0.7
3.18	9.5	20.0	30.0	0.2	0.5	0.7
3.81	10.0	22.0	33.0	0.2	0.5	0.8
4.45	10.5	24.0	36.0	0.3	0.6	0.9
5.08	11.0	26.0	39.0	0.3	0.6	0.9
7.62	12.0	30.0	46.0	0.3	0.7	1.1
10.16	13.0	34.0	53.0	0.3	0.8	1.3

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	1.6	1.3	1.6
30	1.25	3.3	3.2	3.3
56	1.34	4.9	4.7	4.9

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.63	3.16	1.31
30	0.65	2.06	1.21
65	0.33	1.29	0.82



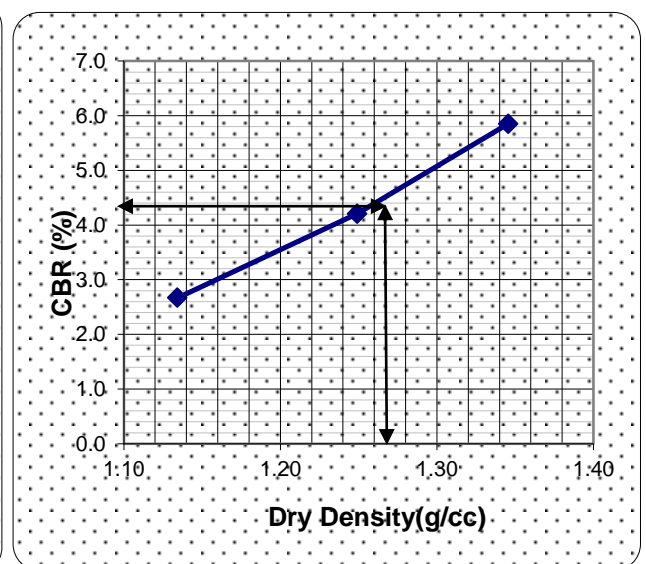
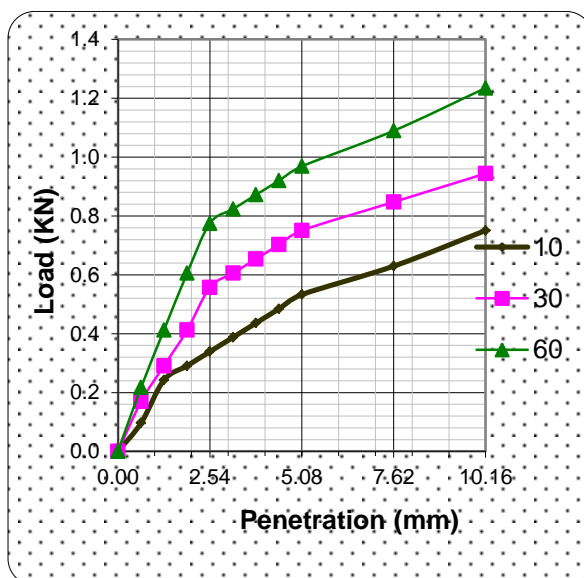
CBR at 95%MDD = 3.3

Sample no 23

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	7.0	9.0	0.1	0.2	0.2
1.27	10.0	12.0	17.0	0.2	0.3	0.4
1.91	12.0	17.0	25.0	0.3	0.4	0.6
2.54	14.0	23.0	32.0	0.3	0.6	0.8
3.18	16.0	25.0	34.0	0.4	0.6	0.8
3.81	18.0	27.0	36.0	0.4	0.7	0.9
4.45	20.0	29.0	38.0	0.5	0.7	0.9
5.08	22.0	31.0	40.0	0.5	0.8	1.0
7.62	26.0	35.0	45.0	0.6	0.8	1.1
10.16	31.0	39.0	51.0	0.8	0.9	1.2

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	2.6	2.7	2.7
30	1.25	4.2	3.8	4.2
56	1.35	5.9	4.9	5.9

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.63	3.16	1.31
30	0.65	2.06	1.21
65	0.33	1.29	0.82



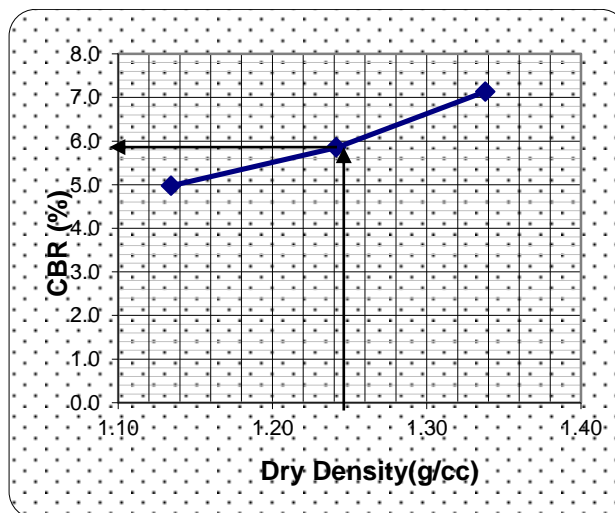
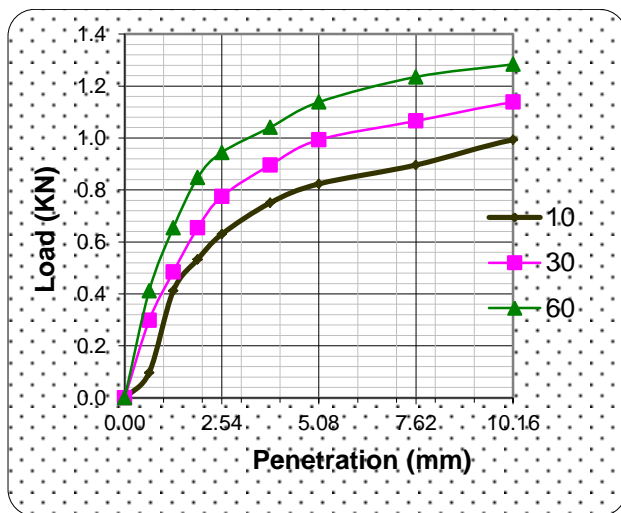
CBR at 95%MDD = 4.4

Sample no 24

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	12.3	17.0	0.1	0.3	0.4
1.27	17.0	20.0	27.0	0.4	0.5	0.7
1.91	22.0	27.0	35.0	0.5	0.7	0.8
2.54	26.0	32.0	39.0	0.6	0.8	0.9
3.81	31.0	37.0	43.0	0.8	0.9	1.0
5.08	34.0	41.0	47.0	0.8	1.0	1.1
7.62	37.0	44.0	51.0	0.9	1.1	1.2
10.16	41.0	47.0	53.0	1.0	1.1	1.3
12.7	43.0	49.0	55.0	1.0	1.2	1.3

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	4.8	5.0	5.0
30	1.24	5.9	5.7	5.9
56	1.34	7.1	6.4	7.1

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	483	650	1.43
30	519	710	1.64
65	608	812	1.75



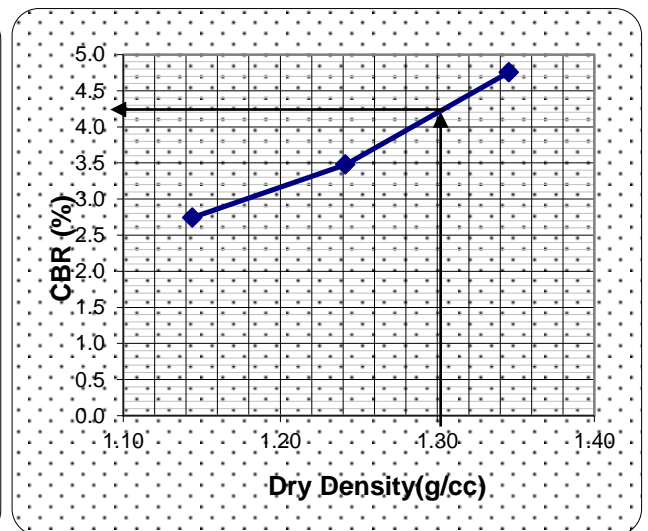
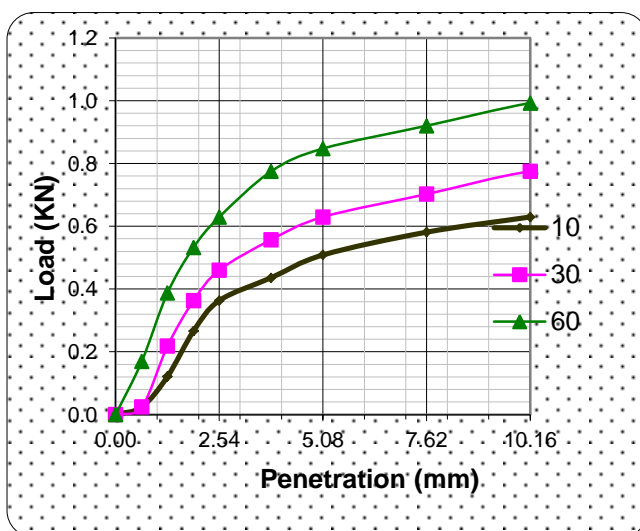
CBR at 95%MDD = 5.9

Sample no 25

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	1.0	1.0	7.0	0.0	0.0	0.2
1.27	5.0	9.0	16.0	0.1	0.2	0.4
1.91	11.0	15.0	22.0	0.3	0.4	0.5
2.54	15.0	19.0	26.0	0.4	0.5	0.6
3.81	18.0	23.0	32.0	0.4	0.6	0.8
5.08	21.0	26.0	35.0	0.5	0.6	0.8
7.62	24.0	29.0	38.0	0.6	0.7	0.9
10.16	26.0	32.0	41.0	0.6	0.8	1.0
12.7	28.0	33.0	43.0	0.7	0.8	1.0

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.14	2.7	2.5	2.7
30	1.24	3.5	3.2	3.5
56	1.35	4.8	4.2	4.8

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	456	580	1.06
30	521	655	1.15
65	560	630	0.6



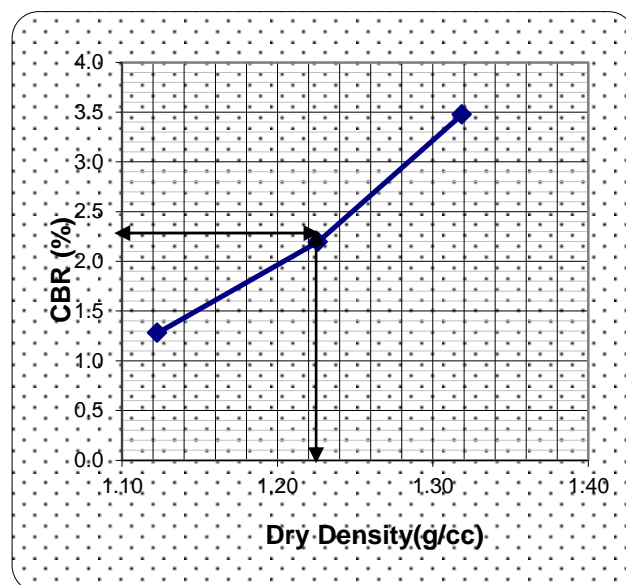
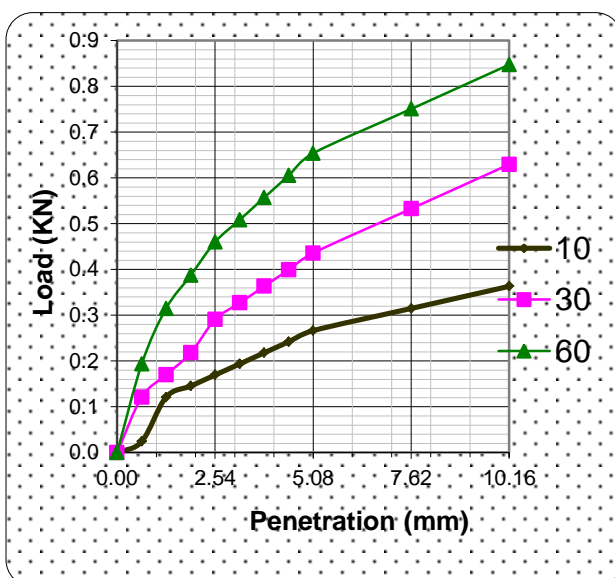
CBR at 95%MDD = 4.4

Sample no 26

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	1.0	5.0	8.0	0.0	0.1	0.2
1.27	5.0	7.0	13.0	0.1	0.2	0.3
1.91	6.0	9.0	16.0	0.1	0.2	0.4
2.54	7.0	12.0	19.0	0.2	0.3	0.5
3.18	8.0	13.5	21.0	0.2	0.3	0.5
3.81	9.0	15.0	23.0	0.2	0.4	0.6
4.45	10.0	16.5	25.0	0.2	0.4	0.6
5.08	11.0	18.0	27.0	0.3	0.4	0.7
7.62	13.0	22.0	31.0	0.3	0.5	0.8
10.16	15.0	26.0	35.0	0.4	0.6	0.8

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.12	1.3	1.1	1.3
30	1.23	2.2	1.8	2.2
56	1.32	3.5	2.8	3.5

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.11	3.44	2
30	0.56	2.87	1.98
65	0.87	3.14	1.95



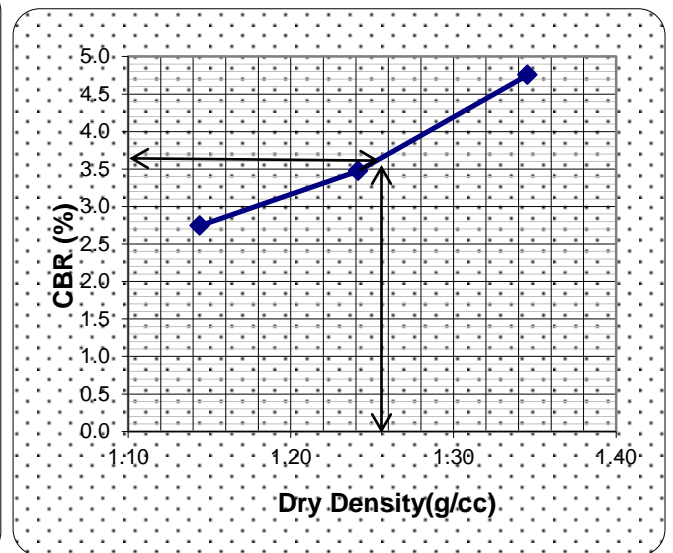
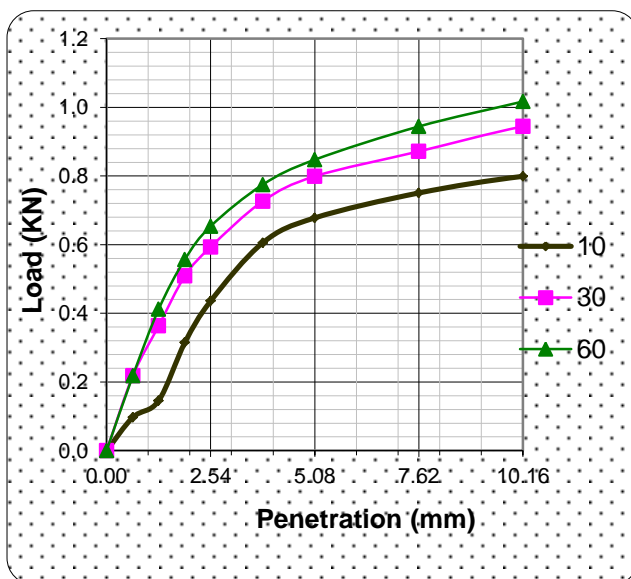
CBR at 95%MDD = 2.3

Sample no 27

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	9.0	9.0	0.1	0.2	0.2
1.27	6.0	15.0	17.0	0.1	0.4	0.4
1.91	13.0	21.0	23.0	0.3	0.5	0.6
2.54	18.0	24.5	27.0	0.4	0.6	0.7
3.81	25.0	30.0	32.0	0.6	0.7	0.8
5.08	28.0	33.0	35.0	0.7	0.8	0.8
7.62	31.0	36.0	39.0	0.8	0.9	0.9
10.16	33.0	39.0	42.0	0.8	0.9	1.0
12.7	34.0	41.0	45.0	0.8	1.0	1.1

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.12	3.3	3.4	3.4
30	1.24	4.5	4.0	4.5
56	1.35	4.9	4.2	4.9

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	98	175	0.66
30	16	290	2.35
65	105	512	3.49



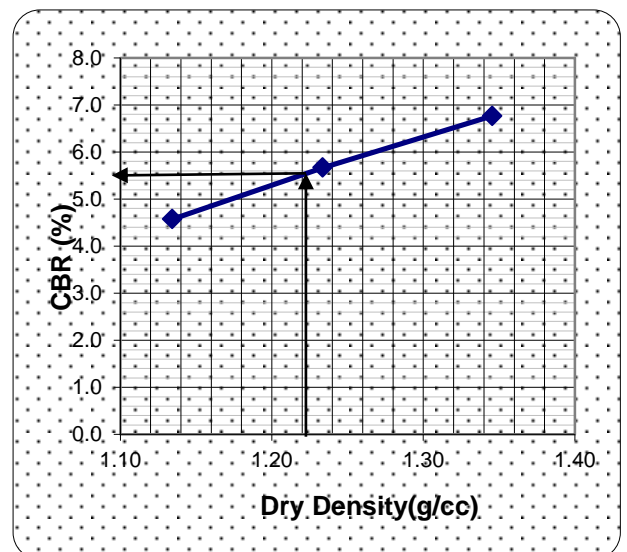
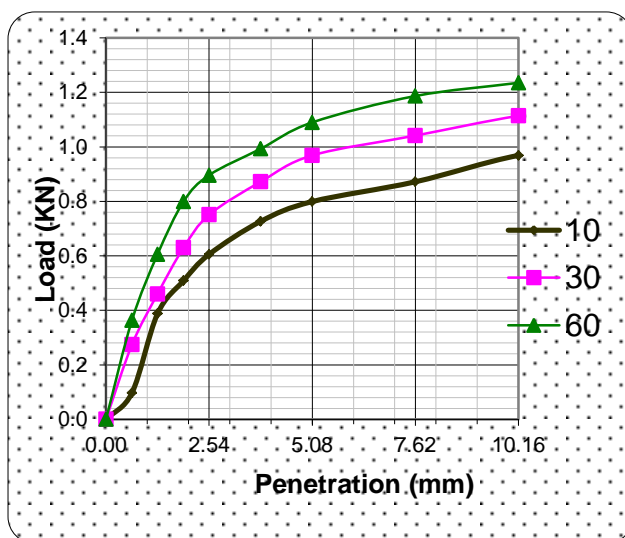
CBR at 95%MDD = 3.6

Sample no 28

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	11.3	15.0	0.1	0.3	0.4
1.27	16.0	19.0	25.0	0.4	0.5	0.6
1.91	21.0	26.0	33.0	0.5	0.6	0.8
2.54	25.0	31.0	37.0	0.6	0.8	0.9
3.81	30.0	36.0	41.0	0.7	0.9	1.0
5.08	33.0	40.0	45.0	0.8	1.0	1.1
7.62	36.0	43.0	49.0	0.9	1.0	1.2
10.16	40.0	46.0	51.0	1.0	1.1	1.2
12.7	42.0	48.0	53.0	1.0	1.2	1.3

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	4.6	4.0	4.6
30	1.23	5.7	4.9	5.7
56	1.35	6.8	5.5	6.8

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	587	756	1.45
30	658	895	2.03
65	745	987	2.07



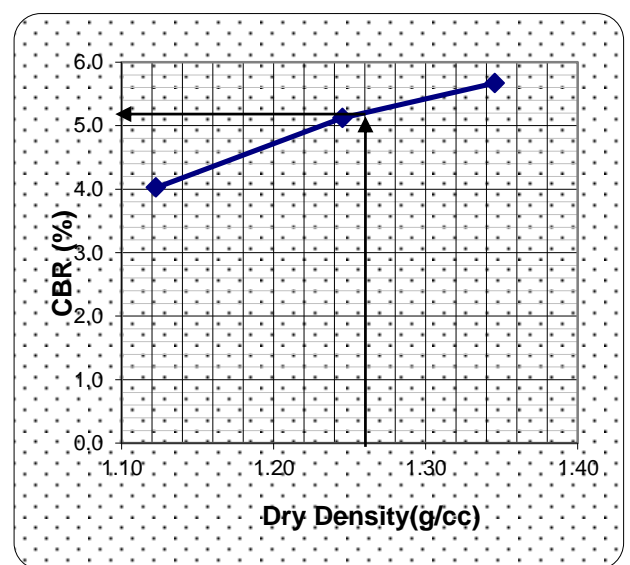
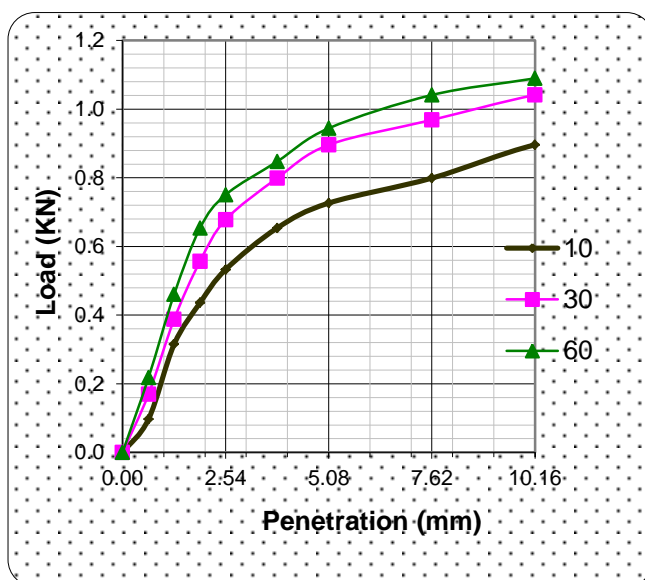
CBR at 95%MDD = 5.6

Sample no 29

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	7.0	9.0	0.1	0.2	0.2
1.27	13.0	16.0	19.0	0.3	0.4	0.5
1.91	18.0	23.0	27.0	0.4	0.6	0.7
2.54	22.0	28.0	31.0	0.5	0.7	0.8
3.81	27.0	33.0	35.0	0.7	0.8	0.8
5.08	30.0	37.0	39.0	0.7	0.9	0.9
7.62	33.0	40.0	43.0	0.8	1.0	1.0
10.16	37.0	43.0	45.0	0.9	1.0	1.1
12.7	39.0	45.0	47.0	0.9	1.1	1.1

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.12	4.0	3.6	4.0
30	1.25	5.1	4.5	5.1
56	1.35	5.7	4.7	5.7

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	585	759	1.49
30	650	898	2.13
65	740	983	2.08



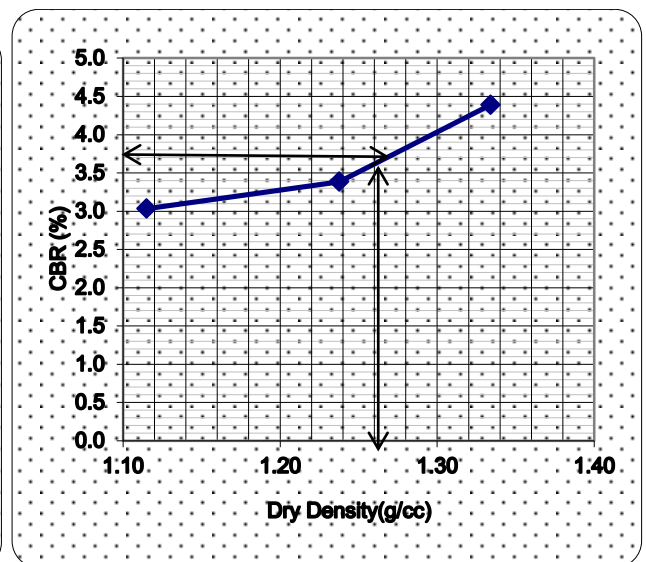
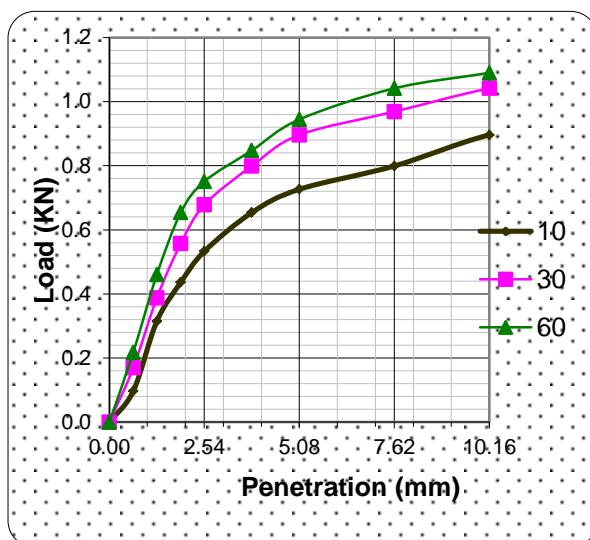
CBR at 95%MDD = 5.2

Sample no 30

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	2.0	6.0	0.1	0.0	0.1
1.27	3.0	9.0	14.0	0.1	0.2	0.3
1.91	10.0	15.0	20.0	0.2	0.4	0.5
2.54	15.0	18.5	24.0	0.4	0.4	0.6
3.81	22.0	24.0	29.0	0.5	0.6	0.7
5.08	25.0	27.0	32.0	0.6	0.7	0.8
7.62	28.0	30.0	36.0	0.7	0.7	0.9
10.16	30.0	33.0	39.0	0.7	0.8	0.9
12.7	31.0	35.0	42.0	0.8	0.8	1.0

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.12	2.7	3.0	3.0
30	1.24	3.4	3.3	3.4
56	1.33	4.4	3.9	4.4

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	587	756	1.45
30	658	895	2.03
65	745	987	2.07



