ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
COLLEGE OF TECHNOLOGY AND BUILT ENVIRONMENT
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

PREDICTION OF CBR VALUE OF THE SUBGRADE USING DYNAMIC CONE PENETRATION TEST

(a case study on Beredimtu – Imi Road Project)

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 Civil Engineering (Geotechnical Engineering)

By

Samson Molla

Advisor

Samuel Tadesse (Dr. Ing.)

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List of Symbols

A	Percent Passing Sieve No. 10 (2mm Sieve Size)
B	Diameter of Plunger or Width of Foundation
c	Cohesion of Soil
c_u	Undrained Cohesion of Soil
D_{60}	Diameter on the Cumulative Size Distribution Curve where 60 percent of Particles are fines
I_P	Plasticity Index
M_R	Resilient Modulus
N_c	Terzaghi's Bearing Capacity Cohesion Coefficient
N_q	Terzaghi's Bearing Capacity Surcharge Coefficient
N_γ	Terzaghi's Bearing Capacity Dry Unit Weight Coefficient
P_o	Overburden or Surcharge Load
P_{200}, F	Percent Passing Sieve No. 200 (0.075mm Sieve Size)
q_u	Bearing Capacity
R	Pearson Product Moment Correlation Coefficient
R^2	Coefficient of Determination
R-Value	Resistance Value
τ	Shear Strength of Soil
w_l	Liquid Limit
w	Moisture Content
α	Standard Significant Error
$\alpha_1, \alpha_2, \alpha_3, \alpha_n$	Coefficients of the Multiple Linear Regression Equation
γ	Bulk density of Soil
$\beta_1, \beta_2, \beta_3, \beta n$	Coefficients of the Single Linear Regression Equation
σ_n	Normal Stress
σ^2	Statistical Variance
ϕ	Internal Friction Angle
ε	Statistical Random Error

List of Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABC	Aggregate Base Course
ASTM	American Society for Testing and Materials
BS	British Standards
CBR	California Bearing Ratio
CH	High Plasticity Clay
CL	Inorganic Silts of Low to Medium Plasticity
CPT	Cone Penetration Test
DCP	Dynamic Cone Penetration
DCPI	Dynamic Cone Penetration Index
FDT	Field Density Test
GC	Clayey Gravels
GI	Group Index
GM	Silty Gravels
GP	Poorly Graded Gravels
GW	Well Graded Gravel
kg	Kilogram
kN	Kilo Newton
LFWD	Light Falling Weight Deflectometer
LL	Liquid Limit
MDD	Maximum Dry Density
MH	Inorganic Silts of High Plasticity
ML	Inorganic Silts of Low Plasticity
MnDOT	Minnesota Department of Transportation
MPa	Mega Pascal
N	Newton
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program

NMC	Natural Moisture Content
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
R2	Coefficient of determination
S1	ERA Subgrade class with a CBR Range of 0 to 2
S2	ERA Subgrade class with a CBR Range of 3 to 4
S3	ERA Subgrade class with a CBR Range of 5 to 7
S4	ERA Subgrade class with a CBR Range of 8 to 14
SPSS	Statistical Package for Social Science Software
TRRL/ TRL	Transport Road Research Laboratory/ Transport Research Laboratory
U.S.A	United States of America
USCS	Unified Soil Classification System

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Abstract

The significant advantage of the Dynamic Cone Penetration (DCP) test is that it is a low cost, robust apparatus that is quick and simple to use. With the DCP testing, very little damage is made to the pavement being tested (effectively non-destructive) whereas very useful information is obtained. Another interesting advantage of the test is that the pavement is tested in the condition at which it performs. The simplicity of the test allows repeated testing to minimize errors and also to account for temporal effects.

On the other hand, California Bearing Ratio (CBR) is a very popular in the construction industry especially, in road construction as a soil support value of the pavement. However, CBR cannot be easily determined in the field. This initiated the need to investigate the relationship CBR value has with other field tests like DCP.

As part of this study, primary field and laboratory subgrade tests for the locally available subgrade soil of the case project, Beredimtu – Imi – Gode road project, were conducted. Using the test results, the relationship between field and laboratory subgrade soil strength tests were in-depth investigated. Based on this laboratory and field test results, CBR values were correlated with DCPI values using a simple regression coming up with an R^2 of 0.958 and low standard error of estimate. On the other hand, the CBR has been correlated with the DCPI and the bulk density using a multiple regression technique with the equation having and R^2 of 0.854. Hence, the equation obtained with and R^2 of 0.958 is used for validation puepose.

Chapter-1: Introduction

1.1 Background

The highway engineering, being one of the core disciplines under the science of civil engineering, plays an outstanding role in the development of a country through its stake holders, especially in developing countries like Ethiopia. Highway engineering broadly covers relation to highway pavements the major tasks including the subgrade soil characterization, construction material identification and pavement design.

In our country, supplemented with Transport and Road Research Laboratory (TRRL) manual and other internationally accepted design manuals, like AASHTO manuals and hand books, the Ethiopian Roads Authority and Addis Ababa City Roads Authority Design Manuals are used in the roads design process. According to both manuals the design of highway pavements, i.e. the determination of the pavement material and thicknesses of the various layers of both flexible and rigid pavement is basically contingent on the strength of the Subgrade soil and the traffic. The strength of the subgrade soil is defined by its CBR value which is directly obtained by undertaking the laboratory CBR test.

Desalegn, 2012 [5] states "the CBR test was developed by the California State Highways Department in the 1930's. It is in essence a simple penetration test developed to evaluate the strength of road sub grades (soil below the pavement) and makes no attempt to determine any of the standard soil properties such as density. It is merely a value and it is integral to the process of road design. It is however, by far the most commonly used in Pavement Design. The CBR test should be used with soil at the calculated equilibrium moisture content. Almost all design charts for the road foundations are based on the CBR value of the sub grade materials."

The Dynamic Cone Penetrometer (DCP) test was first developed by Scala, in 1956 in Australia, to evaluate the shear strength of the pavement material. It consists a steel rod with a steel cone of 30° attached to the bottom tip and driven into the pavement structure or sub grade using a 9 kg of mass dropping from 508 mm height and driving the cone into the material being tested. This development was standardized in South Africa with modifying the cone to 60°, the mass to 8kg and its falling height to 575mm [13].

It is worth noting that, in relative terms, the laboratory CBR test is an expensive and time-consuming test. On the other hand, the DCP test, being an in-situ test with three operators is relatively a quick and easy strength test. Obviously, developing a correlation relation between these strength tests highly benefits the industry.

There are a number of DCP – CBR correlation developed for various zones of the world and various types of subgrade soils. Among these, the one developed by TRRL for tropical countries is in use in our country regardless of the specific subgrade soil type of the site.

The correlation equation given by TRRL is generally presented as:

$Log(CBR) = a - b * Log(mm/blow)$ ....Equation 1.1

Where: a=2.48, and b=1.057
Note that the DCP – CBR correlation given in TRRL manual is developed by the use of 60 degrees' cone.

This correlation relation sounds very generic which fails to provide specific coefficients to the specific soil type. Since the currently available correlation was not developed for specific soil types, it may provide inappropriate strength value of the soil. This may have a negative impact on the economy of the country in general and on the construction industry in particular [5].

1.2 Statement of the Problem

The analysis and design of highways and airfields pavement layers is based on the strength of the subgrade soil represented by CBR value which is obtained from the California Bearing Ratio test. In-situ CBR determination is not common in our country; rather, even though it is time taking and expensive, the laboratory CBR test is the only dependable source in this regard. Since the CBR test needs transportation of samples to central laboratories, it is expensive, relatively slow to conduct and generally not favored by Highway Engineers [18].

Finding an alternative quicker and cheaper soil testing procedure which would indicate the in-situ subgrade soil strength would be of a great importance. Valuing this, different researchers have developed correlation relations between CBR and DCP tests for various soil types of different localities. Picking and using one of the existing relations would not give reliable output.

Thus, developing an appropriate correlation between CBR and DCP for the locally available subgrade soil is justifiable; then, the relation can be used to evaluate the in-situ subgrade strength of identical soil which could be used for design and evaluation purpose.

1.3 Objective of the Research

It is known that different soils have different engineering properties requiring each to be studied differently. Thus, applying an existing correlation to estimate the CBR values of a soil based on its field DCP test result may not give a dependable result. Engineering wise understanding of the difference between soils.

The main objective of this thesis is, to establish a dependable correlation relation between the field DCP and the lab CBR results for a locally available subgrade material. In addition to this, the research also aims at proofing the applicability of the existing correlations developed between Dynamic Cone Penetrometer test and California Bearing Ratio tests giving special attention to the one suggested by the TRL since it is highly in use in our country even though it is generic among tropical countries.

1.3.1 General Objective

The main objective of this thesis is to give more attention to find correlation between California Bearing Ratio with soil index properties for representative soil samples recovered from different localities of Addis Ababa.

1.3.2 Specific Objectives

- To check and come up with a correlation between CBR values and DCPI values for the case project.
- To validate and evaluate previously developed correlation using a control test results.

1.4 Scope of the Study

The subject study is desired to conduct localized research particularly on samples recovered from Addis Ababa city. In order to conduct the proposed correlation forty-two laboratory test results are used in this research work.

With regard to the regression analysis, depending on the trends of the scattering of test results the correlation is analyzed using a linear regression model. The required correlation is carried out by applying a single linear regression model and multiple linear regression models with the aid of SPSS Software. Furthermore, the scope of the developed correlation is limited to the test procedures followed in the subject research work.

1.5 Methodology

So as to meet the objectives of the research, basic theories and applications of the Dynamic Cone Penetration test (DCP) and California bearing ratio test (CBR) have been studied at early stage of the study by collecting and reviewing relevant literatures. Technical papers, journals, handbooks, investigation manuals and published reports were reviewed to obtain all the possible information and the nature of the DCP and CBR relation.

As part of the research work, primary data have been collected by the researcher on the selected case-project; i.e., along the Beredimtu – Imi road. Field tests have been undertaken and pits have been dug and samples were collected for laboratory tests. The tests undertaken are in-situ DCP tests, Moisture Content determination, Field density test, Atterberg limits determination, Sieve analysis, Free swell tests and Laboratory CBR tests. Then, discussions on sample collection and summary of laboratory test results have been made.

Utilizing the test results, statistical regression analyses were carried out and correlation relations were determined. As part of the discussions of the obtained results the suitability of the developed correlations was examined. Finally, conclusions and recommendations were drawn.

1.6 Structure of the Thesis

For convenience and ease of reference, this thesis is organized as described below.

Chapter 1. Introduction: briefs the background, research objective, statement of problems and research methodology.

Chapter 2. Literature review: presents the review of the existing studies on the CBR-DCP relations stated in different literatures. Discussion of DCP and CBR test apparatus, test procedures, applications are also included.

Chapter 3. Materials, Methods and Procedures: describes the type of data collected, the tests undertaken and their use in the study.

Chapter 4. Data Analysis, Development of Correlation Equations and Validations: describes the study made on the nature of the existing relations between CBR and DCP, presents the regression analysis undertaken in the research and explains the correlation relation obtained.

In addition, the validation procedure of the newly obtained relation using additional test data is included in this section of the report.

Chapter 5. Discussion of Test Results and Soil Classification: briefly discusses the test results and presents the soil classification.

Chapter 6. Conclusions and Recommendations: details conclusion drawn from the research and recommendations made regarding the DCP-CBR relations and suggestion forwarded for further development of the science.

Appendices: Presents test result summaries, test result plots and charts.

Chapter-2: Literature Review

2.1 Characterization of Subgrade Soil

Technically the interest in dealing with the subgrade soils takes one to its mechanical properties finally represented by its strength values. Though the subgrade soil is characterized by its type (according to the classification scheme adopted), its strength representation is the main interest in highways and airfields pavement design procedure. Subgrade strength and stiffness are very important for pavement design, construction and performance evaluation, as it is the foundation for pavement structures. The strength of the subgrade soil can be expressed as the California Bearing Ratio (CBR), the R-Value or resilient modulus (Mr) [15].

In Ethiopia, the subgrade soil strength representation of the CBR value obtained from the laboratory CBR test is used for the design of both flexible and rigid pavements.

2.2 The CBR Test and Its Application

2.2.1 Historical Background of the CBR Test

The shear strength is a measure with fundamental meaning though shear strength tests are not always convenient to carry out. The California bearing ratio (CBR) was developed by the California State Highways Department in the 1930s as an index test for soils, for the purpose of pavement design, providing a general indication of soil shear strength. This index is still in use worldwide, and various specifications describe the CBR test, with only minor variations. However, it is notable that it is an empirical measure and has no absolute and fundamental meaning [19].

The CBR test procedure involves the compaction of a potential road-building material into a standard mold under a standard compaction effort at a predetermined moisture content, soaking the mold for 4 days and then penetration with a standard plunger at a fixed rate. To obtain the CBR value of a material, the loads applied to penetrate to selected depths are then compared to those required to penetrate a standard material [13].

The CBR value is obtained as the ratio of the Test Unit Load (in kN/m) required to cause a certain penetration depth of the plunger (penetration piston) into the material under test, at some water content and density, to the Standard Unit Load required to obtain identical penetration depth on a standard sample of crushed stone. It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to the one required for the corresponding penetration of a standard material [5].

2.2.2 CBR Test Measurement

The California Bearing Ratio (CBR) test can be performed both on field and at laboratory according to the test procedures of ASTM D 4429 or ASSHTO T193 (for the laboratory test) and BS1377:1990 or ASTM D1883-73 (for the field test).

2.2.2.1 Laboratory CBR

CBR test in the laboratory is carried out as per the procedure outlined in AASHTO [2] or ASTM D1883-73. The difference between the two procedures is on samples preparation [5].

The typical layout of the laboratory CBR apparatus is as presented in Figure 2-1.

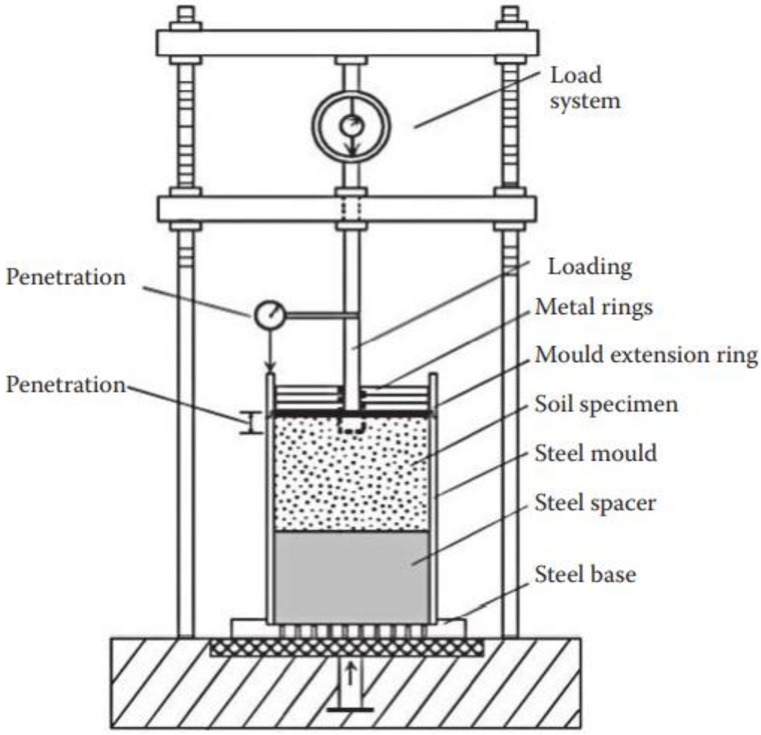


Figure 2-1: Laboratory CBR Apparatus Diagram

The CBR tests are usually undertaken on test specimens at the optimum moisture value for the soil as determined using the standard (or modified) compaction test using method 2 or 4 of ASTM D698-70 or of D1557-70 (for the 15.2 cm diameter mold). The specimens are prepared for the test applying the compaction effort shown in Table 2-2.

Table 2-1: The number of blows and corresponding number of layers for different grade of soils [5]

Method	Blows	Layers	Hammer Weight (N)
D698:2 (fine grained soil)	56	3	24.5
D698:4 (coarse grained soil)	56	3	24.5
D1557:2 (fine grained soil)	56	5	24.5
D1557:4 (coarse grained soil)	56	5	24.5

In the laboratory CBR test procedure, two molds of soil are often prepared. The first mold is for immediate penetration testing. The second specimen is soaked for four days (to simulate its worst condition) with a surcharge load approximately equal to the pavement weight used in the field under any condition not less than 4.5 kg. Swell readings will be taken during this period at randomly selected times. After the four days soaking, the CBR penetration test will be carried out to obtain a CBR value for the soil in the saturated condition.

In both penetration tests for the CBR values, a surcharge of the same magnitude as for the swell test is placed on the sample. The test on soaked sample furnishes two things:

- ✓ It provides the information regarding expected soil expansion beneath the pavement when the soil becomes saturated.
- ✓ It gives some indication of strength loss from field saturation.

After placing annular weights on the specimen, the specimen (compacted and soaked) is placed on the CBR apparatus. Testing is then carried out in the compression machine using 1.27mm/min penetration rate; reading and record of load versus penetration are made at each 0.5mm of penetration to include the value of 5.08 mm, and then at 2.54 mm increment thereafter until a total penetration of 12.7mm is achieved.

The pair values of penetration applied load are placed in linear coordinates and a curve of form A or B is obtained (as shown in Figure 2-2). If the "A" curve is obtained, no correction is needed; else, the part of the curve concaving upwards (in the case of curve "B") after the initial loading needs to be corrected. The correction is made by drawing a tangent at the point of greatest slope and then transposing the axis of load such that zero penetration is taken as the point where the tangent cuts the axis of penetration (the horizontal axis) [11].

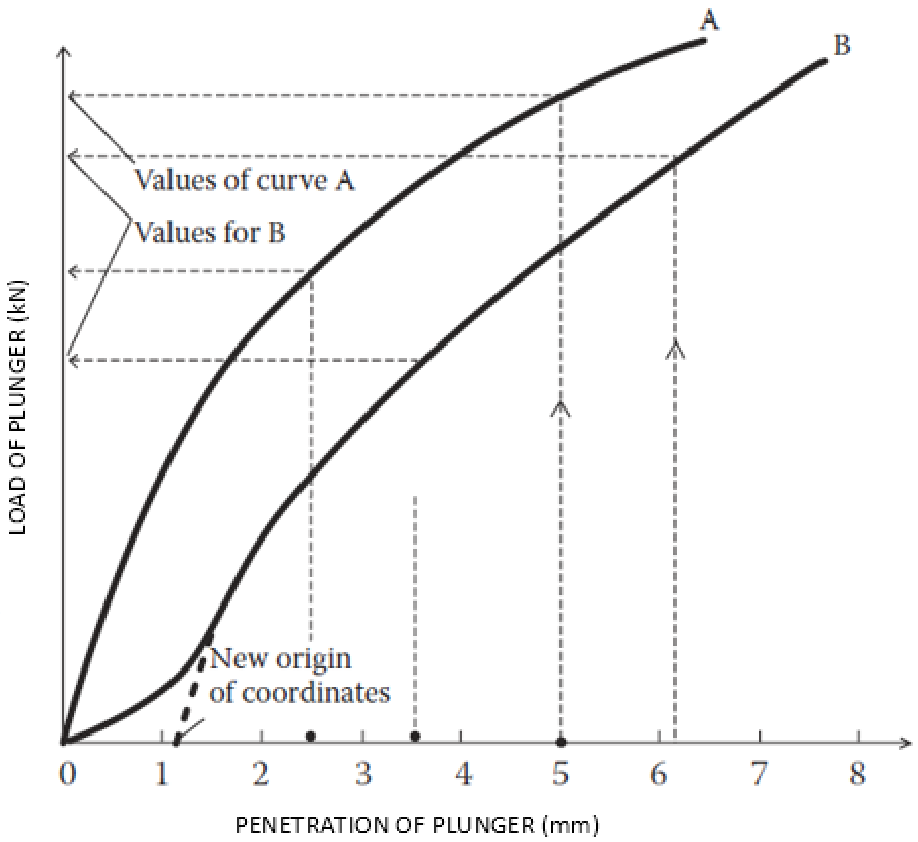


Figure 2-2: Diagram for CBR Determination [11]

Then, the applied loads are determined for penetration of 2.54 and 5.08 mm, respectively. The CBR is calculated using the underlying equation; where 6.9 MPa or 10.3 MPa is the applied stress which causes the plunger's penetration in the standard crushed stone of 2.54 mm or 5.08 mm, respectively.

The two CBR values will finally be compared and the one corresponding to 2.54mm will be taken as the CBR of the material if and only if it is greater that of the 5.08mm penetration; otherwise, the test will be repeated and in case similar result is obtained the value corresponding to the 5.08mm will be taken as the CBR of the material tested [6].

2.2.3 Field CBR

When an engineer requires a quick information regarding the material, he has to handle at a specific natural moisture content then the CBR of compacted soil can also be measured 'in situ'. (Nikolaides, 2015)

The field CBR test is used to determine the CBR value of the soil/ material on site and it is obtained, in a similar fashion as the laboratory CBR test, as a ratio of the penetration load of the material under test to that of a standard material. It is applied for the evaluation and design of components of flexible pavement like base, subbase and subgrade.

It is worth mentioning that the CBR values determined in situ always differ from values obtained in the laboratory though undertaken on identical specimens (with the same moisture content and degree of compaction). This is principally due to the difference on the confinement conditions on each case. The restriction imposed by steel mold (in the laboratory CBR test case) in soil material is higher than that of the compacted layer (in the in-situ case). Thus, the CBR values determined in the laboratory are usually higher than the values obtained in situ, of course on identical specimens. This difference is noted being high in coarse soils. Moreover, it should be mentioned that the in-situ determination of CBR of coarse soils should be avoided. (Nikolaides, 2015).

In table 2-3 the comparisons between laboratory and field CBR a variety of soil material are indicated

Table 2-2: Comparison between laboratorial and in-situ CBR values [11]

Type of soil	*Dry density (kg/m^3)*	*Moisture content (%)*	*CBR values (%)*	
			Laboratorial	*In situ*
Clay (w_L = 69, w_p = 27)	1522	24.8	8.9	7.9
Clay (w_L = 59, w_p = 23)	1538	25.1	3.9	3.0
Silty clay (w_L = 37, w_P = 23)	1746	19.5	2.0	1.2
	1714	19.0	5.0	1.1
	1666	16.1	2.2	2.2
Sandy clay (w_L = 30, w_P = 18)	1522	19.2	2.2	3.1
	1858	12.2	14	7.0
Clayey sand	1826	12.6	10	9.0
	1746	10.0	12	18.0
Well-graded sand	1750	8.0	24	7.5
Crushed slag	2243	4.8	41	44

The ASTM in-situ CBR test procedure (ASTM D4429-04) states that the field CBR test is used when CBR is the desired strength parameter. If the field CBR is to be used directly for evaluation or design without consideration of change in water content, the test should be conducted under one of the following conditions:

a. When the degree of saturation (percentage of voids filled with water) is 80 % or greater,
b. When the material is coarse grained and cohesion less, so that it is not significantly affected by changes in water content, or
c. When the soil has not been modified by construction activities in the preceding two years. In the last-named case, the water content does not actually become constant, but generally fluctuates within a rather narrow range. Therefore, the field in-place test data may be used to satisfactorily indicate the average load-carrying capacity.

For design purpose, the in-place CBR test result can be used under conditions of nominal stability of moisture, density, and general characteristics of the material. However, significant disturbance or moisture fluctuation can affect the soil strength and initiates to repeat the test. (Desalegn, 2012)

2.2.4 Application of CBR test

The strength of the subgrade soil, along with other factors, is a key consideration in the design of highway pavements. Being one of the measures of subgrade support capacity, the CBR test result is used in the empirical pavement design procedure of flexible pavements of highways [1].

The CBR test is also used in evaluating the strength of subgrade, subbase, and base course material, including recycled materials for use in road and airfield pavements [2].

As part of the quality control procedure in the construction projects of highways the CBR is used to evaluate the strength of subgrade soil and/or the pavement components against the requirement before the overlying pavement component is placed.

2.3 The Dynamic Cone Penetration Test and Its Application

As a simple alternative approach, the dynamic cone penetration test (DCPT) was originally developed by Scala, in 1956 Australia, for evaluating the strength of flexible pavement or subgrade soils. The custom approach to evaluate strength and stiffness properties of asphalt and subgrade soils involves a core sampling procedure and a complicated laboratory testing program such as resilient modulus, Marshall tests and others [10]. For its simplicity for operation, time saving and economical preference, better understanding of the DCPT results can reduce significantly the effort and cost involved in the evaluation of pavement and subgrade soils [14].

DCP testing is in use in the characterization of soil properties in many ways The dynamic cone penetration test (DCPT) is being used widely to characterize in-situ materials on field exploration and quality assessment of subsoil layers. Perhaps the most important advantage of the dynamic cone Penetrometer (DCP) device is related to its ability to provide a continuous record of relative soil strength with depth [13]. DCP device is worth choosing for its economy and simplicity to operate and its advantage to provide repeatable results and rapid assessment.

The device Scala developed consisted of a 15.9 mm diameter rod calibrated in 50.8 mm increments, a 9.1-kg drop hammer freely falling from a height of 508 mm and a 30 degrees' cone at the tip. Scala conducted tests correlating CBR with DCP data and suggested a pavement design approach based on this correlation. Use of this DCP device was then adopted by the Country Roads Board, Victoria, and gained widespread acceptance. (Desalegn, 2012)

The TRL's DCP uses 8Kg hammer dropping from a height of 575mm and a 60° cone having a maximum of 20mm diameter which creates a clearance hole to ensure there is no friction on the rods. A reading rod is given with measuring marks which enables to record the penetration.

DCP has been used for various applications. Some applications of the DCP technique include correlations with resilient modulus, California Bearing Ratio (CBR), unconfined compressive strength, and shear strengths, as well as its uses in quality control of compaction of fills on construction projects and performance evaluation of pavement layers [3].

The DCP test is simply conducted by three operators, two laborers and one supervisor are required. The supervisor controls the reading and recording of the results, whilst the two laborers alternate between holding the apparatus vertical and handling the hammer. The first step of the test is to put the cone tip on surface prepared for the test. The lower shaft containing the cone moves independently from the reading rod sitting on the testing surface throughout the test. The initial reading is not usually equal to 0 due to the disturbed loose state of the ground surface and the self-weight of the testing equipment. The value of the initial reading is counted as initial penetration corresponding to blow 0. (Desalegn, 2012)

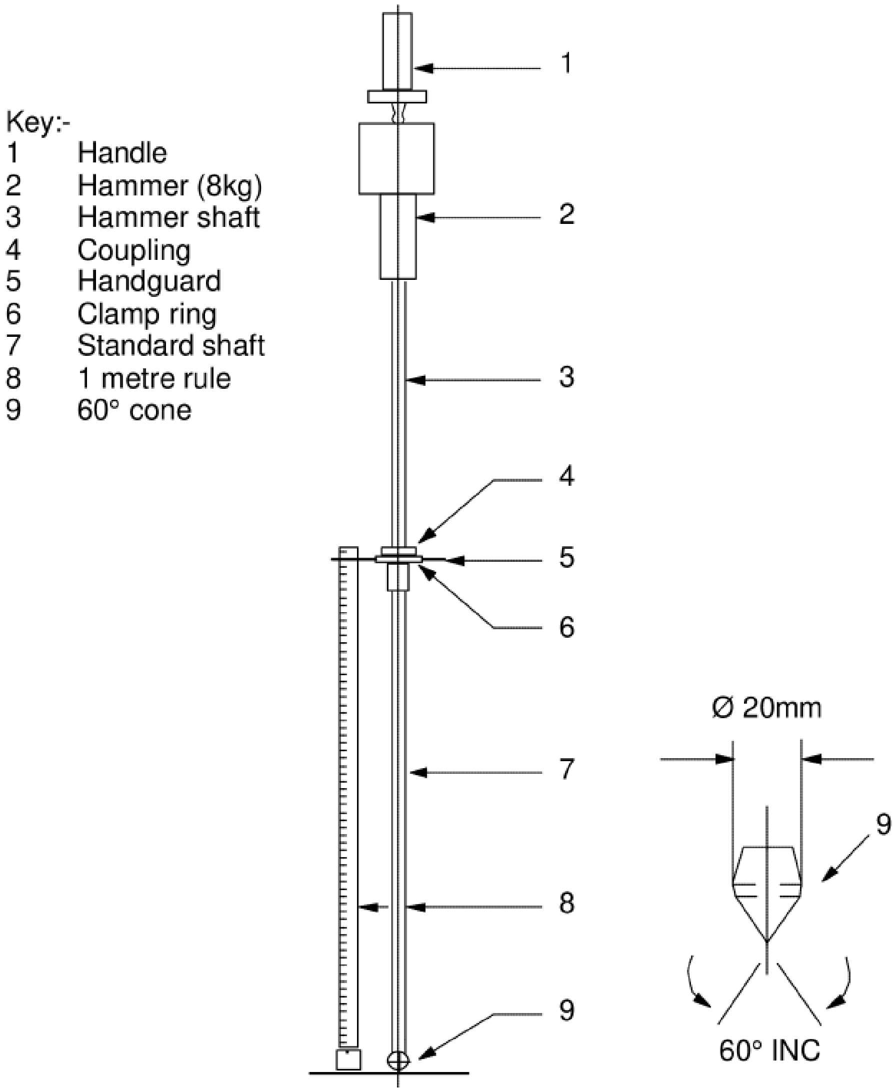


Figure 2-3: Dynamic Cone Penetrometer

DCP test result is a function of number of blow count and the penetration depth. The recorded blow count is changed to cumulative number of blows and the result of penetration index from the test can be calculated as follows:

$DCPI = \frac{\Delta Dp}{\Delta Bc}$……………………………………………………………………Equation 2.1

Where:

DCPI is Direct Cone Penetration Index (mm/blow)

ΔDp is Penetration Depth and

ΔBc is Blow counts corresponding to the penetration depth ΔDp

To analyze the DCP test result, one has to see it on a scatter plot of blow count versus penetration depth. The plot provides information regarding the in-situ material strength and its variation. The between any two points in the plot 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 [8].