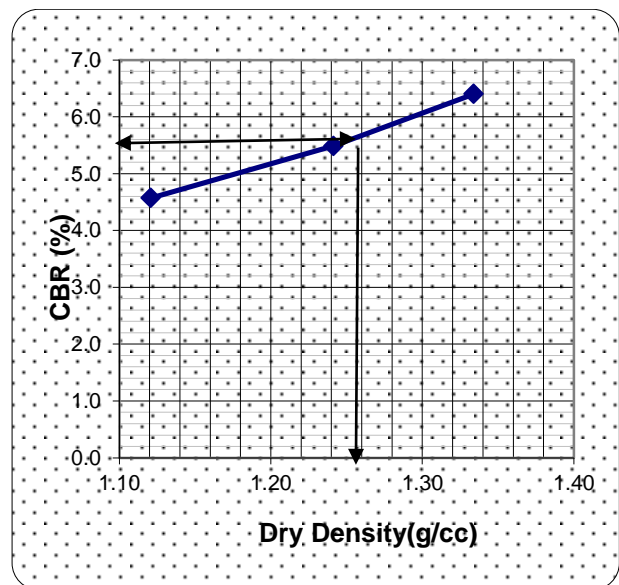
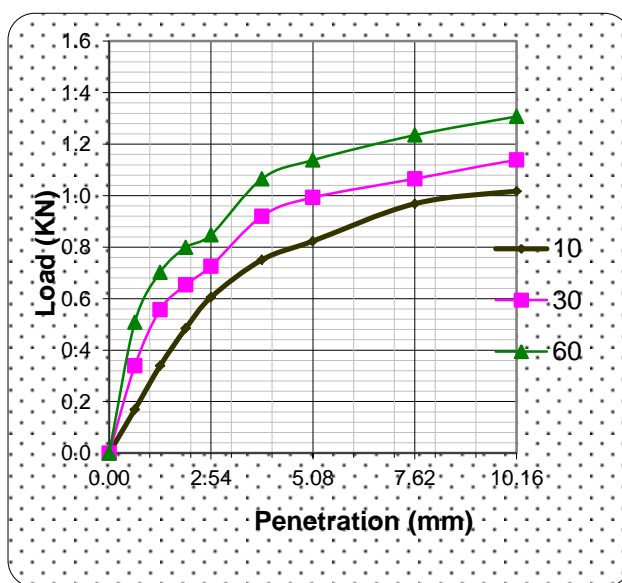
CBR at 95%MDD = 3.7

Sample no 31

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	7.0	14.0	21.0	0.2	0.3	0.5
1.27	14.0	23.0	29.0	0.3	0.6	0.7
1.91	20.0	27.0	33.0	0.5	0.7	0.8
2.54	25.0	30.0	35.0	0.6	0.7	0.8
3.81	31.0	38.0	44.0	0.8	0.9	1.1
5.08	34.0	41.0	47.0	0.8	1.0	1.1
7.62	40.0	44.0	51.0	1.0	1.1	1.2
10.16	42.0	47.0	54.0	1.0	1.1	1.3
12.7	43.0	49.0	57.0	1.0	1.2	1.4

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.12	4.6	4.1	4.6
30	1.24	5.5	5.0	5.5
56	1.33	6.4	5.7	6.4

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.11	3.44	2.00
30	0.56	2.87	1.98
56	0.87	3.14	1.95



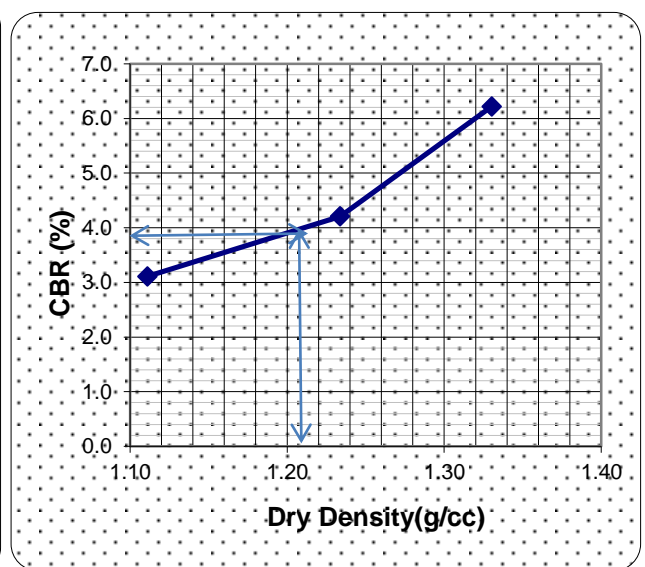
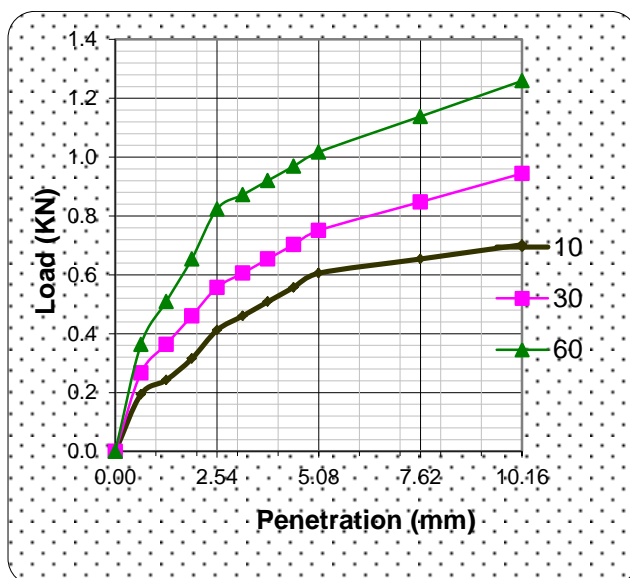
CBR at 95%MDD = 5.6

Sample no 32

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	8.0	11.0	15.0	0.2	0.3	0.4
1.27	10.0	15.0	21.0	0.2	0.4	0.5
1.91	13.0	19.0	27.0	0.3	0.5	0.7
2.54	17.0	23.0	34.0	0.4	0.6	0.8
3.18	19.0	25.0	36.0	0.5	0.6	0.9
3.81	21.0	27.0	38.0	0.5	0.7	0.9
4.45	23.0	29.0	40.0	0.6	0.7	1.0
5.08	25.0	31.0	42.0	0.6	0.8	1.0
7.62	27.0	35.0	47.0	0.7	0.8	1.1
10.16	29.0	39.0	52.0	0.7	0.9	1.3

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.11	3.1	2.5	3.1
30	1.23	4.2	3.3	4.2
56	1.33	6.2	4.6	6.2

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	0.64	2.93	1.97
30	1.13	3.16	1.74
65	0.98	2.87	1.62



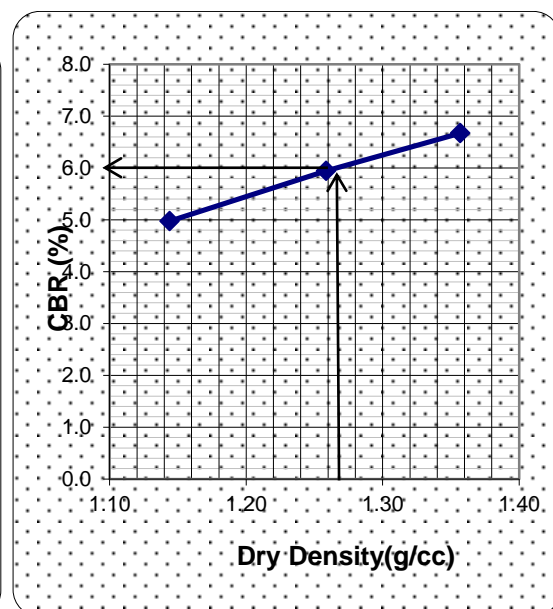
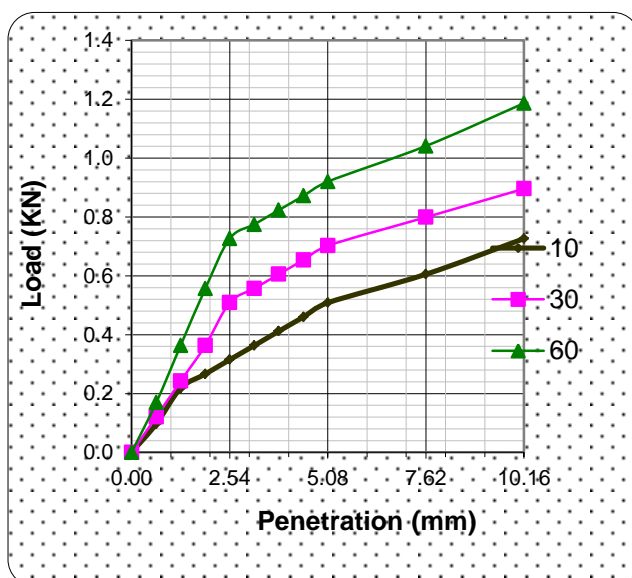
CBR at 95%MDD = 3.9

Sample no 33

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	5.0	7.0	0.1	0.1	0.2
1.27	9.0	10.0	15.0	0.2	0.2	0.4
1.91	11.0	15.0	23.0	0.3	0.4	0.6
2.54	13.0	21.0	30.0	0.3	0.5	0.7
3.18	15.0	23.0	32.0	0.4	0.6	0.8
3.81	17.0	25.0	34.0	0.4	0.6	0.8
4.45	19.0	27.0	36.0	0.5	0.7	0.9
5.08	21.0	29.0	38.0	0.5	0.7	0.9
7.62	25.0	33.0	43.0	0.6	0.8	1.0
10.16	30.0	37.0	49.0	0.7	0.9	1.2

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.14	4.4	5.0	5.0
30	1.26	5.9	5.9	5.9
56	1.36	6.6	6.7	6.7

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.63	3.16	1.31
30	0.65	2.06	1.21
65	0.33	1.29	0.82



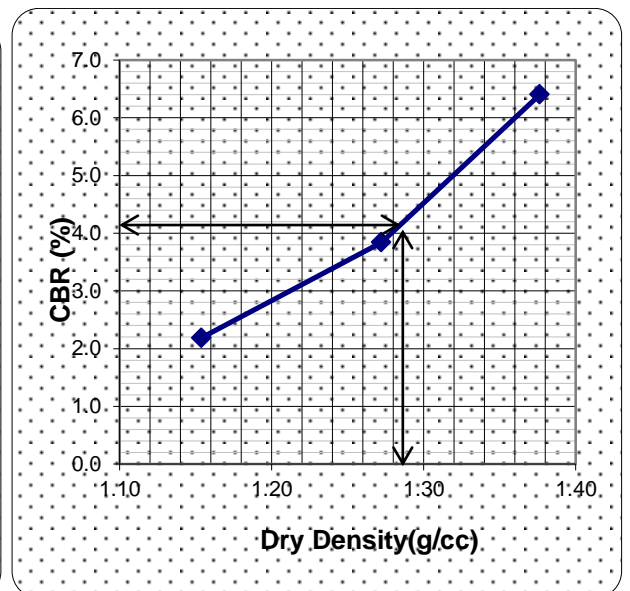
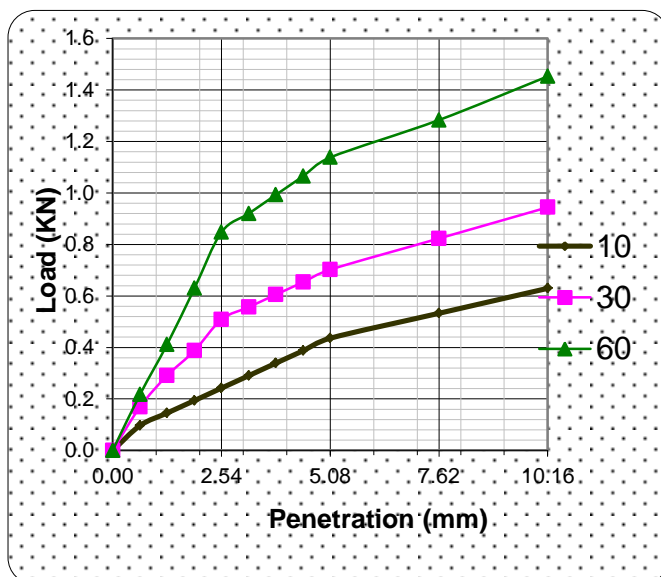
CBR at 95%MDD =6

Sample no 34

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	4.0	7.0	9.0	0.1	0.2	0.2
1.27	6.0	12.0	17.0	0.1	0.3	0.4
1.91	8.0	16.0	26.0	0.2	0.4	0.6
2.54	10.0	21.0	35.0	0.2	0.5	0.8
3.18	12.0	23.0	38.0	0.3	0.6	0.9
3.81	14.0	25.0	41.0	0.3	0.6	1.0
4.45	16.0	27.0	44.0	0.4	0.7	1.1
5.08	18.0	29.0	47.0	0.4	0.7	1.1
7.62	22.0	34.0	53.0	0.5	0.8	1.3
10.16	26.0	39.0	60.0	0.6	0.9	1.5

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.15	1.8	2.2	2.2
30	1.27	3.8	3.5	3.8
56	1.38	6.4	5.7	6.4

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.21	3.48	1.95
30	0.65	2.93	1.96
56	0.84	3.07	1.92



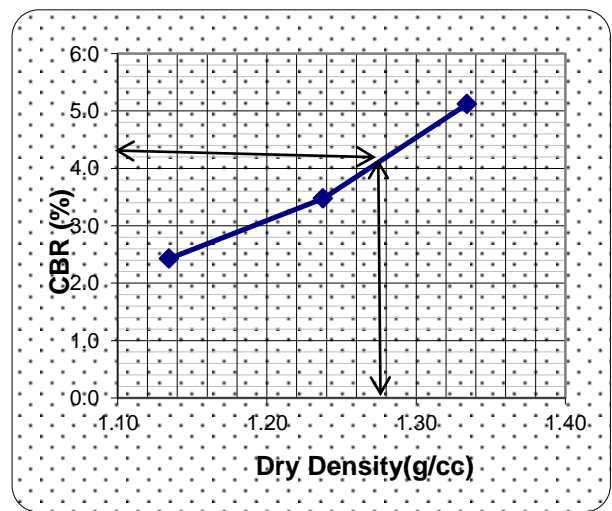
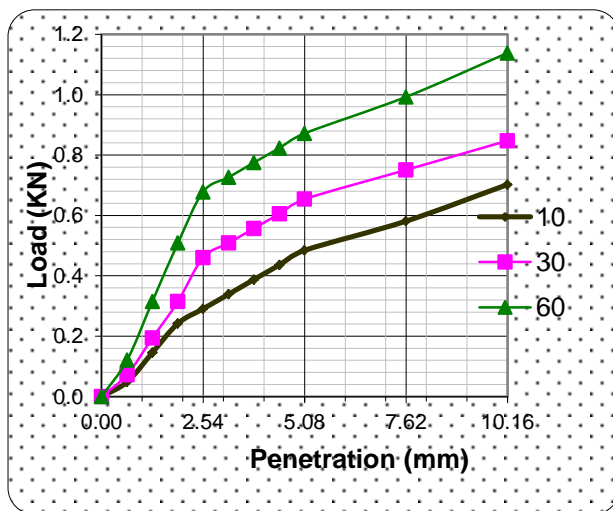
CBR at 95%MDD =4.1

Sample no 35

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
Pen.(mm)	10	30	65	10	30	65
	Dial Reading	Dial Reading	Dial Reading	Load (KN)	Load (KN)	Load (KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	2.0	3.0	5.0	0.0	0.1	0.1
1.27	6.0	8.0	13.0	0.1	0.2	0.3
1.91	10.0	13.0	21.0	0.2	0.3	0.5
2.54	12.0	19.0	28.0	0.3	0.5	0.7
3.18	14.0	21.0	30.0	0.3	0.5	0.7
3.81	16.0	23.0	32.0	0.4	0.6	0.8
4.45	18.0	25.0	34.0	0.4	0.6	0.8
5.08	20.0	27.0	36.0	0.5	0.7	0.9
7.62	24.0	31.0	41.0	0.6	0.8	1.0
10.16	29.0	35.0	47.0	0.7	0.8	1.1

No. of Blows	DD (g/cm3)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.13	2.2	2.4	2.4
30	1.24	3.5	3.3	3.5
56	1.33	5.1	4.4	5.1

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	1.52	3.01	1.28
30	0.71	1.98	1.09
65	0.32	1.31	0.85



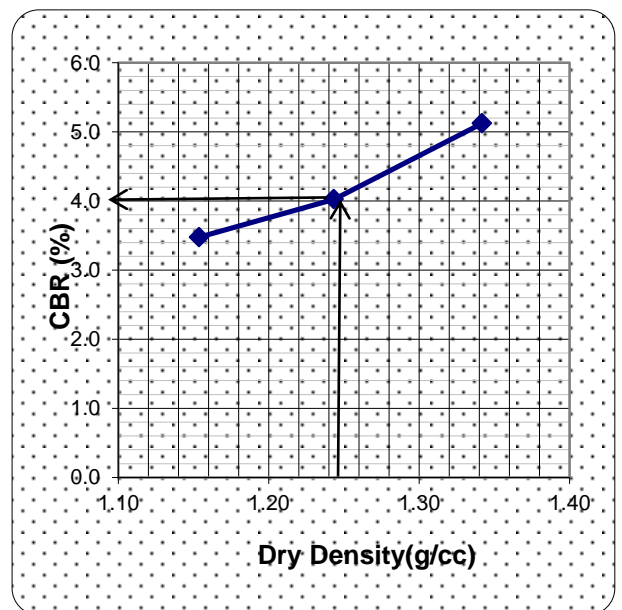
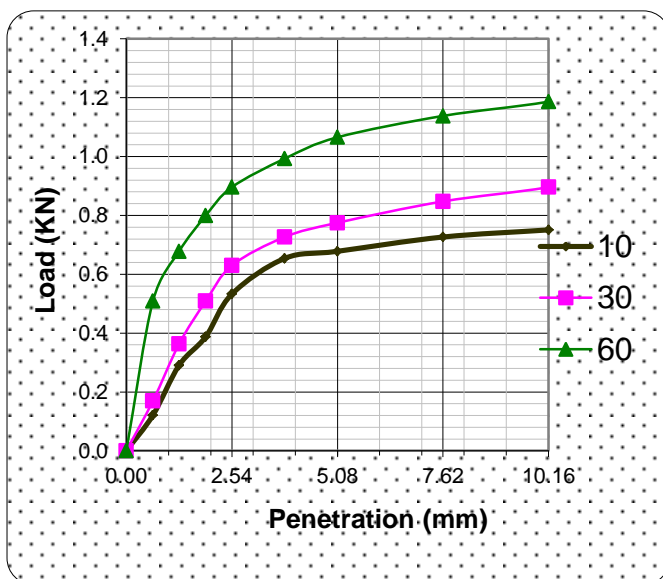
CBR at 95%MDD =5.3

Sample no 36

PENETRATION DATA						
Ring Factor (KN/DIV)						0.024217
						0.042419
	10	30	65	10	30	65
Pen.(mm)	Dial	Dial	Dial	Load	Load	Load
	Reading	Reading	Reading	(KN)	(KN)	(KN)
0	0.0	0.0	0.0	0.0	0.0	0.0
0.64	2.0	3.0	12.0	0.0	0.1	0.3
1.27	9.0	11.0	19.0	0.2	0.3	0.5
1.91	13.0	17.0	24.0	0.3	0.4	0.6
2.54	19.0	22.0	28.0	0.5	0.5	0.7
3.81	24.0	26.0	32.0	0.6	0.6	0.8
5.08	25.0	28.0	35.0	0.6	0.7	0.8
7.62	27.0	31.0	38.0	0.7	0.8	0.9
10.16	28.0	33.0	40.0	0.7	0.8	1.0
12.7	29.0	36.0	43.0	0.7	0.9	1.0

No. of Blows	DD (g/cm ³)	CBR %		CBR (%)
		2.54mm	5.08mm	
10	1.15	3.5	3.0	3.5
30	1.24	4.0	3.4	4.0
56	1.34	5.1	4.2	5.1

No. of Blows	Swell Data		
	Initial R.	Final R.	Swell (%)
10	0.61	2.92	1.98
30	1.59	3.06	1.26
65	1.01	2.91	1.63



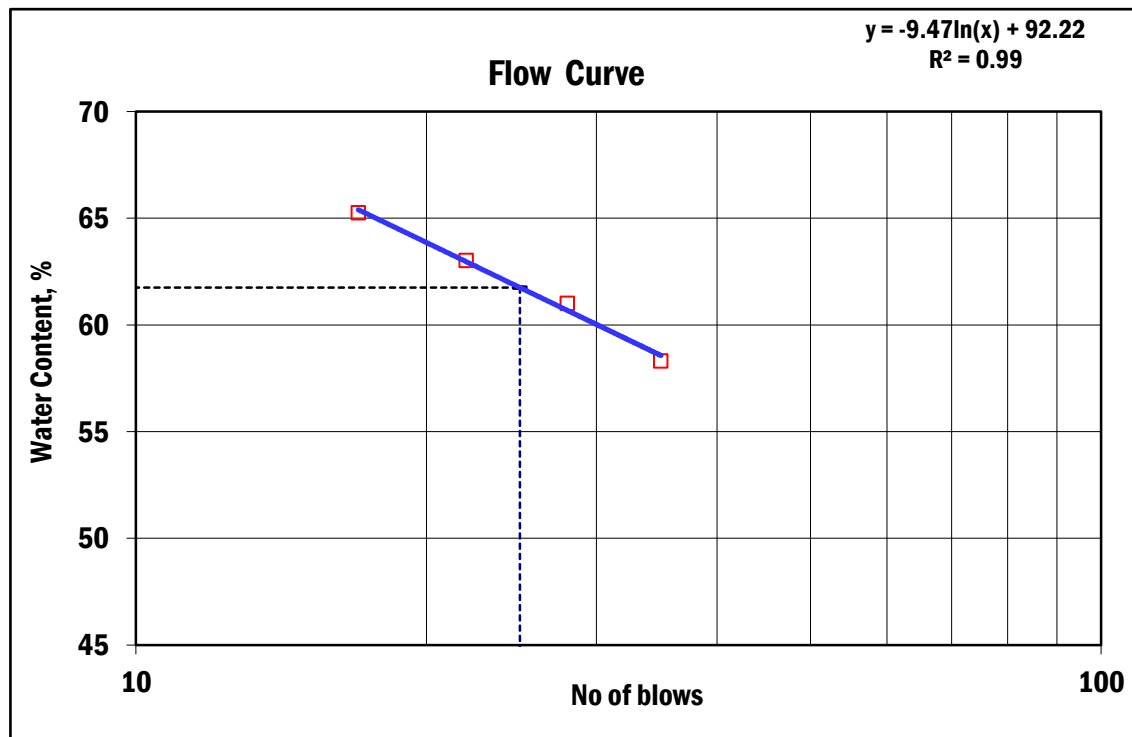
CBR at 95%MDD =4

APPENDIX C – ATTERBERG LIMITS

Sample no 1

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	36	10	D26	C12	D11	C35
Mass of container, g	15.61	15.43	21.95	15.56	15.67	13.69
Mass of container + Wet soil, g	35.13	34.22	38.79	32.78	17.2	15.17
Mass of container + Dry soil, g	27.94	27.1	32.28	25.98	16.85	14.8
Mass of water, g	7.19	7.12	6.51	6.8	0.35	0.37
Mass of dry soil, g	12.33	11.67	10.33	10.42	1.18	1.11
Water content, %	58.31	61.01	63.02	65.26	29.66	33.33
No of blows	35	28	22	17	-----	-----

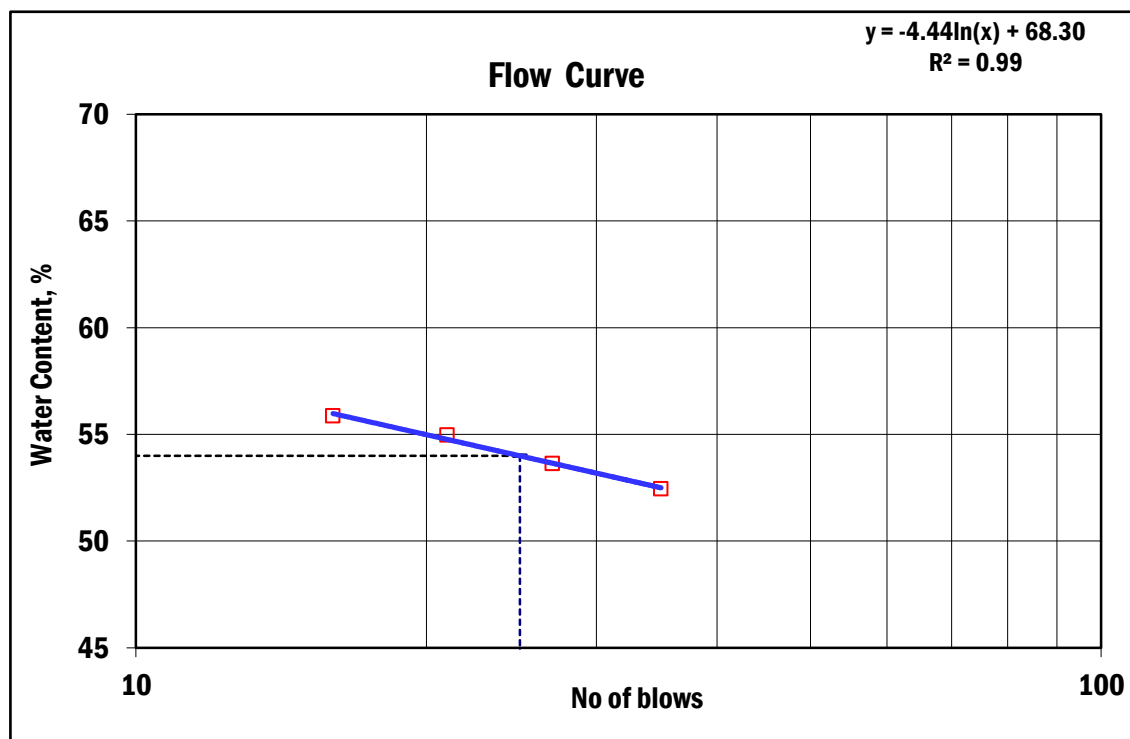
Liquid Limit, % = 62 Plastic Limit, % = 31 PI, %= 31



Sample no 2

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	26	A36	C31	C18	C34	71
Mass of container, g	14.16	15.42	13.7	15.45	15.38	15.6
Mass of container + Wet soil, g	35.99	32.35	34.48	32.08	16.60	17.53
Mass of container + Dry soil, g	28.48	26.44	27.11	26.12	16.32	17.1
Mass of water, g	7.51	5.91	7.37	5.96	0.2766	0.42863
Mass of dry soil, g	14.32	11.02	13.41	10.67	0.94	1.5
Water content, %	52.44	53.63	54.96	55.86	29.43	28.58
No of blows	35	27	21	16	-----	-----

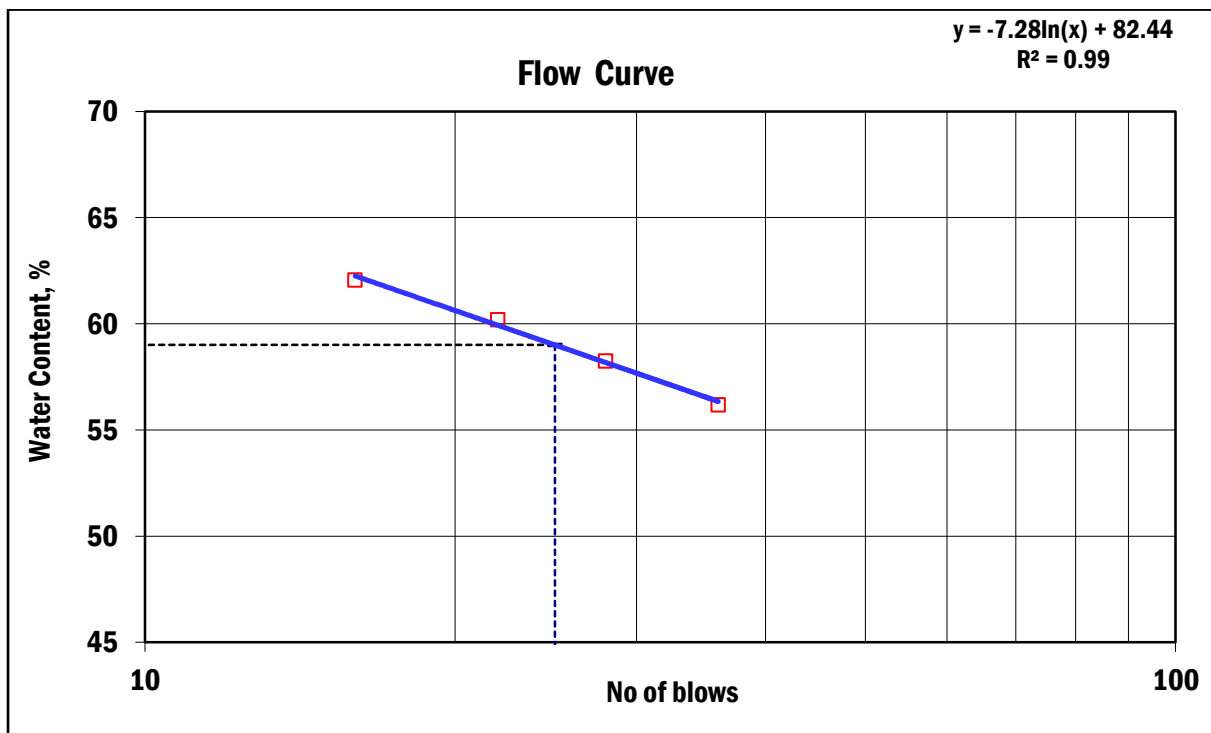
Liquid Limit, % = 54 Plastic Limit, % = 29 PI, % = 25



Sample no 3

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C10	14	33	17	B10	43
Mass of container, g	15.66	15.61	15.61	13.82	15.66	14.06
Mass of container + Wet soil, g	32.50	36.40	36.64	40.27	17.88	16.21
Mass of container + Dry soil, g	26.44	28.75	28.74	30.14	17.37	15.71
Mass of water, g	6.06	7.65	7.90	10.13	0.51	0.50
Mass of dry soil, g	10.78	13.14	13.13	16.32	1.71	1.65
Water content, %	56.19	58.25	60.20	62.07	29.75	30.25
No of blows	36	28	22	16	-----	-----

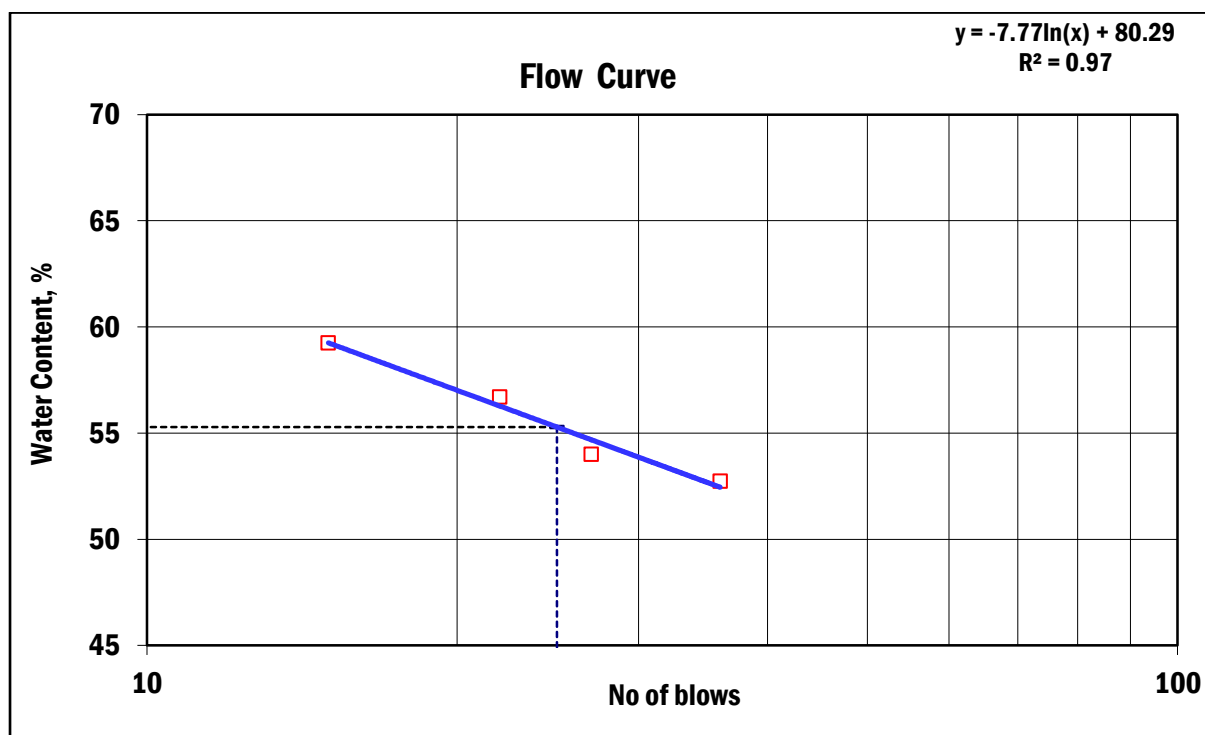
Liquid Limit, % = 59 Plastic Limit, % = 30 PI, % = 29



Sample no 4

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	33	D35	C15	A18	C23	14
Mass of container, g	15.2	15.6	15.34	15.44	15.2	15.33
Mass of container + Wet soil, g	33.68	35.62	34.55	35.6	17.84	17.88
Mass of container + Dry soil, g	27.3	28.6	27.6	28.1	17.29	17.35
Mass of water, g	6.38	7.02	6.95	7.50	0.55	0.53
Mass of dry soil, g	12.10	13.00	12.26	12.66	2.09	2.02
Water content, %	52.73	54.00	56.69	59.24	26.32	26.24
No of blows	36	27	22	15	-----	-----

Liquid Limit, % = 55 Plastic Limit, % = 26 PI, % = 29



Sample no 5

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	24	C15	D61	D33	A14	D22
Mass of container, g	15.75	15.5	15.56	15.5	15.67	15.76
Mass of container + Wet soil, g	41.62	34.35	35.05	39.24	17.99	18.24
Mass of container + Dry soil, g	32.1	27.23	27.56	29.96	17.46	17.66
Mass of water, g	9.52	7.12	7.49	9.28	0.53	0.58
Mass of dry soil, g	16.35	11.73	12.00	14.46	1.79	1.90
Water content, %	58.22	60.72	62.45	64.17	29.61	30.39
No of blows	35	27	21	16	-----	-----

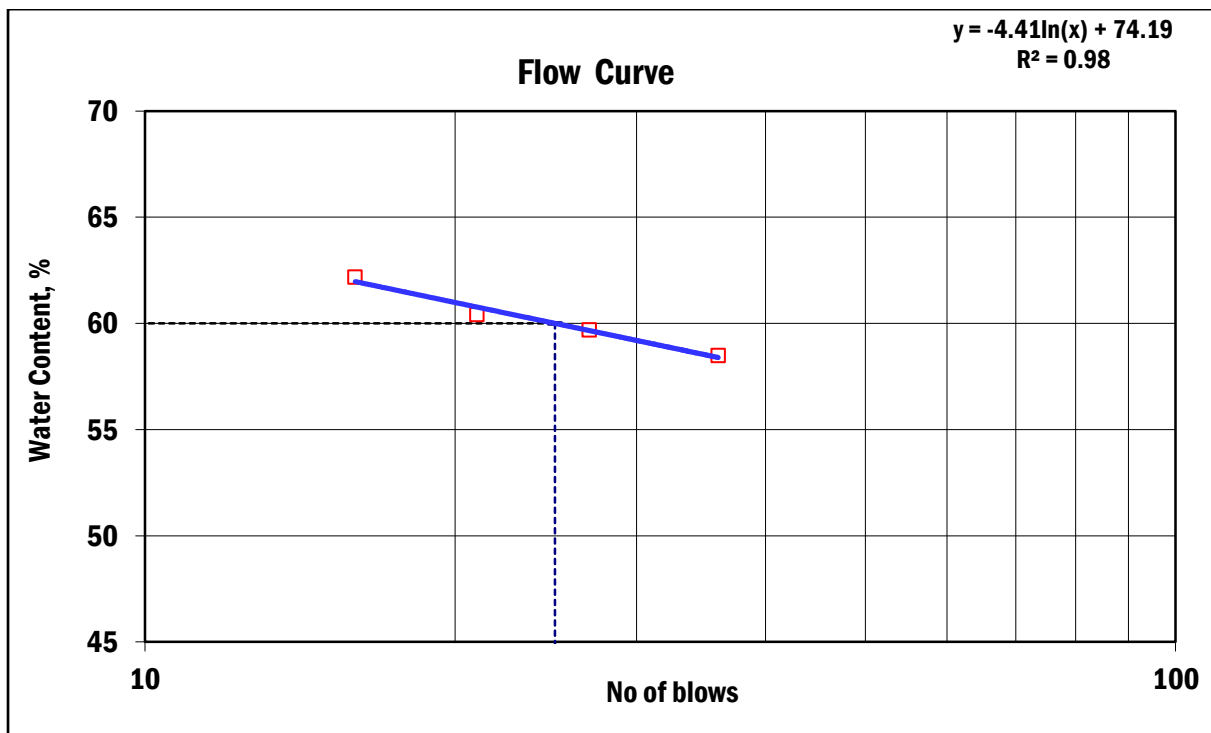
Liquid Limit, % = 61 Plastic Limit, % = 30 PI, % = 31



Sample no 6

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	c29	45	D31	A18	26	41
Mass of container, g	14.68	16.76	16.67	16.49	15.62	15.6
Mass of container + Wet soil, g	30.08	34.28	36.16	34.09	17.19	17.02
Mass of container + Dry soil, g	24.4	27.73	28.82	27.34	16.82	16.69
Mass of water, g	5.68	6.55	7.34	6.75	0.37	0.33
Mass of dry soil, g	9.72	10.97	12.15	10.85	1.20	1.09
Water content, %	58.49	59.69	60.42	62.19	30.83	30.28
No of blows	36	27	21	16	-----	-----

Liquid Limit, % = 60 Plastic Limit, % = 31 PI, % = 29



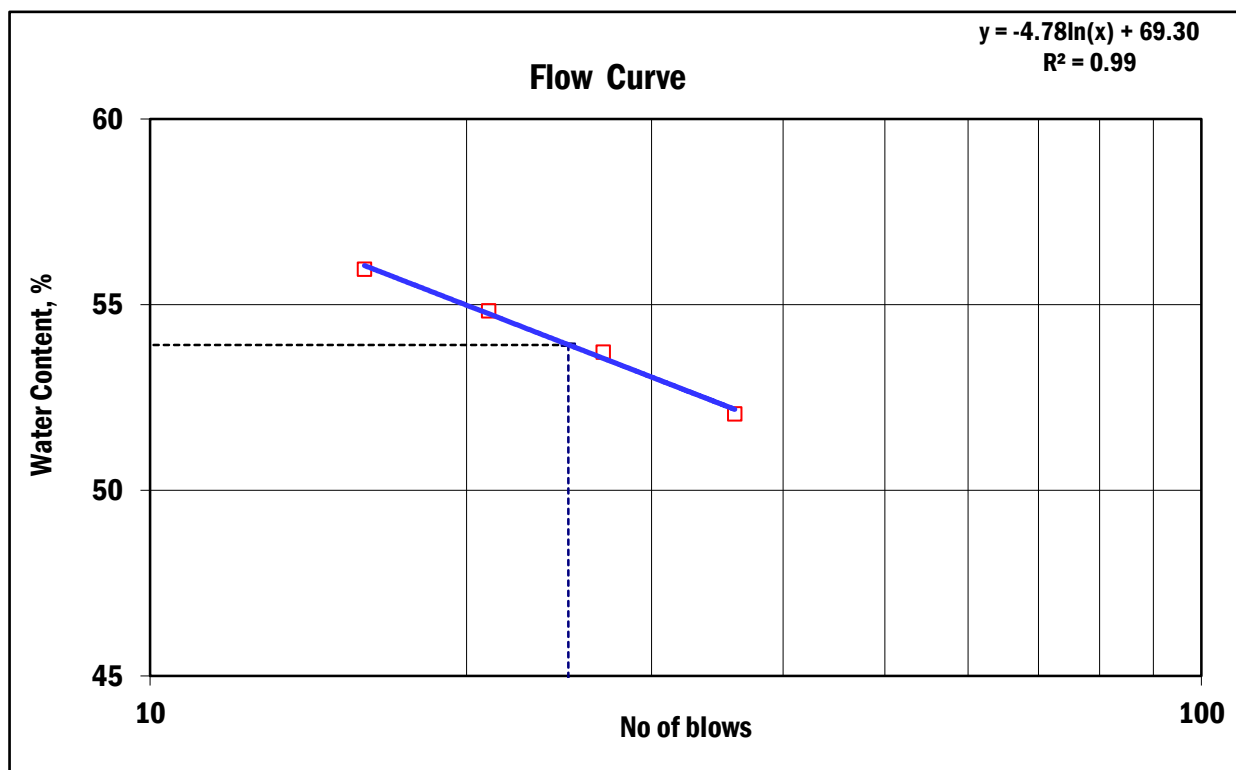
Sample no 7

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	c29	45	D31	A18	26	41
Mass of container, g	13.68	15.76	15.67	15.49	15.62	15.60
Mass of container + Wet soil, g	29.98	34.16	36.03	33.97	17.19	17.02
Mass of container + Dry soil, g	24.40	27.73	28.82	27.34	16.81	16.69
Mass of water, g	5.58	6.43	7.21	6.63	0.38	0.33
Mass of dry soil, g	10.72	11.97	13.15	11.85	1.19	1.09
Water content, %	52.05	53.72	54.83	55.95	31.93	30.28
No of blows	36	27	21	16	-----	-----

Liquid Limit, % = 54

Plastic Limit, % = 31

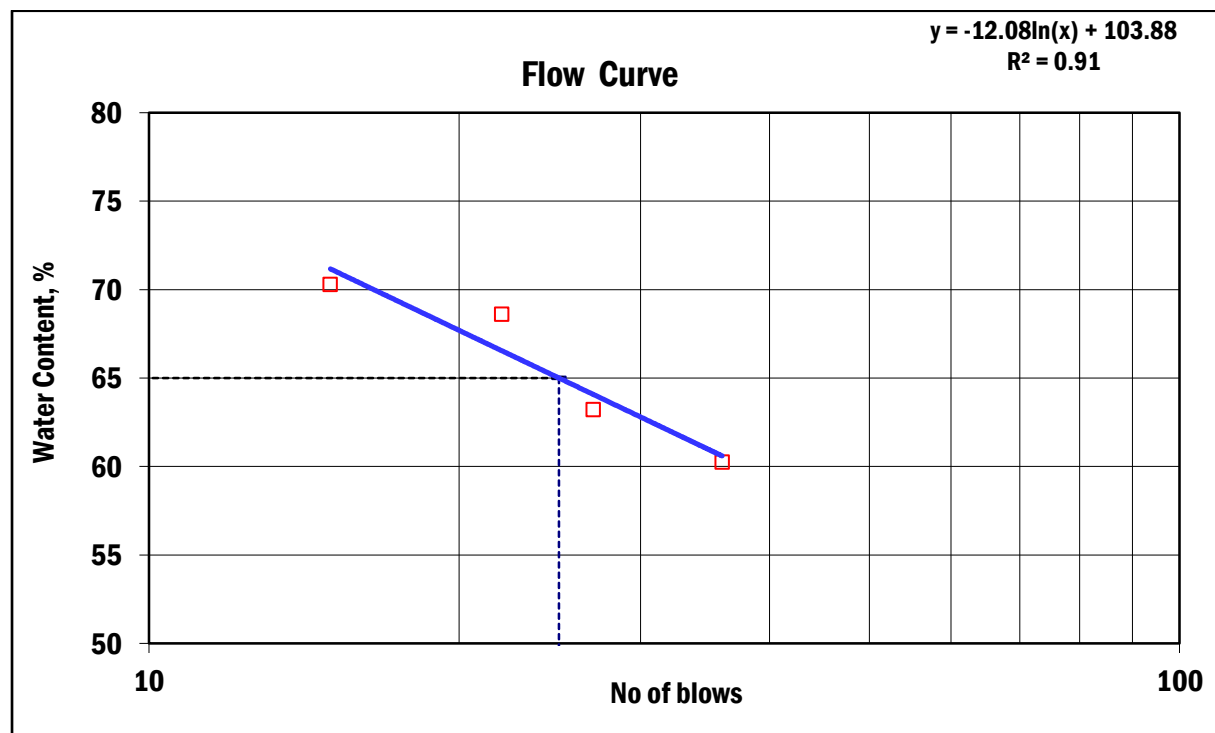
PI, % = 23



Sample no 8

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	33	D35	C15	A18	C23	14
Mass of container, g	15.63	15.83	15.55	15.88	12.62	14.86
Mass of container + Wet soil, g	44.86	41.59	47.01	47.35	17.64	20.41
Mass of container + Dry soil, g	33.87	31.61	34.21	34.36	16.44	19.05
Mass of water, g	10.99	9.98	12.80	12.99	1.20	1.36
Mass of dry soil, g	18.24	15.78	18.66	18.48	3.82	4.19
Water content, %	60.26	63.22	68.62	70.28	31.53	32.47
No of blows	36	27	22	15	-----	-----

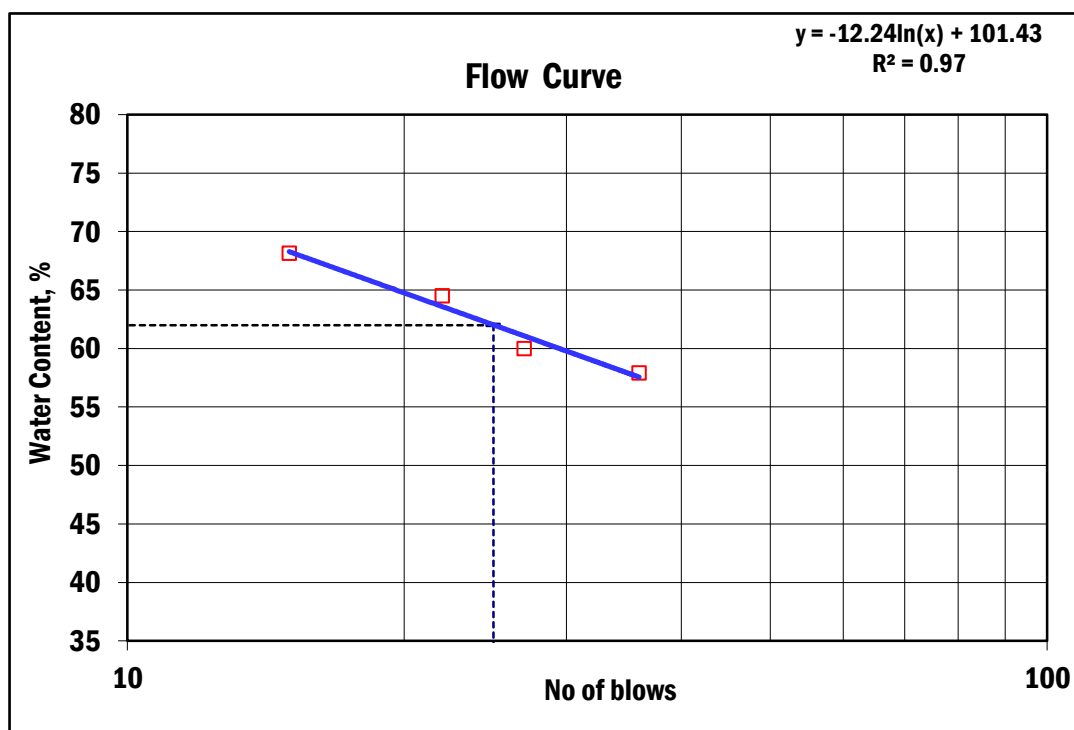
Liquid Limit, % = 65 Plastic Limit, % = 32 PI, % = 33



Sample no 9

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	10	36	D26	C12	C35	D11
Mass of container, g	15.83	15.63	15.55	15.88	15.86	13.62
Mass of container + Wet soil, g	44.44	41.18	48.53	47.79	20.34	17.35
Mass of container + Dry soil, g	33.95	31.6	35.6	34.86	19.2	16.38
Mass of water, g	10.49	9.58	12.93	12.93	1.14	0.97
Mass of dry soil, g	18.12	15.97	20.05	18.98	3.34	2.76
Water content, %	57.89	59.99	64.49	68.12	34.13	35.14
No of blows	36	27	22	15	-----	-----

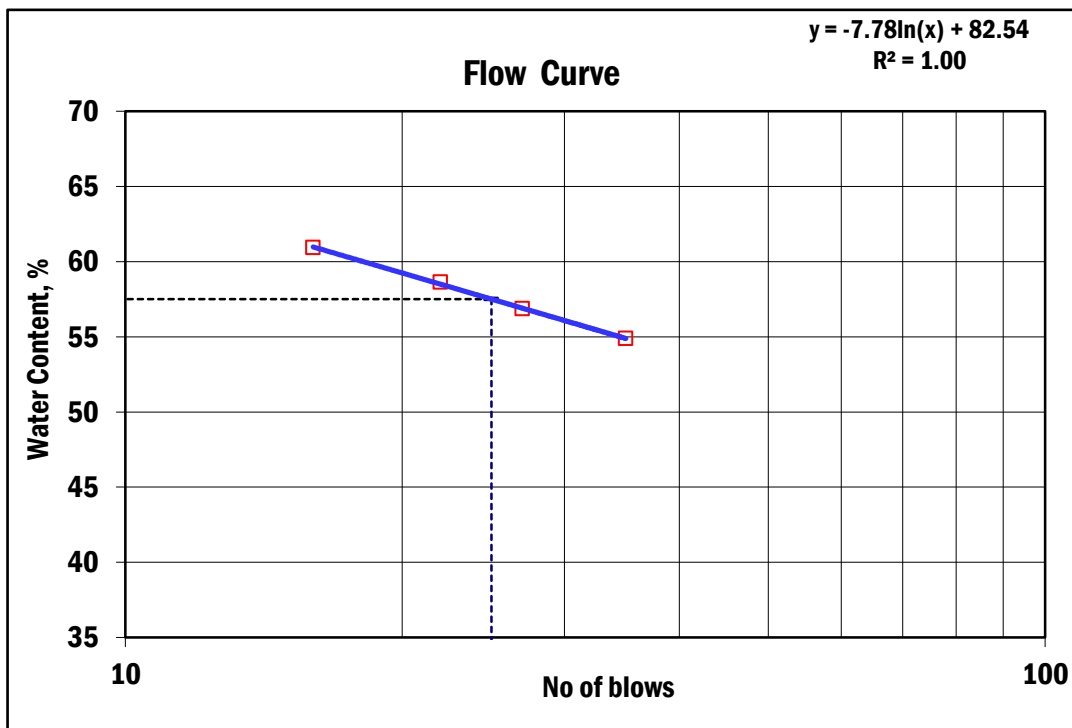
Liquid Limit, % = 62 Plastic Limit, % = 35 PI, %= 27



Sample no 10

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A34	56	64	21	14	32
Mass of container, g	15.65	15.66	15.61	15.74	15.60	14.99
Mass of container + Wet soil, g	33.60	34.67	35.20	34.60	17.85	17.80
Mass of container + Dry soil, g	27.24	27.78	27.96	27.46	17.26	17.08
Mass of water, g	6.36	6.89	7.24	7.14	0.59	0.72
Mass of dry soil, g	11.59	12.12	12.35	11.72	1.66	2.09
Water content, %	54.87	56.85	58.62	60.92	35.54	34.45
No of blows	35	27	22	16	-----	-----