It is worth noting that the variation in DCPI usually imply variation in soil layer.

Typical plot of the blow count versus the penetration depth is as shown in Figure 2-4.

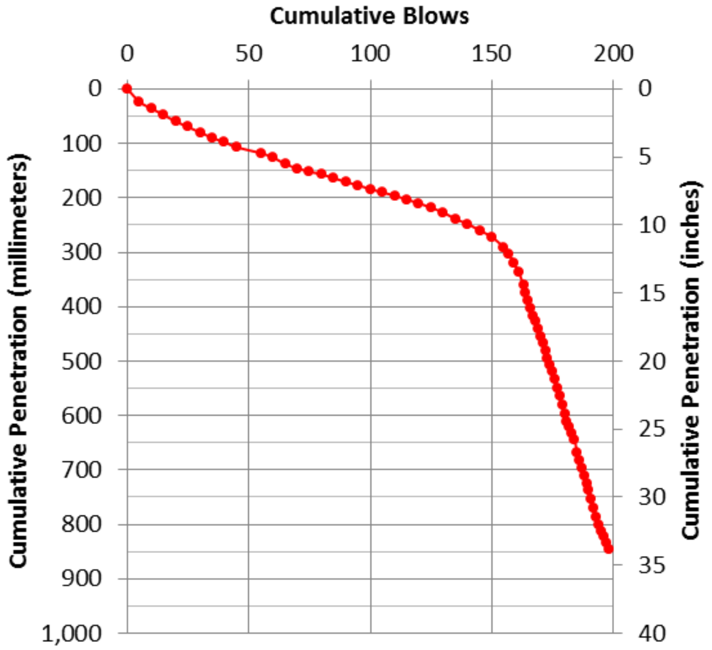


Figure 2-4: Typical plot of DCP test results (Cumulative number of blows versus cumulative penetration depth)

2.3.1 Applications and Use of DCP Test

Generally, understanding the strength of the soil under any structure is very essential. Particularly, if the soil beneath a roadway is not compacted to the requirement, with time cycling loads of the passing traffic will compact the soil further, leading to surface failure by development of large cracks, potholes and displaced pavement.

The Dynamic Cone Penetrometer test is one of in-situ soil tests that fits good to evaluate density of sub grade. It gives continuous profile as the tool is driven deeper into the soil under investigation.

The Dynamic Cone Penetrometer test can also provide efficiently and effectively a view of strength characteristics throughout a soil or roadbed and its application in structural evaluation of existing pavements, embankment and backfill construction control, preliminary soil surveys, and supplementing foundation testing for design purposes [13].

In its application to evaluate existing pavement, the test can be used to measure the residual road strength in a non-destructive way. The test can be used to measure residual pavement strength in terms of CBR rather than taking samples at a dense interval and perform laboratory CBR test for each layers of the pavement, which is a destructive approach. However, before performing DCP test it is proper to remove any dense and sound surface materials like hot mix asphalt or cement treated bases. The existence of the cemented material significantly affects the result as the DCP fails to penetrate strong materials. Such cemented layers need to be removed before the test begins and their strength can be assessed using different approach.

Burnham [20] states that the DCP is applied as a quality control device in granular base layer compaction and the backfill compaction of pavement and edge drain trenches.

Based on general relation between the DCPI and percent compaction, the Minnesota Department of Transportation limits penetration rate of base layer compaction to the following (Siekmeier et al., 1998): (Desalegn, 2012)

a. 15 mm/blow in the upper 75 mm;
b. 10 mm/blow at depths between 75 and 150 mm; and
c. 5 mm/blow at depths below 150 mm.

Wu and Sargand [21)] also reported that the DCP is a practical device to evaluate the base and subgrade during construction which can greatly develop the quality monitoring of unbound pavement materials. In addition, the required time to run one test was reduced to one-fifth using an automated DCP. However, very small penetration rates were observed in some of the tests, which they related to the non-homogenous nature of subgrade soil and presence of small rocks.

The DCP test can also be used as part of the construction quality control to assess the degree of compaction of the constructed work on engineering fills and backfill.

The acceptance of Direct Cone Penetration test into pavement design methods was suggested by many researchers, and the validity of DCP to measure the soil strength was proven.

2.3.2 Aspects Which Need to Be Controlled During Conducting the Test

Paige-Green [13] pointed out main aspects which needs to be carefully controlled during performing DCP test as follows:

- The apparatus must be held vertically at all times. Any deviation from the vertical results in difficulties getting repeatable readings from the measuring staff. In addition, the friction effects between the falling mass and the upper rod reduce the energy imparted to the cone.
- The hammer must just touch the base of the handle before being released, without jolting the equipment vertically. The hammer should be released to fall under its own mass and not "thrown" down.
- When testing “hard” materials, the hammer will often bounce a number of times on the anvil before coming to rest. It should not be lifted for the next drop before coming to total rest.
- The test should start with the upper portion of the shoulder of the cone flush with the surface of the layer being tested.
- During testing of hard materials, it is common to note that uplift or mounding of the

layer around the DCP hole occurs. This may result in a gradual rise of the measuring staff relative to the test apparatus and hence a reduction in the reading obtained. Care should be taken that the base of the measuring staff is not affected by this "mounding".

It is worth pointing that when the cone rests on a large stone

- The stone may either break and the test continues normally;
- The cone may be deflected and the rod will be found to move off the vertical; or
- Refusal may be reached and the test cannot proceed.

2.3.3 Drawback of Direct Cone Penetration Test

There are a few drawbacks to use the cone penetrometer test. They are as briefed below.

- **Problems during the extraction of the DCP apparatus after deep test**

Problems are faced on the removal of the DCP apparatus after deep tests. However, using disposable cone tips, as suggested by different researches and manufacturers, can be an option. ASTM D 6951 suggests application of extraction jack as another solution if disposable cone tips are not used.

- **Limitations related to maximum aggregate size DCP can handle**

The maximum aggregate size has also an important influence on the test results. DCP is not suitable for soils having significant portion of aggregates greater than 50 mm [17].

- **Potential problem related to operators' caution**

The physical rise and drop of the hammer could be a source of error in a DCPT. Webster et al. [17] reported that the user has to ensure that the hammer is touching the bottom of the handle but not lifting the cone before it is allowed to drop. They also stated that the operators should be careful not to exert force in any direction on the handle and not to influence the free fall of the hammer by hand movement.

The manual reading and recording of the number of blows and depth of the DCP could also result some mistake. Since the DCPT requires on operator to lift and drop the hammer while keeping the device vertical, another operator should read the penetration after each blow. To overcome such problem manufacturers introduced tools which uses to write the number of blows for each set of blows on a removable tape along the ruler, or use a magnetic ruler data collection device. [2]

Figure 2-5: Magnetic Ruler

The effect of side friction between the DCP device and the surrounding ground on DCPI was also mentioned by Yitagesu [5]. He also pointed out the effect is greater in collapsible granular materials than cohesive soils. Suggestions were also mentioned to use correction factor to correct the effect of the side friction.

2.4 Existing CBR-DCP Correlation Relations

There are numerous research works conducted to develop correlation equation between DCP and laboratory CBR. Some of the works done both internationally and locally are discussed under.

Harison [7] developed a theoretical explanation for the linear log-log relation of DCP and CBR. In addition, he undertaken couple DCP and CBR tests on 72 specimens on clay, well-graded sand, and well-graded gravel samples prepared in standard CBR molds and presented correlation equations. In addition, the regression analysis showed that the log-log model relates DCP and CBR better than the inverse model. Further, it was determined that moisture content and dry density had significant effects on CBR and DCP correlation. Moreover, it was concluded that the soaking process did not have a significant effect on the calibration.

Smith and Pratt [16] developed a correlation between DCPI (30-degree cone, hammer weighted 9.08 kg, with a dropping distance of 508 mm) and in-situ CBR tests in clayey materials. Moreover, they reported that the DCP results were as acceptable as the in-situ CBR while the coefficient of variation of DCP tests was smaller than that of the in-situ CBR tests at the same place.

Most studies about correlation between DCP and CBR indicates, the most reliable relation between the two is in the form of Log-Log equation [4].

$$\log(CBR) = A + B\log(DCPI)$$ ……………………………………………….Equation 2.2

Where: -

CBR is California Bearing Ratio (%)

DCPI is Direct Cone Penetration Index (mm / blow)

A and B are constants of the relationship

Summary of some of the correlation equations are listed in table 2-3.

Table 2-3: Summary of correlation equations by various authors [4] and [5]

Correlation Equation	Soil Type	Reference
log(CBR) = 2.56 - 1.16 log(DCPI)	Cohesive	Harison [7]
log(CBR) = 3.03-1.51 log (DCPI)	Granular	Harison [7]
log (CBR) = 2.46 -. 1.12 log(DCPI)	Granular and Cohesive	Livneh et al. (1992)
log(CBR) = 2.62 -1.27 log(DCPI)	Unknown	Kleyn (1975)
log(CBR) = 2.44 -1.07 log(DCPI)	Aggregate base	Ese et al. (1995)
log(CBR) = 2.60 -1.07 log(DCPI)	Aggregate base	NCDOT(Pavement design procedure)
log(CBR) = 1.4 -0.55 log (DCPI)	Aggregate base	Gabrel 2000
log(CBR) = 2.53 - 1.14 log(DCPI)	Piedmont residual	Coonse (1999)
log CBR = 2.465 – 1.12 (log PR)	All Soil Types	U.S. Army Corps of
log(CBR) = 6.15 – 1.248(DCPI)	PI > 6 materials	Sampson
log(CBR) = 5.93 – 1.1 loge(DCPI)	Plastic Materials	
log(CBR) = 5.7 – 0.82 loge(DCPI)	PI < 6 materials	
log(CBR) = 5.86 – 0.69(DCPI)	PI =0 materials	
log(CBR) =2.555 –1.145 log(DCPI)	For all Soil Types	Smith and Pratt(30o)
log10(CBR) = 2.48 – 1.057 log10 (DCP)	All Soil Types	TRRL [21]
log10 (SCBR) =2.015-0.906 log10 (DCPI)	Fine Grained Soils	Araya [4]
log10 (SCBR) =2.197-0.852 log10 (DCPI)	Coarse Grained Soils	Araya [4]
log (CBR) = 2.954-1.496 log (DCPI)	Clay soils	Yitagesu [5]

Yitagesu [5] states that all studies have found that the results are material and moisture dependent, and that equations should be used with care and only with a full understanding of the material properties of the soils on which the equation was developed and the soil being tested. In addition, he notes that strengths predicted from DCP penetration are determined at the in-situ moisture content and density of the sub grade soils at the time of testing, which must be taken into consideration when relating these values back to those determined in a laboratory.

Chapter-3: Materials, Methods and Procedures

3.1 Introduction

To accomplish the defined objectives of a research work, collecting and organizing data and materials relevant to the study in a scientific approach is very wise. For this research work relevant primary data have been collected and field and laboratory tests have been carried out by the researcher on the samples on the selected stretch along the case-project. The specific project has been selected for the reason that it is on a design stage and suitable to get recent and organized data.

3.2 Experimental Works and Procedures

Through the development process of an empirical correlation using primary data experimental investigations play a vital role. The strength of an empirical models essentially depends on the reliability of the test results obtained from the experimental investigations. These experimental investigations are to be performed in controlled environmental influences.

The experimental works undertaken involved both field and laboratory tests.

3.2.1 In-situ Tests

In-situ tests at the selected spots of the case-project have been undertaken as part of the main research work. The teste undertaken are field density determination, moisture content determination and dynamic cone penetration.

a. Field Density

Field density has been determined by the sand cone replacement method following the AASHTO T191 test procedure.

As a sample the field density determination result of the first trial pit (TR_01) is as tabulated in Table 3-1, the remaining results are included in the annex part of this research work.

Table 3-1: Typical Bulk Density Determination of Sample TR_01

Test ID:	TR_01
Mass of sand + cylinder before pouring, w1 (gm)	8555
Mass of sand + cylinder after pouring, w2 (gm)	3120
Mass of sand in hole + cone, w3 = (w1-w2) (gm)	5435.00
Mass of sand in cone, w4 (gm)	1395.00
Bulk Density of sand, w5 (gm/cc)	1.47
Mass of sand in hole, w6 (gm)=(w3-w4)	4040.00
Volume of hole, w7 = w6/w5 cc	2748.30
Mass of wet soil from hole, w8 (gm)	4514
Wet (Bulk) Density of soil = w8/w7 (gm/cc)	1.64

Having a look at the result of the field density tests, the minimum and maximum results are found being 1.25 and 1.76gm/cc respectively.

b. **Dynamic Cone Penetration Test (DCP)**

The dynamic cone penetration test has been undertaken for each sample location using the test procedure ASTM D6951.

From the conducting penetration depth versus corresponding number of blows were collected and the data was analyzed using excel spread sheet to determine the penetration index in mm/blow. The DCPI obtained from this test indicates the strength value of the soil and it is mainly used in estimating the CBR using existing correlations and in developing a new correlation.

The DCP test result of the first trial pit (TR_01) is as presented in Table 3-2 and Figure 3.1, the remaining results are included in the annex part of this research work.

Table 3-2: Typical Dynamic Cone Penetration Test Result of Sample TR_01

Test ID: TR_01				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	250	55	55
1	2	280	85	30
1	3	312	117	32
1	4	350	155	38
1	5	378	183	28
1	6	412	217	34
1	7	444	249	32
1	8	477	282	33
1	9	512	317	35
1	10	540	345	28
1	11	570	375	30
1	12	600	405	30
1	13	632	437	32
1	14	660	465	28
1	15	695	500	35
1	16	728	533	33
1	17	760	565	32
1	18	790	595	30
1	19	823	628	33
1	20	855	660	32
1	21	887	692	32
1	22	919	724	32
1	23	952	757	33

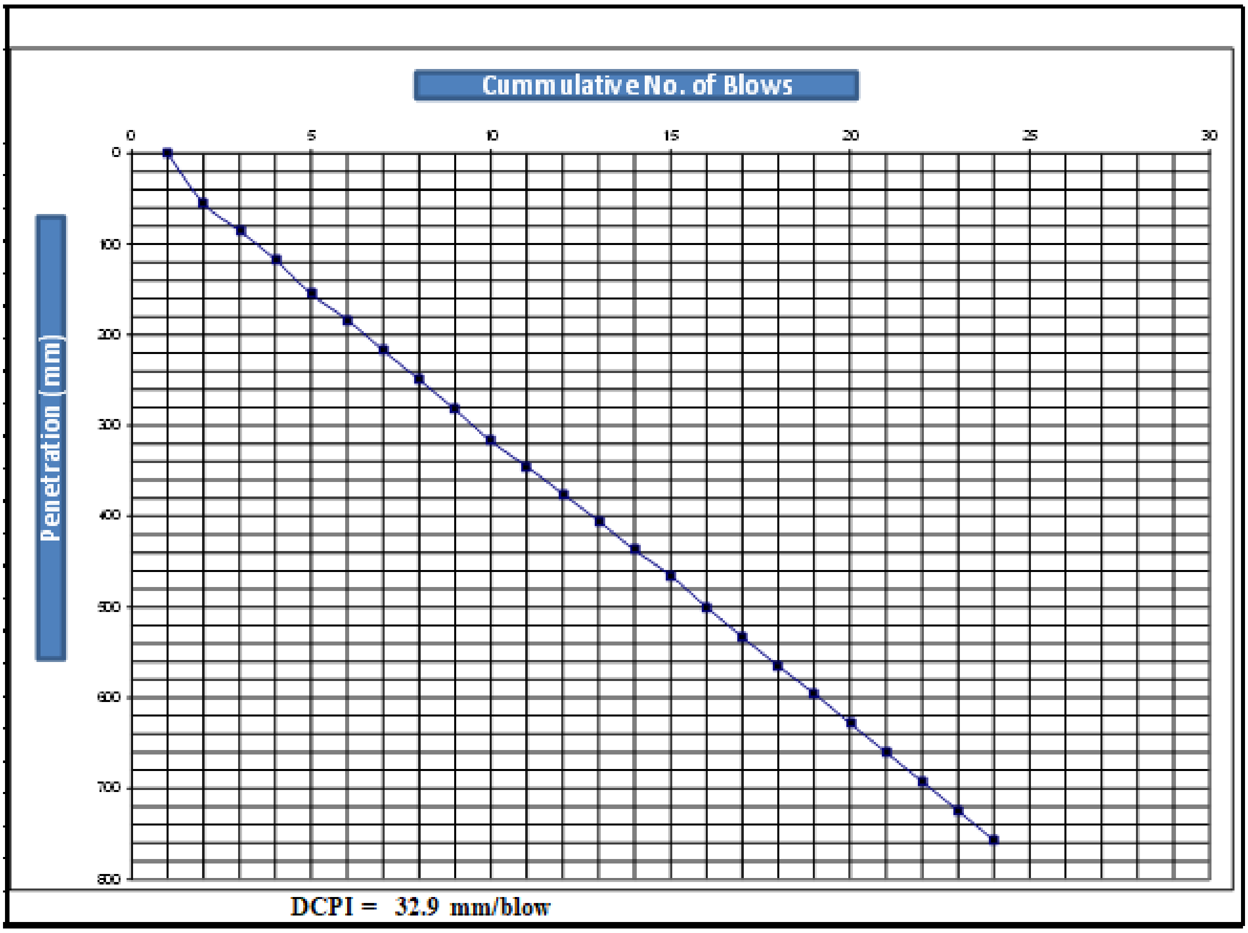


Figure 3-1: Typical Dynamic Cone Penetration Test Result Plot for Sample Location TR_01

3.2.2 Laboratory Tests

Laboratory tests at each selected spot of the case-project have been undertaken as part of the main research work. The teste undertaken are moisture content determination, sieve analysis, Atterberg limits determination, free swell, modified proctor tests and CBR.

a. Moisture Content Determination

The moisture content of each specimen has been undertaken in the laboratory. The test procedure followed is BS1377.

The moisture content determination result of the first trial pit (TR_01) is as presented in Table 3-3, the remaining results are included Table 3-8 (summary of test results).

Table 3-3: Typical Moisture Content Determination of Sample TR_01

Test ID:	TR_01
Cont No.	21
Weight of container, (gm)	19.1
Mass of wet soil+ container, (gm)	232.4
Mass of dry soil + container, (gm)	221.9
Mass of Moisture, (gm)	10.50
Mass of dry soil, (gm)	202.80
Moisture content, (%)	5.2%

b. Sieve Analysis

The Sieve Analysis of each specimen has been undertaken in the laboratory. The test procedure followed is ASTM D6913.

The objective of particle size distribution is to characterize the soil by determining the percentage of soils passing different sieve opening sizes. Wet sieve and dry sieve analysis were carried out on the samples obtained from the case-project site. If percent passing No.200 (75µm) is greater than 35%, this soil is categorized as fine-grained soil (Silt-Clay material); otherwise, the soil is categorized as coarse-grained soil (granular material) according to AASHTO M145. Particle size distribution test is not only used to categorize soil as coarse and fine grained but also to classify the soil class in conjunction with Atterberg limits.

The sieve analysis result of the first trial pit (TR_01) is as shown in Table 3-4 and Figure 3-2, the remaining results are included in the annex part of this research work.

Table 3-4: Typical Sieve Analysis Test Result of Sample TR_01

Test ID: TR_01					
SIEVE ANALYSIS					
Weight of sample = 1000gm					
Sieve No.	**Diameter (mm)**	**Wt. of Soil Retained (gm)**	**% Weight retained**	**Cumulative Percent Retained**	**Percent Passing**
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	367.0	36.7%	36.7%	63.3%
40	0.425	65.0	6.5%	43.2%	56.8%
100	0.15	145.0	14.5%	57.7%	42.3%
200	0.075	177.0	17.7%	75.4%	24.6%
Pan		246.00	24.60%	100.00%	0.00%

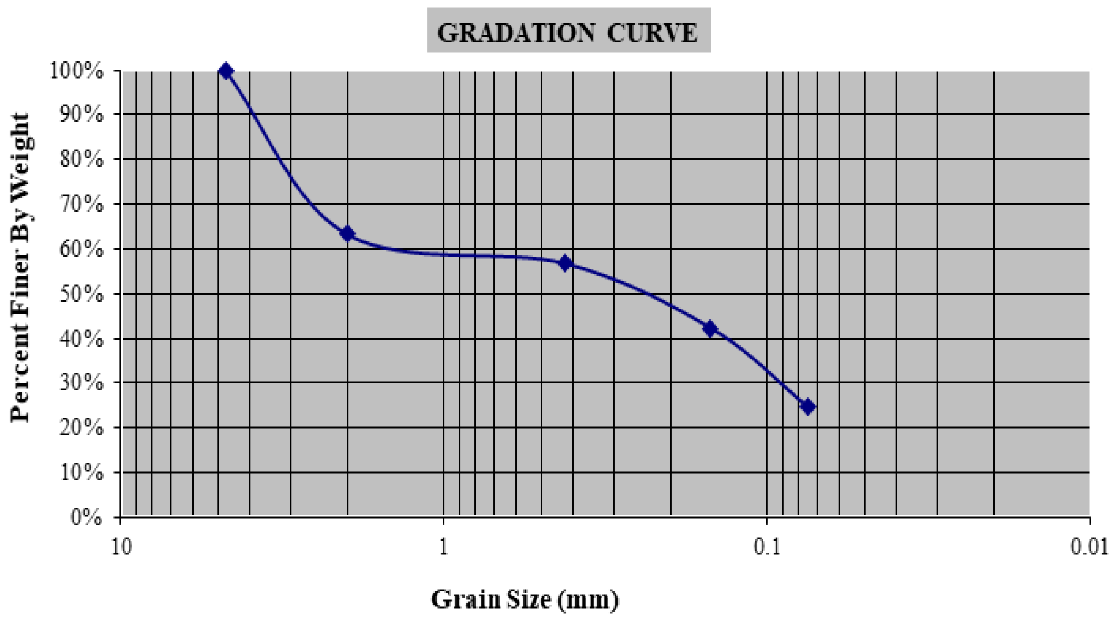


Figure 3-2: Typical Grains Size Plot of Sample TR_01

c. Atterberg Limits

The Atterberg limit tests of each specimen have been undertaken in the laboratory. The test procedure followed is AASTO T89-90.

The aim of obtaining the Atterberg limits of a soil is to know the plasticity property of the soil passing the No. 40 (425 μm) sieve with varying degrees of moisture content. In this study Atterberg limits together with the particle size distribution results are used for classification of the soil.

The Atterberg limits test result of the first trial pit (TR_01) is as shown in Table 3-5 and Figure 3-3, the remaining results are included in the annex part of this research work.

Table 3-5: Typical Atterberg Limits Determination of Sample TR_01

TEST ID: TR_01				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-64	A-60	A-18	A-25
Wt of wet soil + container (gm)	47.40	47.36	44.05	45.30
Wt of dry soil + container (gm)	42.79	42.23	39.44	40.41
Wt of water (gm)	4.61	5.13	4.61	4.89
Wt of container (gm)	20.11	19.36	19.38	19.69
Wt of dry soil (gm)	22.68	22.87	20.06	20.72
Water content, %	20.3	22.4	23.0	23.6
No. of blows	34	26	21	17

Liquid Limit (%)	22.1
Plastic Limit (%)	15.6
Plasticity Index	6.5

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-17	A-26	
Wt of wet soil + container (gm)	21.29	22.61	15.6
Wt of dry soil + container (gm)	20.99	22.3	
Wt of water (gm)	0.30	0.31	
Wt of container (gm)	19.25	20.07	
Wt of dry soil (gm)	1.74	2.23	
Water content, %	17.2	13.9	

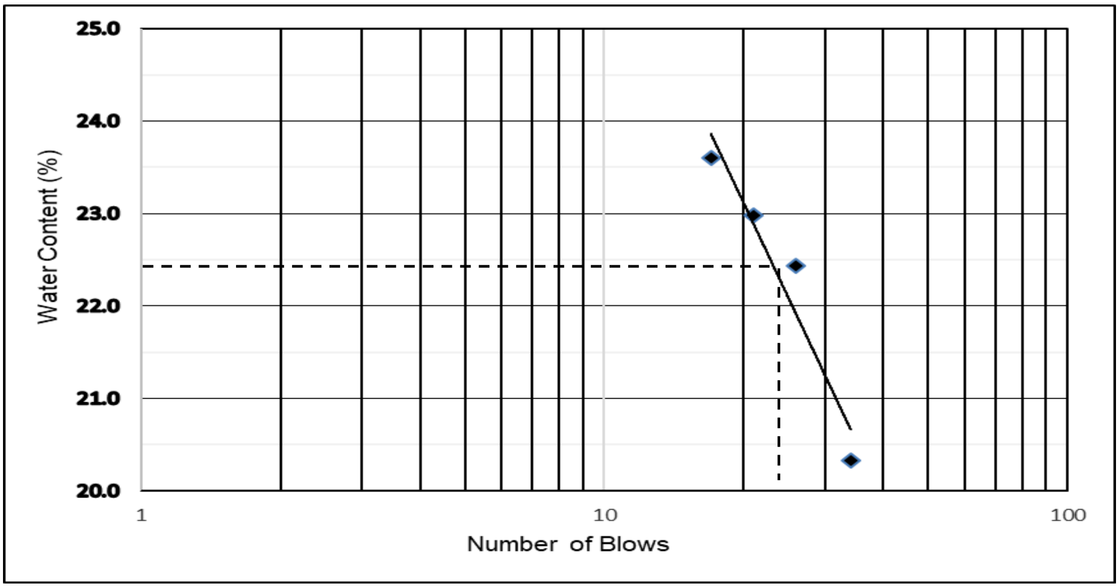


Figure 3-3: Typical Plot of Liquid Limit Determination of Sample TR-01

d. Free Swell

The Free Swell tests of each specimen have been undertaken in the laboratory. The test procedure followed is ASTM D4546.

The Free Swell test result of the first trial pit (TR_01) is as shown in Table 3-6, the remaining results are included table 3-8 (summary of test results).

Table 3-6: Typical Free Swell Test of Sample TR_01

Test ID: TR_01				
Initial	**Final Volume**		**Average**	**Free**
Volume	**Sample No.1**	**Sample No.2**	**Final Volume**	**Swell Index**
(cc)	**(cc)**	**(cc)**	**(cc)**	**(%)**
10.0	11.0	10.5	10.8	7.5

The free swell test results show that the results are within 5 and 14%.

e. Moisture – Density Relationship (Compaction Tests)

Compaction of a soil improves the engineering properties, i.e., it increases the shear strength of the soil and hence, the bearing capacity. It increases the stiffness and thus, reduces future settlement, void ratio and permeability. At lower water content than the optimum the soil is rather stiff and has a lot of void spaces and hence, the dry density is low. On the other hand, at water content more than the optimum the additional water reduces the dry density as it occupies the space that might have been occupied by solid particles [7].

The laboratory standard proctor and modified proctor tests are performed as per (AASHTO T 99 or ASTM D 698) and (AASHTO T 180 or ASTM D 1557) respectively. The tests are performed on disturbed samples of soil particles passing sieve sizes 4.75mm or 19mm mixed with water to form samples at various moisture contents ranging from the dry state to wet state. These samples are compacted in three or five layers at 25 blows per layer in accordance with the specified nominal compaction energy of standard or modified proctor test respectively. Dry density is determined based on the moisture content and the unit weight of compacted soil. The corresponding water content at which the maximum dry density occurs is termed as the optimum moisture content [10].

Grading and Atterberg limits alone are not sufficient to qualify the performance of construction materials since variation of moisture content and density play a considerable role. Different researches show that the moisture content and density conditions have a greater influence, on the value of shear strength of a soil, on coarser materials than fine grained materials.

f. California Bearing Ratio (CBR)

Following the AASHTO T193 testing procedure, the California Bearing Ratio test has been conducted on each specimen collected from the case-project site and the results are as included in the annex part of this research paper.

The CBR test in the laboratory was performed using 4 days socked samples to simulate the worst condition that the subgrade may face. The Optimum Moisture content obtained from Modified Proctor test was used to prepare the specimen for CBR determination.

The CBR test result of the first sample, TR_01 is as presented in Table 3-7.

Table 3-7: Typical CBR Test of Sample TR_01

Ring factor (kN/div.) =		0.01848		
TEST ID: - TR_01				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	3	0.06		
1.27	11	0.20		
1.96	21	0.39		
2.54	28	0.52	0.52	3.88
3.18	36	0.67		
3.81	44	0.81		
4.45	51	0.94		
5.08	59	1.09	1.09	5.45
7.62	88	1.63		
10.16				
12.7				

The laboratory CBR test results show that the results are within 4 and 45.

3.3 Summary of Test Results

The details of the test results are presented in the appendix part of this thesis and the summary of laboratory and field test results are presented hereunder in Table 3-8.