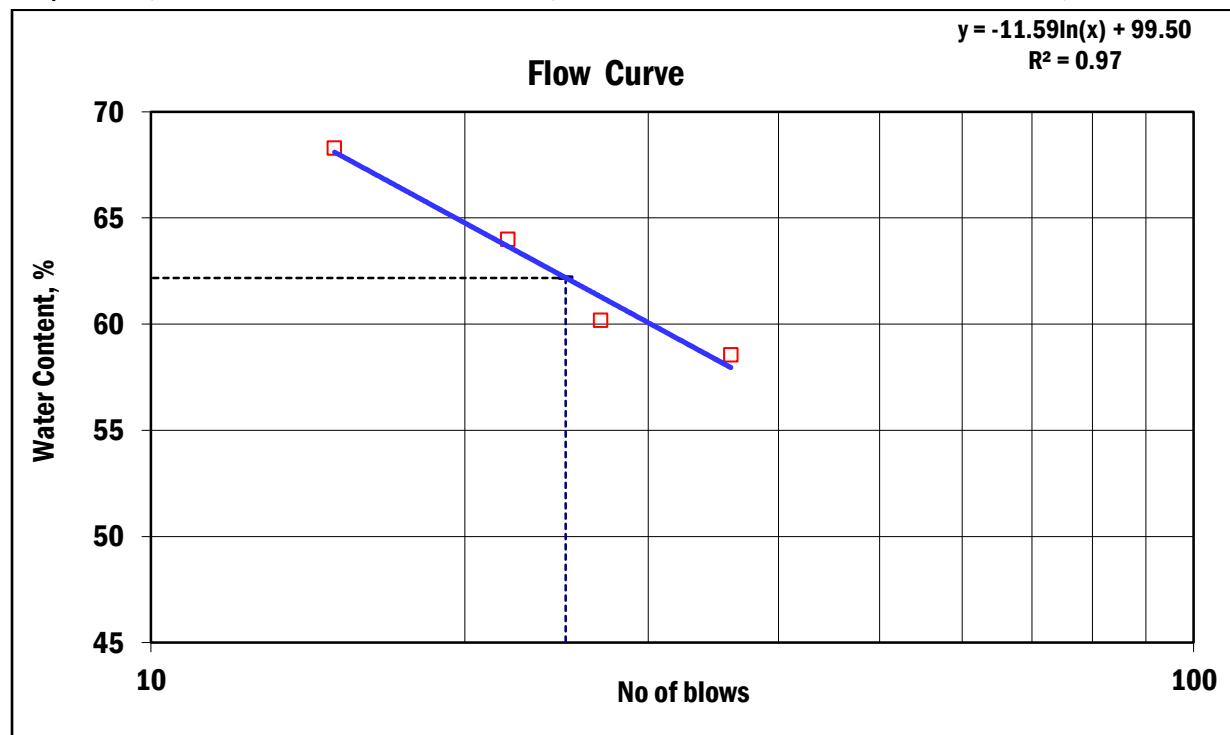
Liquid Limit, % = 57 Plastic Limit, % = 35 PI, % = 22



Sample no 11

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	10	36	D26	C12	C35	D11
Mass of container, g	15.83	15.63	15.55	15.88	15.86	13.62
Mass of container + Wet soil, g	44.56	41.21	48.43	47.82	20.30	17.14
Mass of container + Dry soil, g	33.95	31.6	35.6	34.86	19.2	16.27
Mass of water, g	10.61	9.61	12.83	12.96	1.10	0.87
Mass of dry soil, g	18.12	15.97	20.05	18.98	3.34	2.65
Water content, %	58.55	60.18	63.99	68.28	32.98	33.02
No of blows	36	27	22	15	-----	-----

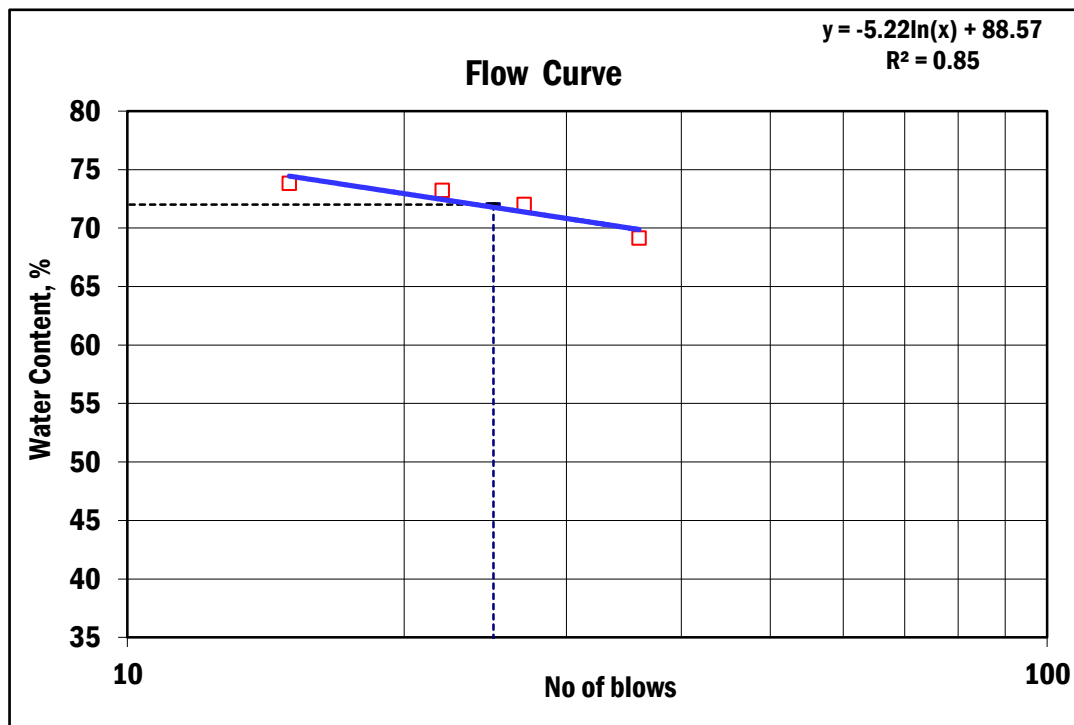
Liquid Limit, % = 62 Plastic Limit, % = 33 PI, % = 29



Sample no 12

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A1	70	D-5	D-33	7	A34
Mass of container, g	15.18	15.72	15.7	15.51	15.56	15.67
Mass of container + Wet soil, g	41.09	36.05	45.37	40	21.8	22.46
Mass of container + Dry soil, g	30.5	27.54	32.83	29.6	20.24	20.66
Mass of water, g	10.59	8.51	12.54	10.40	1.56	1.80
Mass of dry soil, g	15.32	11.82	17.13	14.09	4.68	4.99
Water content, %	69.13	72.00	73.20	73.81	33.33	36.07
No of blows	36	27	22	15	-----	-----

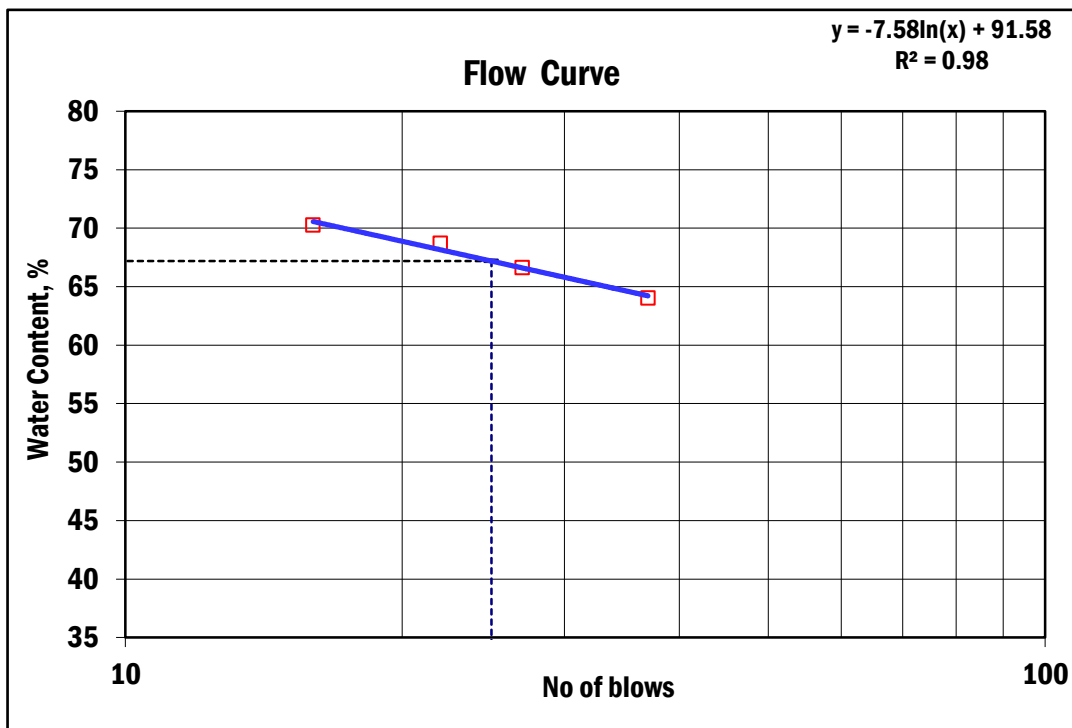
Liquid Limit, % = 72 Plastic Limit, % = 35 PI, % = 37



Sample no 13

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C29	24	D18	A33	75	D5
Mass of container, g	20.54	22.23	22.17	22.15	21.87	22.16
Mass of container + Wet soil, g	38.27	43.14	39.83	40.06	22.87	23.03
Mass of container + Dry soil, g	31.35	34.78	32.64	32.67	22.62	22.82
Mass of water, g	6.92	8.36	7.19	7.39	0.25	0.21
Mass of dry soil, g	10.81	12.55	10.47	10.52	0.75	0.66
Water content, %	64.01	66.61	68.67	70.25	33.33	31.82
No of blows	37	27	22	16	-----	-----

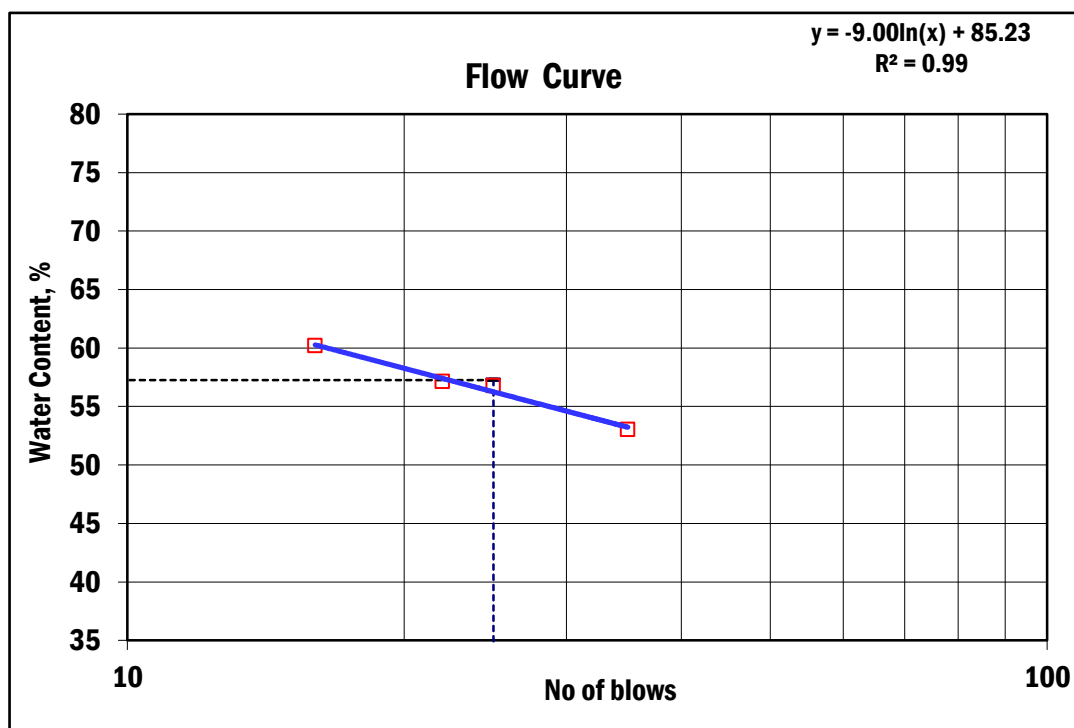
Liquid Limit, % = 67 Plastic Limit, % = 33 PI, % = 34



Sample no 14

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	24	C15	A36	69	C21	D29
Mass of container, g	15.47	15.68	15.62	15.76	15.65	13.89
Mass of container + Wet soil, g	29.11	30.28	30.95	30.86	19.10	17.88
Mass of container + Dry soil, g	24.38	25.00	25.38	25.19	18.26	16.91
Mass of water, g	4.73	5.29	5.57	5.68	0.84	0.97
Mass of dry soil, g	8.92	9.32	9.76	9.43	2.61	3.02
Water content, %	53.04	56.77	57.13	60.21	32.21	32.11
No of blows	35	25	22	16	-----	-----

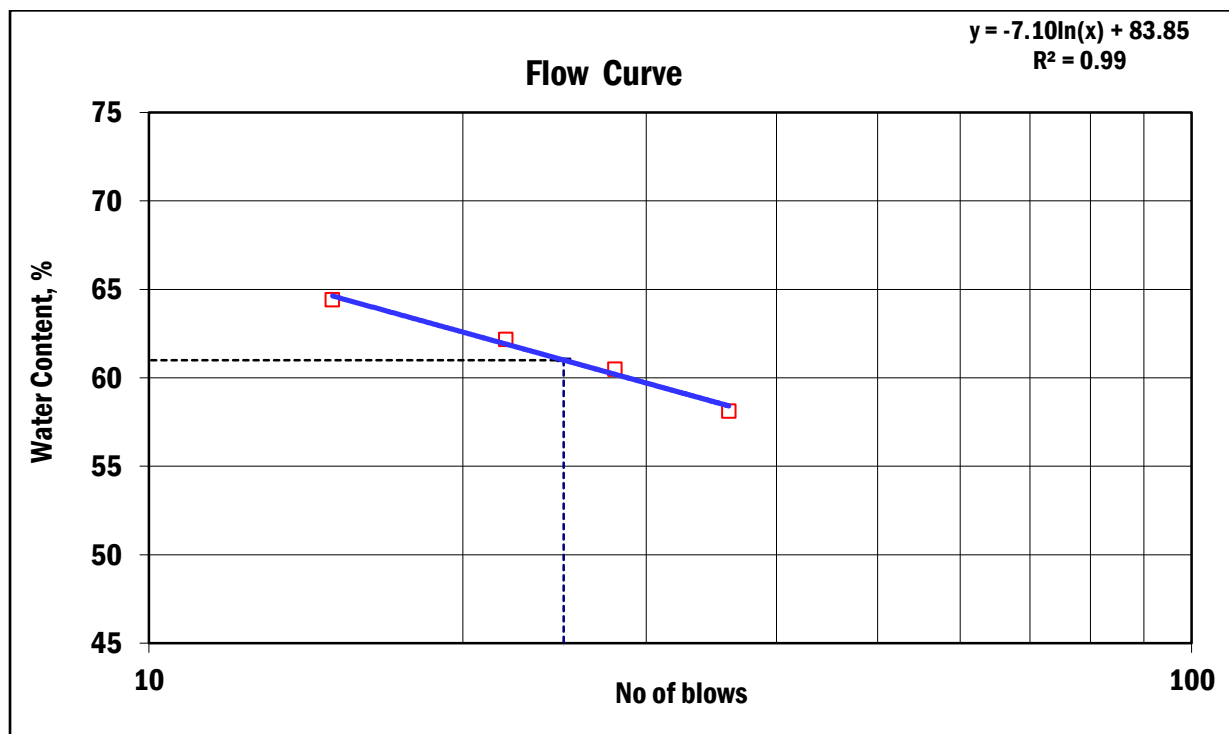
Liquid Limit, % = 57 Plastic Limit, % = 32 PI, % = 25



Sample no 15

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	79	10	31	A19	D11	C2
Mass of container, g	15.61	15.43	21.95	15.56	15.67	13.69
Mass of container + Wet soil, g	35.21	34.22	38.90	32.89	17.23	15.2
Mass of container + Dry soil, g	28.01	27.14	32.4	26.1	16.82	14.81
Mass of water, g	7.20	7.08	6.50	6.79	0.41	0.39
Mass of dry soil, g	12.40	11.71	10.45	10.54	1.15	1.12
Water content, %	58.10	60.47	62.16	64.40	35.65	34.82
No of blows	36	28	22	15	-----	-----

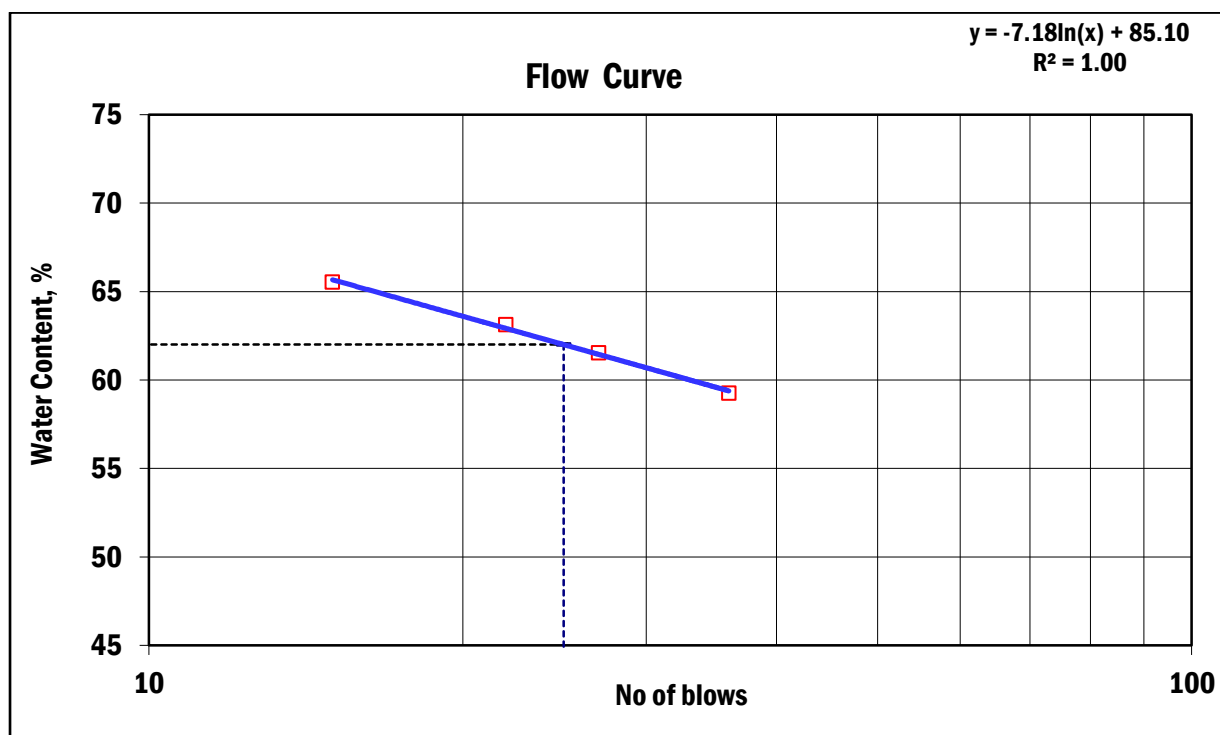
Liquid Limit, % = 61 Plastic Limit, % = 35 PI, % = 26



Sample no 16

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	53	65	C24	A14	D33	51
Mass of container, g	13.7	15.45	15.66	15.42	15.62	15.6
Mass of container + Wet soil, g	33.96	41.41	39.70	33.43	17.86	17.88
Mass of container + Dry soil, g	26.42	31.52	30.4	26.3	17.31	17.34
Mass of water, g	7.54	9.89	9.30	7.13	0.55	0.54
Mass of dry soil, g	12.72	16.07	14.74	10.88	1.69	1.74
Water content, %	59.24	61.52	63.13	65.52	32.54	31.03
No of blows	36	27	22	15	-----	-----

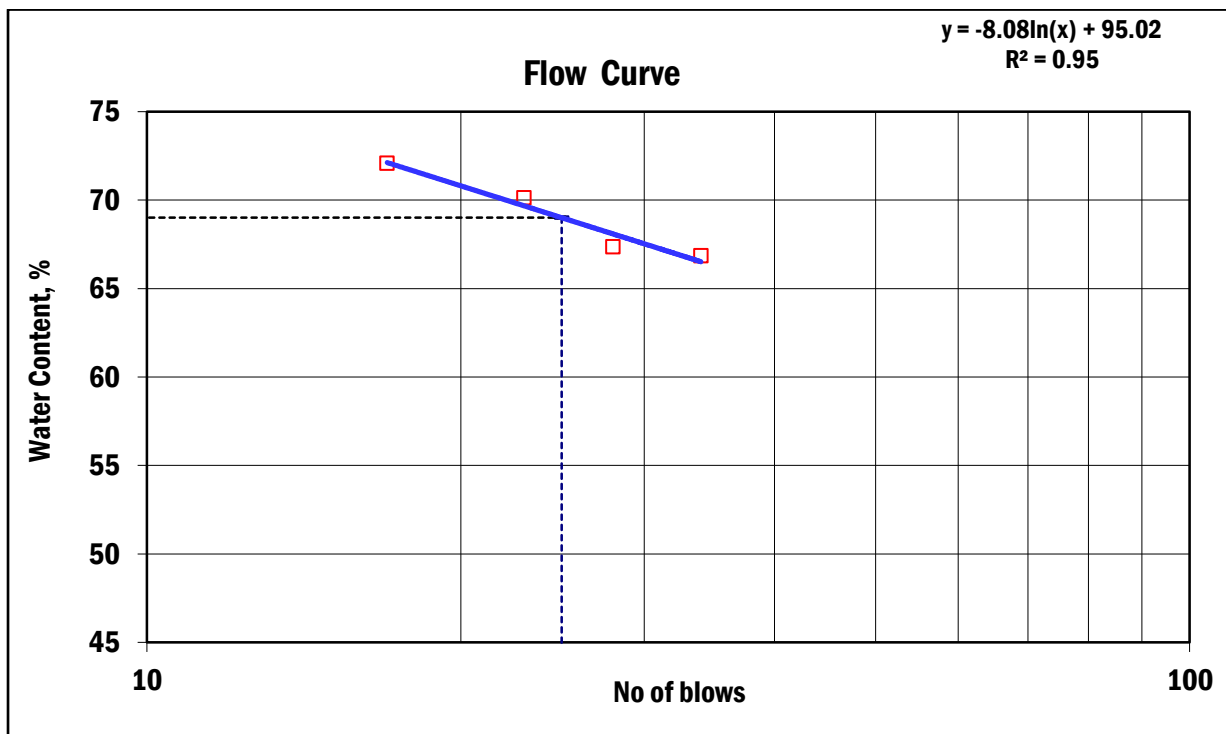
Liquid Limit, % = 62 Plastic Limit, % = 32 PI, % = 30



Sample no 17

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	17	15	64	18	23	40
Mass of container, g	15.82	15.64	15.24	15.38	15.44	15.42
Mass of container + Wet soil, g	36.04	37.83	36.01	35.22	17.56	17.68
Mass of container + Dry soil, g	27.94	28.9	27.45	26.91	17.03	17.12
Mass of water, g	8.10	8.93	8.56	8.31	0.53	0.56
Mass of dry soil, g	12.12	13.26	12.21	11.53	1.59	1.70
Water content, %	66.84	67.35	70.13	72.07	33.24	32.76
No of blows	34	28	23	17	-----	-----

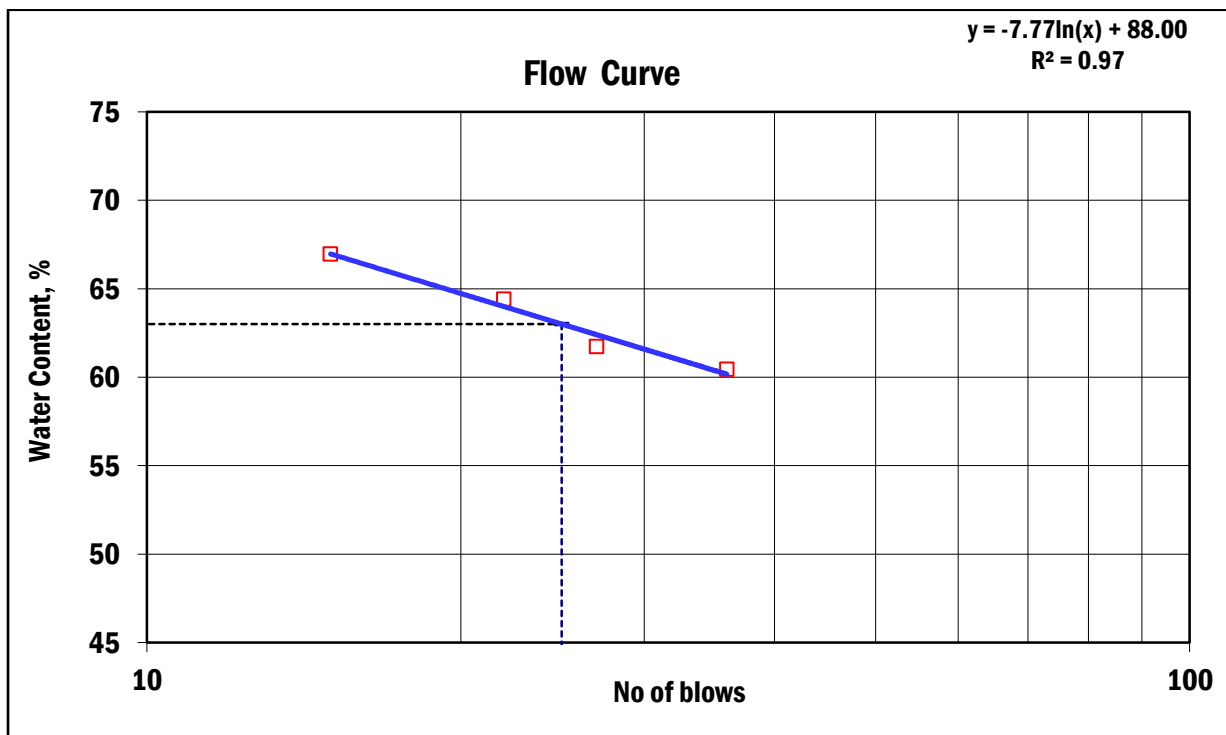
Liquid Limit, % = 69 Plastic Limit, % = 33 PI, % = 36



Sample no 18

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	33	D35	C15	A18	C23	14
Mass of container, g	15.2	15.6	15.34	15.44	15.2	15.33
Mass of container + Wet soil, g	34.61	36.62	35.50	36.58	17.84	17.88
Mass of container + Dry soil, g	27.3	28.6	27.6	28.1	17.16	17.22
Mass of water, g	7.31	8.02	7.90	8.48	0.68	0.66
Mass of dry soil, g	12.10	13.00	12.26	12.66	1.96	1.89
Water content, %	60.45	61.72	64.41	66.96	34.69	34.92
No of blows	36	27	22	15	-----	-----

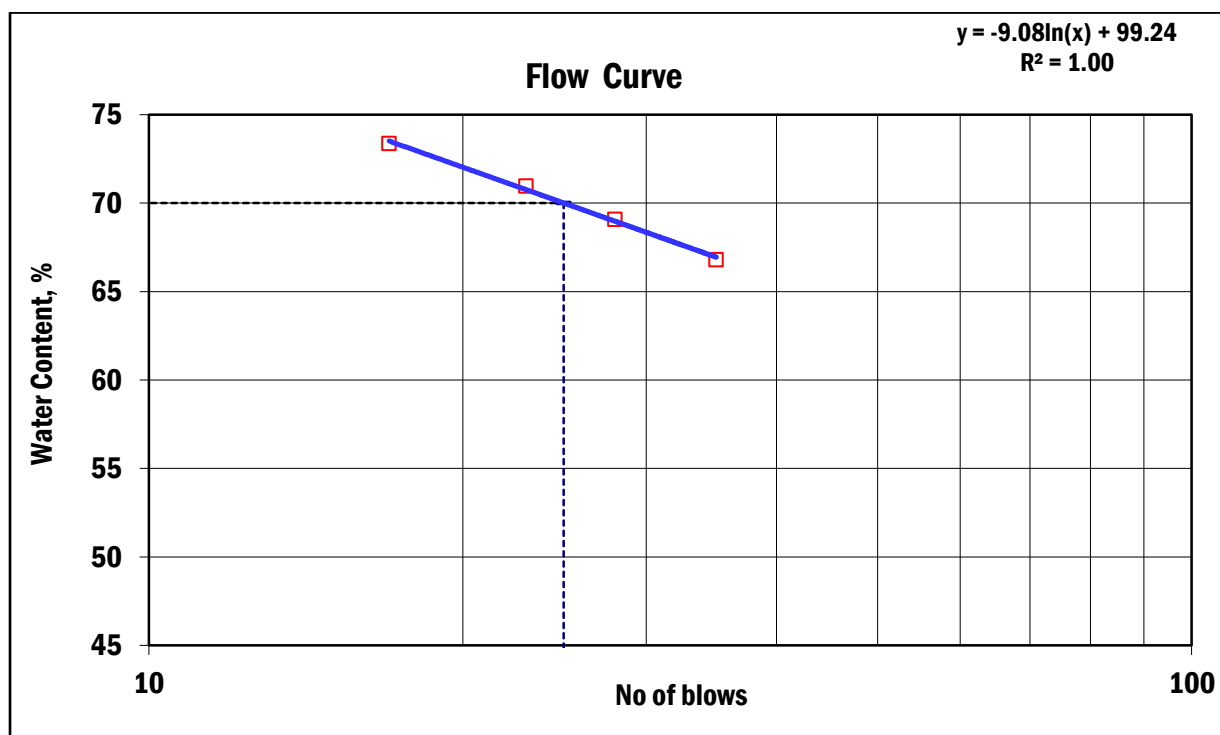
Liquid Limit, % = 63 Plastic Limit, % = 35 PI, % = 28



Sample no 19

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A23	37	A19	c35	c21	14
Mass of container, g	15.6	15.3	15.42	15.32	15.4	14.23
Mass of container + Wet soil, g	36.20	37.11	37.78	37.34	17.82	17.33
Mass of container + Dry soil, g	27.95	28.2	28.5	28.02	17.22	16.56
Mass of water, g	8.25	8.91	9.28	9.32	0.60	0.77
Mass of dry soil, g	12.35	12.90	13.08	12.70	1.82	2.33
Water content, %	66.80	69.07	70.95	73.36	33.08	32.92
No of blows	35	28	23	17	-----	-----

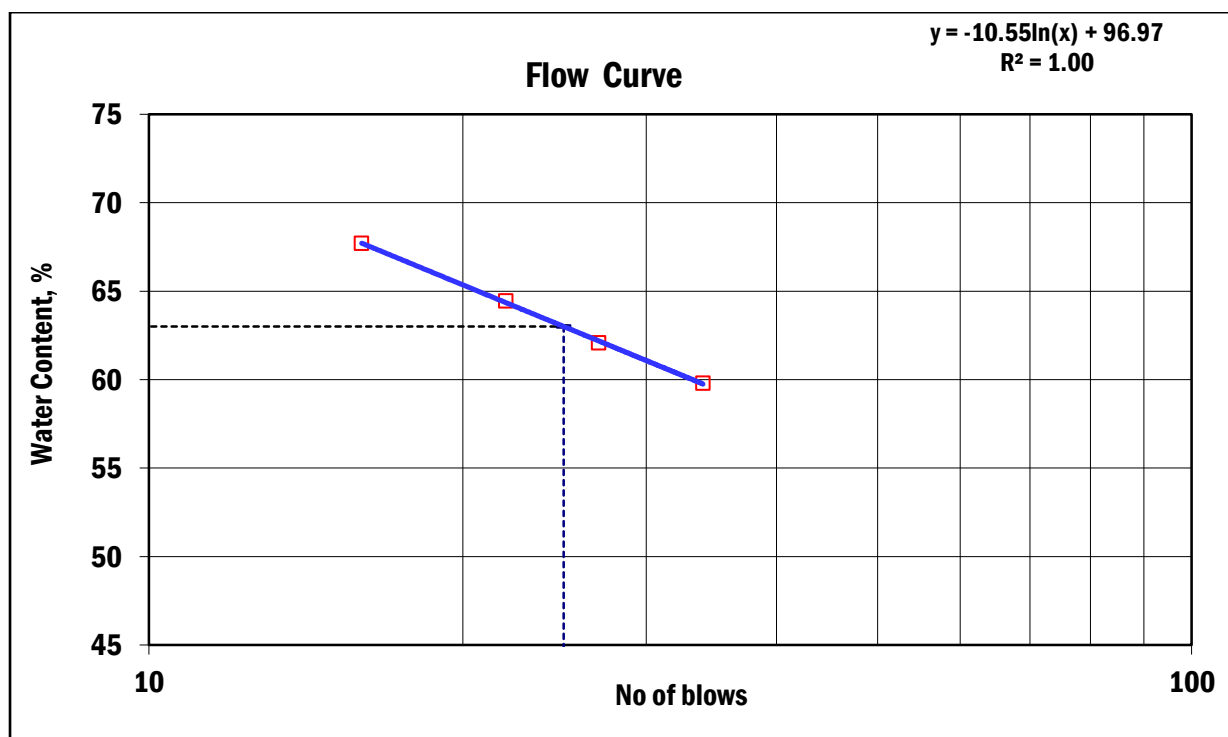
Liquid Limit, % = 70 Plastic Limit, % = 33 PI, % = 37



Sample no 20

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	33	16	52	67	D35	A14
Mass of container, g	14.36	15.2	15.48	14.99	15.82	15.32
Mass of container + Wet soil, g	38.55	37.65	36.48	38.32	17.45	17.24
Mass of container + Dry soil, g	29.5	29.05	28.25	28.9	17.09	16.81
Mass of water, g	9.05	8.60	8.23	9.42	0.36	0.43
Mass of dry soil, g	15.14	13.85	12.77	13.91	1.27	1.49
Water content, %	59.79	62.08	64.45	67.69	28.35	28.86
No of blows	34	27	22	16	-----	-----

Liquid Limit, % = 63 Plastic Limit, % = 29 PI, % = 34



Sample no 21

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A23	D25	D33	C14	D15	C16
Mass of container, g	15.27	14.65	15.34	15.33	15.2	14.65
Mass of container + Wet soil, g	37.26	36.51	35.41	37.14	17.45	17.24
Mass of container + Dry soil, g	29.48	28.45	27.8	28.55	16.9	16.58
Mass of water, g	7.78	8.06	7.61	8.59	0.55	0.66
Mass of dry soil, g	14.21	13.80	12.46	13.22	1.70	1.93
Water content, %	54.78	58.37	61.11	64.97	32.35	34.20
No of blows	35	27	21	15	-----	-----

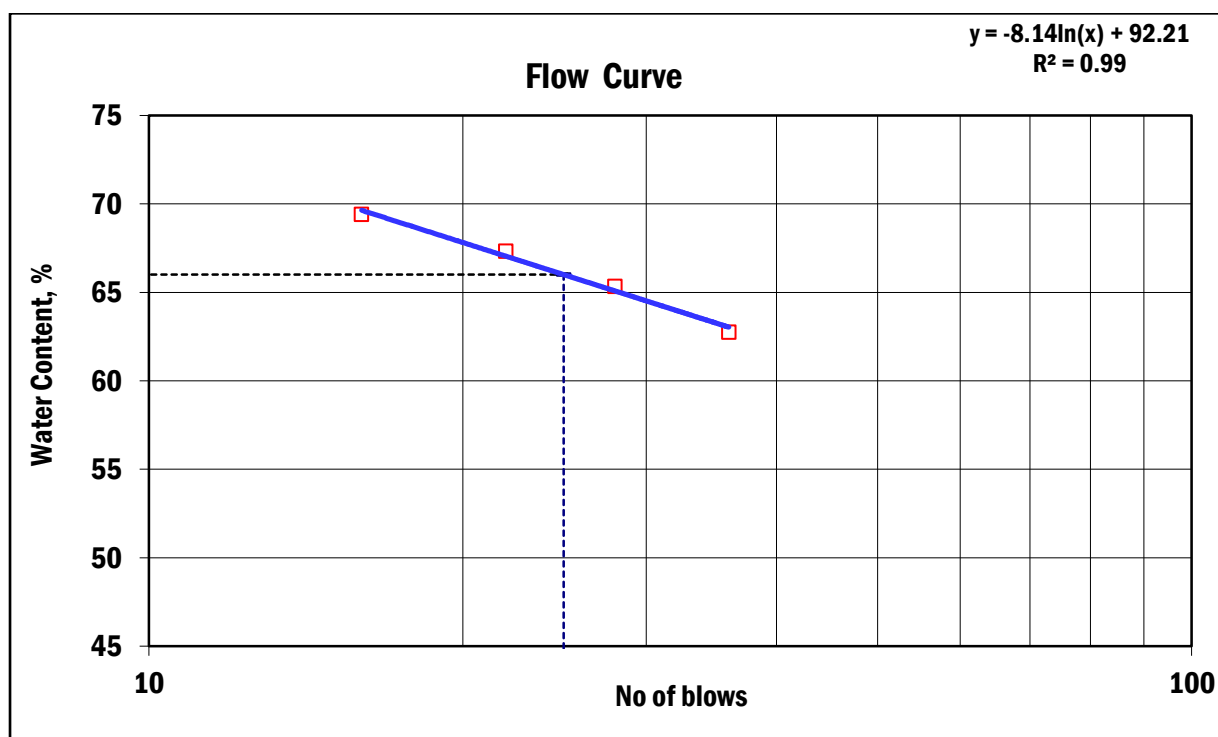
Liquid Limit, % = 59 Plastic Limit, % = 33 PI, % = 26



Sample no 22

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	22	C15	15	D33	24	D22
Mass of container, g	15.75	15.5	15.56	15.5	15.67	15.76
Mass of container + Wet soil, g	42.38	35.75	37.81	40.01	18.56	18.54
Mass of container + Dry soil, g	32.11	27.75	28.86	29.97	17.88	17.87
Mass of water, g	10.27	8.00	8.95	10.04	0.68	0.67
Mass of dry soil, g	16.36	12.25	13.30	14.47	2.21	2.11
Water content, %	62.75	65.33	67.32	69.39	30.77	31.75
No of blows	36	28	22	16	-----	-----

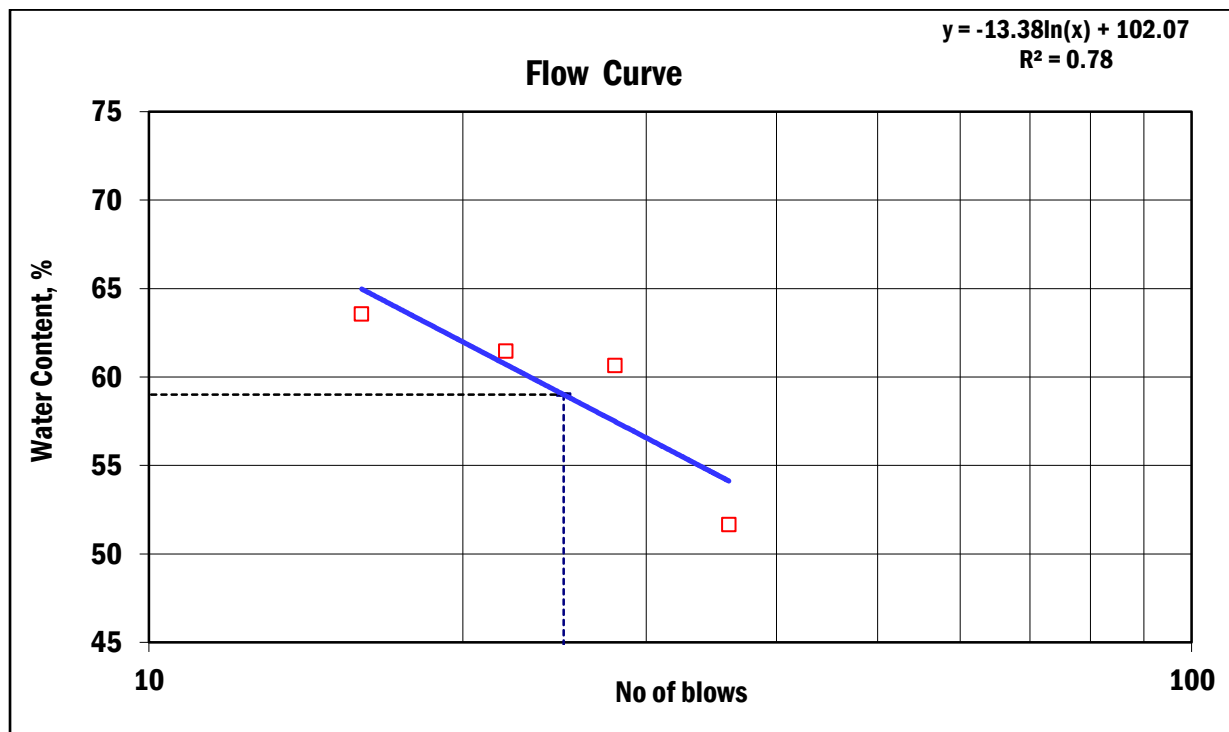
Liquid Limit, % = 66 Plastic Limit, % = 31 PI, % = 35



Sample no 23

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C15	21	40	C30	12	D10
Mass of container, g	14.5	15.3	14.66	15.2	15.62	15.34
Mass of container + Wet soil, g	36.94	35.94	37.73	35.64	17.22	17.58
Mass of container + Dry soil, g	29.3	28.15	28.95	27.7	16.83	17.05
Mass of water, g	7.64	7.79	8.78	7.94	0.39	0.53
Mass of dry soil, g	14.80	12.85	14.29	12.50	1.21	1.71
Water content, %	51.65	60.64	61.45	63.55	32.23	30.99
No of blows	36	28	22	16	-----	-----

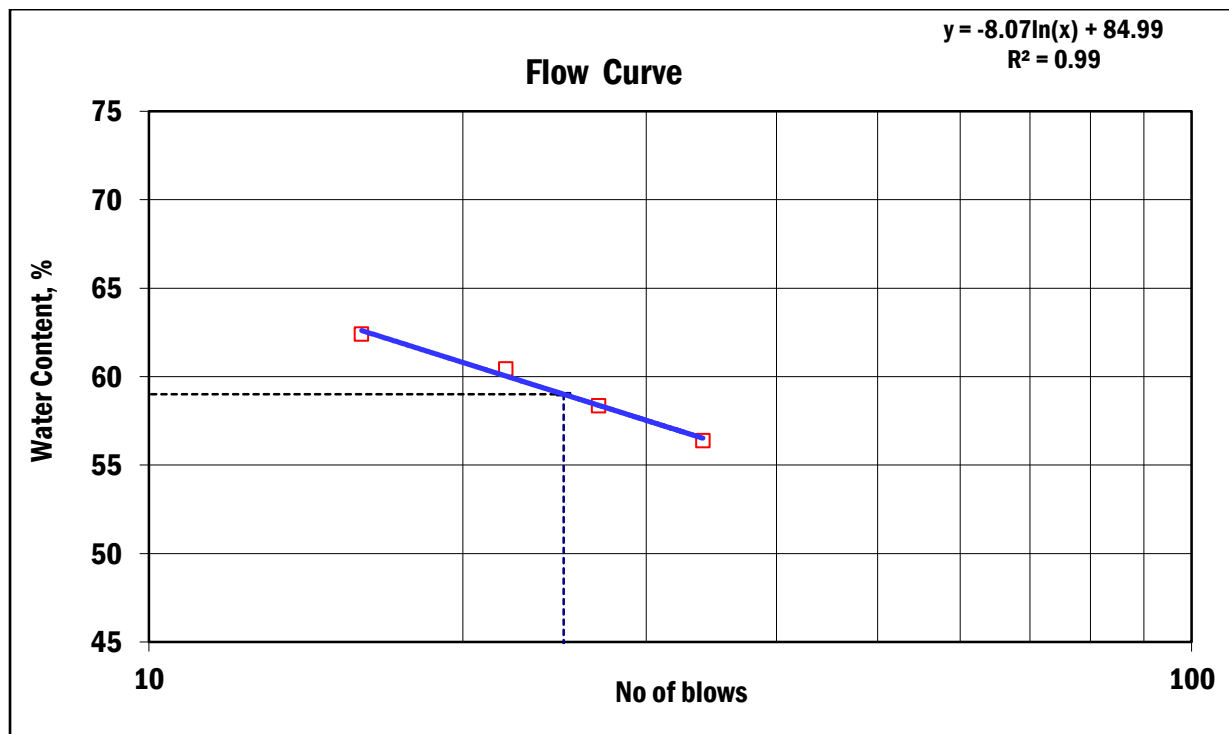
Liquid Limit, % = 59 Plastic Limit, % = 32 PI, % = 27



Sample no 24

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A12	31	C35	52	64	C17
Mass of container, g	15.14	15.33	15.24	15.65	15.45	15.44
Mass of container + Wet soil, g	35.03	37.05	36.05	36.06	17.56	17.75
Mass of container + Dry soil, g	27.86	29.05	28.21	28.22	17.05	17.2
Mass of water, g	7.17	8.00	7.84	7.84	0.51	0.55
Mass of dry soil, g	12.72	13.72	12.97	12.57	1.60	1.76
Water content, %	56.38	58.34	60.43	62.39	31.87	31.25
No of blows	34	27	22	16	-----	-----

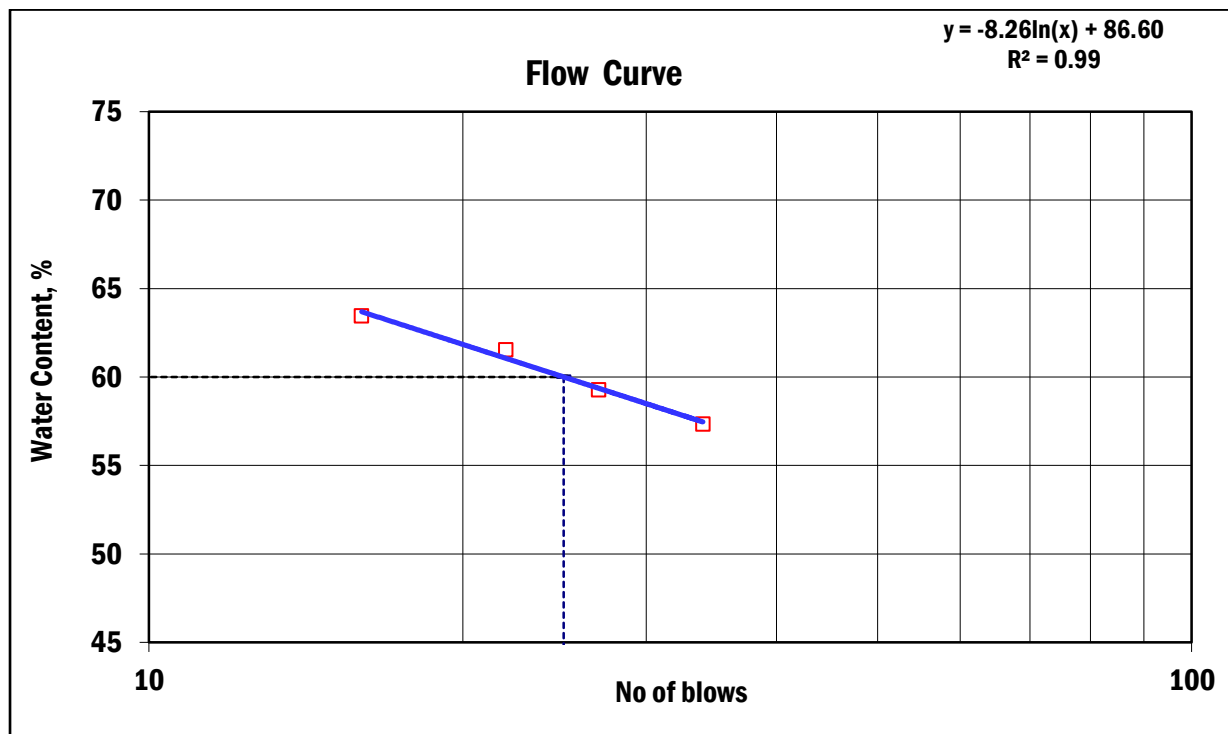
Liquid Limit, % = 59 Plastic Limit, % = 32 PI, % = 27



Sample no 25

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C21	C2	32	D29	47	35
Mass of container, g	15.6	15.22	15.47	15.6	15.47	15.44
Mass of container + Wet soil, g	35.80	36.05	36.84	36.29	17.68	18.04
Mass of container + Dry soil, g	28.44	28.3	28.7	28.26	17.14	17.41
Mass of water, g	7.36	7.75	8.14	8.03	0.54	0.63
Mass of dry soil, g	12.84	13.08	13.23	12.66	1.67	1.97
Water content, %	57.33	59.27	61.52	63.45	32.22	31.78
No of blows	34	27	22	16	-----	-----

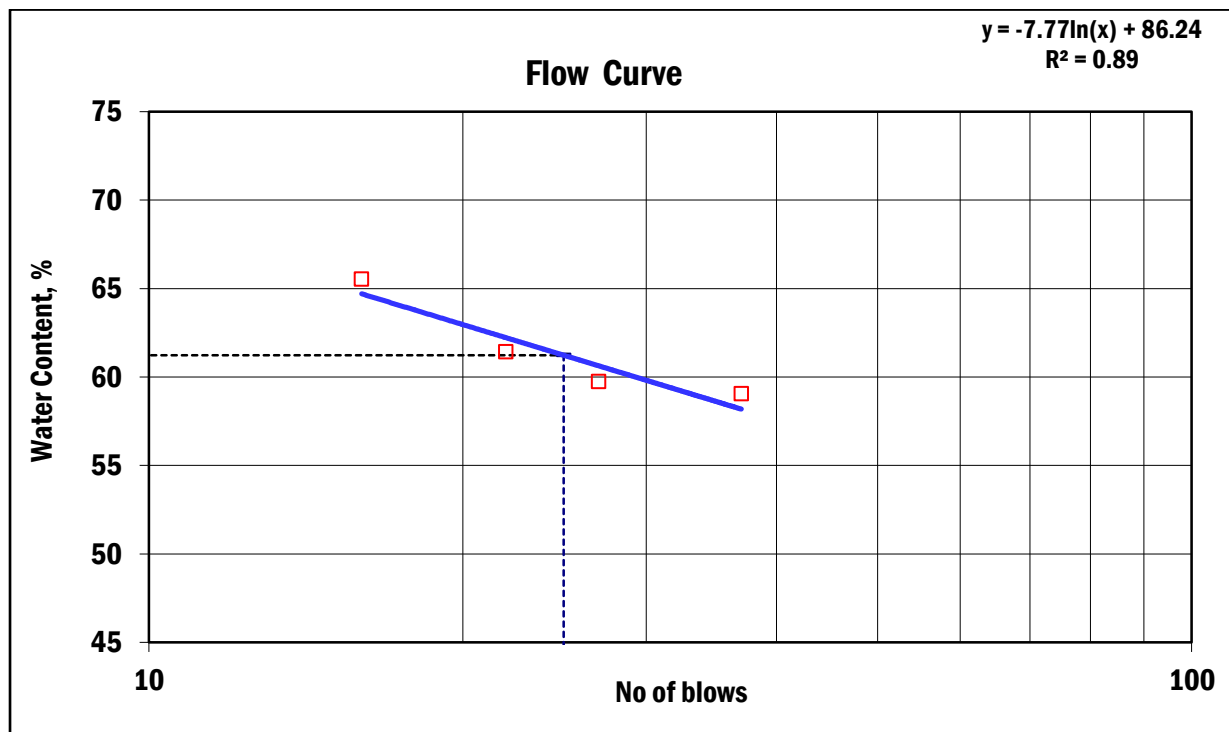
Liquid Limit, % = 60 Plastic Limit, % = 32 PI, % = 28