Table 3-8: Summary of Test Results

Pit ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Field DCP	Natural Moisture Content (%)	Field Density (g/cc)	Free Swell (%)	Lab. CBR (%)	Percent Passing Sieve No, 200 (%)
TR_01	22.09	15.57	6.52	32.91	5.18	1.64	7.5	5.45	24.6%
TR_02	24.36	12.36	12	32.3	5.95	1.55	7.5	4.99	29.2%
TR_03	26.41	16.11	10.3	12.94	4.48	1.66	7.5	17.09	18.3%
TR_04	27.72	15.54	12.18	34.5	4.72	1.41	10	4.62	27.5%

Pit ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Field DCP	Natural Moisture Content (%)	Field Density (g/cc)	Free Swell (%)	Lab. CBR (%)	Percent Passing Sieve No, 200 (%)
TR_05	21.58	12.23	9.35	9.97	1.84	1.69	7.5	23.75	25.5%
TR_06	25.63	16.24	9.39	9.09	3.67	1.72	10	27.72	23.5%
TR_07	25.45	15.52	9.92	10.63	3.31	1.74	10	34.37	16.4%
TR_08	22.33	15.14	7.19	7.82	2.65	1.66	5	45.55	15.6%
TR_09	22.3	14.51	7.79	10.97	2.71	1.75	10	29.11	27.5%
TR_10	24.17	16.46	7.71	31.39	2.97	1.48	7.5	6.19	23.2%
TR_11	22.64	14.14	8.5	23.63	3.47	1.66	7.5	10.44	22.7%
TR_12	24.48	15.43	9.05	32.91	4.9	1.5	10	6.01	24.7%
TR_13	23.22	16.31	6.9	27.67	3.91	1.33	7.5	6.01	25.1%
TR_14	24.45	15.14	9.3	26.5	3.9	1.52	10	8.04	16.0%
TR_15	21.55	15.17	6.38	7.79	2.86	1.76	10	43.71	24.9%
TR_16	21.27	13.97	7.3	15.84	2.84	1.7	7.5	14.41	28.5%
TR_17	19.85	12.92	6.94	10.16	2.67	1.65	14	36.5	18.6%
TR_18	19.66	14.08	5.58	31.3	2.37	1.62	10	5.91	22.4%
TR_19	18.79	12.29	6.5	30	2.58	1.57	10	6.65	18.2%
TR_20	23.74	15.22	8.52	32.73	2.8	1.53	10	5.27	24.7%
TR_21	22.42	15.54	6.88	32.75	3.12	1.33	10	5.54	27.0%
TR_22	21.09	13.12	7.97	34.86	2.61	1.41	10	4.53	22.2%
TR_23	23.58	15.48	8.1	36.07	1.27	1.6	10	5.08	21.1%
TR_24	24.52	16.33	8.19	37.24	3.83	1.25	10	4.44	21.1%
TR_25	24.03	15.29	8.74	24.73	3.74	1.56	10	6.65	24.6%
TR_26	24.58	12.53	12.05	32.89	5.95	1.54	7.5	4.99	23.5%
TR_27	25.69	16.3	9.39	13.53	3.67	1.72	10	27.72	19.0%
TR_28	25.46	15.31	10.14	14.58	3.31	1.69	10	34.37	20.8%
TR_29	20.11	13	7.12	10.2	2.67	1.66	14	36.5	24.4%
TR_30	21.19	13.18	8	38.06	2.61	1.41	10	4.53	22.1%
TR_31	23.68	15.43	8.25	34.87	5.09	1.53	7.5	4.99	24.1%
TR_32	23.41	16.18	7.22	32.17	4.14	1.36	10	5.54	22.5%
TR_33	24.67	15.02	9.65	32.95	4.08	1.55	7.5	5.27	12.8%
TR_34	21.69	15.09	6.6	12.87	3.11	1.73	10	25.23	24.3%
TR_35	21.54	13.91	7.64	11.45	3.02	1.73	10	24.12	28.6%

Pit ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Field DCP	Natural Moisture Content (%)	Field Density (g/cc)	Free Swell (%)	Lab. CBR (%)	Percent Passing Sieve No, 200 (%)
TR_36	20.08	12.84	7.23	12.55	2.85	1.68	7.5	20.05	14.2%
TR_37	19.87	14.03	5.84	13.34	2.57	1.65	14	19.96	18.9%
TR_38	19.04	12.19	6.85	14.49	2.75	1.6	10	19.03	14.2%
TR_39	23.97	15.22	8.75	29.05	3.02	1.56	7.5	6.75	22.1%
TR_40	22.67	15.38	7.29	34.15	2.17	1.36	10	5.54	29.4%

From the summary, it can be observed that soil samples which have lesser CBR value have higher DCPI value in magnitude. This is because soil with a better CBR value have a better resistance to penetration.

Chapter-4: Discussion of Test Results and Soil Classification

4.1 Discussion of Test Results

4.1.1 In-Situ Moisture Content and Field Density

The in-situ moisture content test is undertaken on all samples to obtain the in-place moisture content of each pit. As indicated in table 3-8, the moisture content of the samples ranges between 1.3% and 5.9%. On the other hand, the field density of the samples ranges between 1.2 and 1.8 g/cc. The low moisture content of soil is due to the fact that the area is arid zone with very high temperature and low rainfall intensity.

4.1.2 Grain Size Analysis

Grain size analysis test is performed primarily to determine of the distribution of the grain size present in each sample and for soil classification purpose. The grain size analysis is expressed as a percentage of the total weight. Though there are two methods generally used to find particle size distribution of soil; i.e., the sieve analysis and the hydrometer analysis, the first procedure is undertaken in this research because for all samples the percent passing the 75µm (retaining on the No. 200 Sieve) was less than 35%. Which implies all the samples can be classified to coarse grained soil [1].

The summary of the sieve analysis result of all the samples is as presented in Table 4-1 whereas the complete sieve analysis results for all samples both in tabular and plot forms are presented in the annex part of this research report.

Table 4-1: Summary of sieve analysis results

Sl.No,	Test pit ID	Percent Passing through Each Sieve (Sieve Number)					
		4	10	40	100	200	Pan
1	TR_01	100.0%	63.3%	56.8%	42.3%	24.6%	0.00%
2	TR_02	100.0%	64.5%	40.4%	35.4%	29.2%	0.00%
3	TR_03	100.0%	62.7%	56.0%	39.0%	18.3%	0.00%
4	TR_04	100.0%	62.6%	56.0%	51.7%	27.5%	0.00%
5	TR_05	100.0%	75.5%	64.6%	54.0%	25.5%	0.00%
6	TR_06	100.0%	70.9%	59.2%	49.6%	23.5%	0.00%
7	TR_07	100.0%	41.2%	31.5%	27.4%	16.4%	0.00%
8	TR_08	100.0%	62.2%	52.3%	42.4%	15.6%	0.00%
9	TR_09	100.0%	65.5%	55.2%	47.7%	27.5%	0.00%
10	TR_10	100.0%	70.7%	62.3%	51.7%	23.2%	0.00%
11	TR_11	100.0%	69.7%	61.0%	50.7%	22.7%	0.00%
12	TR_12	100.0%	78.7%	72.0%	59.2%	24.7%	0.00%
13	TR_13	100.0%	89.6%	79.8%	65.0%	25.1%	0.00%
14	TR_14	100.0%	70.1%	60.9%	48.8%	16.0%	0.00%
15	TR_15	100.0%	75.3%	67.8%	56.2%	24.9%	0.00%
16	TR_16	100.0%	66.7%	59.0%	50.8%	28.5%	0.00%
17	TR_17	100.0%	64.9%	57.3%	46.9%	18.6%	0.00%
18	TR_18	100.0%	64.3%	57.4%	47.9%	22.4%	0.00%
19	TR_19	100.0%	72.0%	64.5%	52.0%	18.2%	0.00%
20	TR_20	100.0%	69.0%	60.9%	51.1%	24.7%	0.00%
21	TR_21	100.0%	76.9%	66.2%	55.6%	27.0%	0.00%
22	TR_22	100.0%	67.5%	59.8%	49.6%	22.2%	0.00%
23	TR_23	100.0%	66.9%	57.8%	47.9%	21.1%	0.00%
24	TR_24	100.0%	67.1%	58.8%	48.6%	21.1%	0.00%
25	TR_25	100.0%	64.6%	56.7%	48.0%	24.6%	0.00%
26	TR_26	100.0%	63.8%	40.0%	35.5%	23.5%	0.00%
27	TR_27	100.0%	42.6%	34.5%	30.3%	19.0%	0.00%
28	TR_28	100.0%	43.7%	35.3%	31.4%	20.8%	0.00%

Sl.No,	Test pit ID	Percent Passing through Each Sieve (Sieve Number)					
		4	10	40	100	200	Pan
29	TR_29	100.0%	64.3%	54.8%	46.6%	24.4%	0.00%
30	TR_30	100.0%	66.7%	58.6%	48.7%	22.1%	0.00%
31	TR_31	100.0%	77.9%	71.1%	58.4%	24.1%	0.00%
32	TR_32	100.0%	69.6%	53.1%	44.8%	22.5%	0.00%
33	TR_33	100.0%	68.5%	58.3%	46.0%	12.8%	0.00%
34	TR_34	100.0%	75.3%	67.2%	55.6%	24.3%	0.00%
35	TR_35	100.0%	66.0%	57.7%	49.8%	28.6%	0.00%
36	TR_36	100.0%	64.9%	57.3%	45.7%	14.2%	0.00%
37	TR_37	100.0%	62.6%	55.0%	45.3%	18.9%	0.00%
38	TR_38	100.0%	70.9%	60.5%	48.0%	14.2%	0.00%
39	TR_39	100.0%	67.3%	59.2%	49.2%	22.1%	0.00%
40	TR_40	100.0%	77.5%	68.1%	57.7%	29.4%	0.00%

Table 4-2 and Figure 4-1 show the typical particle size distribution curves of sample TR_04.

Table 4-2: Typical Sieve Analysis Test Result of Sample TR_04

Test ID: TR_04

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	374.0	37.4%	37.4%	62.6%
40	0.425	66.0	6.6%	44.0%	56.0%
100	0.15	43.0	4.3%	48.3%	51.7%
200	0.075	242.0	24.2%	72.5%	27.5%
Pan		275.00	27.50%	100.00%	0.00%

In the Table 4-2, it is seen that there is negligible portion of the soil is retained between the sieves No, 40 and 100; which left the particle size distribution poorly graded and the gap-graded type of distribution.

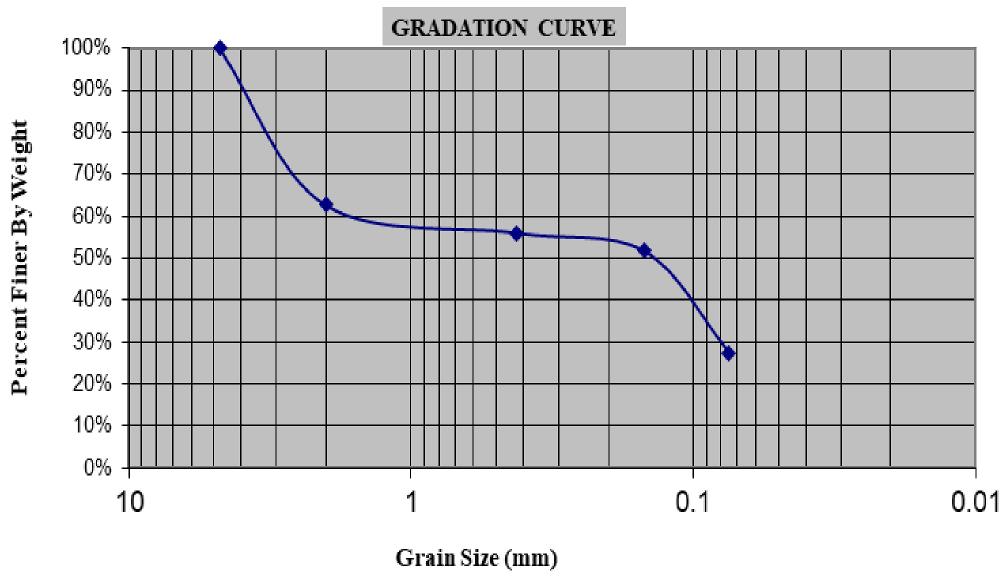


Figure 4-1: Typical Grains Size Plot of Sample TR_04

4.1.3 Atterberg Limits

The Atterberg Limits tests have been used for the soil's classification purpose in supplement with other tests. With this test the liquid limits, plastic limits and plasticity index values of the samples have been determined.

When the liquid limits, plastic limits and PIs of the samples are seen the results of all samples are falling between 18% - 28%, 12% - 16% and 5 and 13 respectively.

According to their plasticity indices and their liquid limit values soils are rated to low, medium, high and very high plasticity. This rating is presented in Tables 4-3 and 4-4.

Table 4-3: Ratings for compressibility and shrink-swell potential based on plasticity index [12]

Rating	Plasticity
Low	<25
Medium	25-35
High	35-45
Very high	>45

When seen in line with the above table, all the samples studied in this research are rated to be of low plasticity.

Table 4-4: Ratings for compressibility and shrink-swell potential based on Liquid limit [12]

Rating	Liquid limit
Low	<45
Medium	45-55
High	55-75
Very high	>75

When seen in line with Table 4-4 all the samples studied in this research are rated to have low potential for compressibility and shrink-swell.

4.1.4 Free Swell

The free swelling of a disturbed soil on wetting from air dry to saturated is a measure of the volume expansion. A volume expansion of 20–40% indicates a large potential expansion on wetting and subsequent shrinkage on drying, and places limitations on the use of the soil as a foundation for earthworks and small buildings [12].

Soils are rated to low, medium, high and very high swelling potential depending on their free swell values. Table 4-5 shows the rate of the swelling potential (volume expansion) of soils.

Table 4-5: Ratings for volume expansion [12]

Rating	Free Swell (%)
Low	<20
Medium	20-30
High	30-40
Very high	>40

The free swell test results of all the samples under study are within 5 and 14%. When seen in line with Table 4-5, all the samples studied in this research are rated to be of low potential for swelling.

4.1.5 CBR

As the most important parameter of the research, all the samples have been subjected to the California Bearing Ratio (CBR) test. The CBR test in the laboratory was performed using 4 days socked samples to simulate the worst condition that the subgrade may encounter and the socked CBR is used for the design of pavement structures. The optimum moisture Content obtained from modified proctor test was used to prepare the specimen for CBR determination.

The CBR values of the samples range from 4.4 to 45.6. Table 4-6 presents the CBR values of all samples.

Table 4-6: Summary of CBR values

Pit ID	Lab. CBR (%)
TR_01	5.45
TR_02	4.99
TR_03	17.09
TR_04	4.62
TR_05	23.75
TR_06	27.72
TR_07	34.37
TR_08	45.55
TR_09	29.11
TR_10	6.19
TR_11	10.44
TR_12	6.01
TR_13	6.01
TR_14	8.04
TR_15	43.71
TR_16	14.41
TR_17	36.50
TR_18	5.91
TR_19	6.65
TR_20	5.27

Pit ID	Lab. CBR (%)
TR_21	5.54
TR_22	4.53
TR_23	5.08
TR_24	4.44
TR_25	6.65
TR_26	4.99
TR_27	27.72
TR_28	34.37
TR_29	36.50
TR_30	4.53
TR_31	4.99
TR_32	5.54
TR_33	5.27
TR_34	25.23
TR_35	24.12
TR_36	20.05
TR_37	19.96
TR_38	19.03
TR_39	6.75
TR_40	5.54

In highway projects, the strength of subgrade soils is rated depending of the laboratory CBR value. In a similar fashion the Ethiopian Roads Authority Pavement Design Manual presents subgrade soils into six subgrade classes; this classification is as presented in table 4-7.

Table 4-7: Subgrade Strength Classes according to Ethiopian Roads Authority Pavement Design Manual 2013

Subgrade Class	CBR Range
S1	<3
S2	3, 4
S3	5, 6, 7
S4	8-14
S5	15-30
S6	>30

When the CBR value of each sample given in Table 4-6 is seen with reference to Table 4-7, one sample falls in the S2 subgrade class, twenty samples fall in the S4 subgrade class, ten samples fall in the S5 subgrade class and six samples fall in the S6 subgrade class.

4.2 Soil Classification

The soil classification gives information:

- ✓ Whether the soil under consideration is categorized as coarse grained or fine-grained soil by seeing on the percent passing.
- ✓ The degree of plasticity of the soil, as it is one basic index property of the soil.
- ✓ The type of the soil class, as each soil class has unique engineering property and applicability.

In this study the AASHTO classification scheme is used.

Generally, in highway, railway and airfield projects, the AASHTO soil classification system is commonly used. This classification scheme helps one determine the suitability of soils as road bed and construction materials. This classification system used the sieve grain size analysis and the soil index tests (Atterberg limits) as basic input. According to the AASHTO classification system, granular soils are soils in which 35% or less are finer than the No. 200 sieve (0.075 mm) and silt-clay soils are soils in which more than 35% are finer than the No. 200 sieve. The granular soils are further classified to gravel (soil mass between sieves 75mm and 2mm) and sand (soil mass between 2mm and 0.075mm). In addition, the fine-grained soils are also classified to silt (PI<10%) and clay (PI>10%).

The AASHTO system classifies soils into seven major groups, A-1 through A-7. The first three groups, A-1 through A-3, are granular (coarse-grained) soils, while the last four groups, A-4 through A-7, are silt-clay (fine-grained) soils. In the coarse-grained category, A-1 is the coarsest and A-3 is the least coarse. On the other hand, in the fine-grained category A-4 and A-5 represent silty soils whereas A-6 and A-7 represent clayey soils.

In addition, in AASHTO soil classification, a group index (GI) value is appended in parentheses to the main group to provide a measure of quality of a soil as highway subgrade material. The group index value is obtained using equation 4.1.

$$GI = (F-35)\ [0.2 + 0.005(LL-40)] + 0.01(F-15)\ (PI-10)$$ ……………………Equation 4.1

where F (whole number) is percent passing No. 200 sieve, LL (whole number) is the liquid limit and PI (whole number) is the plasticity index.

The GI index is reported to the nearest whole number; and if GI, 0, it is set to 0.

GI for groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 is zero. For groups A-2-6 and A-2-7, the partial group index equation is used. The higher the group index, the lower the quality of the soil as a subgrade material. The GI should not exceed 20 for any of group's A-4 through A-7.

Thus, the AASHTO classification system is applied for each specimen. The classification made is as shown in Table 4-3.

Table 4-8: Soil Classification according to AASHTO

Pit ID	Easting	Northing	Portion Passing (%)			Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	AASHTO Classification
			№ 10 (2mm)	№ 40 (0.425mm)	№ 200 (0.075mm)				
TR_01	712464	766456	63.3%	56.8%	24.6%	22.00	16.00	6.00	A-2-4
TR_02	712600	766468	64.5%	40.4%	29.2%	24.00	12.00	12.00	A-2-6
TR_03	712852	766472	62.7%	56.0%	18.3%	26.00	16.00	10.00	A-2-6
TR_04	713099	766481	62.6%	56.0%	27.5%	28.00	16.00	12.00	A-2-6
TR_05	713349	766488	75.5%	64.6%	25.5%	22.00	12.00	10.00	A-2-6
TR_06	713467	766478	70.9%	59.2%	23.5%	26.00	16.00	10.00	A-2-6
TR_07	713600	766491	41.2%	31.5%	16.4%	25.00	16.00	9.00	A-2-4
TR_08	713848	766496	62.2%	52.3%	15.6%	22.00	15.00	7.00	A-2-4
TR_09	713968	766491	65.5%	55.2%	27.5%	22.00	15.00	7.00	A-2-4
TR_10	714100	766502	70.7%	62.3%	23.2%	24.00	16.00	8.00	A-2-4
TR_11	714349	766511	69.7%	61.0%	22.7%	23.00	14.00	9.00	A-2-4

Pit ID	Easting	Northing	Portion Passing (%)			Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	AASHTO Classification
			№ 10 (2mm)	№ 40 (0.425mm)	№ 200 (0.075mm)				
TR_12	714466	766501	78.7%	72.0%	24.7%	24.00	15.00	9.00	A-2-4
TR_13	714596	766515	89.6%	79.8%	25.1%	23.00	16.00	7.00	A-2-4
TR_14	714962	766516	70.1%	60.9%	16.0%	24.00	15.00	9.00	A-2-4
TR_15	715099	766529	75.3%	67.8%	24.9%	22.00	15.00	7.00	A-2-4
TR_16	715346	766535	66.7%	59.0%	28.5%	21.00	14.00	7.00	A-2-4
TR_17	715466	766528	64.9%	57.3%	18.6%	20.00	13.00	7.00	A-2-4
TR_18	715598	766539	64.3%	57.4%	22.4%	20.00	14.00	6.00	A-2-4
TR_19	715849	766546	72.0%	64.5%	18.2%	19.00	12.00	7.00	A-2-4
TR_20	715964	766540	69.0%	60.9%	24.7%	24.00	15.00	9.00	A-2-4
TR_21	716100	766552	76.9%	66.2%	27.0%	22.00	16.00	6.00	A-2-4
TR_22	716345	766557	67.5%	59.8%	22.2%	21.00	13.00	8.00	A-2-4
TR_23	716466	766549	66.9%	57.8%	21.1%	24.00	15.00	9.00	A-2-4
TR_24	716599	766564	67.1%	58.8%	21.1%	25.00	16.00	9.00	A-2-4
TR_25	716851	766570	64.6%	56.7%	24.6%	24.00	15.00	9.00	A-2-4
TR_26	716962	766564	63.8%	40.0%	23.5%	25.00	13.00	12.00	A-2-6
TR_27	717095	766573	42.6%	34.5%	19.0%	26.00	16.00	10.00	A-2-6
TR_28	717349	766590	43.7%	35.3%	20.8%	25.00	15.00	10.00	A-2-6
TR_29	717468	766574	64.3%	54.8%	24.4%	20.00	13.00	7.00	A-2-4
TR_30	717598	766591	66.7%	58.6%	22.1%	21.00	13.00	8.00	A-2-4
TR_31	717841	766593	77.9%	71.1%	24.1%	24.00	15.00	9.00	A-2-4
TR_32	718098	766601	69.6%	53.1%	22.5%	23.00	16.00	7.00	A-2-4
TR_33	718353	766605	68.5%	58.3%	12.8%	25.00	15.00	10.00	A-2-6
TR_34	718464	766598	75.3%	67.2%	24.3%	22.00	15.00	7.00	A-2-4
TR_35	718594	766614	66.0%	57.7%	28.6%	22.00	14.00	8.00	A-2-4
TR_36	718850	766621	64.9%	57.3%	14.2%	20.00	13.00	7.00	A-2-4
TR_37	718966	766611	62.6%	55.0%	18.9%	20.00	14.00	6.00	A-2-4
TR_38	719093	766628	70.9%	60.5%	14.2%	19.00	12.00	7.00	A-2-4
TR_39	719355	766639	67.3%	59.2%	22.1%	24.00	15.00	9.00	A-2-4
TR_40	719468	766624	77.5%	68.1%	29.4%	23.00	15.00	8.00	A-2-4

Out of the forty samples 31 of them are classified to A-2-4 soil class whereas the remaining are classified to A-2-6 soil group.

Both the A-2-4 and A-2-6 soils are the coarse-grained soils, in the A-2 soil group, with liquid limits less than 40 and different plasticity indexes less than 10 (for the A-2-4) and greater than 11 (for the A-2-6). These soils are rated as excellent to good road subgrade material.

Chapter-5: Data Analysis, Development of Correlation Equations and Validations

5.1 General

To study how the variables in this research are related with each other, regression technique is used. Among the regression techniques, the simple regression and the multiple regression techniques have been used to get a complete picture of how the study variables are correlated.

The simple regression is an analysis that works only with two variables named X and Y where X is the independent / explanatory variable and Y is the dependent / explained variable. The general equation used in the simple regression technique is presented as

$$Y= B_0+ B_1X+ u$$

where u is the other unobserved variables affecting the variable Y also called the error term.

In cases where there is the dependent variable is one and the independent variables are more than one, the regression technique to be used is termed multiple regression. The general relation between the dependent variable (Y) and the independent variables (X_1, X_2,…) is presented as

$$Y= B_0+ B_1 X+ B_2 X+ u$$

For the regression analysis to function effectively, there are numerous assumptions considered during the regression process, such as

- in the regression model the parameters used are linear
- non-constant variation between the independent variables
- a constant variation on the error term or unobservable given X.
- in case of the multiple variables case, there is no relationship between the dependent variables and the variance of the error term given all the independent variables is constant.

5.2 **Standard error of the regression**

When analyzing the regression's outcome, the standard error of the regression is utilized. It gauges the precision of our estimators. It involves estimating the standard deviation of the unobservable or error term. Computer packages typically provide the conventional error result.

$\alpha^2\sigma 2 = 1/(n-k-1)\sum_{i=1}^{n} ui2\ _i^2$ and the square root of the error variance ($\sigma 2$) is the standard error variance σ.

To calculate the standard error (S_e) of the estimates we use

$$Se(Bj) = \frac{\sigma}{[SSTj\,(1-Rj2)]1/2}$$

5.3 The t- test and P- value of the OLS result

In statistics to increase the reliability or validity of our study we should make a hypothesis test in order to prove that the variables used in the regression have either effect on Y or not. Thus, we will build a statement called hypothesis. This hypothesis will have a null hypothesis (H_0) and alternative hypothesis (H_1). The null hypothesis says that one of the variable from the set of X variables (x_1, x_2, x_3 …. x_j, x_k …) doesn't have effect on Y whereas the alternative hypothesis states it has either a negative or positive effect on Y.

To increase the truth or validation of our research, we must make a hypothesis to check if the variables used have effect on the dependent variable. If the variables (x_1, x_2, x_3 ….) do not have an effect on the dependent variable Y, then the hypothesis is said to be a null hypothesis (Ho); otherwise, if a negative or positive effect is reflected on Y, then the hypothesis is said to be an alternative hypothesis (H1)

i.e. Ho: B_j=0, H_1: B_j= 0 two sided tail test

H_o: B_j=0, H_1: B_j>0 one sided tail test

H_o: B_j=0, H_1<0

To test this null hypothesis against the alternative, we will use the test method for modeling. One of these methods uses T-test and can be calculated with:

t-ratio= coefficient of the variable X_i/ standard error of the coefficient variable X_i

to test this, a significant level α or the probability of rejecting the null hypothesis will be chosen and the we look in a t-distribution table say C for α with n-k-1 degrees of freedom and α/2 with n-k-1 degrees of freedom for one sided tail test and two-sided tail test respectively.

If the value of C during the one-sided tail test is greater than t-ratio or t-ratio is less than the negative of C then we will reject H0. And in the case of Two tail sided test, we will reject H0 if /t-ratio/ > C.

"P –value is the probability of observing a t- statistics as extreme as we did if the null hypothesis is true." P-value is always between 0 and 1. The larger the p-value, the little evidence we have against our null hypothesis and vice versa.

Coefficient of determination

The R- squared value of regression result is another way of measuring how well the independent variable explains the dependent variable.

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

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

SSR=$\sum_{i=1}^{n}(\mathrm{u})2^{2}$, 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 if the regression line fits our data well. Its value is always between 0 and 1. When the value is near or equal to 1 the regression line matches 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 poorly fits the data very well. When interpreting the result of R-squared value we usually multiply it with 100 and express it in percent.

5.1 Scatter Diagrams

While developing correlations, the first step is creating a scatter plot of the data, to visually assess the strength and form of the relationship. The test results to be used in the regression analyses are presented in table 5-1; in addition, the scatter diagrams of DCPI versus CBR, and DCPI in alternate with CBR versus maximum dry density, natural moisture content, bulk density, optimum moisture content, maximum dry density, Liquid limit are Plastic limit are presented in figures 5-1 to 5-13.