Sample no 26

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C29	24	D18	A33	75	D5
Mass of container, g	20.54	22.23	22.17	22.15	21.87	22.16
Mass of container + Wet soil, g	38.13	43.14	39.83	40.06	22.88	23.05
Mass of container + Dry soil, g	31.6	35.32	33.11	32.97	22.62	22.82
Mass of water, g	6.53	7.82	6.72	7.09	0.26	0.23
Mass of dry soil, g	11.06	13.09	10.94	10.82	0.75	0.66
Water content, %	59.04	59.74	61.43	65.53	34.67	34.85
No of blows	37	27	22	16	-----	-----

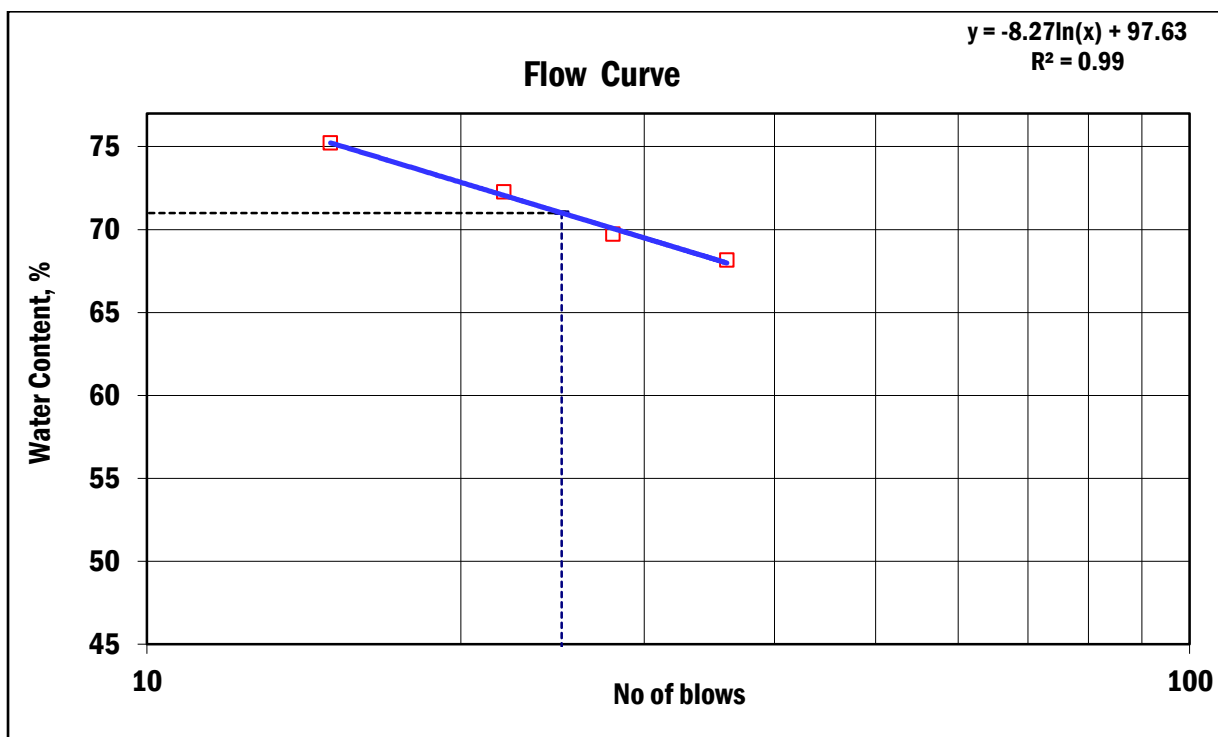
Liquid Limit, % = 61 Plastic Limit, % = 35 PI, % = 26



Sample no 27

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	79	10	31	A19	D11	C2
Mass of container, g	15.61	15.43	21.95	15.56	15.67	13.69
Mass of container + Wet soil, g	36.63	35.64	40.14	34.03	17.33	15.32
Mass of container + Dry soil, g	28.11	27.34	32.51	26.1	16.92	14.91
Mass of water, g	8.52	8.30	7.63	7.93	0.41	0.41
Mass of dry soil, g	12.50	11.91	10.56	10.54	1.25	1.22
Water content, %	68.15	69.71	72.26	75.21	32.60	33.40
No of blows	36	28	22	15	-----	-----

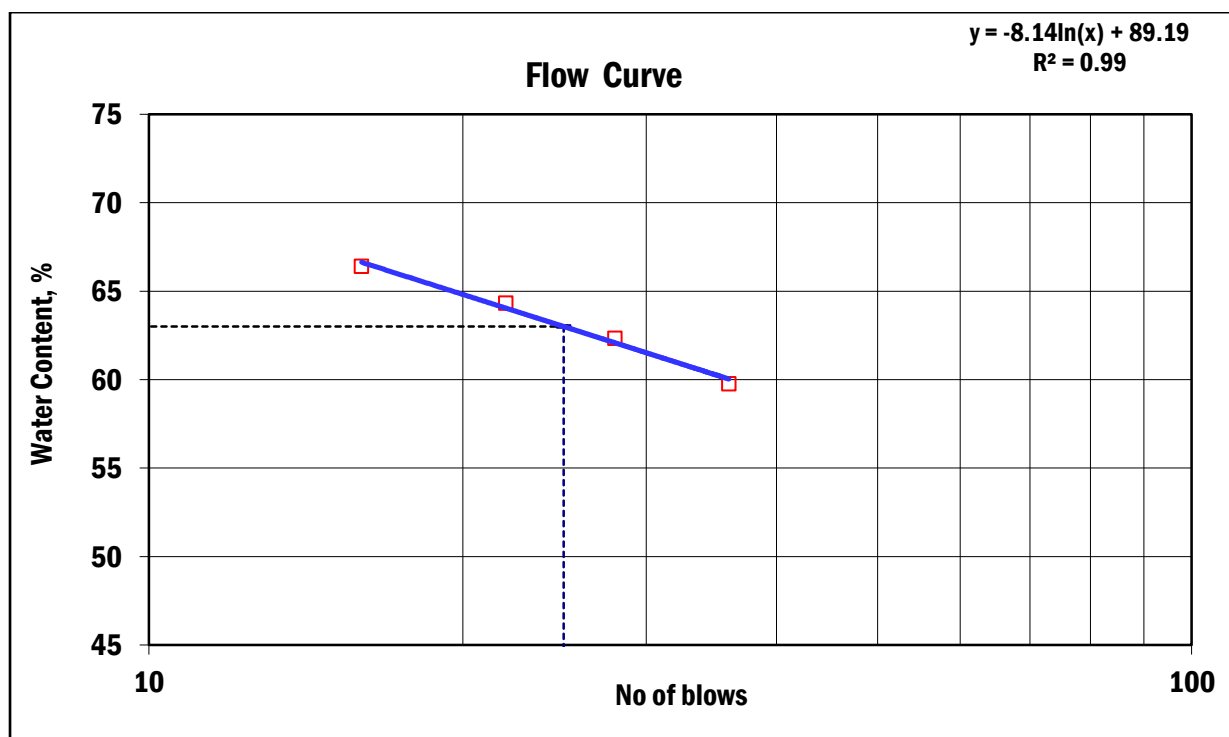
Liquid Limit, % = 71 Plastic Limit, % = 33 PI, % = 38



Sample no 28

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	22	C15	15	D33	24	D22
Mass of container, g	15.75	15.5	15.56	15.5	15.67	15.76
Mass of container + Wet soil, g	41.89	35.38	37.41	39.58	18.56	18.54
Mass of container + Dry soil, g	32.11	27.75	28.86	29.97	17.9	17.89
Mass of water, g	9.78	7.63	8.55	9.61	0.66	0.65
Mass of dry soil, g	16.36	12.25	13.30	14.47	2.23	2.13
Water content, %	59.75	62.32	64.32	66.38	29.60	30.52
No of blows	36	28	22	16	-----	-----

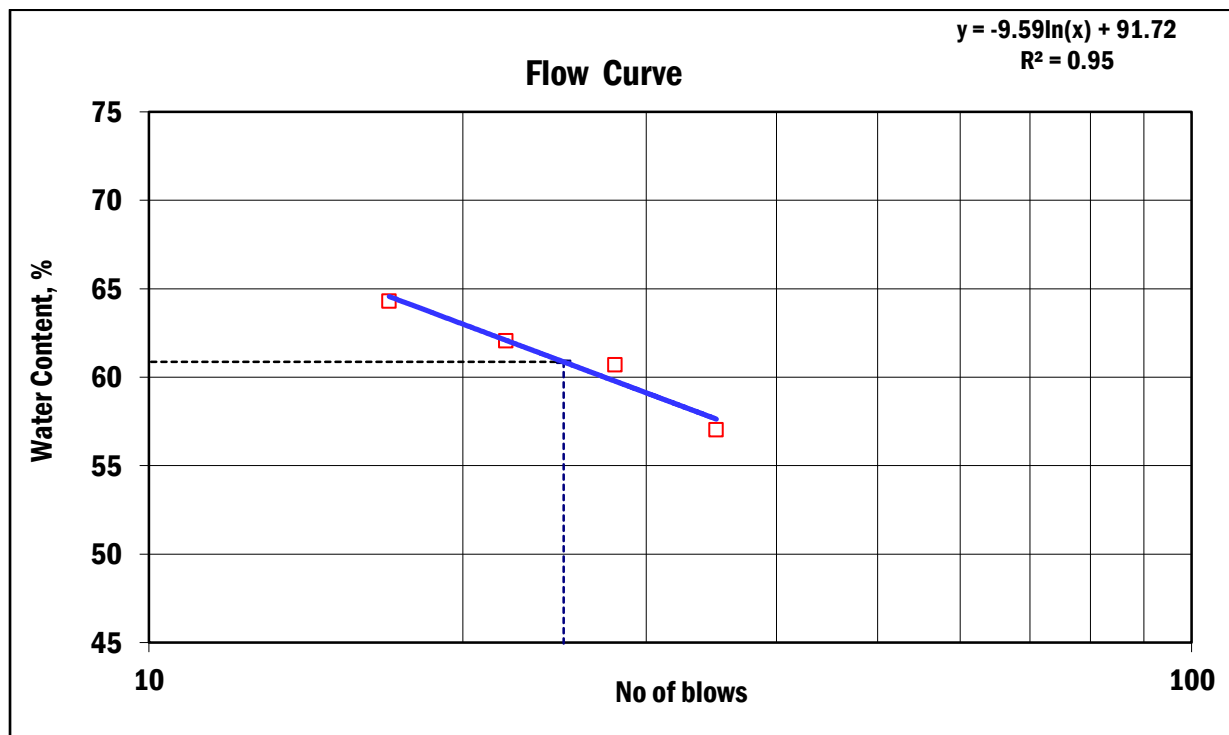
Liquid Limit, % = 63 Plastic Limit, % = 30 PI, % = 33



Sample no 29

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	36	10	D26	C12	D11	C35
Mass of container, g	15.61	15.43	21.95	15.56	15.67	13.69
Mass of container + Wet soil, g	34.97	33.99	38.69	32.68	17.23	15.2
Mass of container + Dry soil, g	27.94	26.98	32.28	25.98	16.85	14.83
Mass of water, g	7.03	7.01	6.41	6.70	0.38	0.37
Mass of dry soil, g	12.33	11.55	10.33	10.42	1.18	1.14
Water content, %	57.02	60.69	62.05	64.30	32.20	32.46
No of blows	35	28	22	17	-----	-----

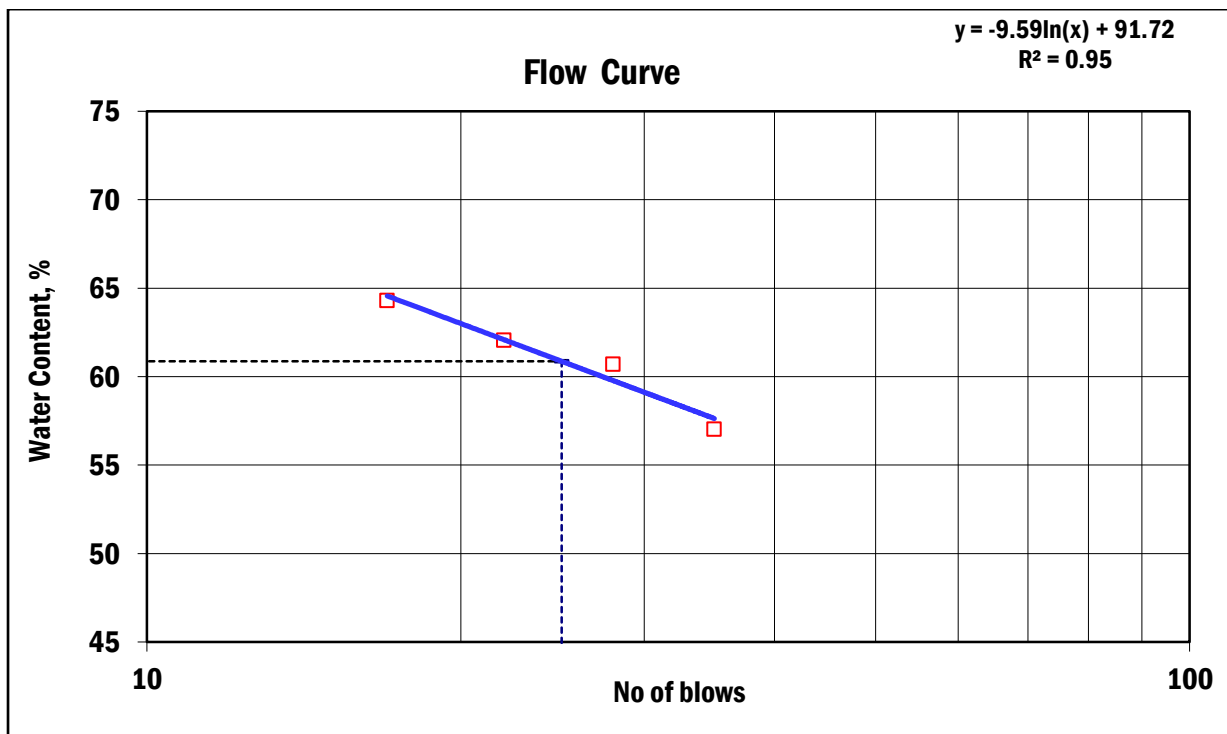
Liquid Limit, % = 61 Plastic Limit, % = 32 PI, %= 29



Sample no 30

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	24	C15	A36	69	C21	D29
Mass of container, g	15.47	15.68	15.62	15.76	15.65	13.89
Mass of container + Wet soil, g	29.21	32.40	31.06	30.96	19.03	17.80
Mass of container + Dry soil, g	24.38	26.2	25.18	24.99	18.24	16.91
Mass of water, g	4.83	6.20	5.88	5.97	0.79	0.89
Mass of dry soil, g	8.91	10.52	9.56	9.23	2.59	3.02
Water content, %	54.19	58.90	61.46	64.70	30.54	29.46
No of blows	35	25	22	16	-----	-----

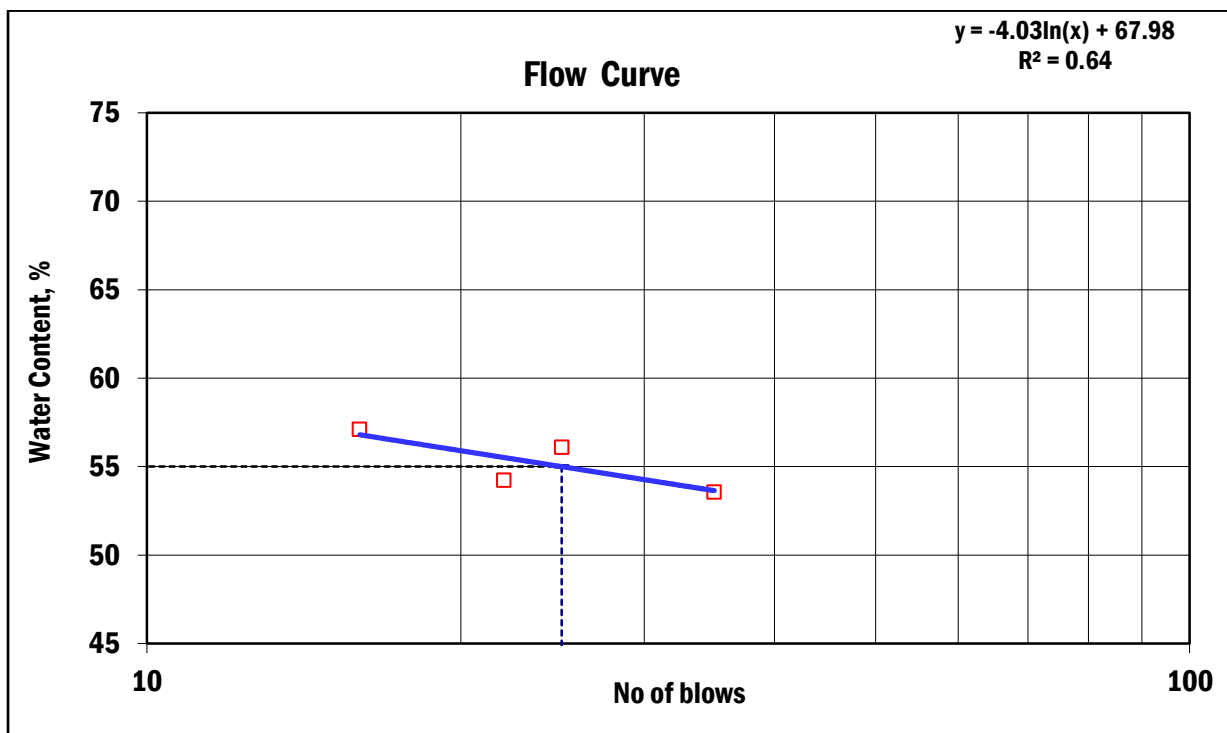
Liquid Limit, % = 59 Plastic Limit, % = 30 PI, % = 29



Sample no 31

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	c29	D25	C35	A18	26	41
Mass of container, g	14.68	14.65	15.24	16.49	15.62	15.6
Mass of container + Wet soil, g	34.06	34.86	34.07	32.86	18.58	17.58
Mass of container + Dry soil, g	27.3	27.6	27.45	26.91	18.24	16.91
Mass of water, g	6.76	7.26	6.62	5.95	0.34	0.67
Mass of dry soil, g	12.62	12.95	12.21	10.42	2.62	1.31
Water content, %	53.55	56.08	54.23	57.10	13.14	50.86
No of blows	35	25	22	16	-----	-----

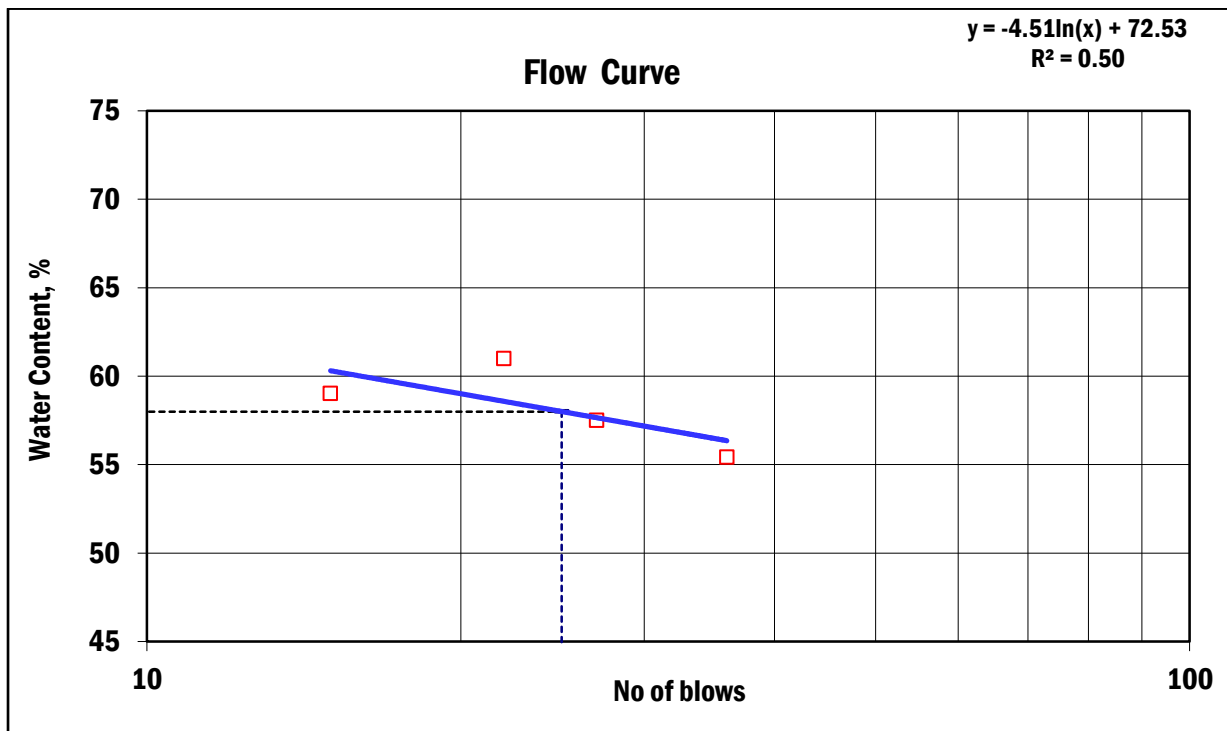
Liquid Limit, % = 55 Plastic Limit, % = 32 PI, % = 23



Sample no 32

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	33	D35	C15	A18	C23	14
Mass of container, g	15.2	15.6	15.34	15.44	15.2	15.33
Mass of container + Wet soil, g	35.25	35.76	34.75	36.21	17.75	17.79
Mass of container + Dry soil, g	28.1	28.4	27.4	28.5	17.16	17.22
Mass of water, g	7.15	7.36	7.35	7.71	0.59	0.57
Mass of dry soil, g	12.90	12.80	12.06	13.06	1.96	1.89
Water content, %	55.41	57.50	60.98	59.01	29.89	30.11
No of blows	36	27	22	15	-----	-----

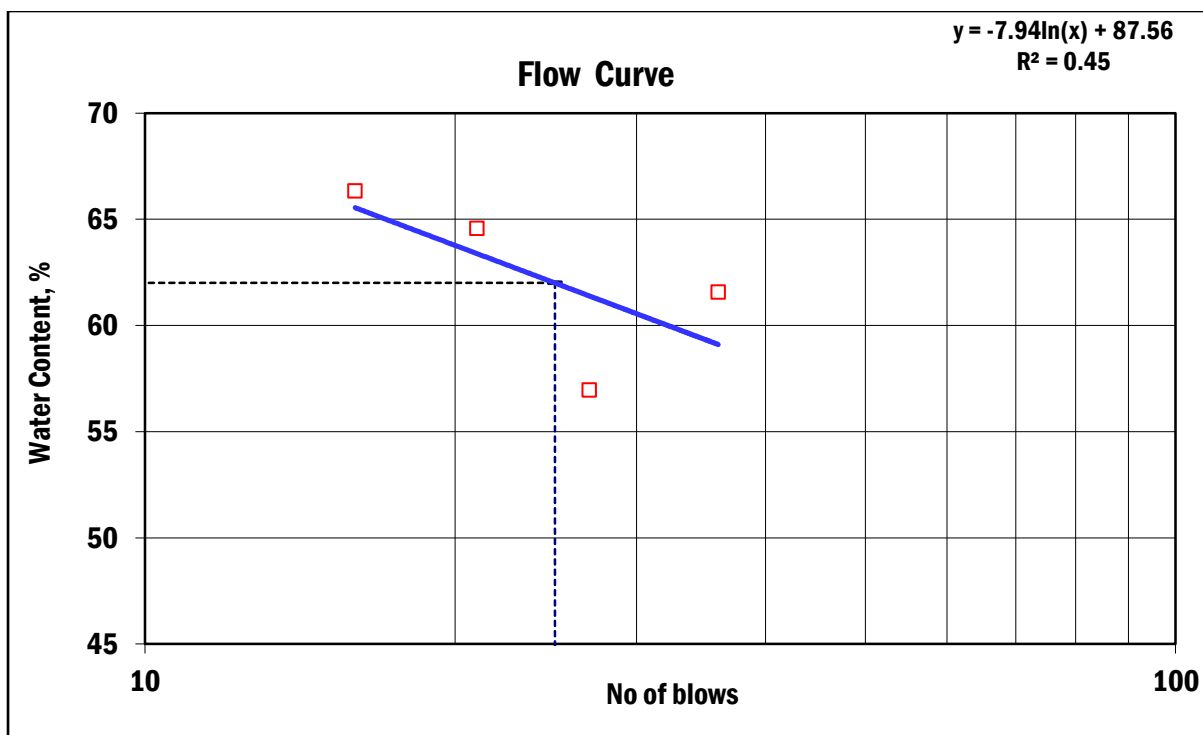
Liquid Limit, % = 58 Plastic Limit, % = 30 PI, %= 28



Sample no 33

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	c15	31	D31	A18	26	41
Mass of container, g	14.5	15.33	16.67	16.49	15.62	15.6
Mass of container + Wet soil, g	30.50	34.79	36.66	34.54	17.19	17.02
Mass of container + Dry soil, g	24.4	27.73	28.82	27.34	16.82	16.69
Mass of water, g	6.10	7.06	7.84	7.20	0.37	0.33
Mass of dry soil, g	9.90	12.40	12.15	10.85	1.20	1.09
Water content, %	61.57	56.96	64.57	66.33	30.83	30.28
No of blows	36	27	21	16	-----	-----

Liquid Limit, % = 62 Plastic Limit, % = 31 PI, % = 31



Sample no 34

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	79	10	31	A19	D11	C2
Mass of container, g	15.61	15.43	21.95	15.56	15.67	13.69
Mass of container + Wet soil, g	35.88	34.93	39.51	33.40	17.35	15.34
Mass of container + Dry soil, g	28.11	27.34	32.51	26.1	16.92	14.91
Mass of water, g	7.77	7.59	7.00	7.30	0.43	0.43
Mass of dry soil, g	12.50	11.91	10.56	10.54	1.25	1.22
Water content, %	62.15	63.71	66.26	69.21	34.60	35.40
No of blows	36	28	22	15	-----	-----

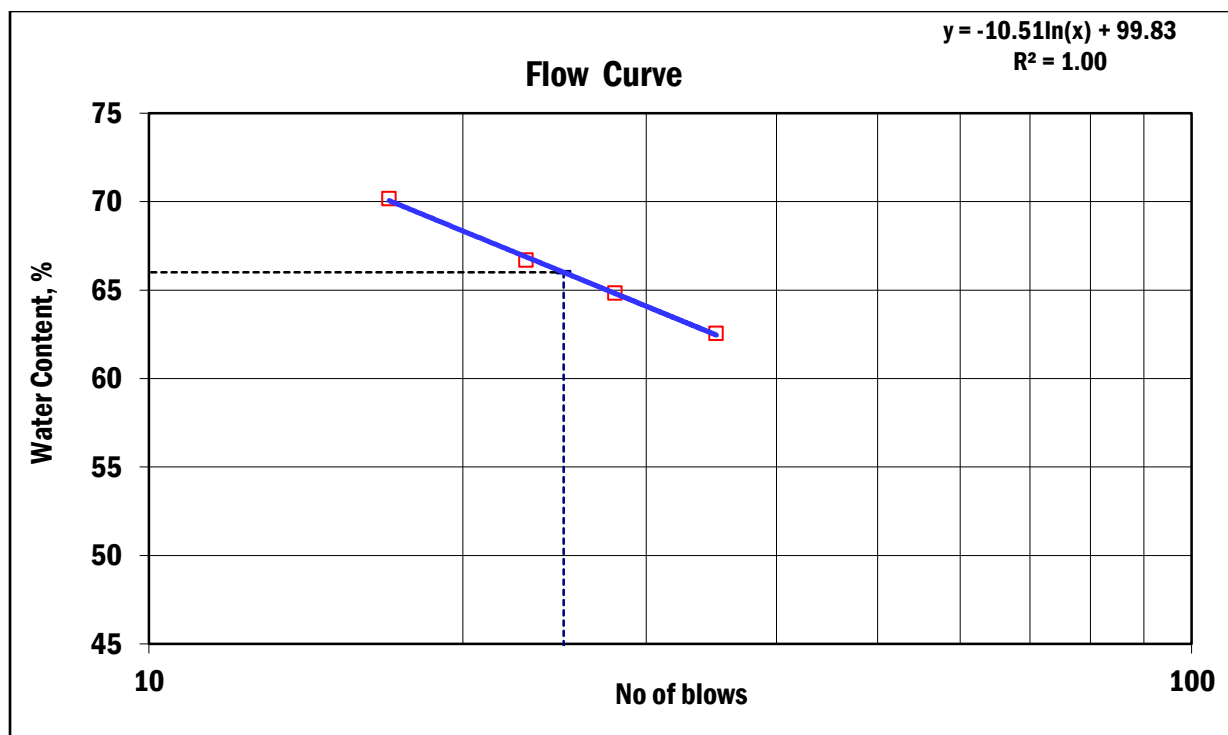
Liquid Limit, % = 65 Plastic Limit, % = 35 PI, % = 30



Sample no 35

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A23	31	A19	D33	c21	14
Mass of container, g	15.6	15.3	15.42	15.5	15.4	14.23
Mass of container + Wet soil, g	35.67	36.56	37.22	36.80	17.82	17.33
Mass of container + Dry soil, g	27.95	28.2	28.5	28.02	17.22	16.56
Mass of water, g	7.72	8.36	8.72	8.78	0.60	0.77
Mass of dry soil, g	12.35	12.90	13.08	12.52	1.82	2.33
Water content, %	62.54	64.81	66.69	70.16	33.08	32.92
No of blows	35	28	23	17	-----	-----

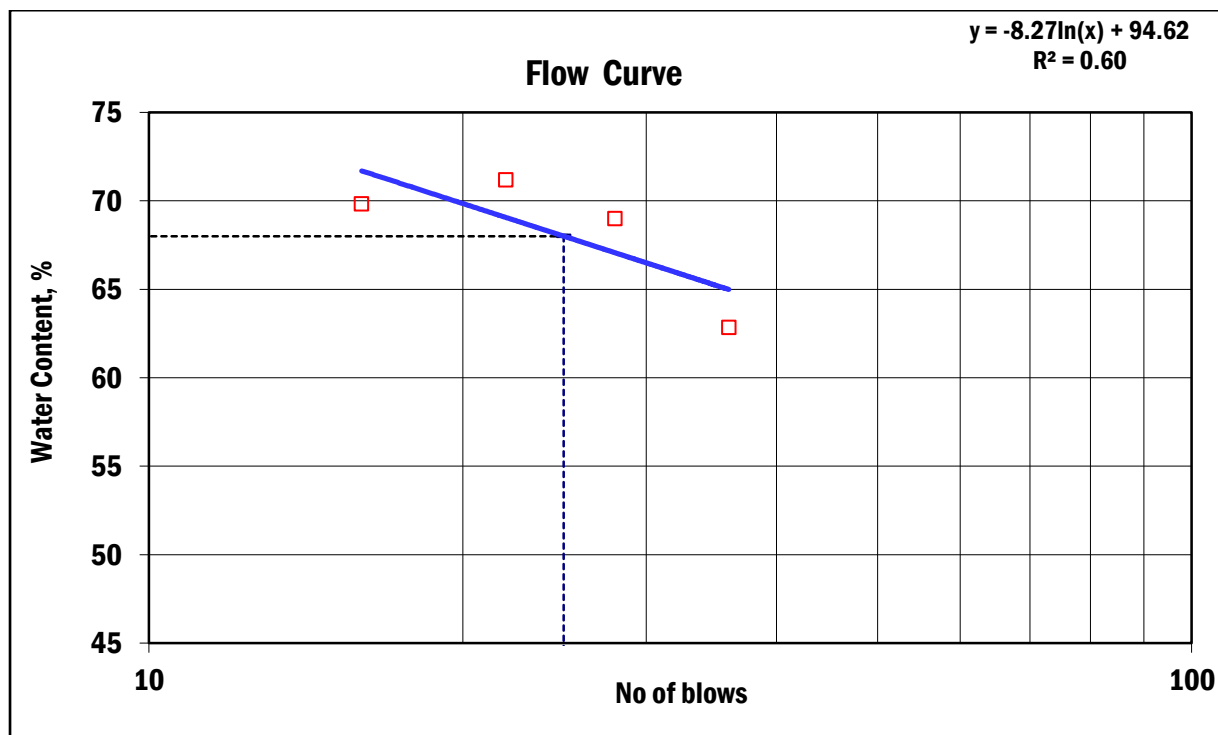
Liquid Limit, % = 66 Plastic Limit, % = 33 PI, % = 33



Sample no 36

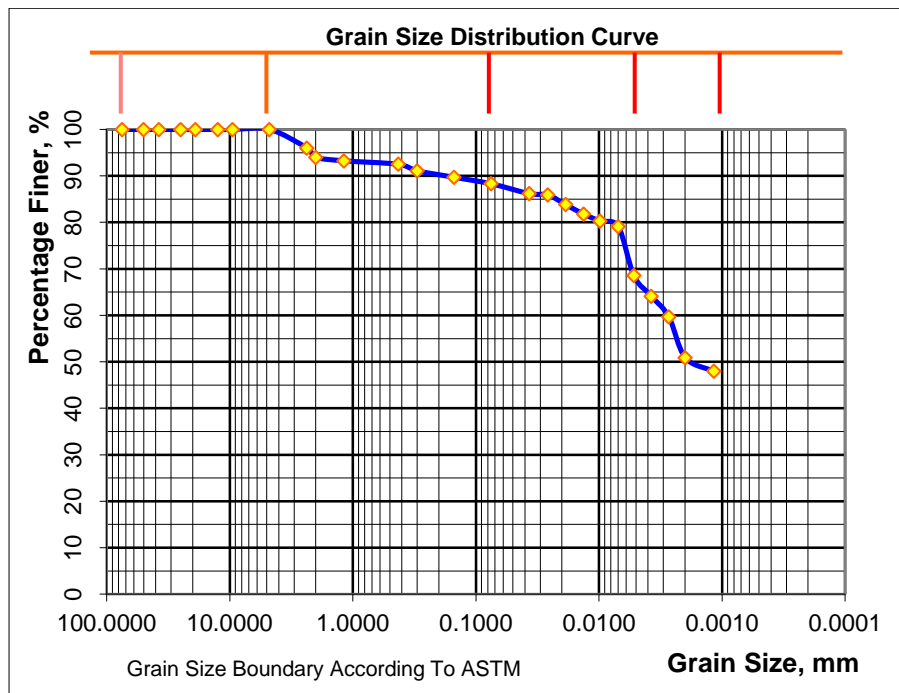
Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	33	C15	A18	D33	24	14
Mass of container, g	15.75	15.5	16.49	15.5	15.67	15.33
Mass of container + Wet soil, g	42.29	35.69	37.75	39.94	18.66	18.65
Mass of container + Dry soil, g	32.05	27.45	28.91	29.89	17.88	17.87
Mass of water, g	10.24	8.24	8.84	10.05	0.78	0.78
Mass of dry soil, g	16.30	11.95	12.42	14.39	2.21	2.54
Water content, %	62.83	68.98	71.16	69.82	35.20	30.80
No of blows	36	28	22	16	-----	-----