Table 5-1: Summary of Test Results

Pit ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Field DCP	Natural Moisture Content (%)	Field Density (g/cc)	Free Swell (%)	Lab. CBR (%)	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
TR_01	22.09	15.57	6.52	32.91	5.18	1.64	7.5	5.45	15.56%	1.78
TR_02	24.36	12.36	12.00	32.30	5.95	1.55	7.5	4.99	12.21%	1.83
TR_03	26.41	16.11	10.30	14.94	4.48	1.66	7.5	17.09	15.12%	1.77
TR_04	27.72	15.54	12.18	34.50	4.72	1.41	10.0	4.62	16.88%	1.77
TR_05	21.58	12.23	9.35	10.97	1.84	1.69	7.5	23.75	14.22%	1.78
TR_06	25.63	16.24	9.39	11.09	3.67	1.72	10.0	27.72	16.77%	1.74
TR_07	25.45	15.52	9.93	10.63	3.31	1.74	10.0	34.37	16.08%	1.72
TR_08	22.33	15.14	7.19	7.82	2.65	1.66	5.0	45.55	15.07%	1.71
TR_09	22.30	14.51	7.79	10.97	2.71	1.75	10.0	29.11	15.00%	1.72
TR_10	24.17	16.46	7.71	31.39	2.97	1.48	7.5	6.19	17.03%	1.74
TR_11	22.64	14.14	8.50	23.63	3.47	1.66	7.5	10.44	13.04%	1.73
TR_12	24.48	15.43	9.05	32.91	4.90	1.50	10.0	6.01	15.55%	1.71
TR_13	23.22	16.31	6.91	31.67	3.91	1.33	7.5	6.01	16.60%	1.72
TR_14	24.45	15.14	9.31	26.50	3.90	1.52	10.0	8.04	15.13%	1.73
TR_15	21.55	15.17	6.38	7.79	2.86	1.76	10.0	43.71	16.60%	1.76
TR_16	21.27	13.97	7.30	16.84	2.84	1.70	7.5	14.41	13.93%	1.78
TR_17	19.85	12.92	6.93	10.16	2.67	1.65	14.0	36.50	14.79%	1.82
TR_18	19.66	14.08	5.58	31.30	2.37	1.62	10.0	5.91	14.60%	1.74
TR_19	18.79	12.29	6.50	30.00	2.58	1.57	10.0	6.65	14.13%	1.79
TR_20	23.74	15.22	8.52	32.73	2.80	1.53	10.0	5.27	14.30%	1.74
TR_21	22.42	15.54	6.88	32.75	3.12	1.33	10.0	5.54	16.55%	1.73
TR_22	21.09	13.12	7.97	34.86	2.61	1.41	10.0	4.53	13.18%	1.77
TR_23	23.58	15.48	8.10	36.07	1.27	1.60	10.0	5.08	14.91%	1.74
TR_24	24.52	16.33	8.19	37.24	3.83	1.25	10.0	4.44	17.09%	1.76
TR_25	24.03	15.29	8.74	24.73	3.74	1.56	10.0	6.65	16.68%	1.76

Pit ID	Liquid Limit (%)	Plastic Limit	Plasticity Index	Field DCP	Natural Moisture Content (%)	Field Density (g/cc)	Free Swell (%)	Lab. CBR (%)	Optimum Moisture Content (%)	Maximum Dry Density (g/cc)
TR_26	24.58	12.53	12.05	32.89	5.95	1.54	7.5	4.99	14.43%	1.77
TR_27	25.69	16.30	9.39	10.53	3.67	1.72	10.0	27.72	16.22%	1.68
TR_28	25.46	15.31	10.15	10.58	3.31	1.69	10.0	34.37	15.29%	1.75
TR_29	20.11	13.00	7.11	10.20	2.67	1.66	14.0	36.50	13.25%	1.85
TR_30	21.19	13.18	8.01	38.06	2.61	1.41	10.0	4.53	13.60%	1.78
TR_31	23.68	15.43	8.25	34.87	5.09	1.53	7.5	4.99	16.44%	1.76
TR_32	23.41	16.18	7.23	32.17	4.14	1.36	10.0	5.54	15.13%	1.73
TR_33	24.67	15.02	9.65	32.95	4.08	1.55	7.5	5.27	16.52%	1.73
TR_34	21.69	15.09	6.60	12.87	3.11	1.73	10.0	25.23	14.57%	1.70
TR_35	21.54	13.91	7.63	11.45	3.02	1.73	10.0	24.12	15.61%	1.74
TR_36	20.08	12.84	7.24	12.55	2.85	1.68	7.5	20.05	12.09%	1.79
TR_37	19.87	14.03	5.84	13.34	2.57	1.65	14.0	19.96	15.70%	1.81
TR_38	19.04	12.19	6.85	14.49	2.75	1.60	10.0	19.03	13.34%	1.79
TR_39	23.97	15.22	8.75	29.05	3.02	1.56	7.5	6.75	15.62%	1.77
TR_40	22.67	15.38	7.29	34.15	2.17	1.36	10.0	5.54	15.26%	1.79