Liquid Limit, % = 68 Plastic Limit, % = 31 PI, % = 37

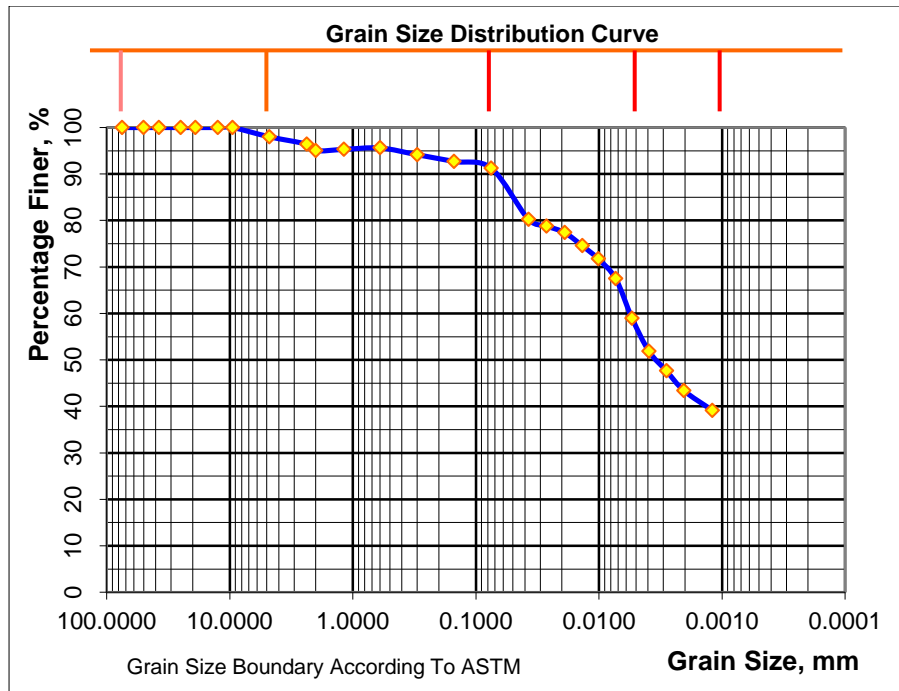


APPENDIX D – PARTICLE SIZE DETERMINATION

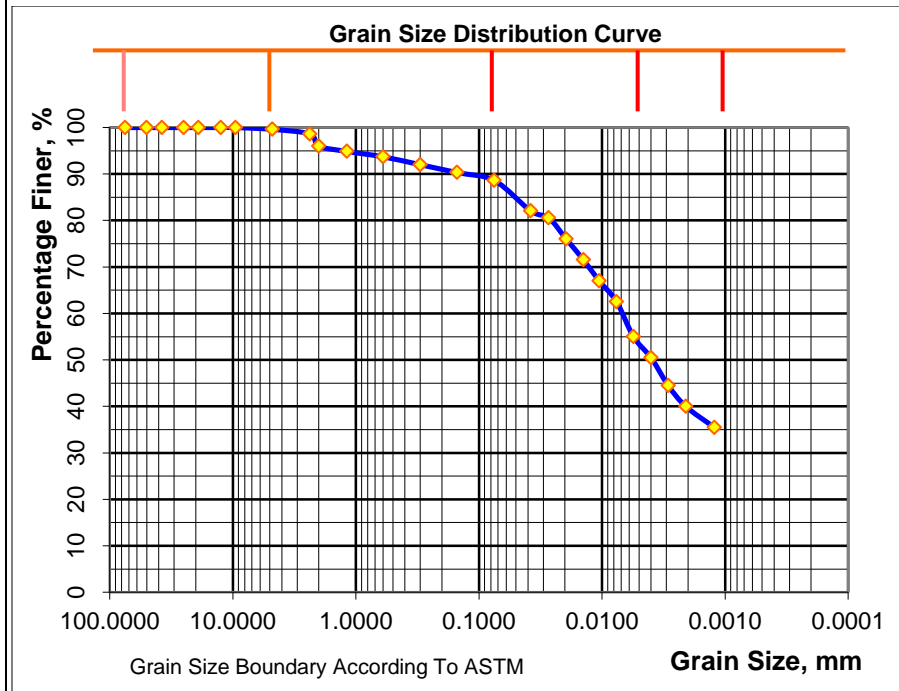
Sample no 1



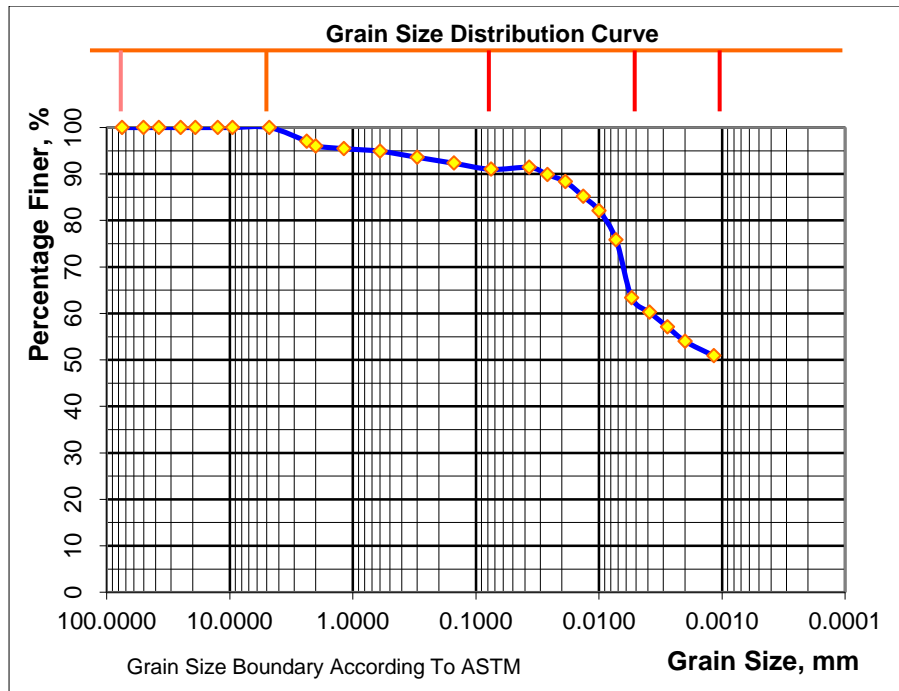
Sample 3



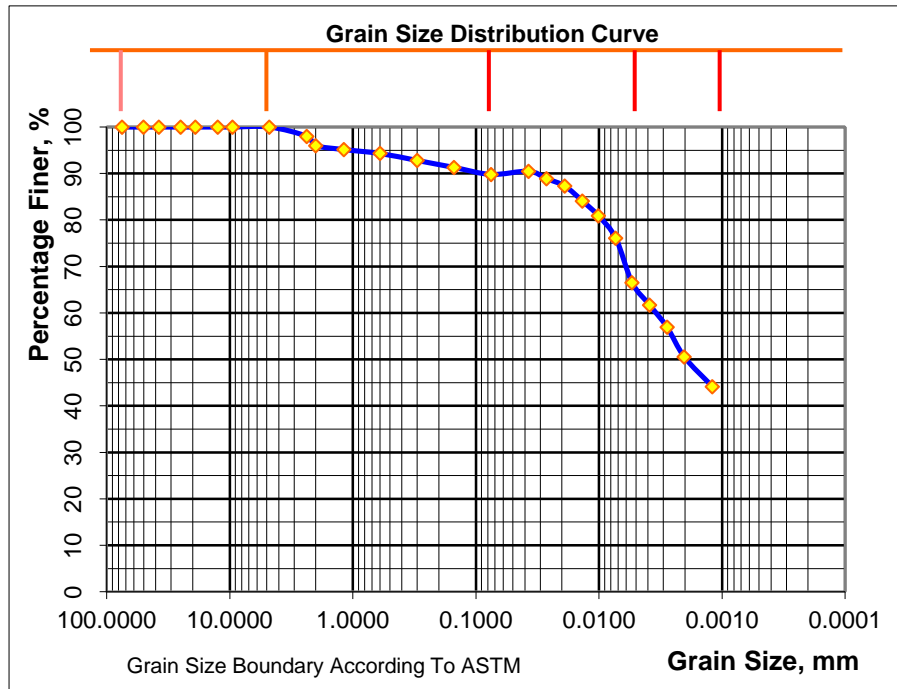
Sample 4



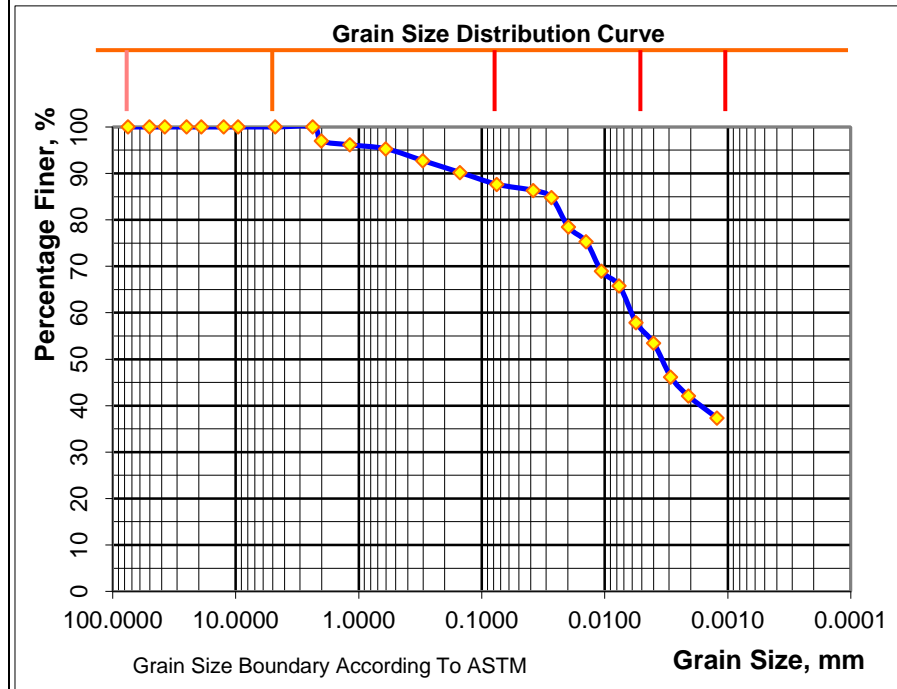
Sample 5



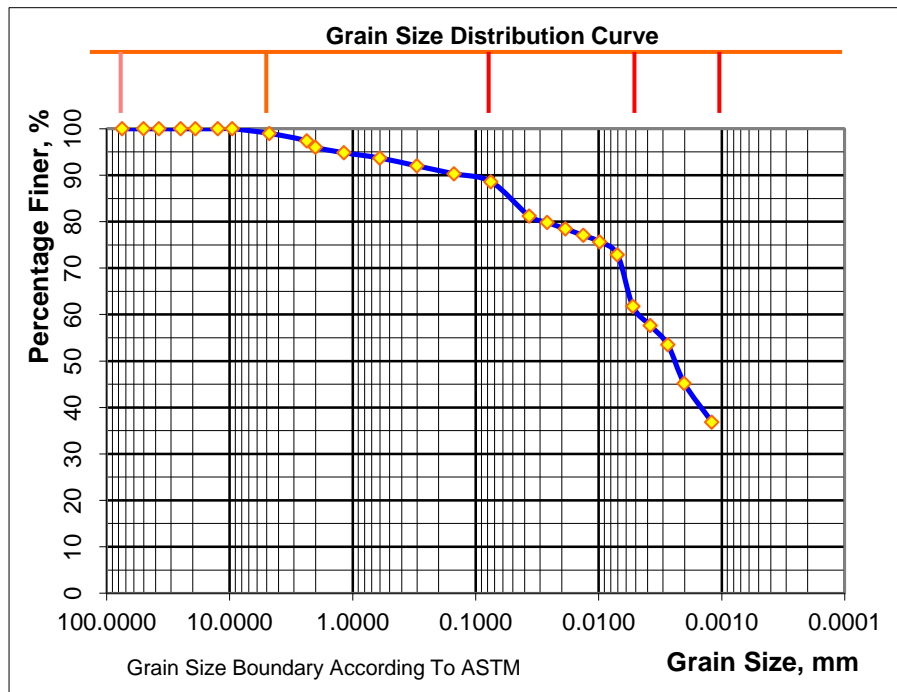
Sample 7



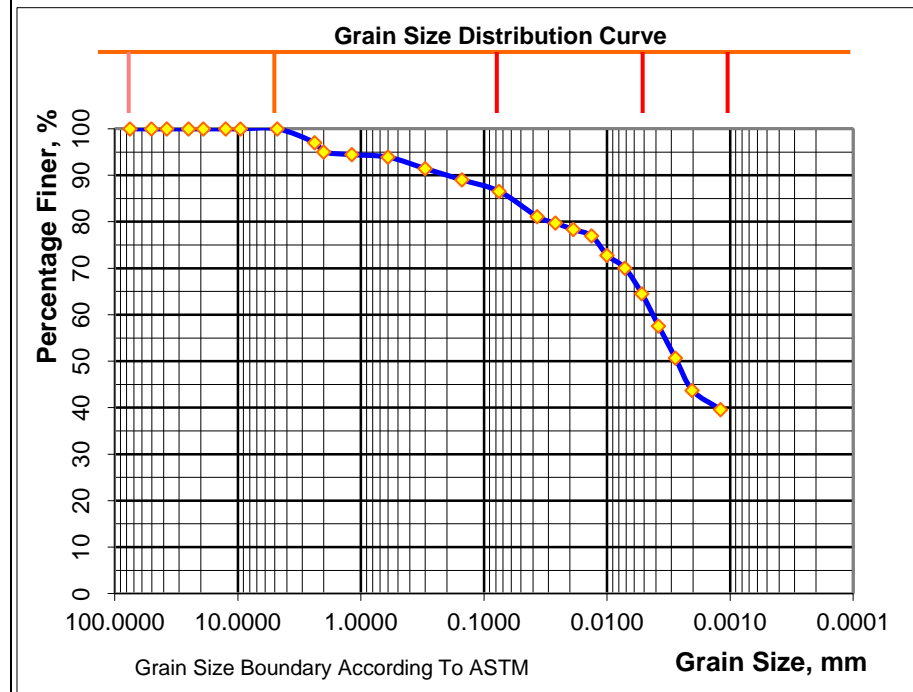
Sample 8



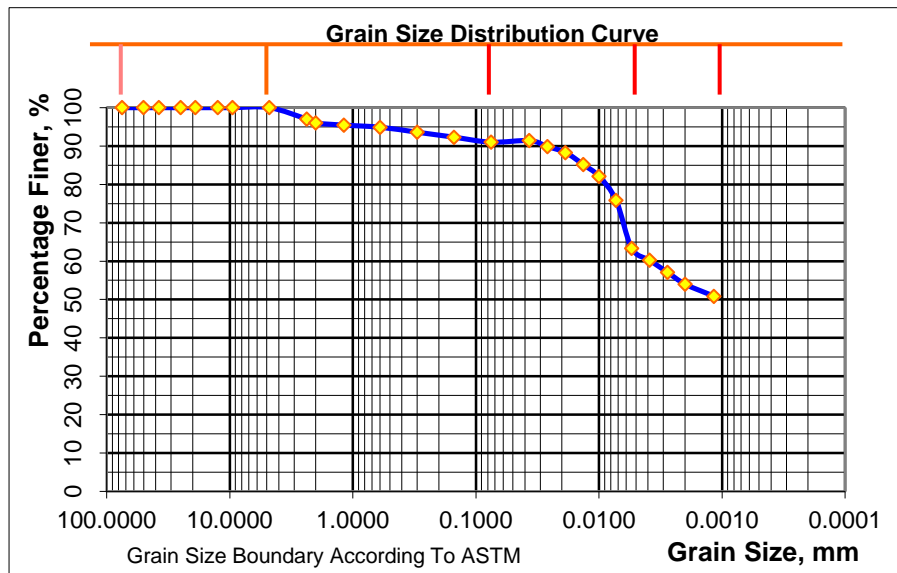
Sample 9



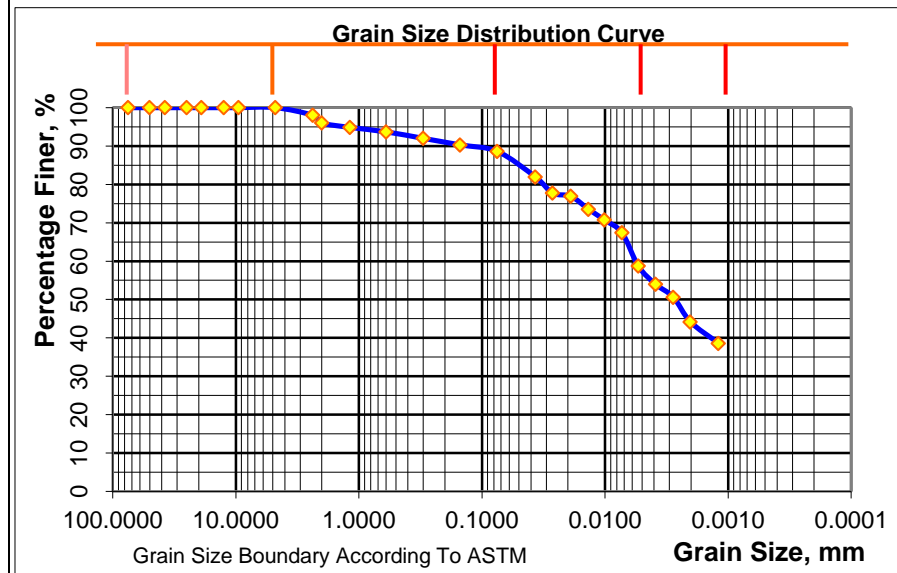
Sample 10



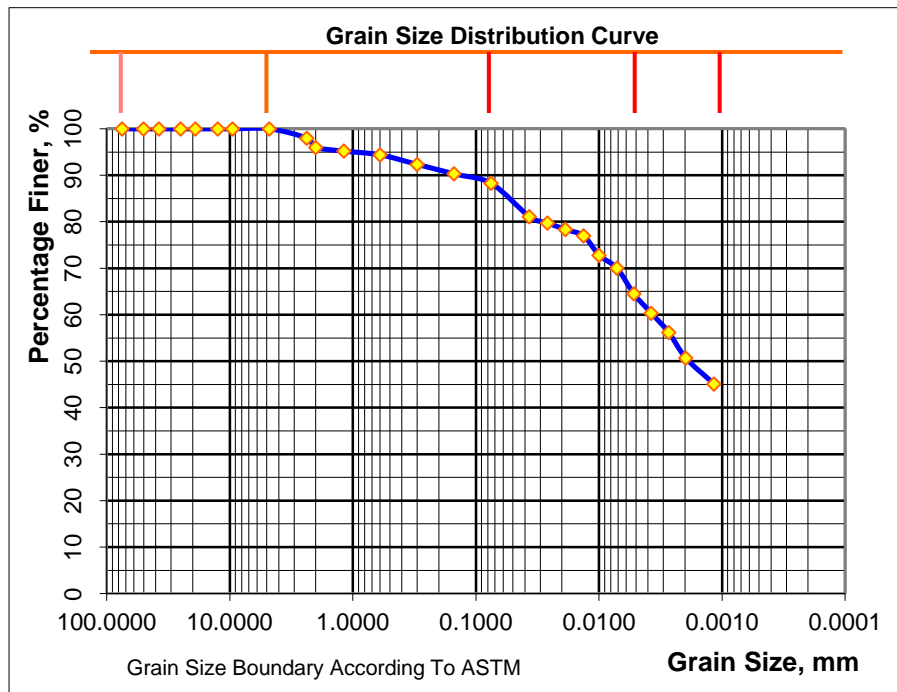
Sample 11



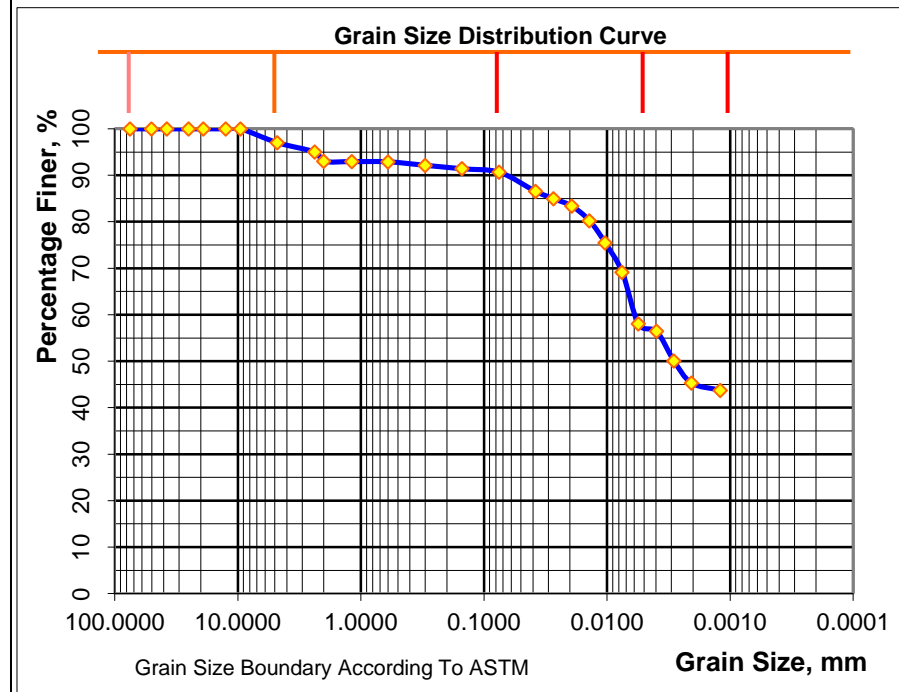
Sample 12



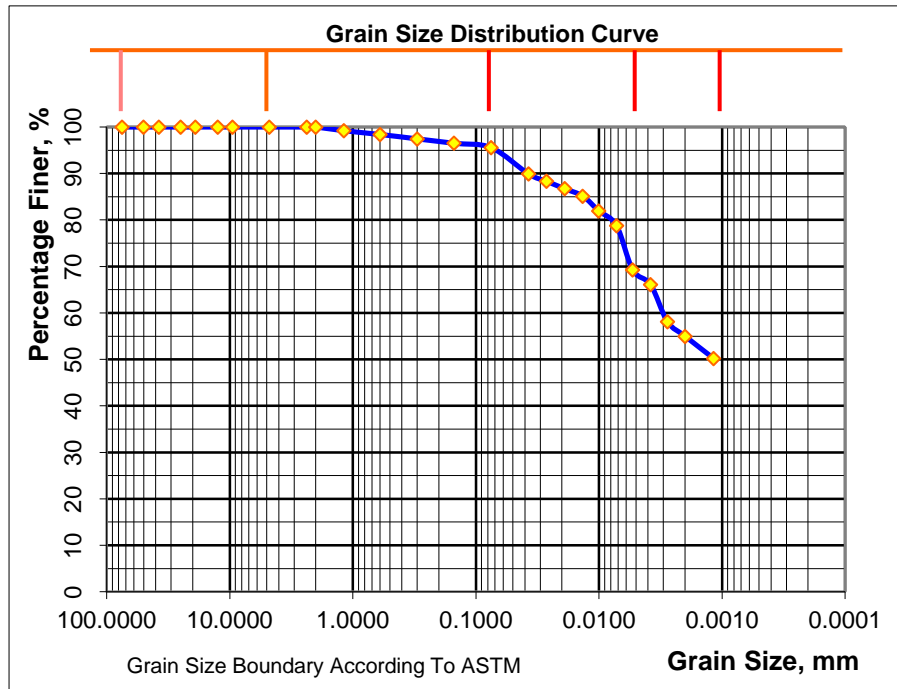
Sample 13



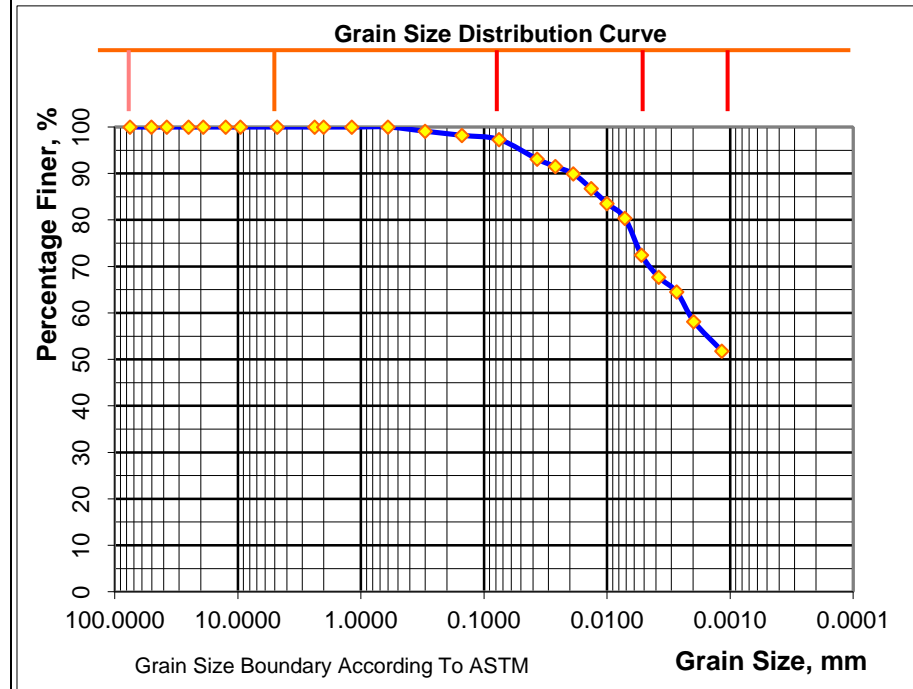
Sample 14



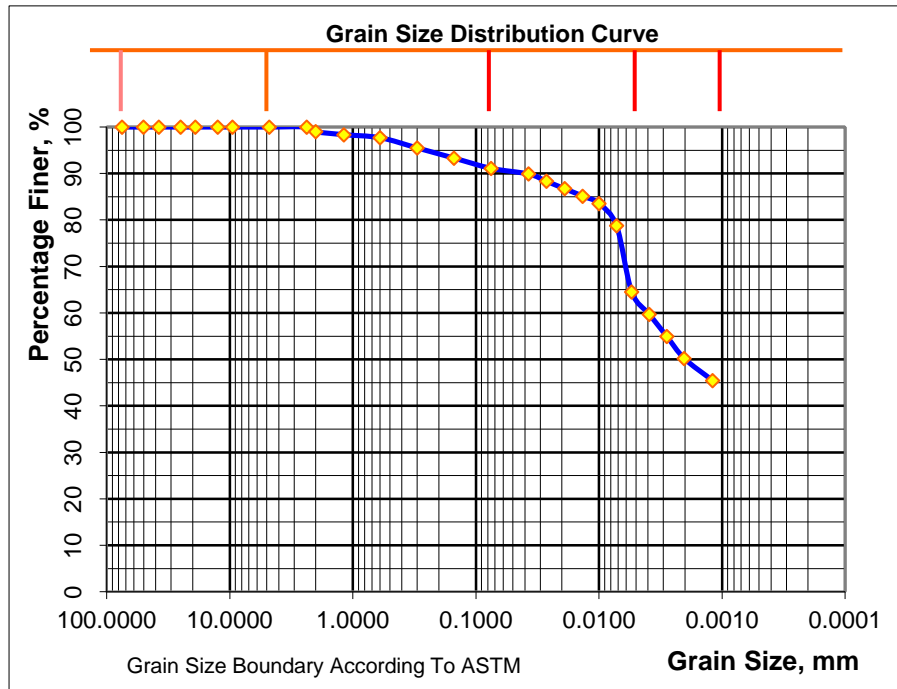
Sample 15



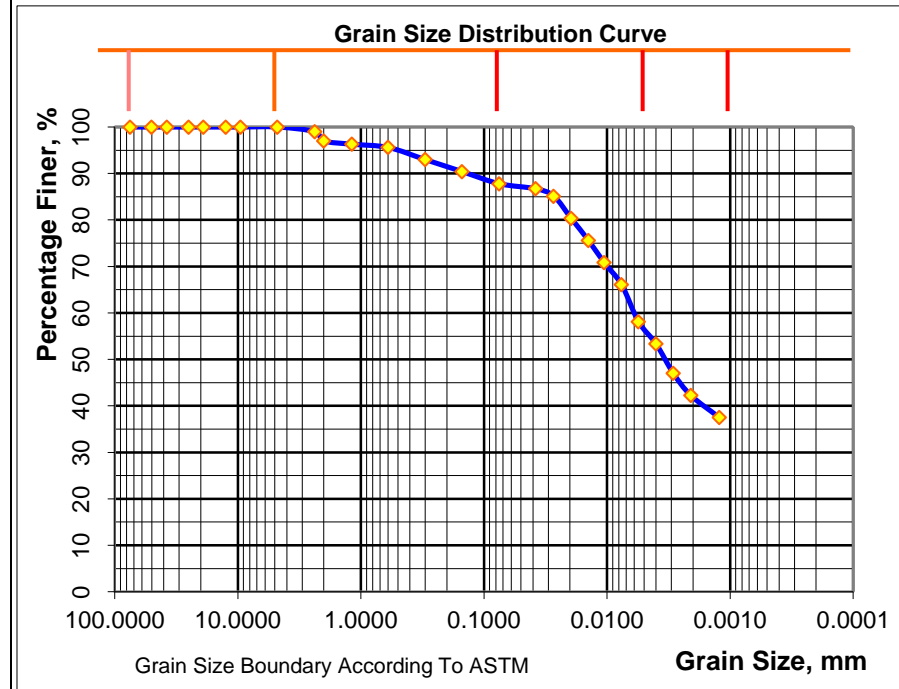
Sample 16



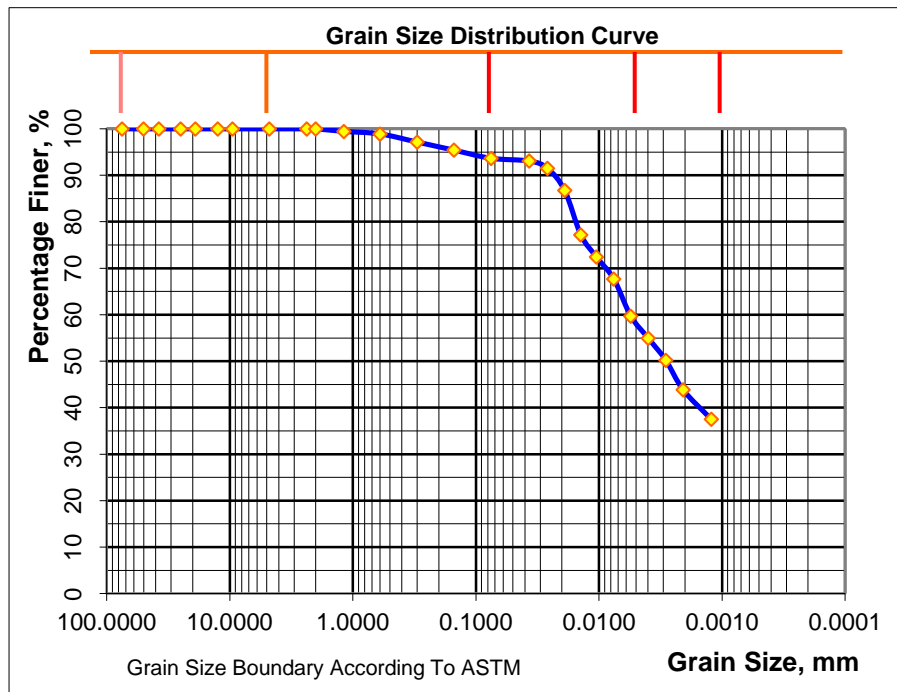
Sample 17



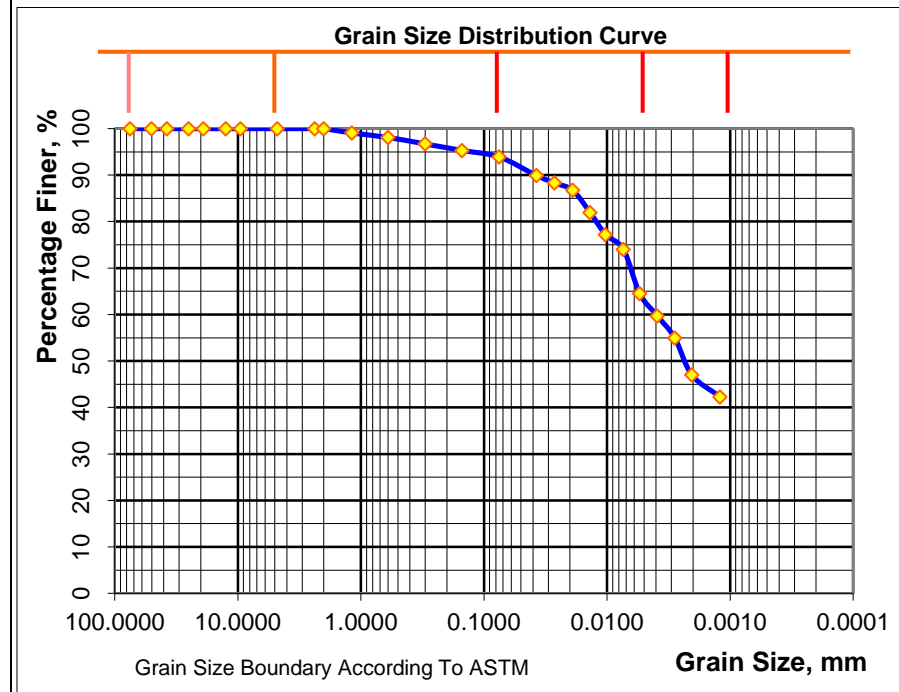
Sample 18



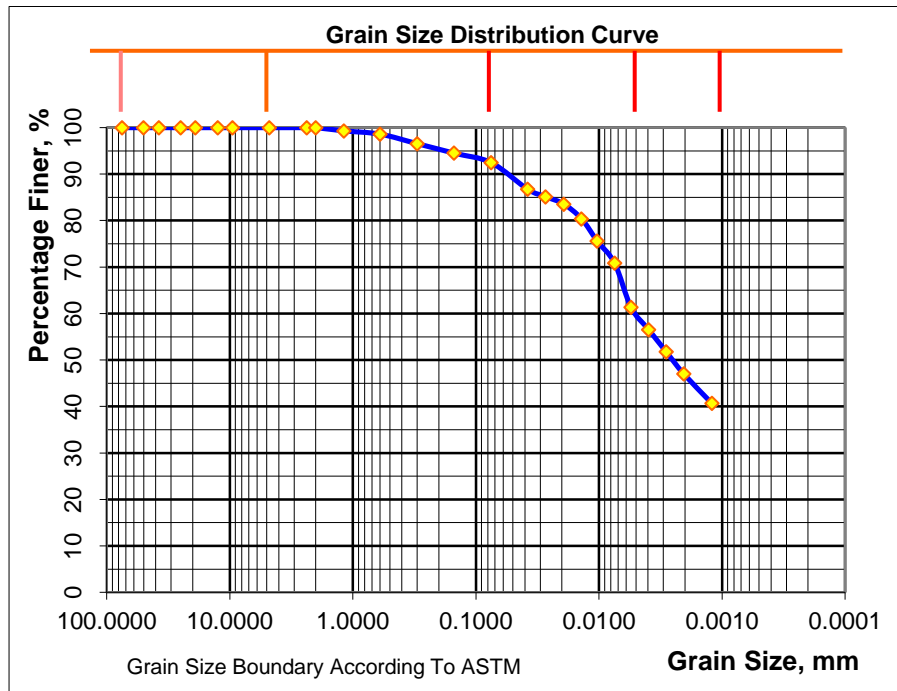
Sample 19



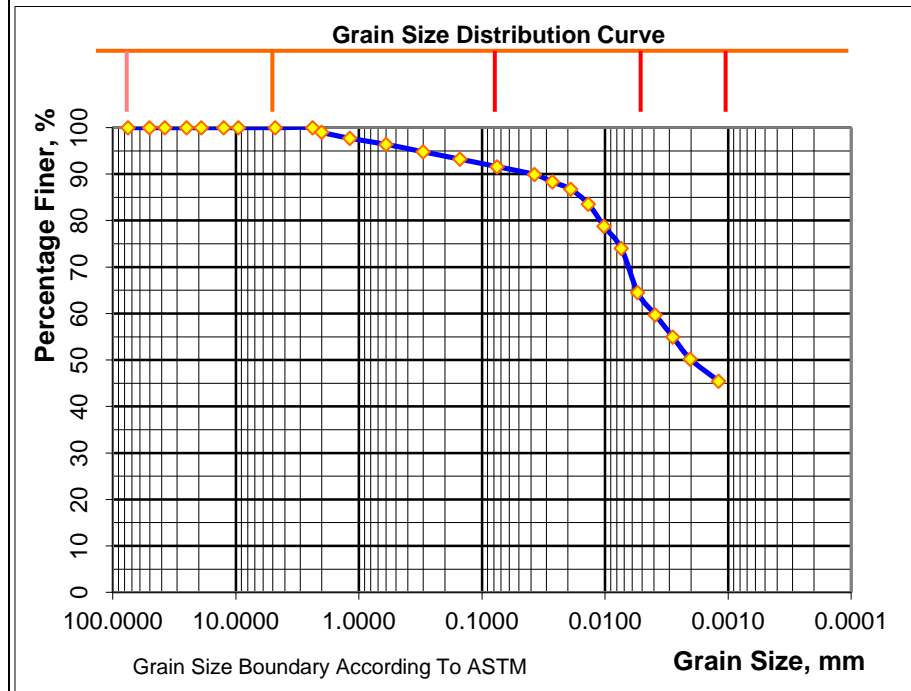
Sample 20



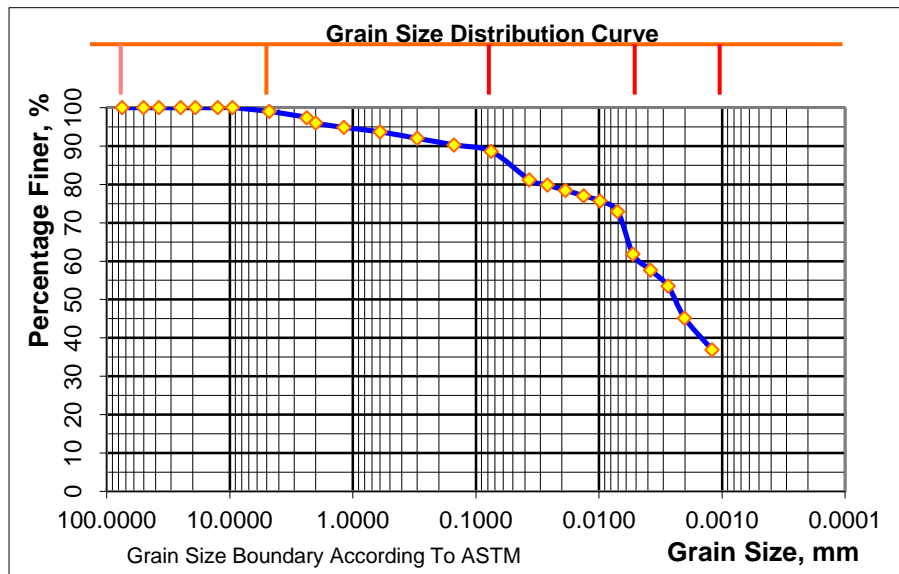
Sample 23



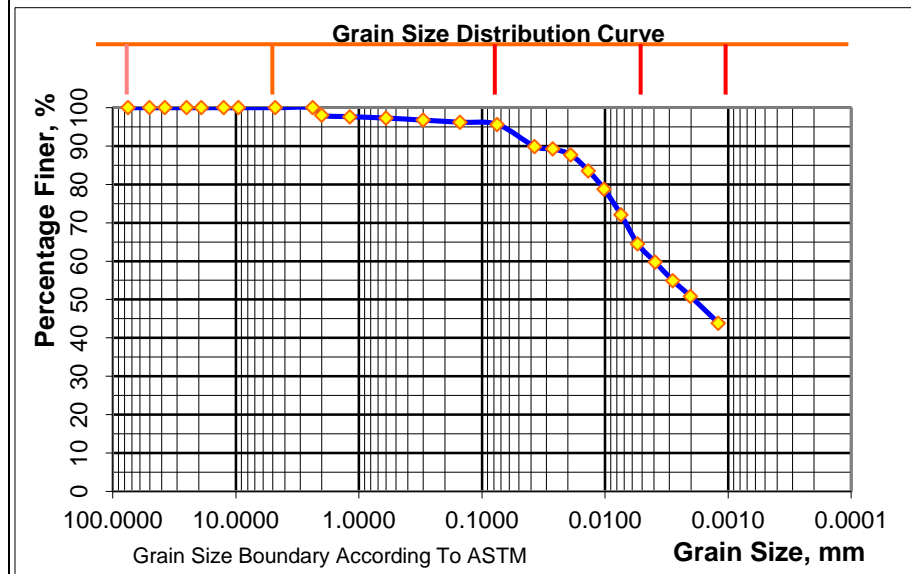
Sample 24



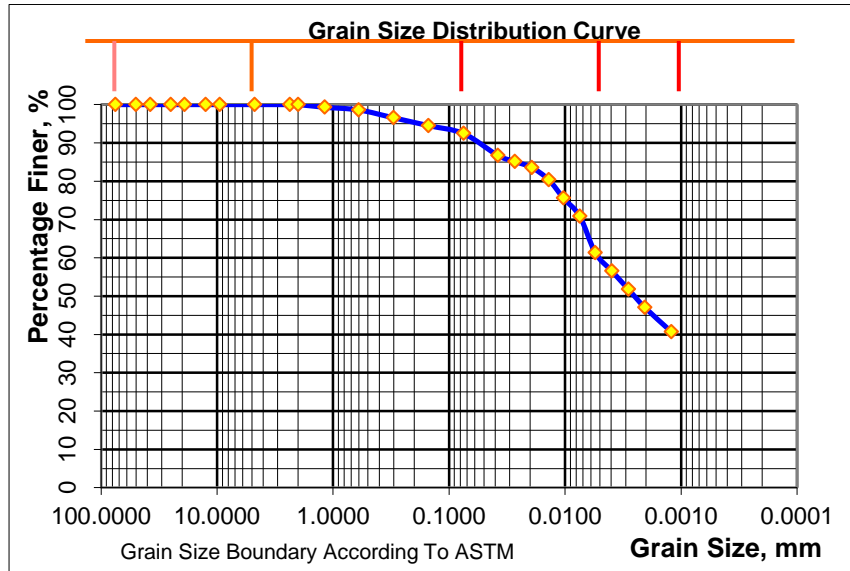
Sample 29



Sample 30



Sample 31



DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Professor Alemayehu Teferra and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

Name: Ermias Genye Endaylalu

Signature

Place: Addis Ababa institute of Technology

School of Graduate Studies,

Department of Civil Engineering,

Addis Ababa.

Date: October 2014