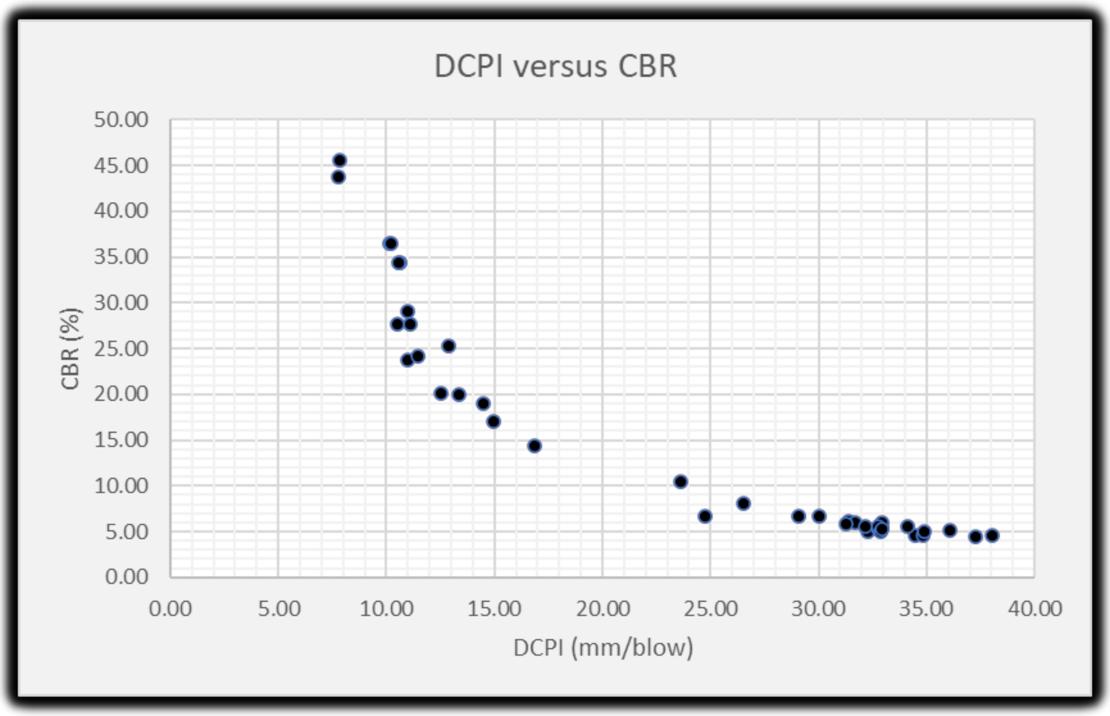


Figure 5-1: Scatter diagram of DCPI versus CBR

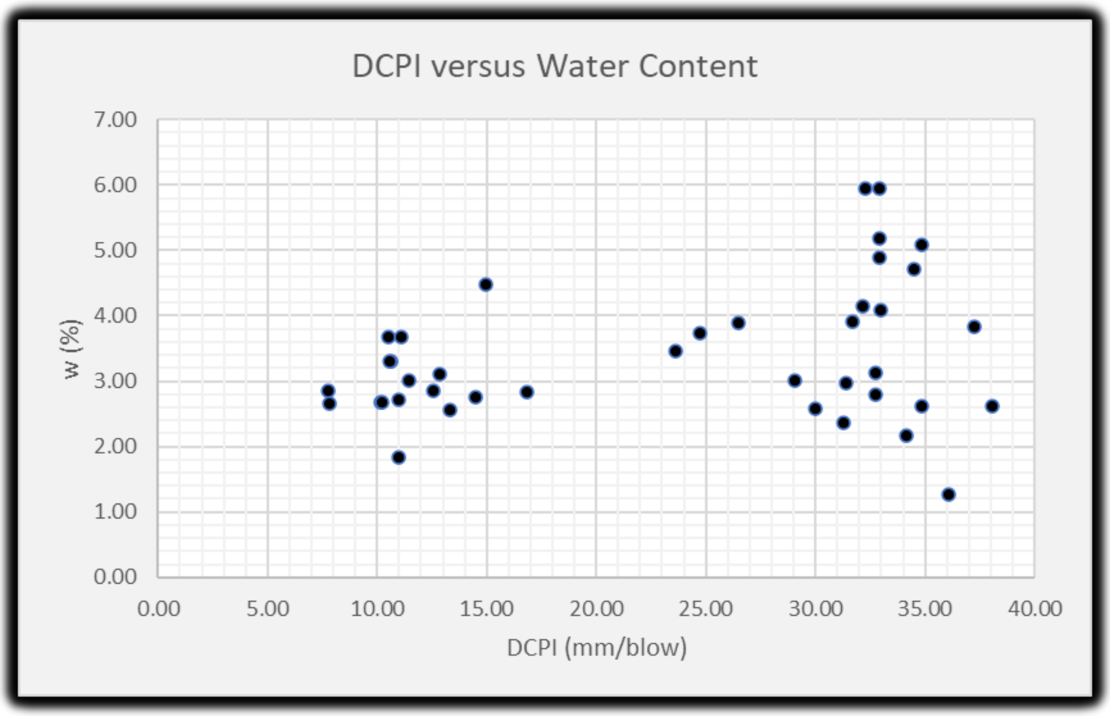


Figure 5-2: Scatter diagram of DCPI versus Water Content

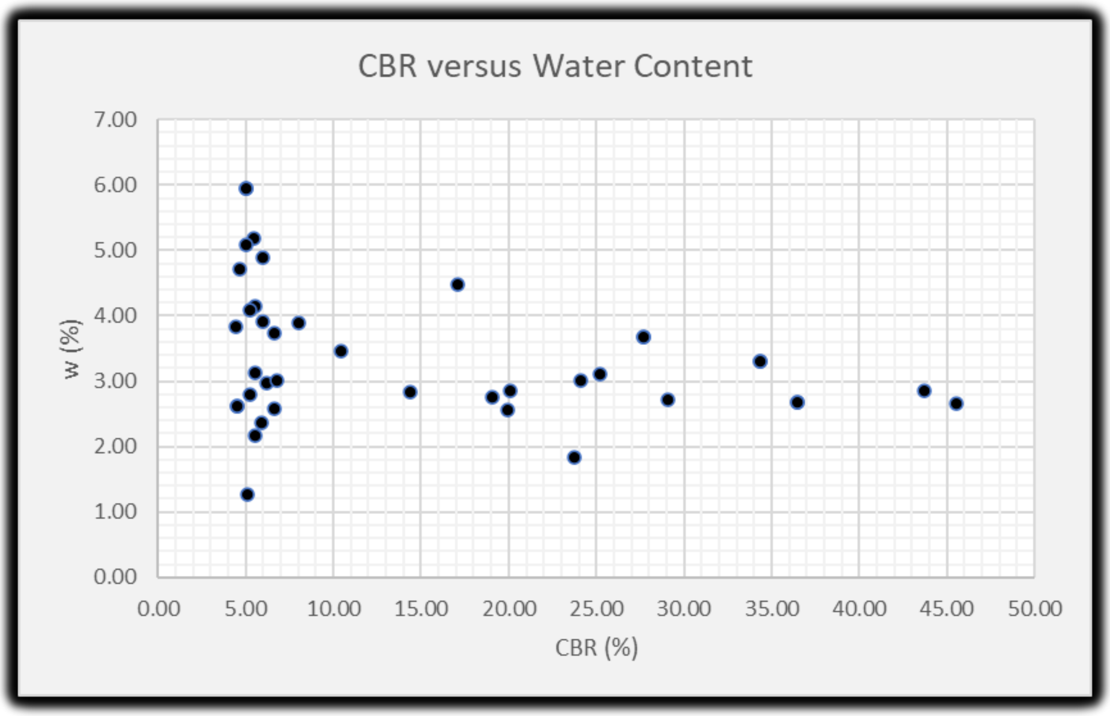


Figure 5-3: Scatter diagram of CBR versus Water Content

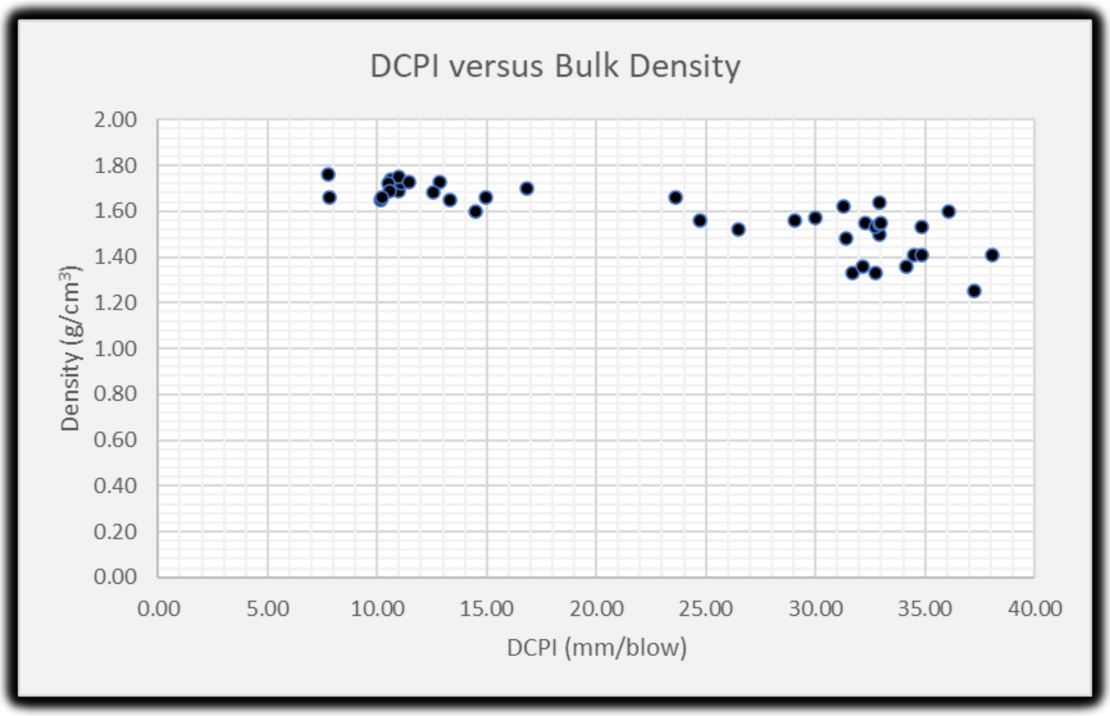


Figure 5-4: Scatter diagram of DCPI and Bulk Density

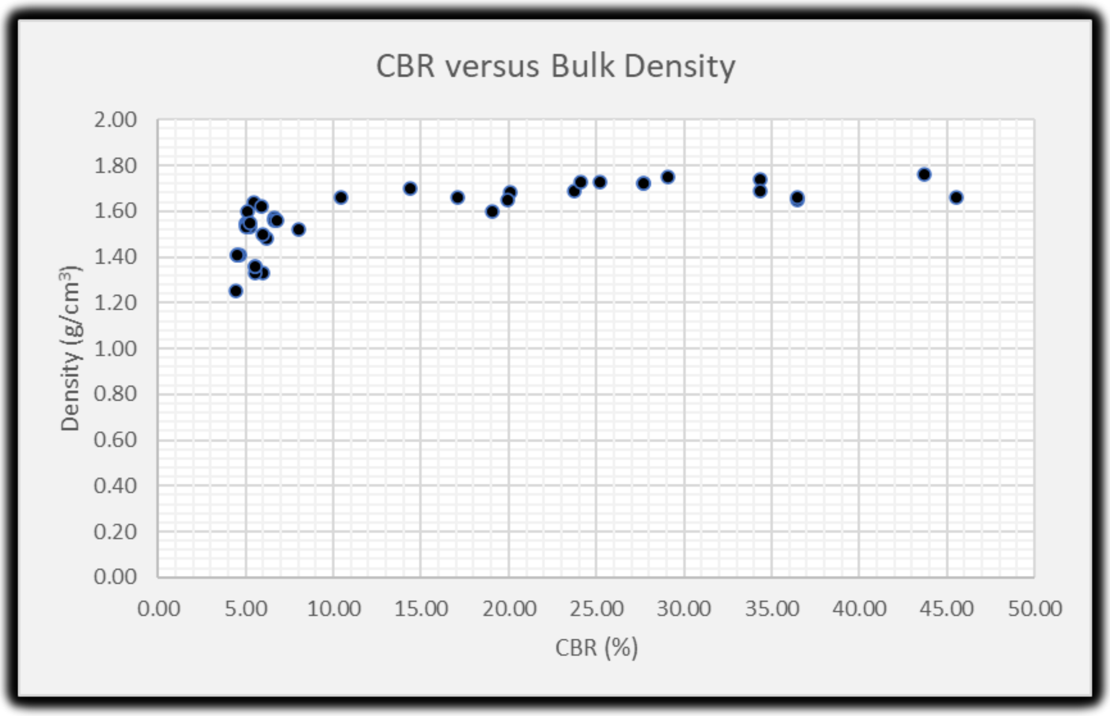


Figure 5-5: Scatter diagram of CBR and Bulk Density

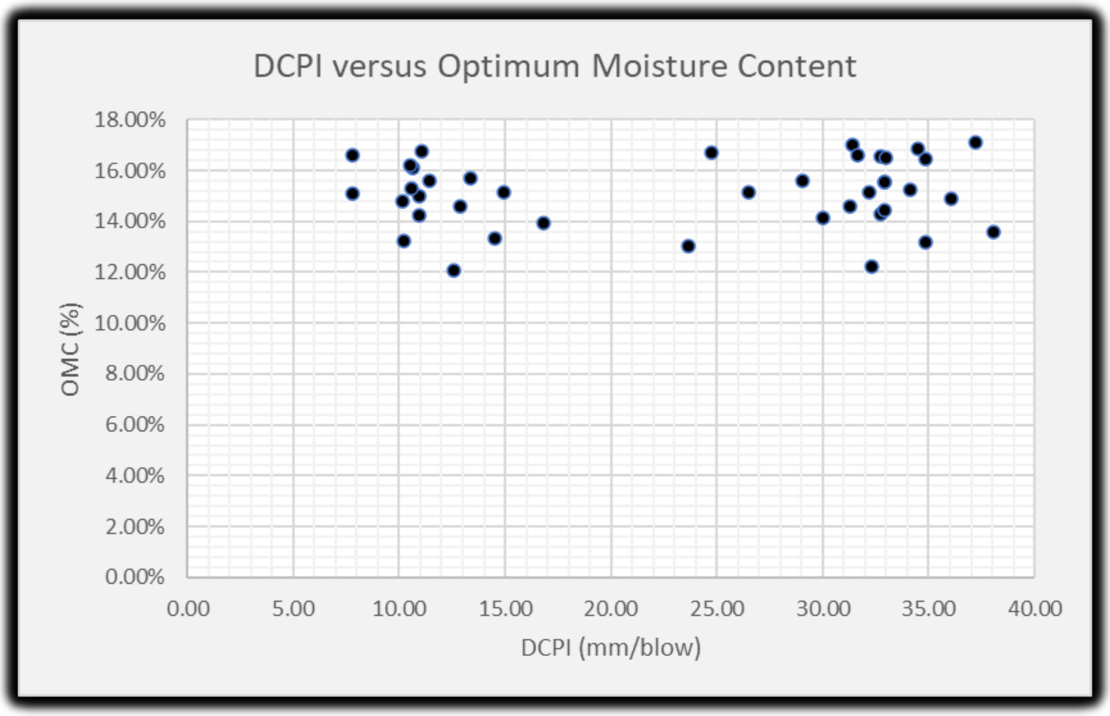


Figure 5-6: Scatter diagram of DCPI and Optimum Moisture Content

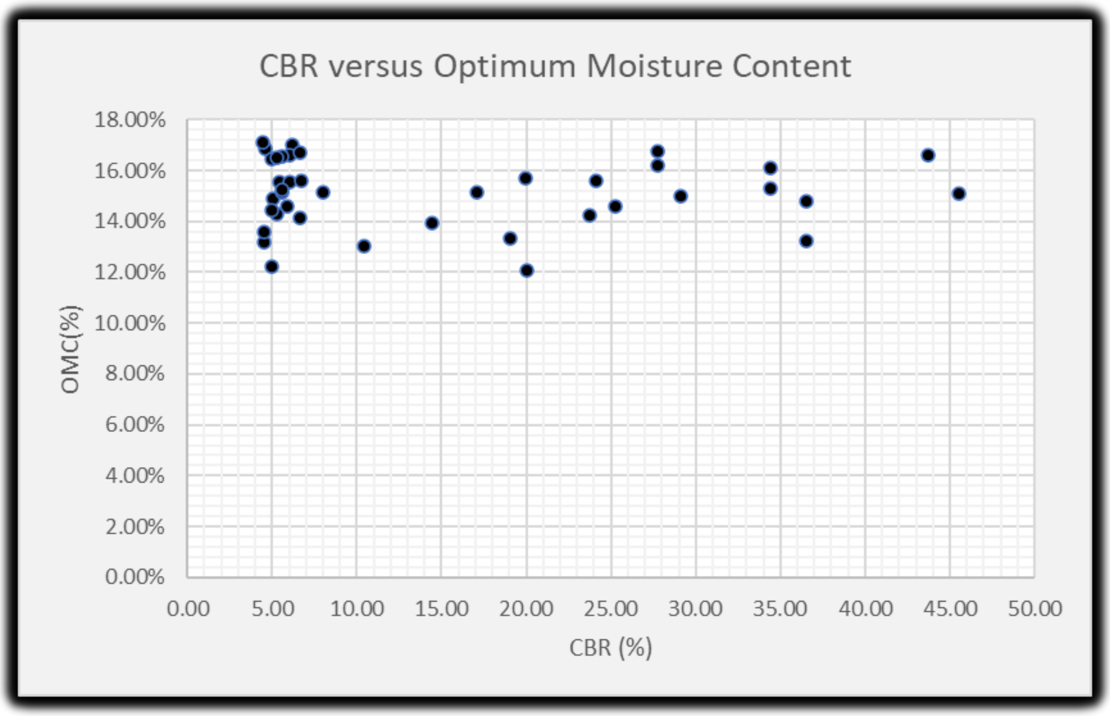


Figure 5-7: Scatter diagram of CBR and Optimum Moisture Content

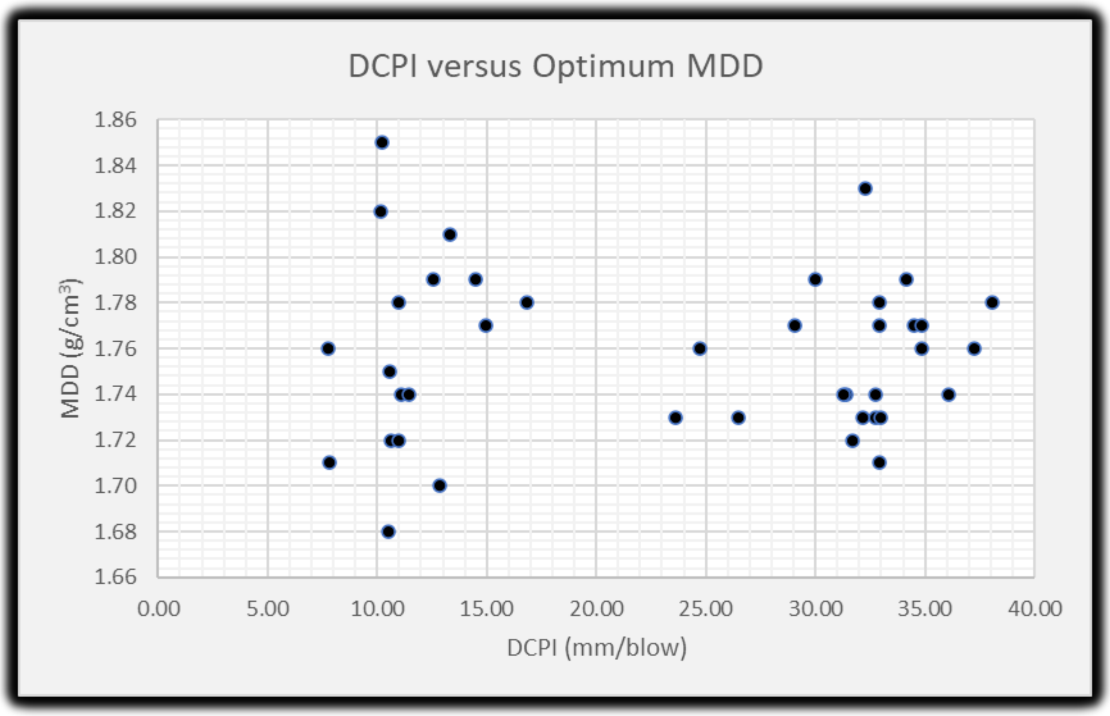


Figure 5-8: Scatter diagram of DCPI versus MDD

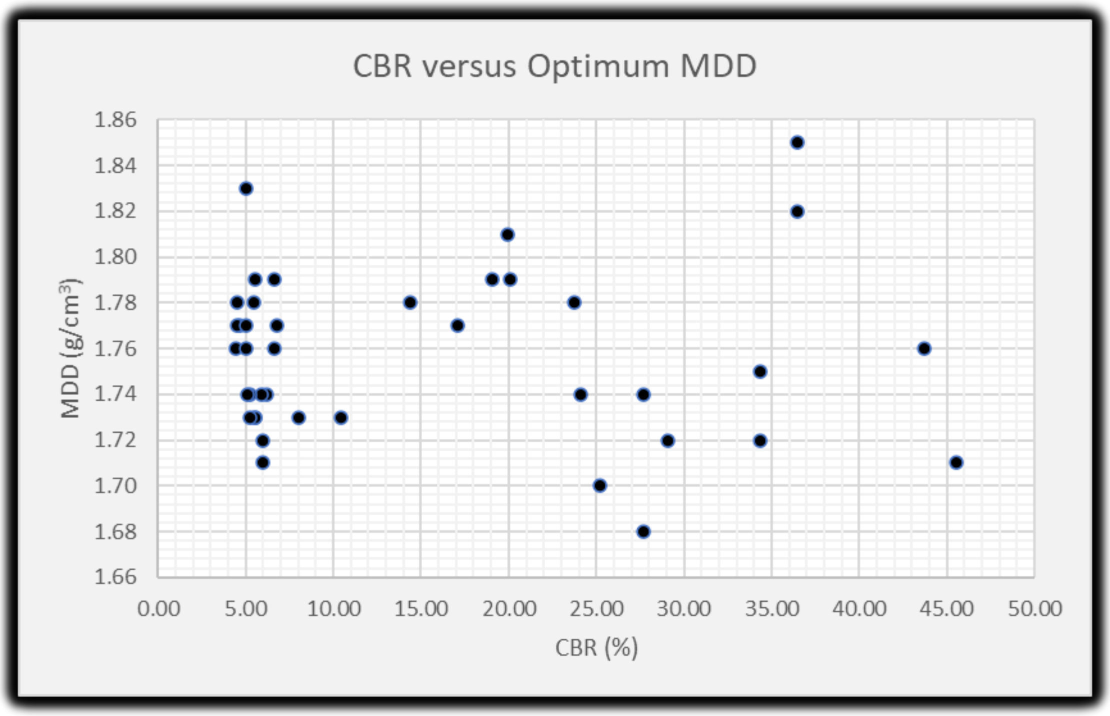


Figure 5-9: Scatter diagram of CBR versus MDD

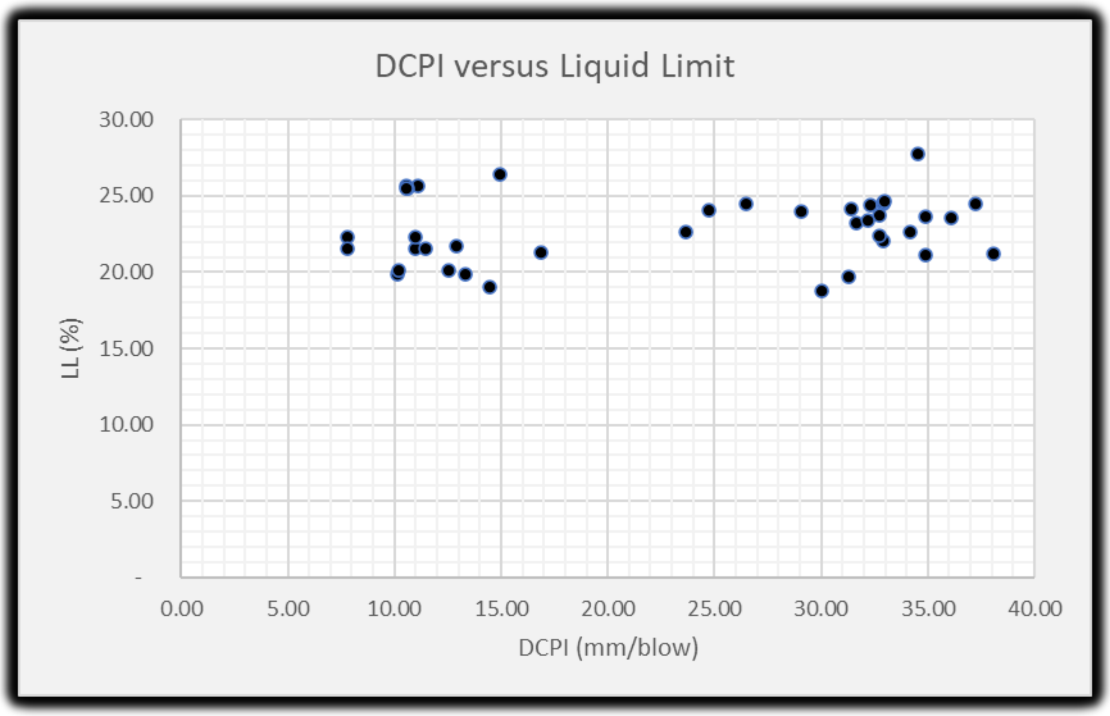


Figure 5-10: Scatter diagram of DCPI versus Liquid Limit

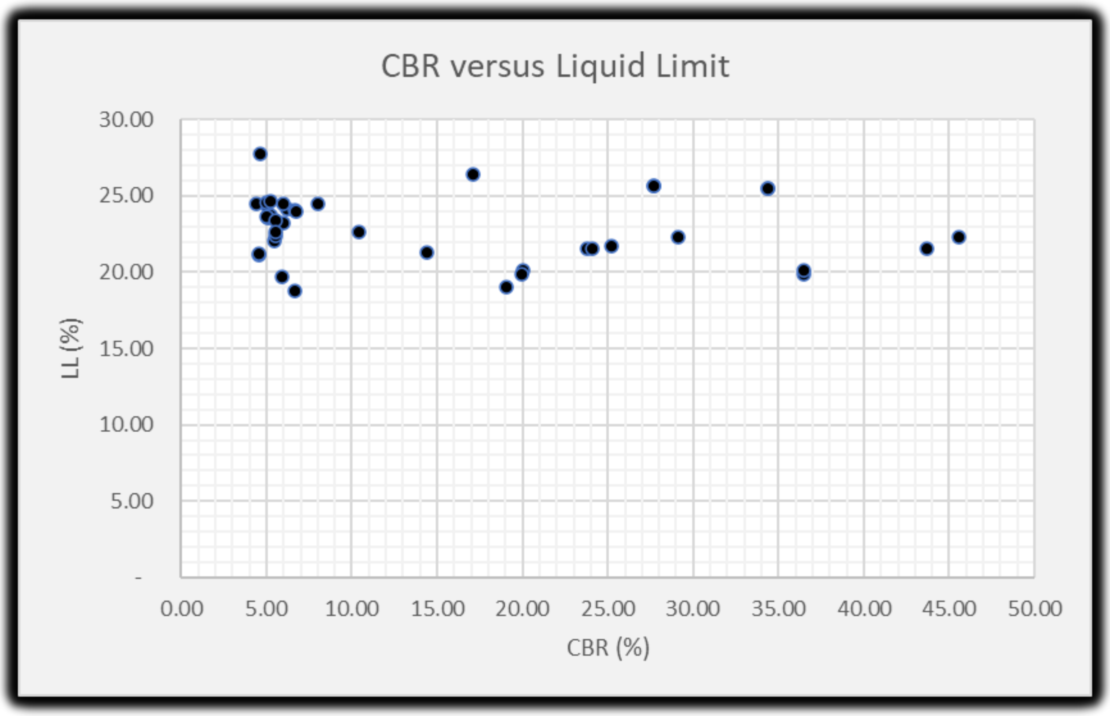


Figure 5-11: Scatter diagram of CBR versus Liquid Limit

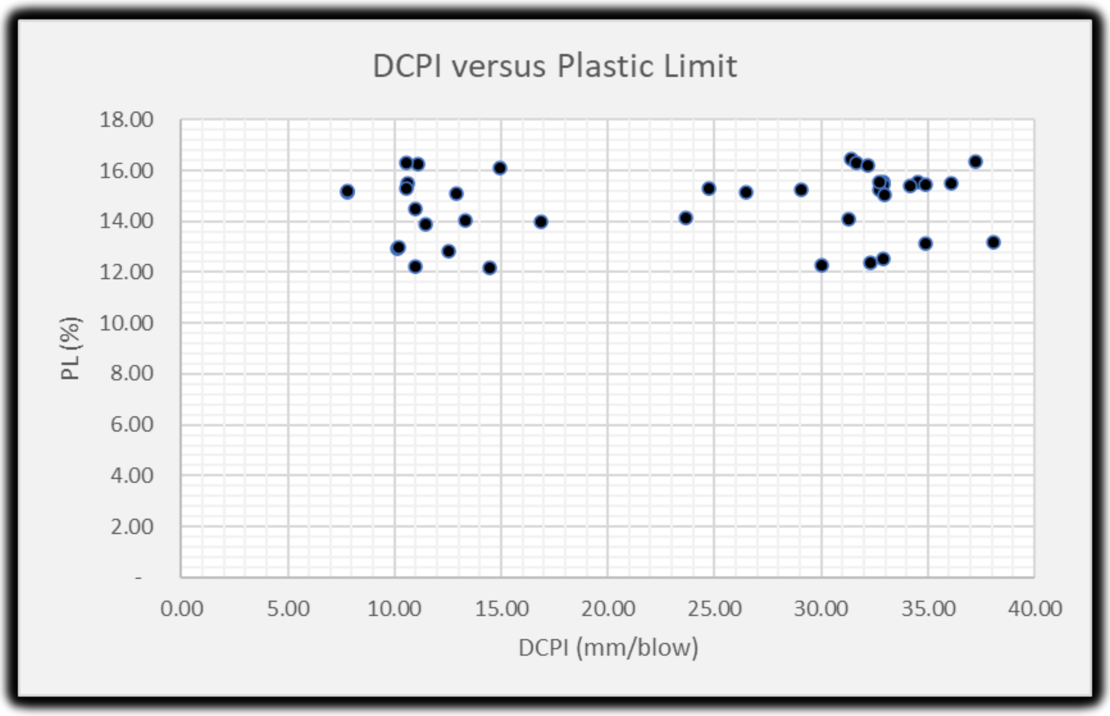


Figure 5-12: Scatter plot for DCPI and Plastic Limit

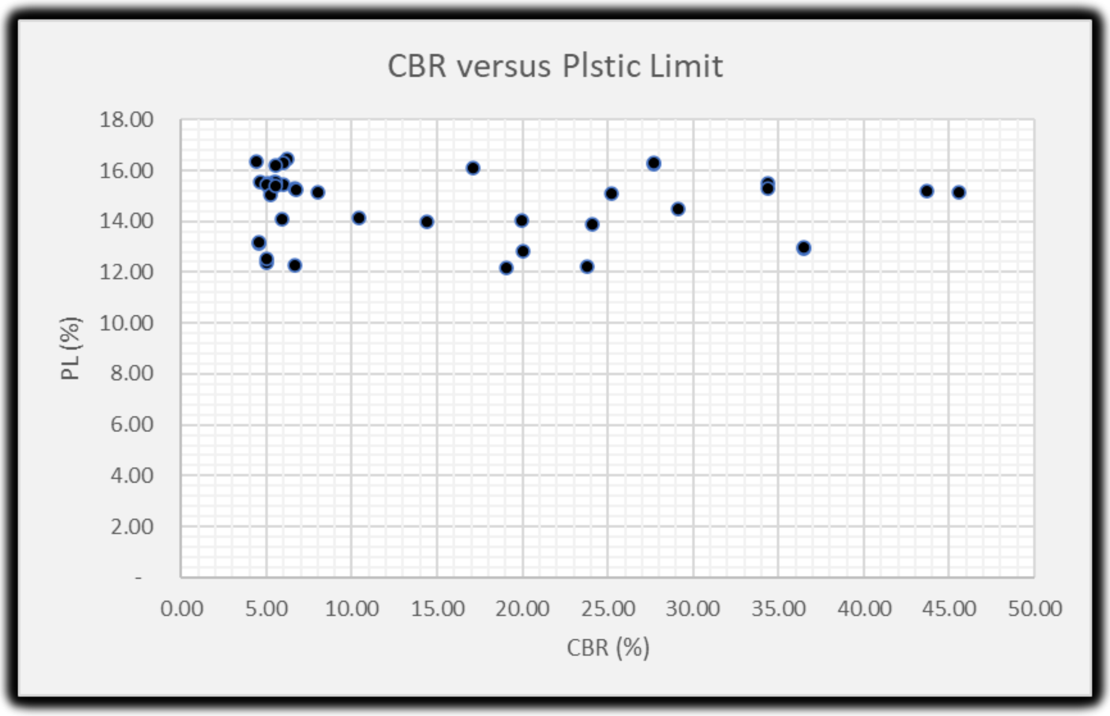


Figure 5-13: Scatter plot for CBR versus Plastic Limit

5.2 Regression

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

$$Y = \beta_0 + \beta_1 x + \varepsilon$$

$$Y = \alpha_0 + \alpha_1 x_1 + \alpha_1 x_2 \ldots + \alpha_n x_n + \varepsilon$$

Where, the slope (β_1) and intercept (β_0) of the simple linear regression model are called regression coefficients. Similarly, coefficients α_0, α_1, α_2 and α_n of the multiple regression model are termed multiple regression coefficients. To generalize this to a probabilistic linear model, the appropriate way 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. The fundamental presumption to obtain estimates of the regression coefficients of the single and multiple regression models is based on the least square method. To recognize the effect of one variable on the other, a stepwise linear regression has been analyzed and as a result, the individual relationship coefficients and level of importance is determined.

5.2.1 Simple Regression

The Pearson correlation coefficient matrix is shown in table 5-2. After studying the above scatter diagrams and applying different models the following correlation equations are developed. The summary of the equations is presented in table 5-2.

Table 5-2: Summary of Correlations

Equation	R^2	Sample Size
Log CBR=3.019-1.506*Log(DCPI)	0.958	35
DCPI=-0.0357w2+0.196w+38.474	0.141	35
DCPI=-0.0120(γ_{bulk})+1.819	0.655	35
CBR=0.1513*OMC$^{63.87}$	0.005	35
DCPI=77.83MDD+11.679	0.001	35
DCPI=0.007OMC+1.756	0.003	35
DCPI=1.002LL+0.4665	0.0402	35
CBR=-0.911LL+37.987	0.0281	35
DCPI=1.233PL+5.363	0.0235	35
CBR=-0.748PL+26.959	0.007	35

As one can read from table 5.2, the R^2 obtained from all correlations is unsatisfactory except the one obtained in the correlation between DCPI and CBR. Hence, the statistical analysis exercised to come to the correlation equation between CBR and DCPI is described.

A statistical software called SPSS is employed to study the relation between the regressor variable and the response variable. Out of the forty couple results, the thirty-five, i.e., from TR_01 to TR_35, couple CBR and DCPI values are used in the analysis. The model summary of the analysis is then as presented in Table 5-3, 5-4 and 5-5.

Table 5-3: Summary for the Regression Model

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.979[a]	.958	.957	.07609

a. Predictors: (Constant), Field DCP (mm/blow)

Table 5-4: Analysis of variance (ANOVA)

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.411	1	4.411	761.917	.000[b]
	Residual	.191	33	.006		
	Total	4.602	34			

a. Dependent Variable: Lab. CBR (%)

b. Predictors: (Constant), Field DCP (mm/blow)

Table 5-5: Coefficients

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.019	.073		41.320	.000
	Field DCP (mm/blow)	-1.506	.055	-.979	-27.603	.000

a. Dependent Variable: Lab. CBR (%)

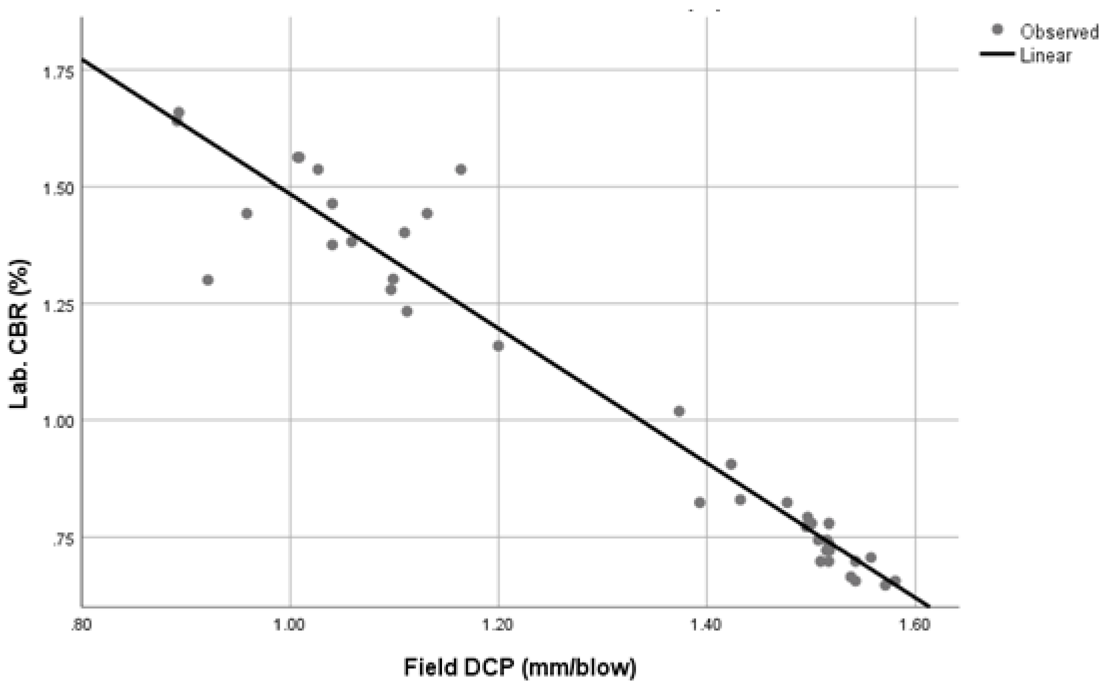


Figure 5-14: Scatter plot of log CBR versus log DCPI

The summary of outputs of the regression analysis includes the regression statistic and ANOVA (analysis of variance) results. In the regression statistics the coefficient of determination R^2 is important to conclude the strength of relationship between two variables. Accordingly, it is observed that the coefficient of determination (R^2) for the log-log (power) model shows better relationship strength than the linear model. In addition to this the ANOVA displays the regression coefficient values which are the major outputs of this study.

Accordingly, the relationship from the analysis can be summarized as equation 5.1:

Log(CBR)=3.019-1.506*Log(DCPI)..Equation 5.1

Where: CBR is in% and DCPI is in mm/blow.

5.2.2 Multiple regression

From the scatter diagram and correlation equation obtained a very good relationship is implied between DCPI and CBR. In addition, a good relationship is also observed between DCPI and bulk density. Apart from these, the interrelationship between the others with the CBR, as observed by the R^2 obtained, is not satisfactory.

Hence, using multiple regression technique, an equation is developed taking the variables which have a relatively good relations from the single regression. The regression is computed taking CBR as a dependent variable and DCPI, and γ_{bulk} as independent variables.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.926039517
R Square	0.857549188
Adjusted R Square	0.849849144
Standard Error	4.913822099
Observations	35

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	5378.172	2689.086	111.3694	2.2E-16
Residual	37	893.389	24.14565		
Total	39	6271.561			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	58.36172338	18.14696	3.21606	0.002699	21.59248	95.13096	21.59248	95.13096
DCPI	-1.188886417	0.124742	-9.53077	1.67E-11	-1.44164	-0.93614	-1.44164	-0.93614
Bulk Density	-9.642383372	9.948776	-0.9692	0.338737	-29.8005	10.51575	-29.8005	10.51575

From the above multiple regression, with an adjusted R^2 of 0.854, we can find that: -

CBR= -1.189(DCPI)-9.642(γ_{bulk})+58.36 …………………………………………………..…………Equation 5.2

5.3 Validating the Newly Developed Correlation Equation

To go through validation, among the correlation relations equations 5.1 and 5.2, the one with the highest R^2 value is chosen as it implies the strength of the correlation between the variables. Hence, the correlation equation developed using CBR and DCPI, i.e., equation 5.1 is used for validation.

There have been forty couple CBR and DCP test conducted for the objectives of this research work; out of the forty couples, 35 of them are used in the regression analyses. the remaining 5 couples have been left to check the validity of the established equations. Thus, the validation is processed using equation 5.1 and the details are presented in Table 5-6.

Table 5-6: Validation of the newly developed correlation equation

Pit ID	Field DCP	Lab. CBR (%)	Estimated CBR Using Existing Correlations		
			CBR Estimated by Newly Developed Equation	Difference between the two CBR Values	Variation of Estimated CBR from Lab CBR (%)
	A	B	C	D=C-B	E (%)=D/B
TR_36	12.55	20.05	23.10	3.05	15.2
TR_37	13.34	19.96	21.10	1.14	5.7
TR_38	14.49	19.03	18.60	-0.43	-2.3
TR_39	29.05	6.75	6.50	-0.25	-3.6
TR_40	34.15	5.54	5.10	-0.44	-8

From table 5-6, it can be seen that the lowest variation (%) is -2.3% and the highest is 15.2%.

5.4 Checking the Applicability of the Existing Correlations

There are a number of existing correlations between field DCP and laboratory CBR which are developed for different soil types of various localities. Prior to picking and applying a correlation relation, it is mandatory to know the soil type it is developed for; else, erroneous outcome may be encountered.

As shown in section three of this research paper, the local subgrade soil under consideration is visually described as silty sand soil with the soil grouping of A-2-4 and A-2-6 as per AASHOT classification.

To see their applicability, four existing correlations developed for soils of close resemblance and the generic ones are selected from table 2-4. The CBR values obtained from these relations and the variations of the results from the lab CBR are as presented in table 5-7 and figure 5-15.

Table 5-7: Comparisons of Laboratory CBR Value and CBR values obtained from Existing correlations

Pit ID	Field DCP	Lab. CBR (%)	Estimated CBR Using Existing Correlations					Variation of Estimated CBR from Lab CBR (%)				
			New Equation	Sampson (PI>6)	Harison (Sand S-W)	Livneh (Granular and Cohesive Soils)	Kleyn and Van Heeden	New Equation	Sampson (PI>6)	Harison (Sand S-W)	Livneh (Granular and Cohesive Soils)	Kleyn and Van Heeden
TR_01	32.91	5.45	5.42	5.99	5.48	5.63	4.73	-0.6	9.9	0.5	3.3	-13.2
TR_02	32.30	4.99	5.57	6.10	5.64	5.75	4.84	11.6	22.3	13	15.2	-3
TR_03	14.94	17.09	17.80	16.00	18.06	13.64	13.09	4.1	-6.4	5.7	-20.2	-23.4
TR_04	34.50	4.62	5.05	5.60	5.10	5.34	4.45	9.3	21.2	10.4	15.6	-3.7
TR_05	10.97	23.75	28.34	23.60	28.79	19.27	19.50	19.3	-0.6	21.2	-18.9	-17.9
TR_06	11.09	27.72	27.88	23.30	28.32	19.04	19.23	0.6	-15.9	2.2	-31.3	-30.6
TR_07	10.63	34.37	29.72	24.50	30.19	19.97	20.31	-13.5	-28.7	-12.2	-41.9	-40.9
TR_08	7.82	45.55	47.19	36.00	48.00	28.16	30.18	3.6	-21	5.4	-38.2	-33.7
TR_09	10.97	29.11	28.34	23.60	28.79	19.27	19.50	-2.6	-18.9	-1.1	-33.8	-33
TR_10	31.39	6.19	5.82	6.40	5.89	5.94	5.03	-6	3.4	-4.9	-4.1	-18.8
TR_11	23.63	10.44	8.92	9.10	9.04	8.16	7.25	-14.6	-12.8	-13.4	-21.8	-30.6
TR_12	32.91	6.01	5.42	6.00	5.48	5.63	4.73	-9.8	-0.1	-8.8	-6.3	-21.2
TR_13	31.67	6.01	5.74	6.30	5.81	5.88	4.97	-4.4	4.9	-3.3	-2.1	-17.2
TR_14	26.50	8.04	7.51	7.80	7.60	7.18	6.25	-6.6	-3	-5.5	-10.7	-22.3
TR_15	7.79	43.71	47.46	36.20	48.28	28.28	30.33	8.6	-17.2	10.5	-35.3	-30.6
TR_16	16.84	14.41	14.86	13.80	15.07	11.93	11.22	3.1	-4.3	4.5	-17.2	-22.2
TR_17	10.16	36.50	31.81	26.00	32.33	21.00	21.53	-12.8	-28.8	-11.4	-42.5	-41
TR_18	31.30	5.91	5.84	6.40	5.91	5.96	5.04	-1.2	8.2	-0.1	0.8	-14.8
TR_19	30.00	6.65	6.23	6.70	6.30	6.25	5.33	-6.4	0.7	-5.3	-6.1	-19.9
TR_20	32.73	5.27	5.46	6.00	5.53	5.67	4.76	3.7	13.9	5	7.7	-9.6
TR_21	32.75	5.54	5.46	6.00	5.52	5.66	4.76	-1.5	8.2	-0.4	2.1	-14.1
TR_22	34.86	4.53	4.97	5.60	5.02	5.28	4.39	9.8	23.7	10.9	16.6	-3
TR_23	36.07	5.08	4.72	5.30	4.77	5.08	4.20	-7.1	4.3	-6.1	0	-17.4
TR_24	37.24	4.44	4.50	5.10	4.55	4.90	4.03	1.5	15	2.6	10.5	-9.1
TR_25	24.73	6.65	8.33	8.60	8.44	7.76	6.84	25.2	29.3	26.9	16.6	2.8
TR_26	32.89	4.99	5.42	6.00	5.49	5.63	4.73	8.6	20.3	10	12.8	-5.2
TR_27	10.53	27.72	30.15	24.80	30.63	20.18	20.56	8.8	-10.5	10.5	-27.2	-25.8

Pit ID	Field DCP	Lab. CBR (%)	Estimated CBR Using Existing Correlations					Variation of Estimated CBR from Lab CBR (%)				
			New Equation	Sampson (PI>6)	Harison (Sand S-W)	Livneh (Granular and Cohesive Soils)	Kleyn and Van Heeden	New Equation	Sampson (PI>6)	Harison (Sand S-W)	Livneh (Granular and Cohesive Soils)	Kleyn and Van Heeden
TR_28	10.58	34.37	29.93	24.70	30.41	20.07	20.44	-12.9	-28.1	-11.5	-41.6	-40.5
TR_29	10.20	36.50	31.63	25.80	32.14	20.91	21.42	-13.3	-29.3	-11.9	-42.7	-41.3
TR_30	38.06	4.53	4.35	5.00	4.40	4.78	3.92	-3.9	10.4	-2.8	5.6	-13.4
TR_31	34.87	4.99	4.97	5.60	5.02	5.28	4.39	-0.4	12.2	0.6	5.8	-12
TR_32	32.17	5.54	5.61	6.20	5.67	5.78	4.87	1.2	11.8	2.3	4.3	-12.2
TR_33	32.95	5.27	5.41	6.00	5.47	5.62	4.72	2.7	13.9	3.9	6.7	-10.4
TR_34	12.87	25.23	22.28	19.30	22.62	16.12	15.87	-11.7	-23.5	-10.3	-36.1	-37.1
TR_35	11.45	24.12	26.57	22.40	26.99	18.37	18.46	10.2	-7.1	11.9	-23.8	-23.5
TR_36	12.55	20.05	23.14	19.90	23.50	16.58	16.40	15.4	-0.8	17.2	-17.3	-18.2
TR_37	13.34	19.96	21.11	18.50	21.43	15.48	15.15	5.8	-7.3	7.4	-22.4	-24.1
TR_38	14.49	19.03	18.64	16.70	18.91	14.11	13.62	-2.1	-12.3	-0.7	-25.9	-28.4
TR_39	29.05	6.75	6.54	7.00	6.62	6.48	5.55	-3	3.8	-1.9	-3.9	-17.7
TR_40	34.15	5.54	5.13	5.70	5.18	5.40	4.51	-7.5	2.8	-6.6	-2.6	-18.7

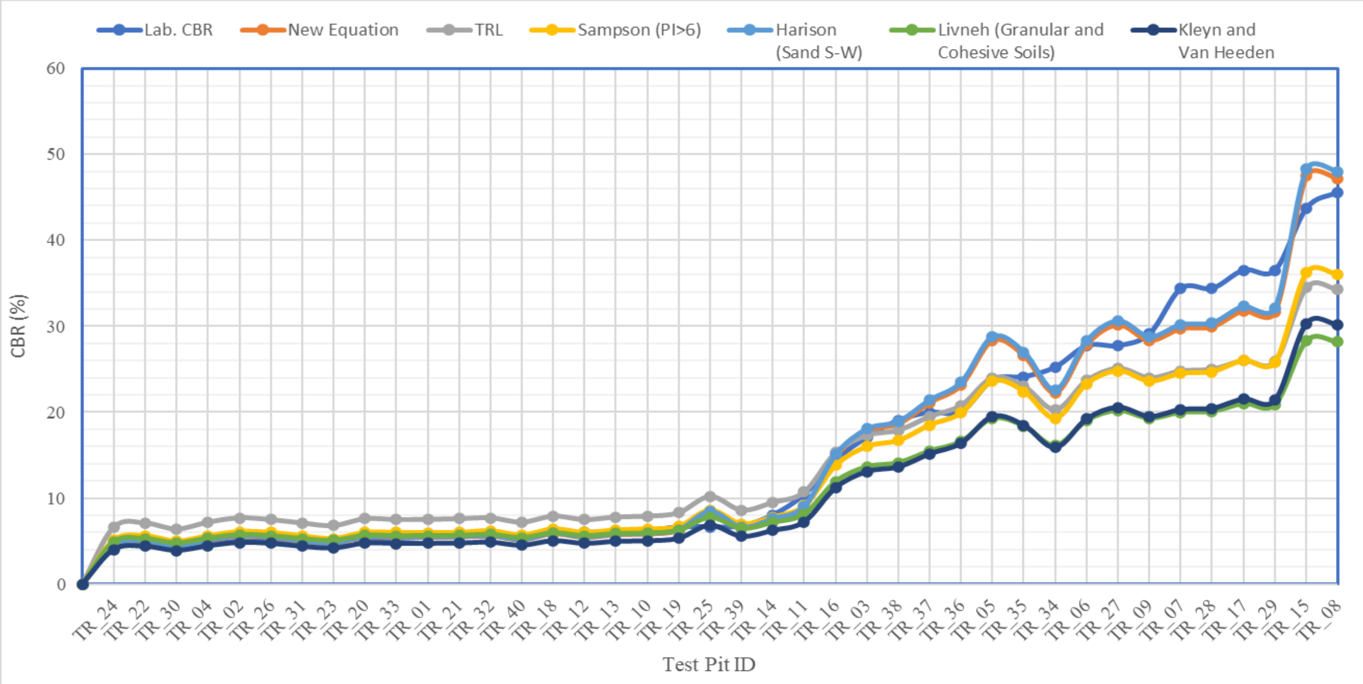


Figure 5-15: Comparisons of Laboratory CBR Value and CBR values obtained from Existing correlations

As presented in the table 5-7 and figure 5-15, the collected DCP data for the analysis is substituted into the existing correlations, to obtain the estimated CBR values. The comparison shows considerable variation between the laboratory CBR and the one estimated using existing correlation. The summary of the variations is as shown in Table 5-8.

Table 5-8: Summary of Variations between the Laboratory CBR Values and the Estimates

Description	New Equation	Sampson (PI>6)	Harison (Sand S-W)	Livneh (Granular and Cohesive Soils)	Kleyn and Van Heeden
Minimum Variation	-14.6	-29.3	-13.4	-42.7	-41.3
Maximum Variation	25.2	29.3	26.9	16.6	2.8
Composition of the estimates less than the lab result	52.5	50	47.5	62.5	97.5
Composition of the estimates greater than the lab result	47.5	50	52.5	37.5	2.5

From table 5-7 and table 5-8 one can note that the estimated CBR values using the newly developed equation and the Harison have close resemblance estimating CBR values closer to the laboratory values; whereas, the others give a bit far result.

5.5 Comparison of the New Correlation Equation with Locally Developed Existing Correlations

The newly developed correlation, i.e., equation 5.3 has also been compared with relevant correlations developed for different localities in our country and the one suggested by TRRL for tropical soils. The relation developed by TRRL [21], Araya [4], Desalegn [5] are as presented in table 5-9.

Table 5-9: Summary of correlation equations selected for comparison

Correlation Equation	Soil Type	Reference
log10(CBR) = 2.48 – 1.057 log10 (DCP)	All Soil Types	TRRL [21]
log10 (SCBR) =2.197-0.852 log10 (DCPI)	Coarse Grained Soils	Araya [4]
log (CBR) = 2.954-1.496 log (DCPI)	Clay soils	Yitagesu [5]

Table 5-10 and figure 5-16 present the comparisons made between equation 5.1 and equations suggested by TRRL [21], Araya [4], Desalegn [5].

Table 5-10: Comparisons among Laboratory CBR Value and CBR values obtained from Existing correlations developed for our country

Pit ID	Field DCP	Lab. CBR (%)		Estimated CBR Using Existing Correlations				Variation of Estimated CBR from Lab CBR (%)		
			New Equation	TRRL [21]	Araya [4]	Desalegn [5]	New Equation	TRRL [21]	Araya [4]	Desalegn [5]
TR_01	32.91	5.45	5.42	7.52	8.02	1.53	-0.6	37.9	47.1	-71.9
TR_02	32.30	4.99	5.57	7.70	8.15	1.57	11.6	54.3	63.3	-68.5
TR_03	14.94	17.09	17.80	17.30	15.72	4.98	4.1	1.2	-8	-70.9
TR_04	34.50	4.62	5.05	7.20	7.71	1.42	9.3	55.8	66.9	-69.3
TR_05	10.97	23.75	28.34	24.00	20.45	7.90	19.3	1.1	-13.9	-66.7
TR_06	11.09	27.72	27.88	23.70	20.26	7.78	0.6	-14.5	-26.9	-71.9
TR_07	10.63	34.37	29.72	24.80	21.01	8.29	-13.5	-27.8	-38.9	-75.9
TR_08	7.82	45.55	47.19	34.30	27.29	13.11	3.6	-24.7	-40.1	-71.2
TR_09	10.97	29.11	28.34	24.00	20.45	7.90	-2.6	-17.5	-29.7	-72.9
TR_10	31.39	6.19	5.82	7.90	8.35	1.64	-6	27.6	34.9	-73.5
TR_11	23.63	10.44	8.92	10.70	10.64	2.51	-14.6	2.5	1.9	-76
TR_12	32.91	6.01	5.42	7.50	8.02	1.53	-9.8	24.9	33.5	-74.5
TR_13	31.67	6.01	5.74	7.80	8.29	1.62	-4.4	29.9	38	-73
TR_14	26.50	8.04	7.51	9.50	9.65	2.11	-6.6	18.2	20	-73.8
TR_15	7.79	43.71	47.46	34.50	27.38	13.19	8.6	-21.1	-37.4	-69.8
TR_16	16.84	14.41	14.86	15.30	14.20	4.16	3.1	6.1	-1.5	-71.1
TR_17	10.16	36.50	31.81	26.00	21.83	8.87	-12.8	-28.8	-40.2	-75.7
TR_18	31.30	5.91	5.84	7.90	8.37	1.65	-1.2	33.6	41.5	-72.1
TR_19	30.00	6.65	6.23	8.30	8.68	1.75	-6.4	24.8	30.5	-73.7
TR_20	32.73	5.27	5.46	7.60	8.06	1.54	3.7	44.3	53	-70.8
TR_21	32.75	5.54	5.46	7.60	8.05	1.54	-1.5	37.1	45.2	-72.2

Pit ID	Field DCP	Lab. CBR (%)		Estimated CBR Using Existing Correlations				Variation of Estimated CBR from Lab CBR (%)		
			New	TRRL	Araya	Desalegn	New	TRRL	Araya	Desalegn [5]
TR_22	34.86	4.53	4.97	7.10	7.64	1.40	9.8	56.8	68.7	-69.1
TR_23	36.07	5.08	4.72	6.80	7.42	1.33	-7.1	33.8	46	-73.8
TR_24	37.24	4.44	4.50	6.60	7.22	1.27	1.5	48.8	62.8	-71.4
TR_25	24.73	6.65	8.33	10.20	10.23	2.34	25.2	53.3	53.8	-64.8
TR_26	32.89	4.99	5.42	7.50	8.03	1.53	8.6	50.3	60.9	-69.3
TR_27	10.53	27.72	30.15	25.10	21.18	8.40	8.8	-9.5	-23.6	-69.7
TR_28	10.58	34.37	29.93	25.00	21.09	8.34	-12.9	-27.3	-38.6	-75.7
TR_29	10.20	36.50	31.63	25.90	21.76	8.81	-13.3	-29	-40.4	-75.9
TR_30	38.06	4.53	4.35	6.40	7.09	1.23	-3.9	41.4	56.6	-72.8
TR_31	34.87	4.99	4.97	7.10	7.64	1.40	-0.4	42.3	53.1	-71.9
TR_32	32.17	5.54	5.61	7.70	8.18	1.58	1.2	38.9	47.5	-71.5
TR_33	32.95	5.27	5.41	7.50	8.01	1.53	2.7	42.4	52.1	-71
TR_34	12.87	25.23	22.28	20.30	17.85	6.22	-11.7	-19.5	-29.2	-75.3
TR_35	11.45	24.12	26.57	23.00	19.72	7.41	10.2	-4.6	-18.2	-69.3
TR_36	12.55	20.05	23.14	20.80	18.24	6.46	15.4	3.7	-9	-67.8
TR_37	13.34	19.96	21.11	19.50	17.31	5.90	5.8	-2.3	-13.3	-70.4
TR_38	14.49	19.03	18.64	17.90	16.14	5.21	-2.1	-6	-15.2	-72.6
TR_39	29.05	6.75	6.54	8.60	8.92	1.84	-3	27.5	32.2	-72.7
TR_40	34.15	5.54	5.13	7.20	7.77	1.45	-7.5	29.9	40.2	-73.8

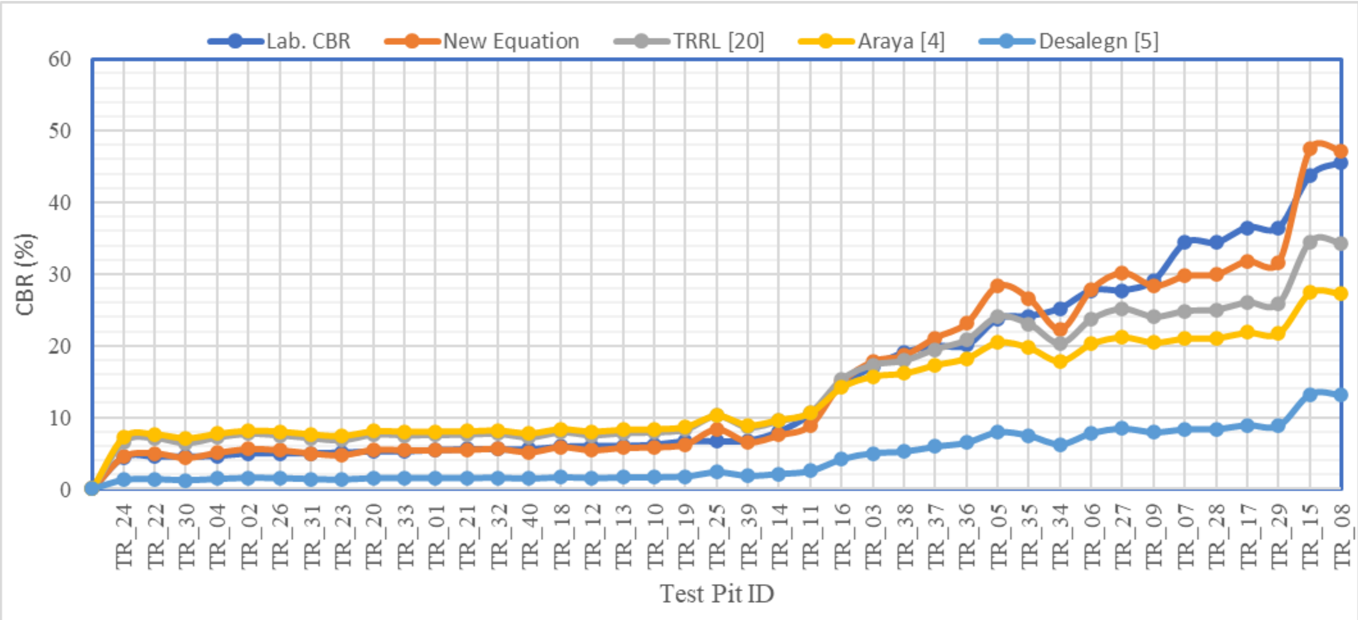


Figure 5-16: Comparisons among Laboratory CBR Value and CBR values obtained from Existing correlations developed for our country

In the Table 5-10, the collected DCP data for the analysis is substituted into the existing correlations developed for different soils of our country and into the correlation suggested by TRRL for our country, to obtain their corresponding CBR estimates. Here also, table 5-10 and figure 5-16 present the comparison among the different equations showing the considerable variation between the laboratory CBR and the one estimated using existing correlations specially the CBR values estimated using Desalegn [5] are generally lower than both the laboratory CBR result and the ones estimated using the other correlations. The summary of the variations is as shown in table 5-11.

Table 5-11: Summary of Variations between the Laboratory CBR Values and the Estimates from Existing correlations developed for our country

Description	New Equation	TRRL [21]	Araya [4]	Desalegn [5]
Minimum Variation	-14.6	-29	-40.4	-76
Maximum Variation	25.2	56.8	68.7	-64.8
Composition of the estimates less than the lab result	52.5	32.5	42.5	100
Composition of the estimates greater than the lab result	47.5	67.5	57.5	0

As presented in the Table 5-10, the collected DCP data for the analysis is substituted into the existing correlations developed for different soils of our country and into the correlation suggested by TRRL for our country, to obtain their corresponding CBR estimates. Here also, the Comparison shows considerable variation between the laboratory CBR and the one estimated using existing correlation. The summary of the variations is as shown in Table 5-11.

It is seen in the above two tables, Table 5-10 and Table 5-11, that the estimated CBR values using the newly developed equation and the one developed by TRRL [21] and Araya, Alemgena A., and Gebremariam G Felek [4] have relatively better resemblance and estimating CBR values closer to the laboratory values; whereas, the other gives a bit far results due to the fact that it is developed for fine grained soils.

It is also noted that, the CBR estimated using the correlation developed by Desalegn [5] yields lower results than CBR values obtained from both the laboratory procedure and the new correlation.

Chapter-6: Conclusions and Recommendations

6.1 Conclusions

The research was conducted to obtain a correlation that better estimates the CBR value from the DCP for the silty sand type of soil encountered in the case project. To achieve this, all relevant in-situ and laboratory tests were conducted on samples retrieved from different pits from the project site. utilizing thirty-five test results a number of single regressions have been analyzed between the CBR and other soil indices; in addition, a single logarithmic regression has been analyzed using the CBR and DCPI. Furthermore, a multiple regression has also been analyzed using the CBR, DCPI and γ_{bulk}. The outcome of the analyses implied that a strong relation exists between the CBR and DCPI having an R^2 of 0.958.

Hence, the applicability of the developed correlation between the CBR and DCPI has been checked by using a set of separate control test results containing five couples CBR-DCP test results. And finally, the following conclusions are drawn after the study:

1. The statistical analysis shows that there exists a good correlation between CBR and DCPI. Moreover, from the validation result it can be seen that the newly developed correlation equation between DCPI and CBR is closer to the laboratory CBR. This indicated that the newly developed correlation equation presented below can be reliably used to predict CBR values from field dynamic cone penetration test for soils of A-2-4 and A-2-6 soils.

2. Log(CBR)=3.019-1.506*Log(DCPI)………………………………………………………….. (6.1)

   The comparison analysis between the CBR results obtained from the new correlation and other existing correlations shows that the estimated CBR values using the newly developed equation and the Harison have close resemblance giving CBR values closer to the laboratory values; whereas, the others give a bit far result. In addition, from the comparison made between the estimated CBR values obtained from the new equation (6.1), the one suggested by TRRL [21], and the correlations developed in our country it is noted that the estimated CBR values using the newly developed equation and the one developed by TRRL [21] and Araya, Alemgena A., and Gebremariam G Felek [4] have relatively better resemblance and estimating CBR values closer to the laboratory values; whereas, the other gives a bit far results due to the fact that it is developed for fine grained soils.

3. It should be noted that the correlation equation is developed for a specific soil type soil encountered in the case-project (A-2-4 and A-2-6 soils according to AASHTO soil classification system); thus, care should be taken in using the correlations as most of the correlations are site and condition specific and their use for other soils requires careful examination and engineering decision.
4. For the A-2-4 and A-2-6 soils (according to AASHTO soil classification system), the above correlation equation (6.1) might be used for preliminary design purpose if the predicted CBR value is within the range of 4% to 48%.

6.2 Recommendations

1. The correlation developed in this study is applicable for locally available subgrade soils. It is recommended that further studies need to be made in different parts of the country and see the relationship for different types of soils. With a strong data base, such correlation equations can be used to facilitate quick evaluation of road subgrades based on simple and cheaper in-situ DCP tests.

2. Further studies need to be carried out on pavement materials too.

3. The DCP– CBR relation proposed in this study was developed by conducting a limited number of field and laboratory tests only on a selected case-project (Beredimtu – Imi – Gode road project). Hence, it is recommended that its applicability for soils of similar nature in other part of the country.

References

[1] AASHTO. 1988. *Manual on Subsurface Investigation; Americal Association of State Highway Transportation Officials.*

[2] AASHTO. 2003. *T 193-99.* AASHTO.

[3] Amini, Farshad. 2003. *POTENTIAL APPLICATIONS OF DYNAMIC AND STATIC CONE PENETROMETERS IN MDOT PAVEMENT DESIGN AND CONSTRUCTION.* Jackson, Mississippi: Jackson State University.

[4] Araya, Alemgena A., and Gebremariam G Feleke. 2016. "PREDICTION OF CBR USING DCP FOR LOCAL SUBGRADE MATERIALS." Mekelle.

[5] Desalegn, Yitagesu. 2012. *DEVELOPING CORRELATION BETWEEN DCP AND CBR FOR LOCALLY USED SUBGRADE MATERIALS.* Civil Engineering, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia: Addis Ababa University.

[6] Ferede, Zelalem Worku. 2010. *PREDICTION OF CALIFORNIA BEARING RATIO (CBR) VALUE FROM INDEX PROPERTIES OF SOIL.* Addis Ababa: Addis Ababa University.

[7] Harison, J. A. 1987. *CORRELATION BETWEEN CALIFORNIA BEARING RATION AND DYNAMIC CONE PENETROMETER STRENGTH MEASUREMENT OF SOILS.* London: Institute of Civil Engineers Proceedings.

[8] K. P., George, and Uddin Waheed. 2000. *SUBGRADE CHARACTERIZATION FOR HIGHWAY PAVEMENT DESIGN.* THE UNIVERSITY OF MISSISSIPPI.

[9] Livneh, M. 1987. "The Use of Dynamic Cone Penetrometer in Determining the Strength of Existing Pavements and Subgrade." *9th Southeast Asia Geotechnical Conference.* Bangkok, Thailand.

[10] Livneh, Moshe, Ilan Ishai, and Noam A Livneh. 1994. "Effect of Vertical Confinement on Dynamic Cone Penetrometer Strength Values in Pavement and Subgrade Evaluations, Transportation Research Record."

[11] Nikolaides, Athanassios. 2015. *Highway Engineering: Pavements, Materials and Control of Quality.* Boca Raton, Florida: CRC Press.

[12] Pam Hazelton and Brian Murphy. 2007. *Interpreting Soil Test Results*. NSW Natural Resources, University of Technology Sydney, Australia: CSIRO Publishing.

[13] Plessis, P Paige Green and L Du. 2009. *THE USE AND INTERPRETATION OF THE DYNAMIC CONE PENETROMETER (DCP) TEST.* Pretoria: CSIR Build Environment.

[14] Rodrigo Salgado, Sungmin Yoon. 2003. *Dynamic Cone Penetration Test (DCPT) for Subgrade Assessment.* School of Civil Engineering, Purdue University, West Lafayette, Indiana: Purdue University.

[15] Saha, Nayan. 2008. *EVALUATION OF SUBGRADE STRENGTH AND FLEXIBLE PAVEMENT DESIGN FOR RELIABILITY.* The University of New Mexico, Albuquerque, New Mexico: The University of New Mexico.

[16] Smith, R B, and D N Pratt. 1983. *A FIELD STUDY OF IN SITU CALIFORNIA BEARING RATIO AND DYNAMIC CONE PENETROMETER TESTING FOR ROAD SUBGRADE INVESTIGATIONS.* Australian Road Research Board.

[17] Steve L, Webster, Gardu Richard H., and Williams Thomsa P. 1992. "DESCRIPTION AND APPLICATION OF DUAL MASS DYNAMIC CONE PENETROMETER."

[18] T.Al-Refeai, A-Al-Suhaibani. 1996. *Prediction of CBR Using Dynamic Cone Penetrometer.* Sauid Arabia: King Saud University.

[19] Thom, Nick. 2014. *Principles of Pavement Engineering.* Nottingham, UK: ICE Publishing.

[20] Thomas, R. Burnham, P.E. 1997. *APPLICATION OF THE DYNAMIC CONE PENETROMETER TO MINESOTA DEPARTMENT OF TRANSPORTATION PAVEMENT ASSESSMENT PROCEDURES.* Minnesota Department of Transportation.

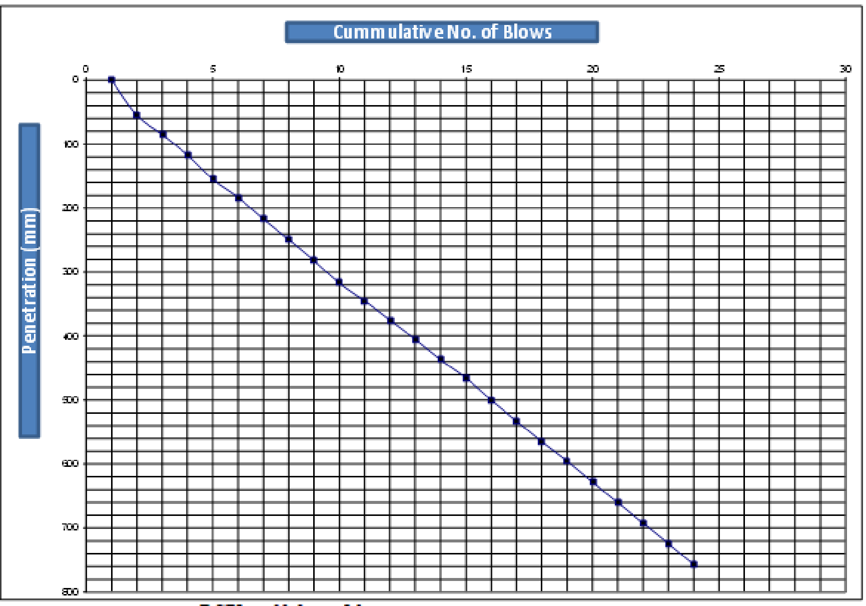
[21] TRRL. 1990. *Overseas Road Note 8: A USER MANUAL FOR A PROGRAM TO ANALYSE DYNAMIC CONE PENETROMETER DATA.* Crowthrone, Berkshire RG11 6AU England.

[22] Wu, S., and S Sargand. 2007. "USE OF DYNAMIC CONE PENETROMETER IN SUBGRADE AND BASE ACCEPTANCE."

Appendices

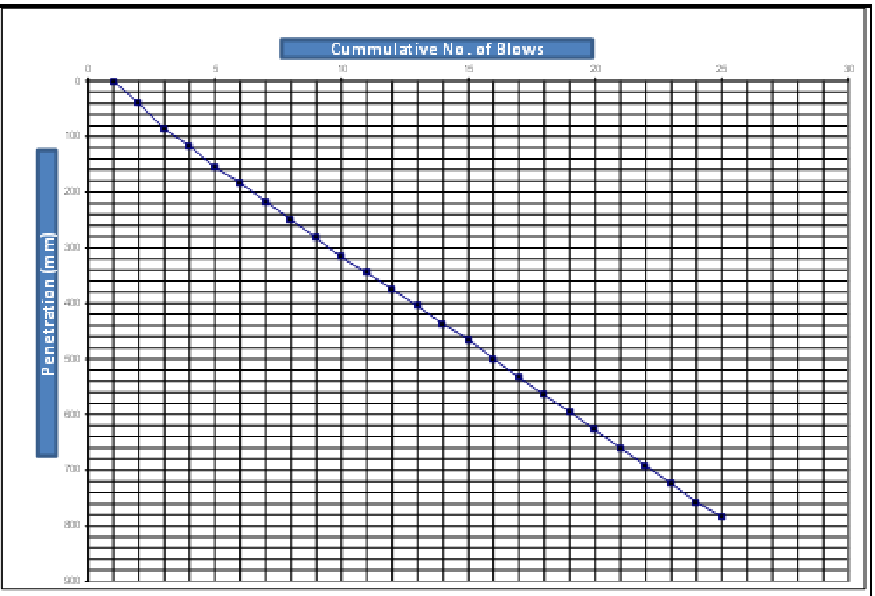
Appendix 1: Plots of DCP versus Cumulative number of blows

Test ID: TR_01				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	250	55	55
1	2	280	85	30
1	3	312	117	32
1	4	350	155	38
1	5	378	183	28
1	6	412	217	34
1	7	444	249	32
1	8	477	282	33
1	9	512	317	35
1	10	540	345	28
1	11	570	375	30
1	12	600	405	30
1	13	632	437	32
1	14	660	465	28
1	15	695	500	35
1	16	728	533	33
1	17	760	565	32
1	18	790	595	30
1	19	823	628	33
1	20	855	660	32
1	21	887	692	32
1	22	919	724	32
1	23	952	757	33



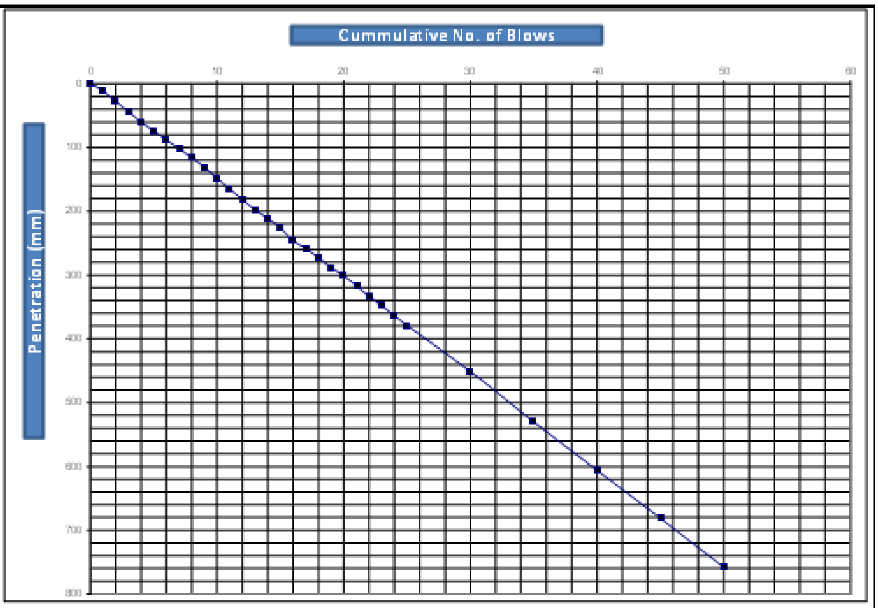
DCPI = 32.9 mm/blow

Test ID: TR_02				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	235	40	40
1	2	280	85	45
1	3	312	117	32
1	4	350	155	38
1	5	378	183	28
1	6	412	217	34
1	7	444	249	32
1	8	477	282	33
1	9	512	317	35
1	10	540	345	28
1	11	570	375	30
1	12	600	405	30
1	13	632	437	32
1	14	660	465	28
1	15	695	500	35
1	16	728	533	33
1	17	760	565	32
1	18	790	595	30
1	19	823	628	33
1	20	855	660	32
1	21	887	692	32
1	22	919	724	32
1	23	952	757	33
1	24	978	783	26



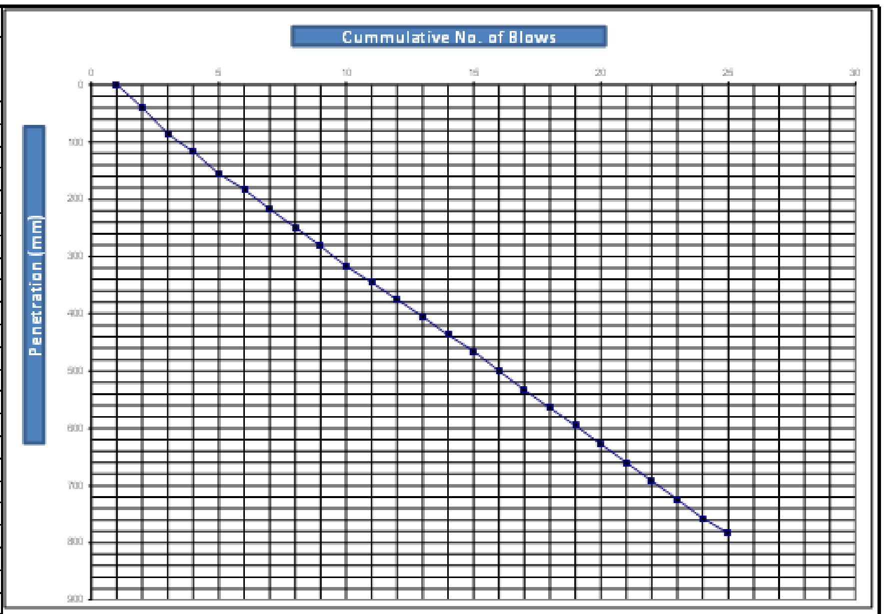
DCPI = 32.3 mm/blow

Test ID: TR_03				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	199	0	
1	1	210	11	11.0
1	2	227	28	17.0
1	3	243	44	16.0
1	4	259	60	16.0
1	5	273	74	14.0
1	6	287	88	14.0
1	7	301	102	14.0
1	8	315	116	14.0
1	9	330	131	15.0
1	10	347	148	17.0
1	11	364	165	17.0
1	12	381	182	17.0
1	13	397	198	16.0
1	14	410	211	13.0
1	15	425	226	15.0
1	16	445	246	20.0
1	17	457	258	12.0
1	18	472	273	15.0
1	19	487	288	15.0
1	20	500	301	13.0
1	21	516	317	16.0
1	22	532	333	16.0
1	23	547	348	15.0
1	24	562	363	15.0
1	25	578	379	16.0
5	30	650	451	14.4
5	35	729	530	15.8
5	40	805	606	15.2
5	45	880	681	15.0
5	50	957	758	15.4



DCPI = 12.9 mm/blow

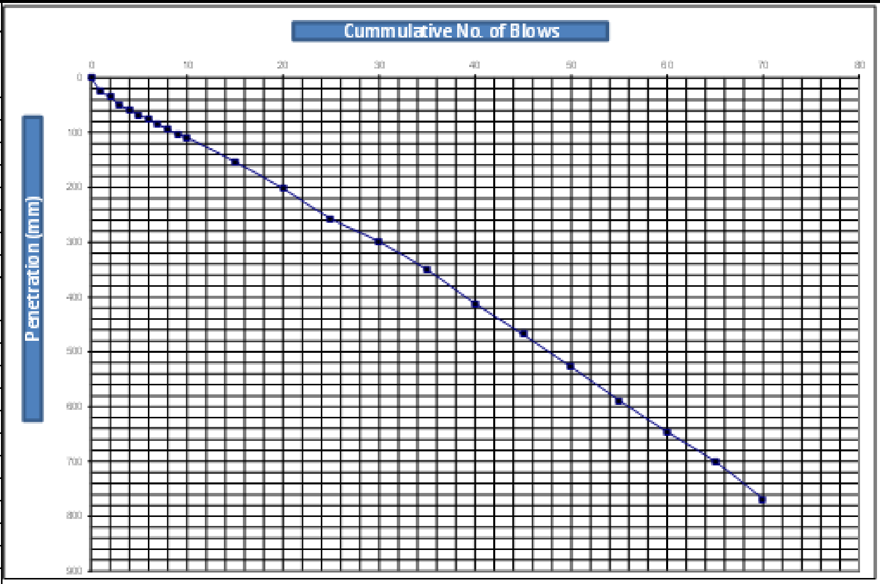
Test ID: TR_04				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	1	195	0	
1	2	235	40	40
1	3	280	85	45
1	4	312	117	32
1	5	350	155	38
1	6	378	183	28
1	7	412	217	34
1	8	444	249	32
1	9	477	282	33
1	10	512	317	35
1	11	540	345	28
1	12	570	375	30
1	13	600	405	30
1	14	632	437	32
1	15	660	465	28
1	16	695	500	35
1	17	728	533	33
1	18	760	565	32
1	19	790	595	30
1	20	823	628	33
1	21	855	660	32
1	22	887	692	32
1	23	919	724	32
1	24	952	757	33
1	25	978	783	26



DCPI = 34.5 mm/blow

Test ID: TR_05

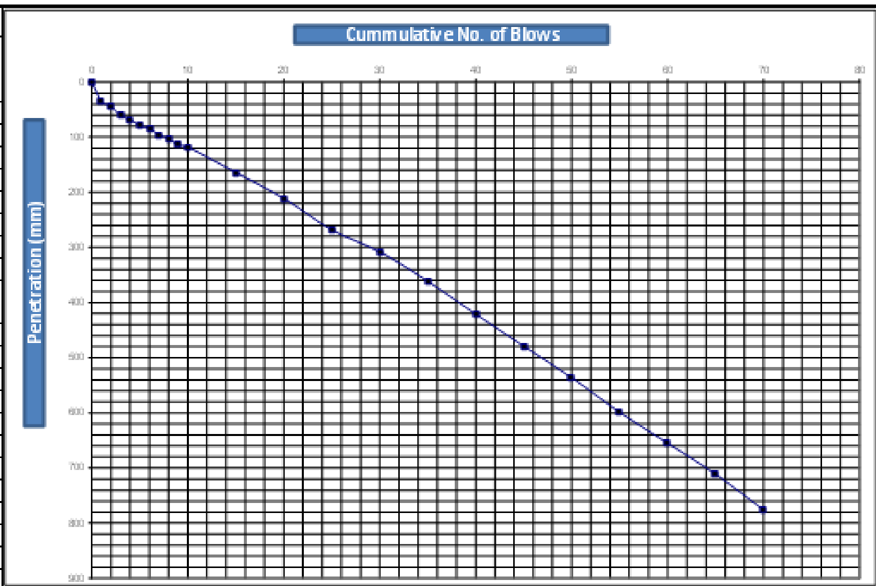
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	221	24	24
1	2	232	35	11
1	3	247	50	15
1	4	256	59	9
1	5	265	68	9
1	6	272	75	7
1	7	282	85	10
1	8	291	94	9
1	9	300	103	9
1	10	306	109	6
5	15	350	153	8.8
5	20	399	202	9.8
5	25	454	257	11
5	30	496	299	8.4
5	35	547	350	10.2
5	40	609	412	12.4
5	45	665	468	11.2
5	50	724	527	11.8
5	55	785	588	12.2
5	60	843	646	11.6
5	65	897	700	10.8
5	70	965	768	13.6



DCPI = 10.0 mm/blow

Test ID: TR_06

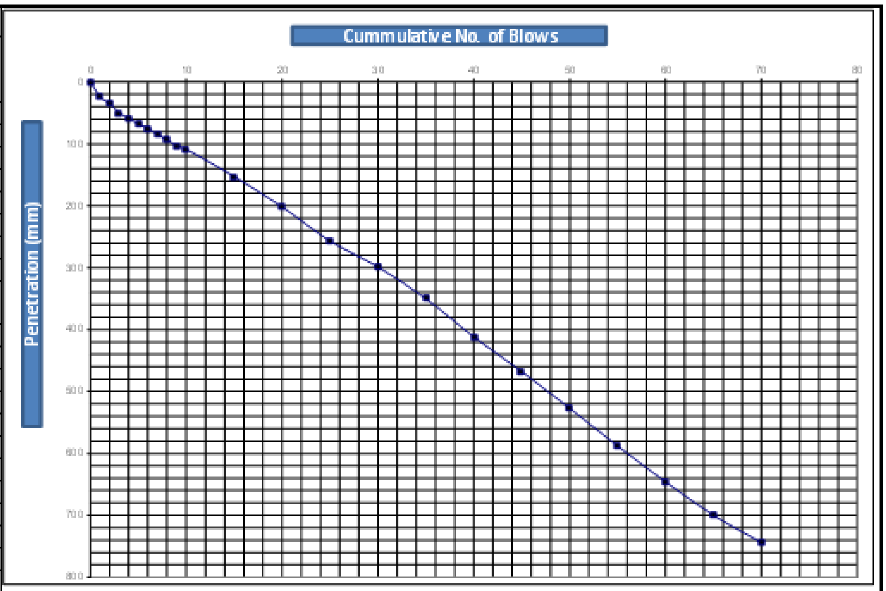
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	196	0	
1	1	231	35	35.0
1	2	240	44	9.0
1	3	257	61	17.0
1	4	264	68	7.0
1	5	275	79	11.0
1	6	280	84	5.0
1	7	292	96	12.0
1	8	299	103	7.0
1	9	310	114	11.0
1	10	314	118	4.0
5	15	360	164	9.2
5	20	407	211	9.4
5	25	464	268	11.4
5	30	504	308	8.0
5	35	557	361	10.6
5	40	617	421	12.0
5	45	675	479	11.6
5	50	732	536	11.4
5	55	795	599	12.6
5	60	851	655	11.2
5	65	907	711	11.2
5	70	972	776	13.0



DCPI = 9.1 mm/blow

Test ID: TR_07

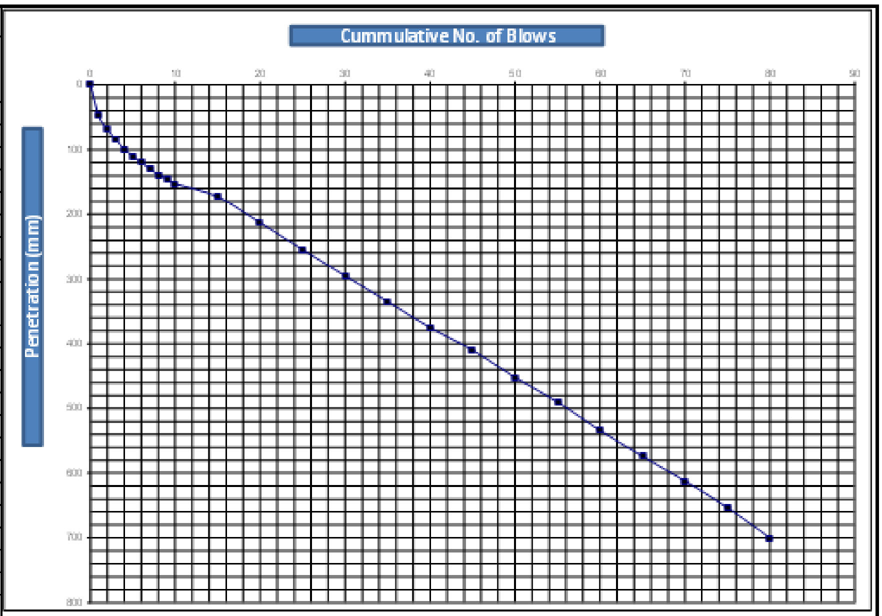
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	200	0	
1	1	224	24	24
1	2	235	35	11
1	3	250	50	15
1	4	259	59	9
1	5	268	68	9
1	6	275	75	7
1	7	285	85	10
1	8	294	94	9
1	9	303	103	9
1	10	309	109	6
5	15	353	153	8.8
5	20	402	202	9.8
5	25	457	257	11
5	30	499	299	8.4
5	35	550	350	10.2
5	40	612	412	12.4
5	45	668	468	11.2
5	50	727	527	11.8
5	55	788	588	12.2
5	60	846	646	11.6
5	65	900	700	10.8
5	70	944	744	8.8



DCPI = 10.6 mm/blow

Test ID: TR_08

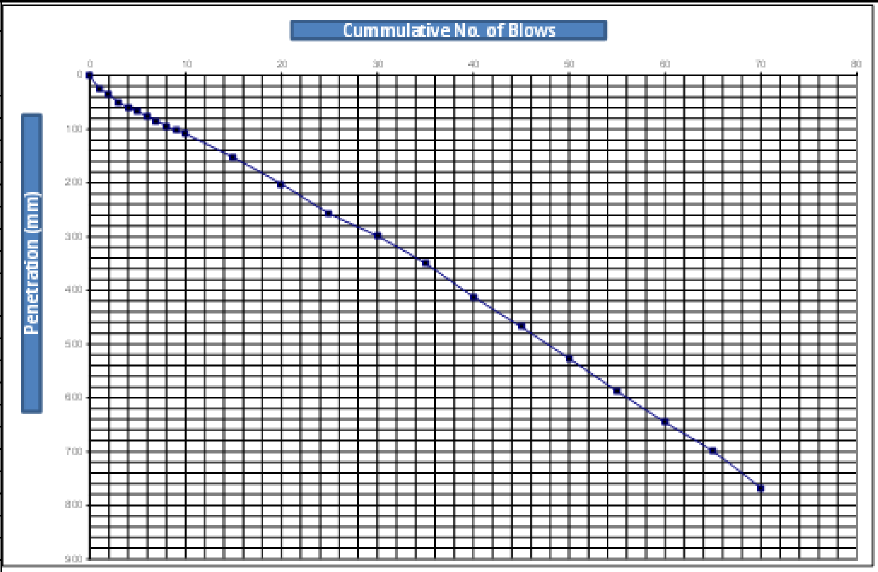
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	198	0	
1	1	246	48	48
1	2	267	69	21
1	3	283	85	16
1	4	297	99	14
1	5	308	110	11
1	6	318	120	10
1	7	328	130	10
1	8	337	139	9
1	9	343	145	6
1	10	351	153	8
5	15	371	173	4
5	20	411	213	8
5	25	453	255	8.4
5	30	493	295	8
5	35	533	335	8
5	40	573	375	8
5	45	608	410	7
5	50	650	452	8.4
5	55	688	490	7.6
5	60	732	534	8.8
5	65	772	574	8
5	70	810	612	7.6
5	75	851	653	8.2
5	80	898	700	9.4



DCPI = 16.1 mm/blow
DCPI = 7.8 mm/blow

Test ID: TR_09

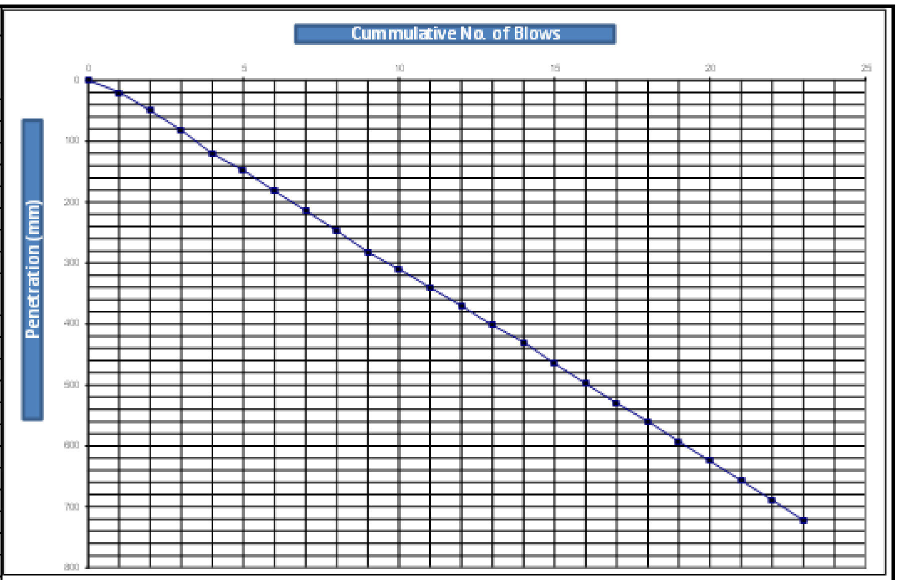
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	219	24	24
1	2	230	35	11
1	3	245	50	15
1	4	254	59	9
1	5	263	68	9
1	6	270	75	7
1	7	280	85	10
1	8	289	94	9
1	9	298	103	9
1	10	304	109	6
5	15	348	153	8.8
5	20	397	202	9.8
5	25	452	257	11
5	30	494	299	8.4
5	35	545	350	10.2
5	40	607	412	12.4
5	45	663	468	11.2
5	50	722	527	11.8
5	55	783	588	12.2
5	60	841	646	11.6
5	65	895	700	10.8
5	70	963	768	13.6



DCPI = 11.0 mm/blow

Test ID: TR_10

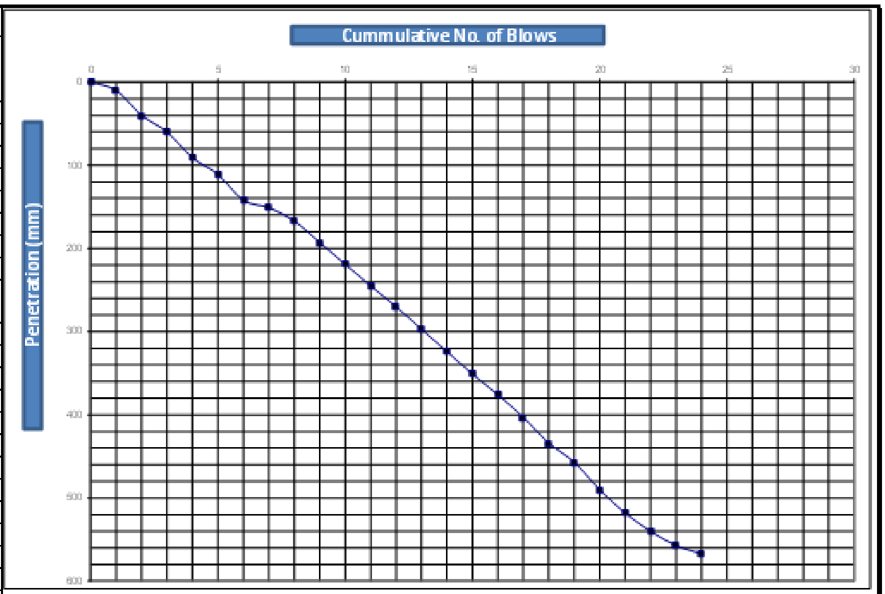
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	217	20	20
1	2	247	50	30
1	3	279	82	32
1	4	317	120	38
1	5	345	148	28
1	6	379	182	34
1	7	411	214	32
1	8	444	247	33
1	9	479	282	35
1	10	507	310	28
1	11	537	340	30
1	12	567	370	30
1	13	599	402	32
1	14	627	430	28
1	15	662	465	35
1	16	695	498	33
1	17	727	530	32
1	18	757	560	30
1	19	790	593	33
1	20	822	625	32
1	21	854	657	32
1	22	886	689	32
1	23	919	722	33



DCPI = 31.4 mm/blow

Test ID: TR_11

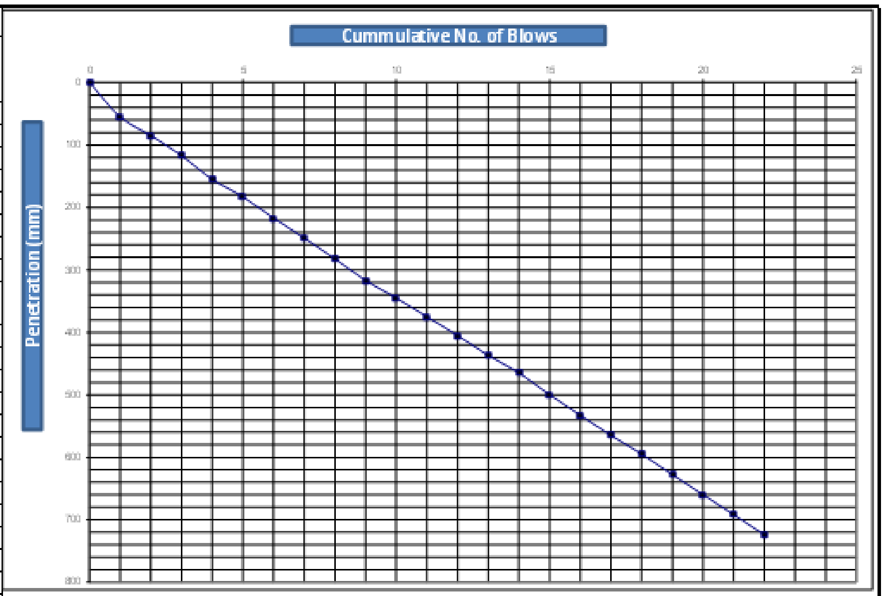
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	205	10	10
1	2	235	40	30
1	3	255	60	20
1	4	286	91	31
1	5	306	111	20
1	6	337	142	31
1	7	346	151	9
1	8	362	167	16
1	9	388	193	26
1	10	414	219	26
1	11	440	245	26
1	12	465	270	25
1	13	492	297	27
1	14	519	324	27
1	15	546	351	27
1	16	571	376	25
1	17	598	403	27
1	18	629	434	31
1	19	652	457	23
1	20	685	490	33
1	21	713	518	28
1	22	735	540	22
1	23	752	557	17
1	24	762	567	10



DCPI = 23.6 mm/blow

Test ID: TR_12

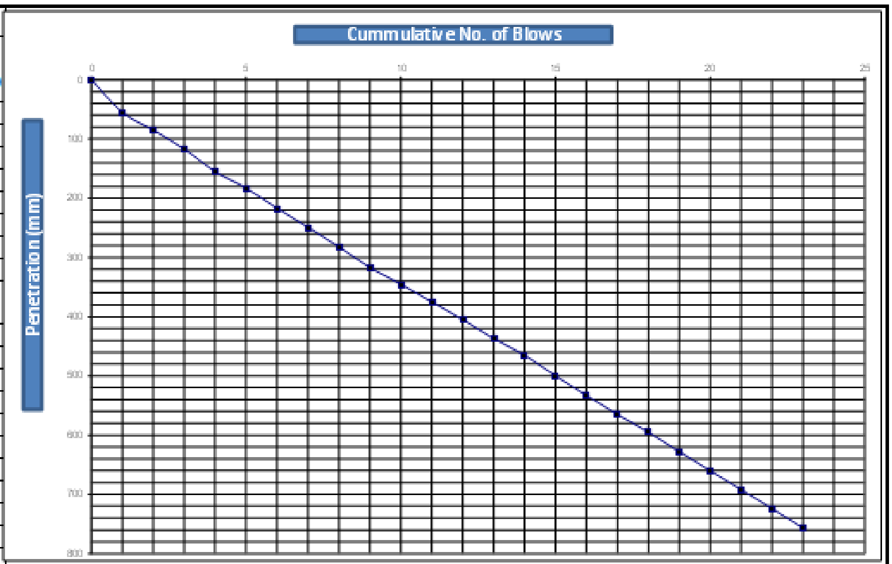
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	250	55	55
1	2	280	85	30
1	3	312	117	32
1	4	350	155	38
1	5	378	183	28
1	6	412	217	34
1	7	444	249	32
1	8	477	282	33
1	9	512	317	35
1	10	540	345	28
1	11	570	375	30
1	12	600	405	30
1	13	632	437	32
1	14	660	465	28
1	15	695	500	35
1	16	728	533	33
1	17	760	565	32
1	18	790	595	30
1	19	823	628	33
1	20	855	660	32
1	21	887	692	32
1	22	919	724	32
1	23	952	757	33



DCPI = 32.9 mm/blow

Test ID: TR_13

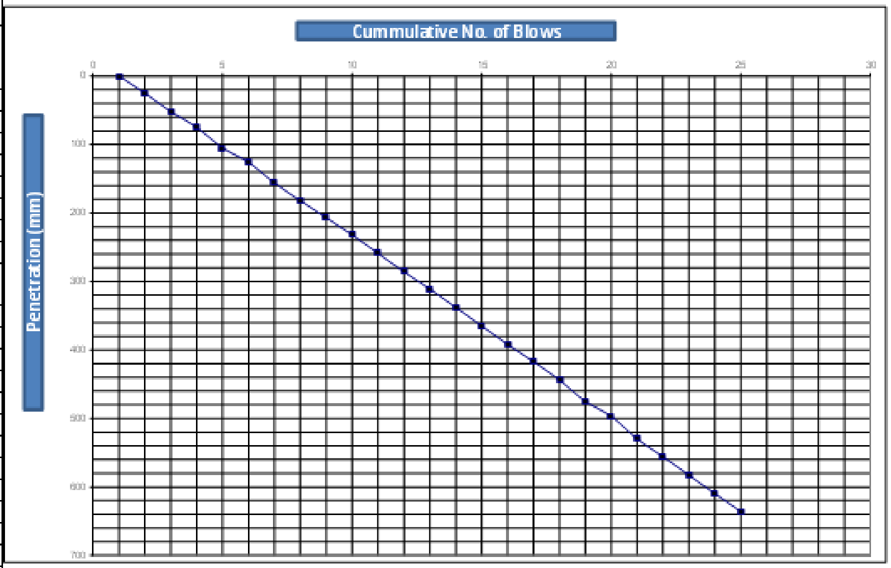
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	250	55	55
1	2	280	85	30
1	3	312	117	32
1	4	350	155	38
1	5	378	183	28
1	6	412	217	34
1	7	444	249	32
1	8	477	282	33
1	9	512	317	35
1	10	540	345	28
1	11	570	375	30
1	12	600	405	30
1	13	632	437	32
1	14	660	465	28
1	15	695	500	35
1	16	728	533	33
1	17	760	565	32
1	18	790	595	30
1	19	823	628	33
1	20	855	660	32
1	21	887	692	32
1	22	919	724	32
1	23	952	757	33



DCPI = 27.7 mm/blow

Test ID: TR_14

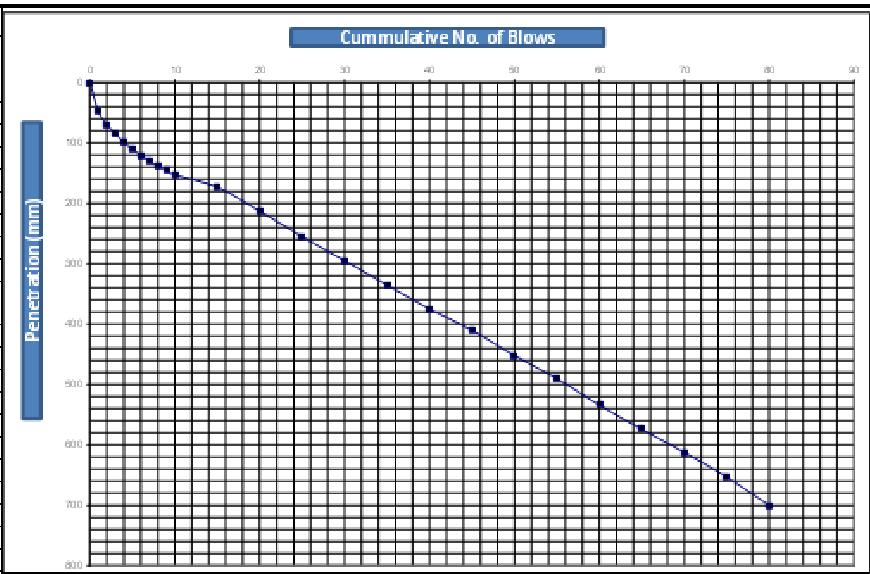
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	220	25	25
1	2	247	52	27
1	3	270	75	23
1	4	300	105	30
1	5	321	126	21
1	6	351	156	30
1	7	377	182	26
1	8	402	207	25
1	9	427	232	25
1	10	454	259	27
1	11	481	286	27
1	12	506	311	25
1	13	533	338	27
1	14	560	365	27
1	15	587	392	27
1	16	612	417	25
1	17	639	444	27
1	18	670	475	31
1	19	692	497	22
1	20	725	530	33
1	21	751	556	26
1	22	778	583	27
1	23	805	610	27
1	24	831	636	26



DCPI = 26.5 mm/blow

Test ID: TR_15

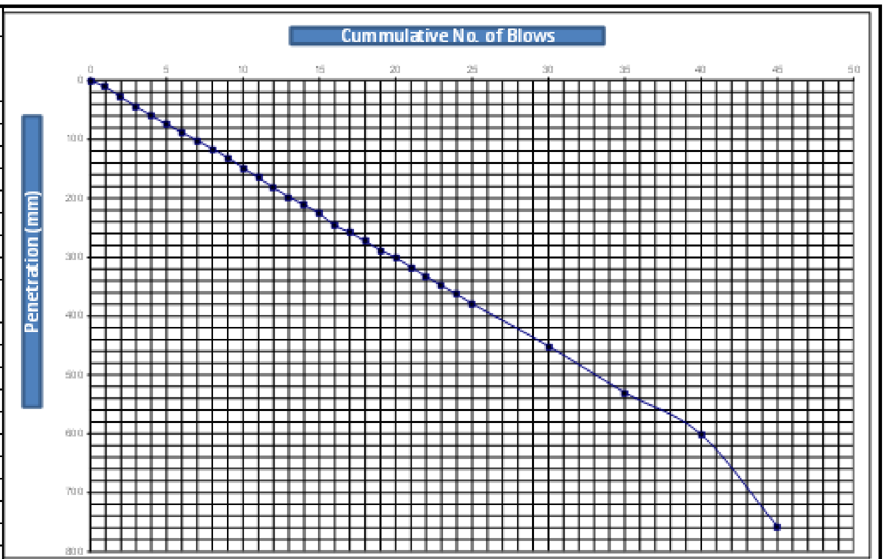
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	198	0	
1	1	246	48	48
1	2	267	69	21
1	3	283	85	16
1	4	297	99	14
1	5	308	110	11
1	6	318	120	10
1	7	328	130	10
1	8	337	139	9
1	9	343	145	6
1	10	351	153	8
5	15	371	173	4
5	20	411	213	8
5	25	453	255	8.4
5	30	493	295	8
5	35	533	335	8
5	40	573	375	8
5	45	608	410	7
5	50	650	452	8.4
5	55	688	490	7.6
5	60	732	534	8.8
5	65	772	574	8
5	70	810	612	7.6
5	75	851	653	8.2
5	80	898	700	9.4



DCPI = 16.1 mm/blow (Upper Layer)
DCPI = 7.8 mm/blow (Lower Layer)

Test ID: TR_16

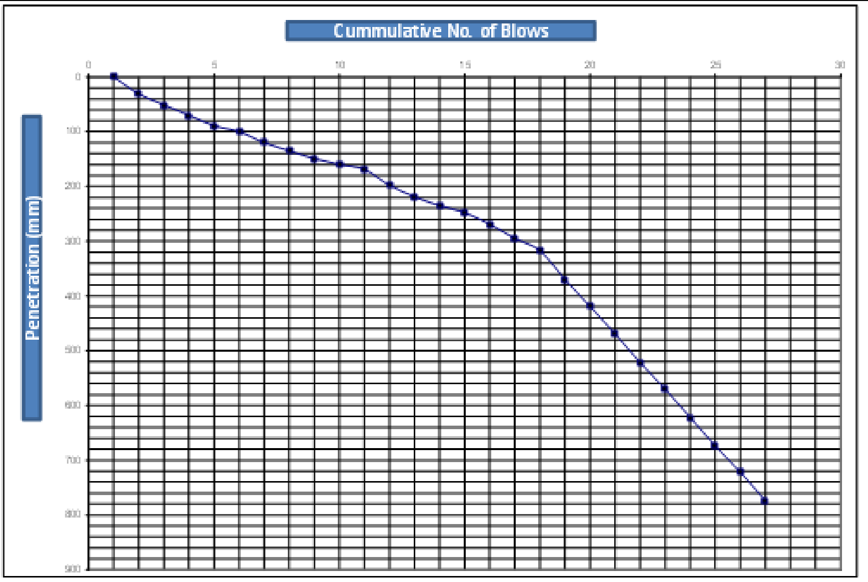
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	199	0	
1	1	210	11	11
1	2	227	28	17
1	3	243	44	16
1	4	259	60	16
1	5	273	74	14
1	6	287	88	14
1	7	301	102	14
1	8	315	116	14
1	9	330	131	15
1	10	347	148	17
1	11	364	165	17
1	12	381	182	17
1	13	397	198	16
1	14	410	211	13
1	15	425	226	15
1	16	445	246	20
1	17	457	258	12
1	18	472	273	15
1	19	487	288	15
1	20	500	301	13
1	21	516	317	16
1	22	532	333	16
1	23	547	348	15
1	24	562	363	15
1	25	578	379	16
5	30	650	451	14
5	35	729	530	16
5	40	800	601	14
5	45	957	758	31



DCPI = 15.8 mm/blow

Test ID: TR_17

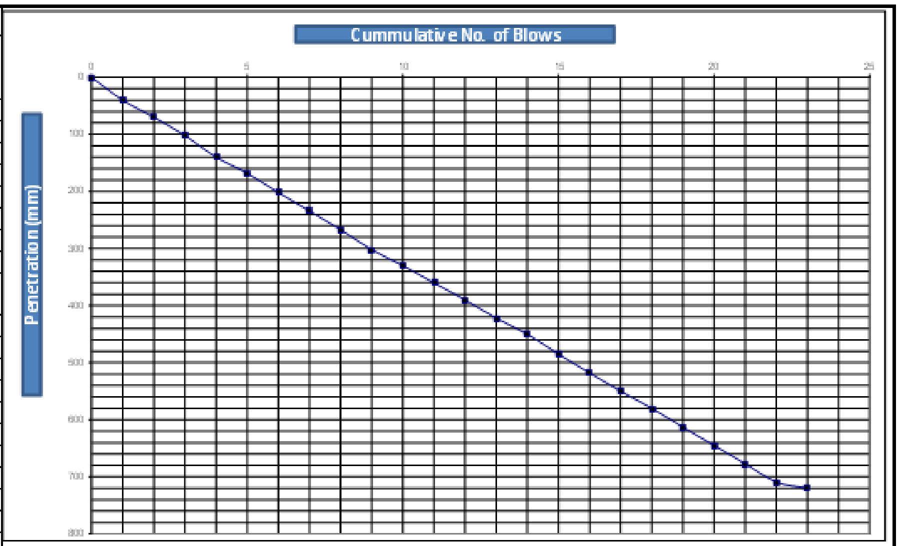
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	228	31	31
1	2	248	51	20
1	3	267	70	19
1	4	286	89	19
1	5	297	100	11
1	6	317	120	20
1	7	332	135	15
1	8	346	149	14
1	9	357	160	11
1	10	366	169	9
5	15	395	198	5.8
5	20	416	219	4.2
5	25	432	235	3.2
5	30	445	248	2.6
5	35	466	269	4.2
5	40	499	295	6.6
5	45	514	317	3
5	50	567	370	10.6
5	55	616	419	9.8
5	60	666	469	10
5	65	719	522	10.6
5	70	767	570	9.6
5	75	819	622	10.4
5	80	871	674	10.4
5	85	919	722	9.6
5	90	971	774	10.4



DCPI = 7.0 mm/blow (Upper Layer)
DCPI = 10.2 mm/blow (Lower Layer)

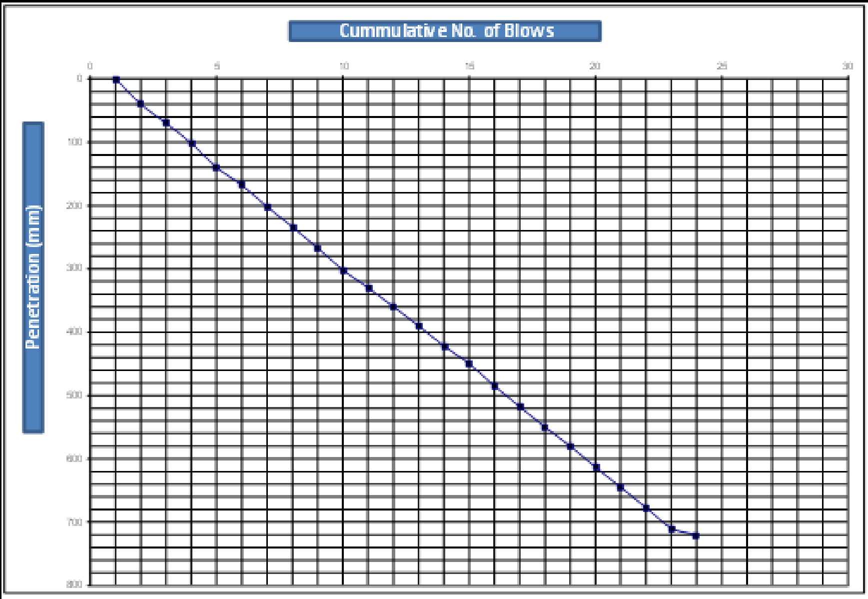
Test ID: TR_18

No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	210	0	
1	1	250	40	40
1	2	280	70	30
1	3	312	102	32
1	4	350	140	38
1	5	378	168	28
1	6	412	202	34
1	7	444	234	32
1	8	477	267	33
1	9	512	302	35
1	10	540	330	28
1	11	570	360	30
1	12	600	390	30
1	13	632	422	32
1	14	660	450	28
1	15	695	485	35
1	16	728	518	33
1	17	760	550	32
1	18	790	580	30
1	19	823	613	33
1	20	855	645	32
1	21	887	677	32
1	22	919	709	32
1	23	930	720	11



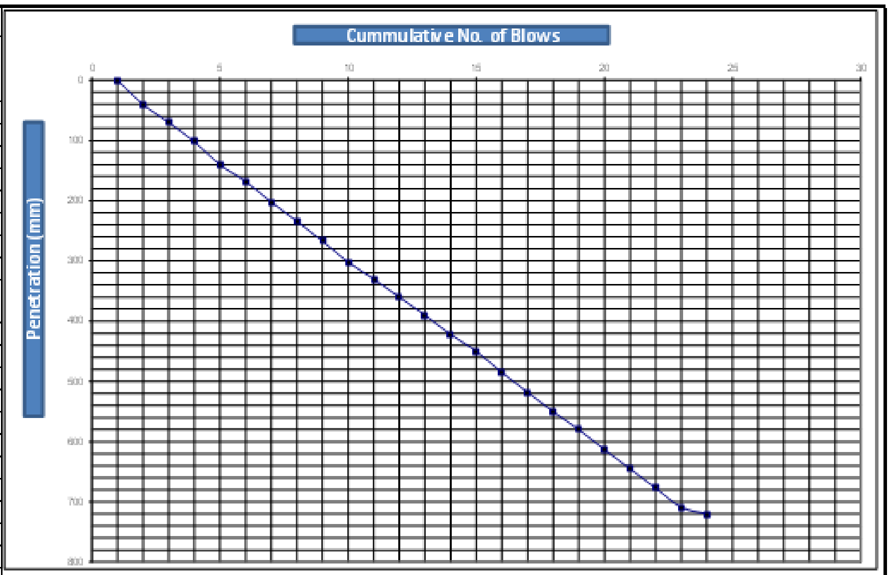
DCPI = 31.3 mm/blow

Test ID: TR_19				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	192	0	
1	1	232	40	40
1	2	262	70	30
1	3	294	102	32
1	4	332	140	38
1	5	360	168	28
1	6	394	202	34
1	7	426	234	32
1	8	459	267	33
1	9	494	302	35
1	10	522	330	28
1	11	552	360	30
1	12	582	390	30
1	13	614	422	32
1	14	642	450	28
1	15	677	485	35
1	16	710	518	33
1	17	742	550	32
1	18	772	580	30
1	19	805	613	33
1	20	837	645	32
1	21	869	677	32
1	22	901	709	32
1	23	912	720	11



DCPI = 30.0 mm/blow

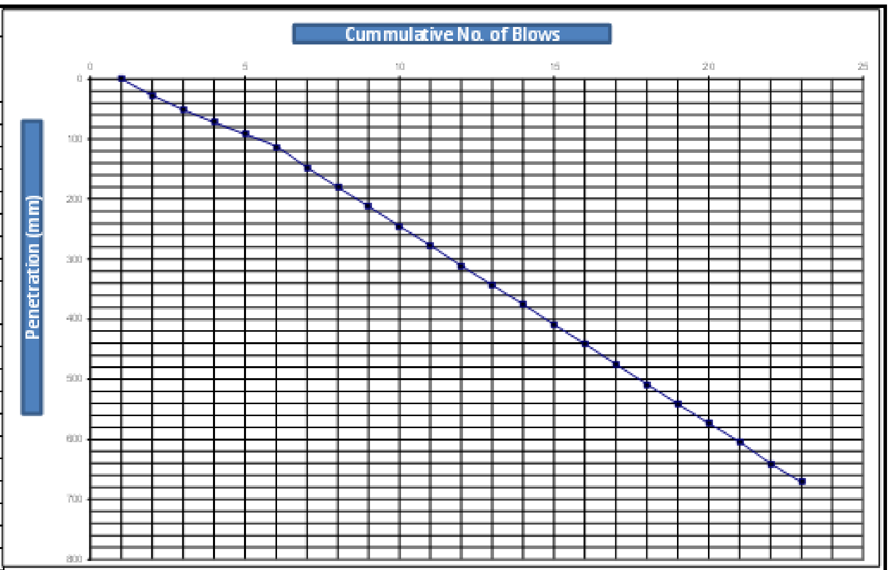
Test ID: TR_20				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	199	0	
1	1	239	40	40
1	2	269	70	30
1	3	301	102	32
1	4	339	140	38
1	5	367	168	28
1	6	401	202	34
1	7	433	234	32
1	8	466	267	33
1	9	501	302	35
1	10	529	330	28
1	11	559	360	30
1	12	589	390	30
1	13	621	422	32
1	14	649	450	28
1	15	684	485	35
1	16	717	518	33
1	17	749	550	32
1	18	779	580	30
1	19	812	613	33
1	20	844	645	32
1	21	876	677	32
1	22	908	709	32
1	23	919	720	11



DCPI = 32.7 mm/blow

Test ID: TR_21

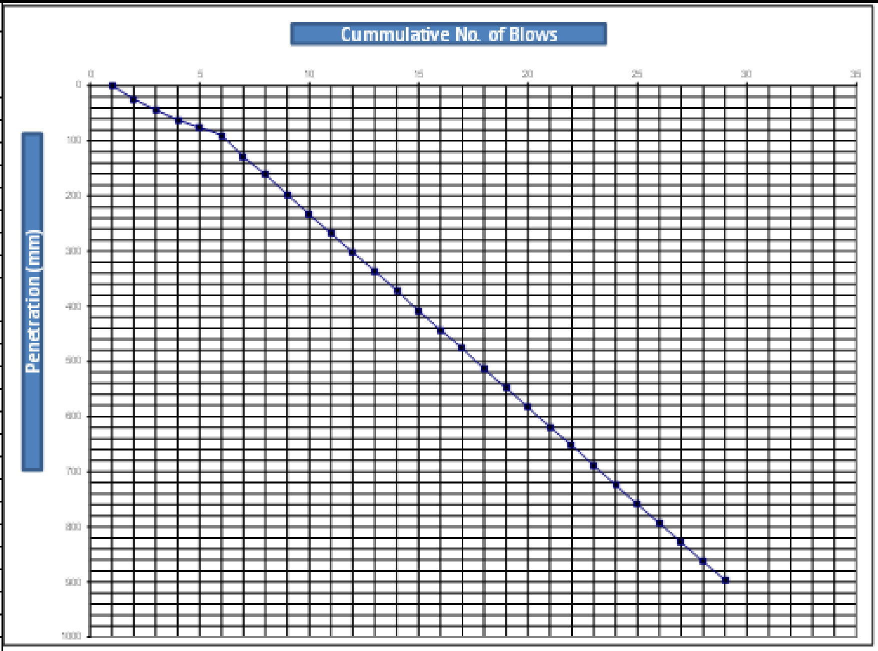
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	222	27	27
1	2	246	51	24
1	3	267	72	21
1	4	287	92	20
1	5	307	112	20
1	6	342	147	35
1	7	375	180	33
1	8	407	212	32
1	9	440	245	33
1	10	472	277	32
1	11	506	311	34
1	12	538	343	32
1	13	570	375	32
1	14	604	409	34
1	15	636	441	32
1	16	670	475	34
1	17	703	508	33
1	18	736	541	33
1	19	768	573	32
1	20	799	604	31
1	21	835	640	36
1	22	866	671	31



DCPI = 24.5 mm/blow
DCPI = 32.8 mm/blow

Test ID: TR_22

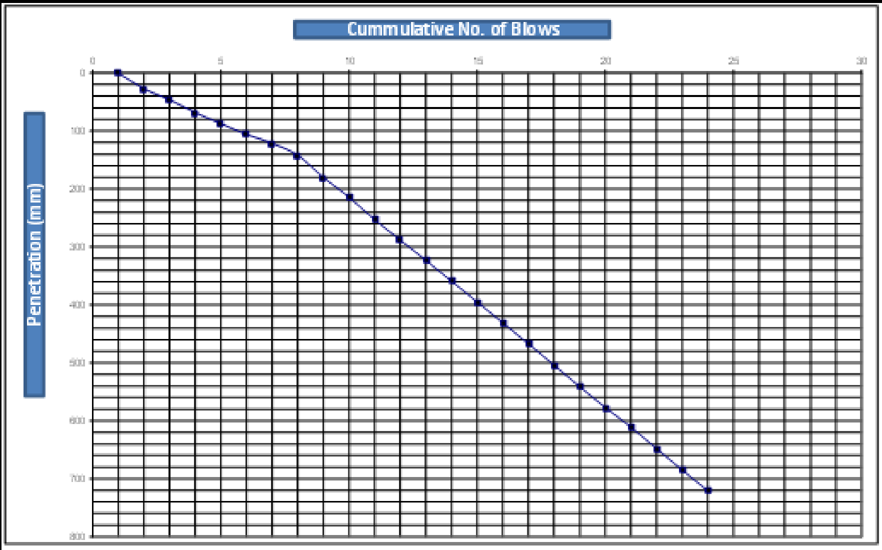
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	200	0	
1	1	224	24	24
1	2	244	44	20
1	3	262	62	18
1	4	276	76	14
1	5	291	91	15
1	6	329	129	38
1	7	361	161	32
1	8	397	197	36
1	9	433	233	36
1	10	468	268	35
1	11	502	302	34
1	12	536	336	34
1	13	571	371	35
1	14	608	408	37
1	15	643	443	35
1	16	676	476	33
1	17	714	514	38
1	18	748	548	34
1	19	783	583	35
1	20	819	619	36
1	21	852	652	33
1	22	888	688	36
1	23	924	724	36
1	24	959	759	35
1	25	993	793	34
1	26	1028	828	35
1	27	1063	863	35
1	28	1096	896	33



DCPI = 21.5 mm/blow (Upper Layer)
DCPI = 34.9 mm/blow (Lower Layer)

Test ID: TR_23

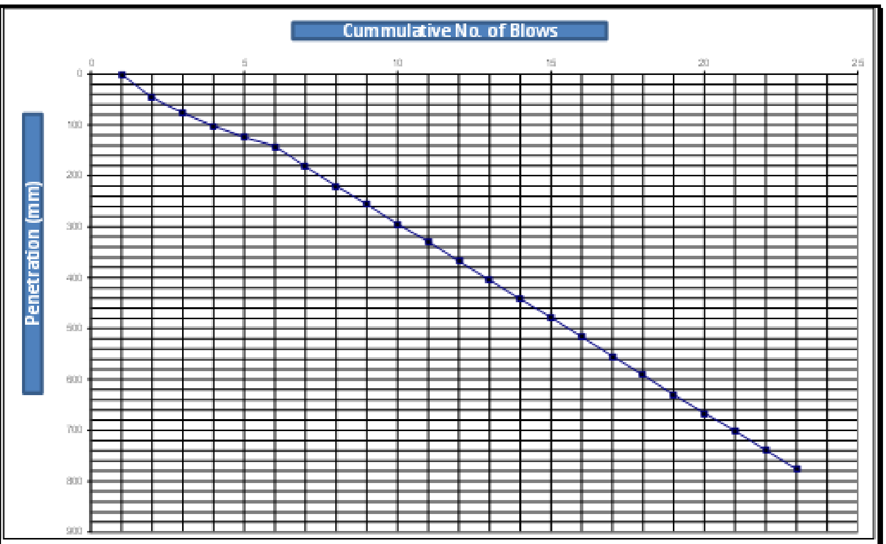
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	213	0	
1	1	240	27	27
1	2	259	46	19
1	3	281	68	22
1	4	300	87	19
1	5	319	106	19
1	6	334	121	15
1	7	355	142	21
1	8	393	180	38
1	9	427	214	34
1	10	466	253	39
1	11	501	288	35
1	12	536	323	35
1	13	572	359	36
1	14	608	395	36
1	15	644	431	36
1	16	680	467	36
1	17	717	504	37
1	18	754	541	37
1	19	790	577	36
1	20	824	611	34
1	21	861	648	37
1	22	898	685	37
1	23	934	721	36



DCPI = 20.3 mm/blow (Uppper Layer)
DCPI = 36.1 mm/blow (Lower Layer)

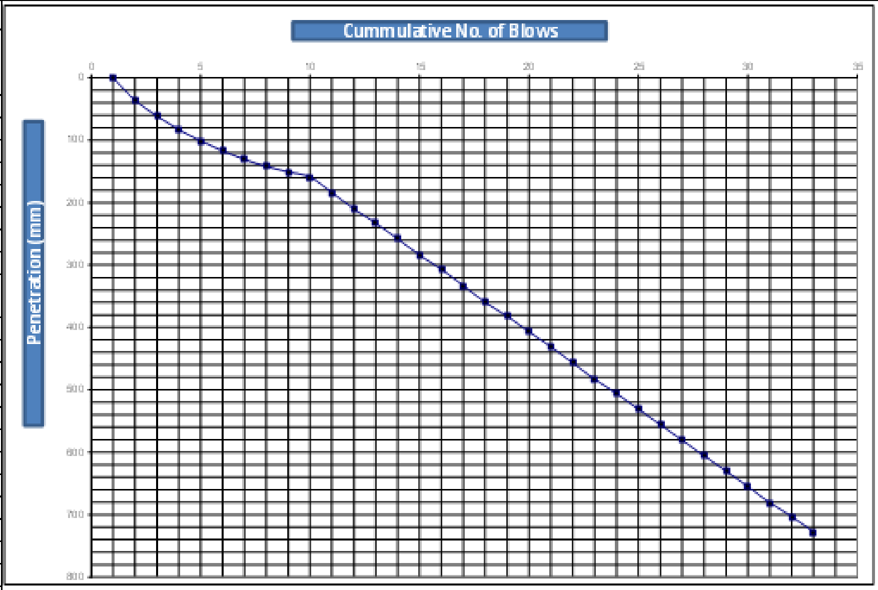
Test ID: TR_24

No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	193	0	
1	1	238	45	45
1	2	269	76	31
1	3	295	102	26
1	4	317	124	22
1	5	336	143	19
1	6	375	182	39
1	7	413	220	38
1	8	449	256	36
1	9	488	295	39
1	10	522	329	34
1	11	561	368	39
1	12	598	405	37
1	13	635	442	37
1	14	671	478	36
1	15	709	516	38
1	16	747	554	38
1	17	784	591	37
1	18	823	630	39
1	19	859	666	36
1	20	894	701	35
1	21	932	739	38
1	22	969	776	37



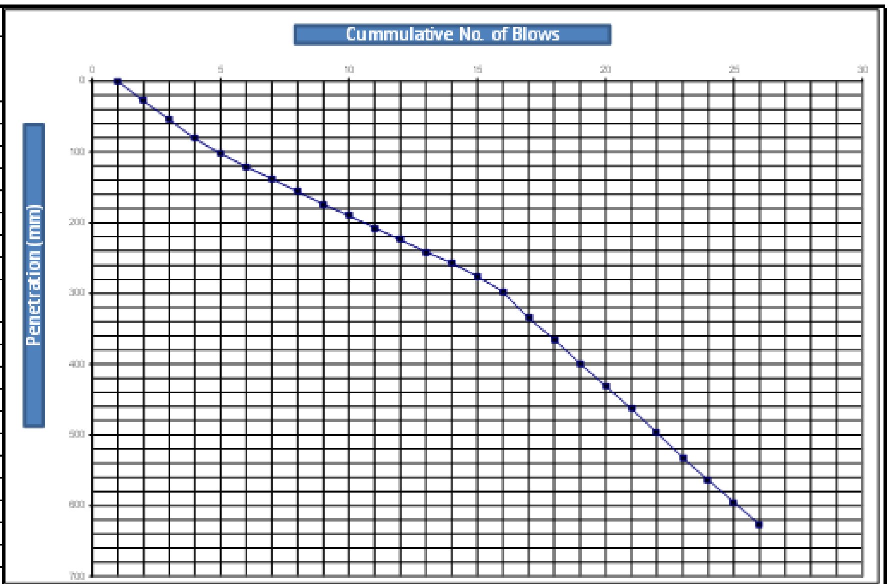
DCPI = 30.3 mm/blow (Upper Layer)
DCPI = 37.2 mm/blow (Lower Layer)

Test ID: TR_25				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	229	0	
1	1	265	36	36
1	2	290	61	25
1	3	312	83	22
1	4	330	101	18
1	5	346	117	16
1	6	360	131	14
1	7	371	142	11
1	8	380	151	9
1	9	388	159	8
1	10	413	184	25
1	11	439	210	26
1	12	462	233	23
1	13	487	258	25
1	14	513	284	26
1	15	536	307	23
1	16	562	333	26
1	17	589	360	27
1	18	611	382	22
1	19	636	407	25
1	20	660	431	24
1	21	686	457	26
1	22	712	483	26
1	23	735	506	23
1	24	760	531	25
1	25	785	556	25
1	26	810	581	25
1	27	835	606	25
1	28	859	630	24
1	29	884	655	25
1	30	910	681	26
1	31	932	703	22
1	32	957	728	25



DCPI = 18.4 mm/blow (Upper Layer)
DCPI = 24.7 mm/blow (Lower Layer)

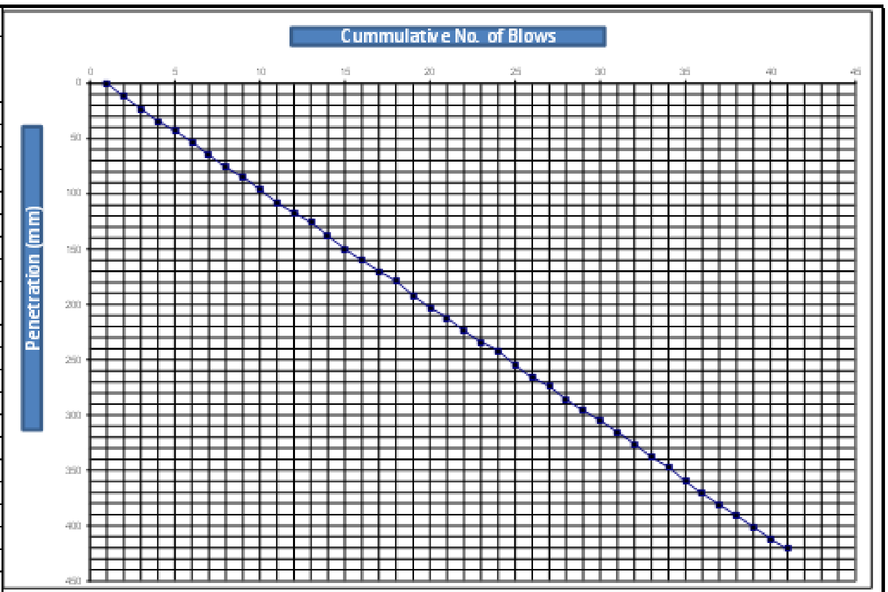
Test ID: TR_26				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	213	0	
1	1	241	28	28
1	2	267	54	26
1	3	294	81	27
1	4	315	102	21
1	5	334	121	19
1	6	351	138	17
1	7	369	156	18
1	8	387	174	18
1	9	403	190	16
1	10	420	207	17
1	11	437	224	17
1	12	454	241	17
1	13	470	257	16
1	14	489	276	19
1	15	512	299	23
1	16	548	335	36
1	17	578	365	30
1	18	612	399	34
1	19	644	431	32
1	20	676	463	32
1	21	710	497	34
1	22	745	532	35
1	23	777	564	32
1	24	808	595	31
1	25	840	627	32



DCPI = 19.9 mm/blow (Upper Layer)
DCPI = 32.9 mm/blow (Lower Layer)

Test ID: TR_27

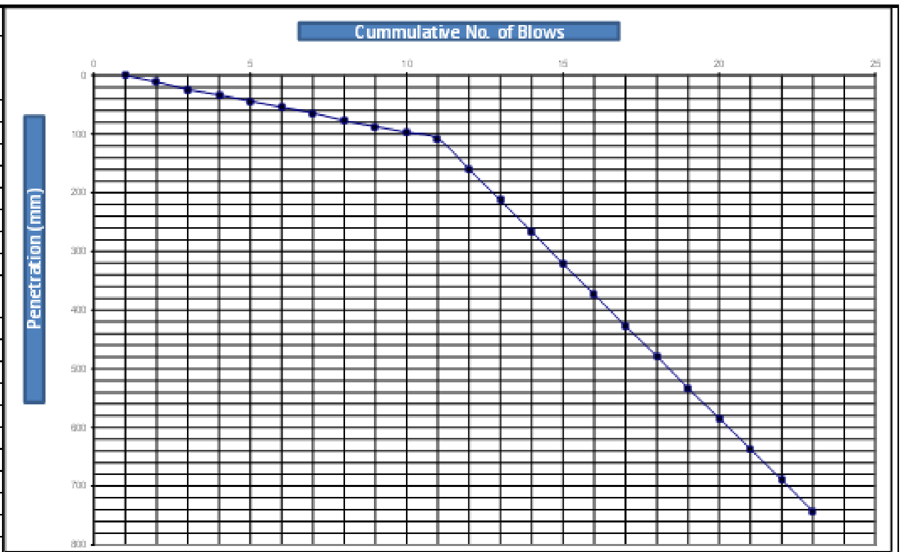
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	209	12	12
1	2	220	23	11
1	3	231	34	11
1	4	240	43	9
1	5	250	53	10
1	6	262	65	12
1	7	273	76	11
1	8	282	85	9
1	9	293	96	11
1	10	305	108	12
1	11	314	117	9
1	12	323	126	9
1	13	335	138	12
1	14	347	150	12
1	15	357	160	10
1	16	367	170	10
1	17	376	179	9
1	18	389	192	13
1	19	400	203	11
1	20	409	212	9
1	21	421	224	12
1	22	431	234	10
1	23	439	242	8
1	24	452	255	13
1	25	463	266	11
1	26	471	274	8
1	27	483	286	12
1	28	493	296	10
1	29	502	305	9
1	30	512	315	10
1	31	523	326	11
1	32	535	338	12
1	33	544	347	9
1	34	557	360	13
1	35	568	371	11
1	36	578	381	10
1	37	588	391	10
1	38	598	401	10
1	39	609	412	11
1	40	618	421	9



DCPI = 13.5 mm/blow

Test ID: TR_28

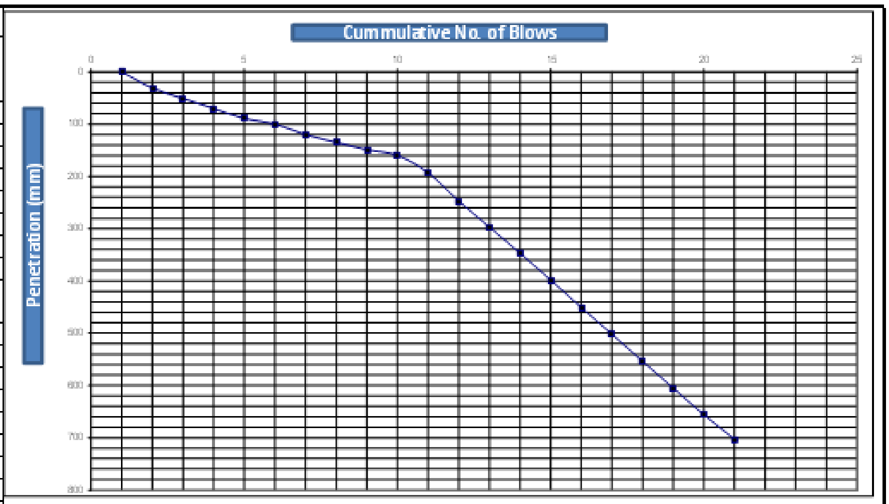
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	192	0	
1	1	203	11	11
1	2	216	24	13
1	3	225	33	9
1	4	236	44	11
1	5	246	54	10
1	6	256	64	10
1	7	269	77	13
1	8	279	87	10
1	9	289	97	10
1	10	300	108	11
5	15	352	160	10.4
5	20	405	213	10.6
5	25	458	266	10.6
5	30	513	321	11
5	35	565	373	10.4
5	40	619	427	10.8
5	45	670	478	10.2
5	50	725	533	11
5	55	776	584	10.2
5	60	829	637	10.6
5	65	881	689	10.4
5	70	935	743	10.8



DCPI = 10.8 mm/blow (Upper Layer)
DCPI = 14.6 mm/blow (Lower Layer)

Test ID: TR_29

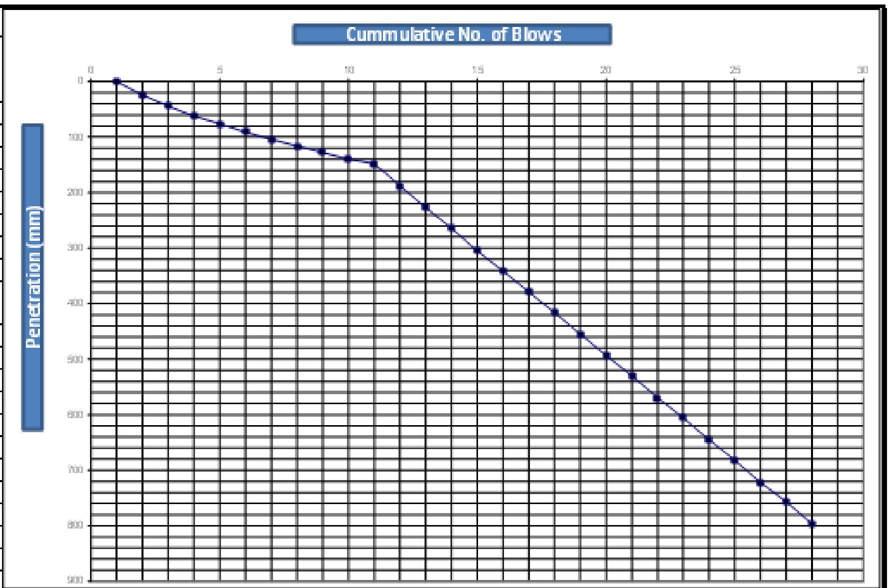
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	228	31	31
1	2	248	51	20
1	3	267	70	19
1	4	286	89	19
1	5	297	100	11
1	6	317	120	20
1	7	332	135	15
1	8	346	149	14
1	9	357	160	11
1	10	390	193	33
5	15	444	247	10.8
5	20	494	297	10
5	25	544	347	10
5	30	595	398	10.2
5	35	648	451	10.6
5	40	699	502	10.2
5	45	751	554	10.4
5	50	802	605	10.2
5	55	853	656	10.2
5	60	900	703	9.4



DCPI = 19.3 mm/blow (Upper Layer)
DCPI = 10.2 mm/blow (Lower Layer)

Test ID: TR_30

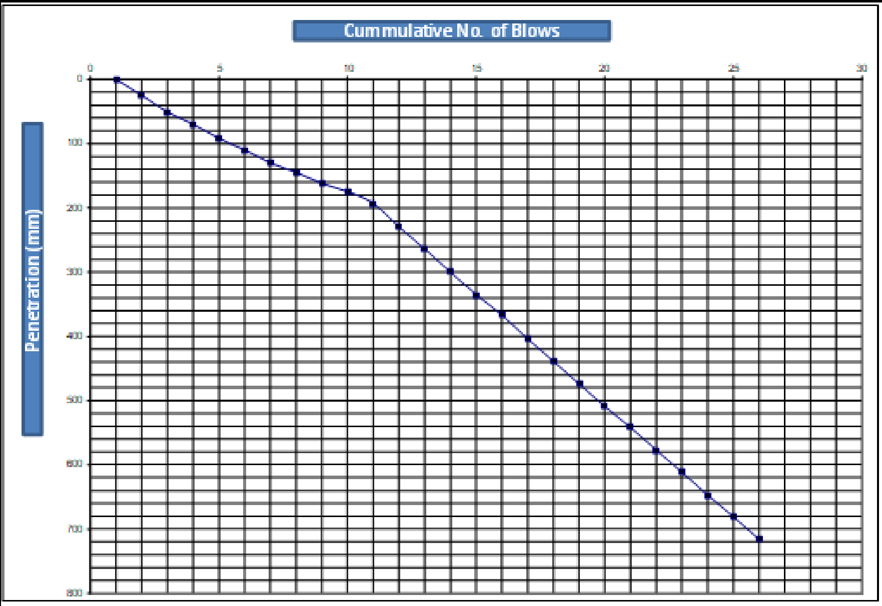
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	200	0	
1	1	224	24	24
1	2	244	44	20
1	3	262	62	18
1	4	276	76	14
1	5	291	91	15
1	6	304	104	13
1	7	316	116	12
1	8	328	128	12
1	9	340	140	12
1	10	350	150	10
1	11	388	188	38
1	12	427	227	39
1	13	464	264	37
1	14	505	305	41
1	15	541	341	36
1	16	579	379	38
1	17	616	416	37
1	18	655	455	39
1	19	693	493	38
1	20	730	530	37
1	21	769	569	39
1	22	806	606	37
1	23	845	645	39
1	24	882	682	37
1	25	922	722	40
1	26	957	757	35
1	27	997	797	40



DCPI = 15.0 mm/blow (Upper Layer)
DCPI = 38.1 mm/blow (Lower Layer)

Test ID: TR_31

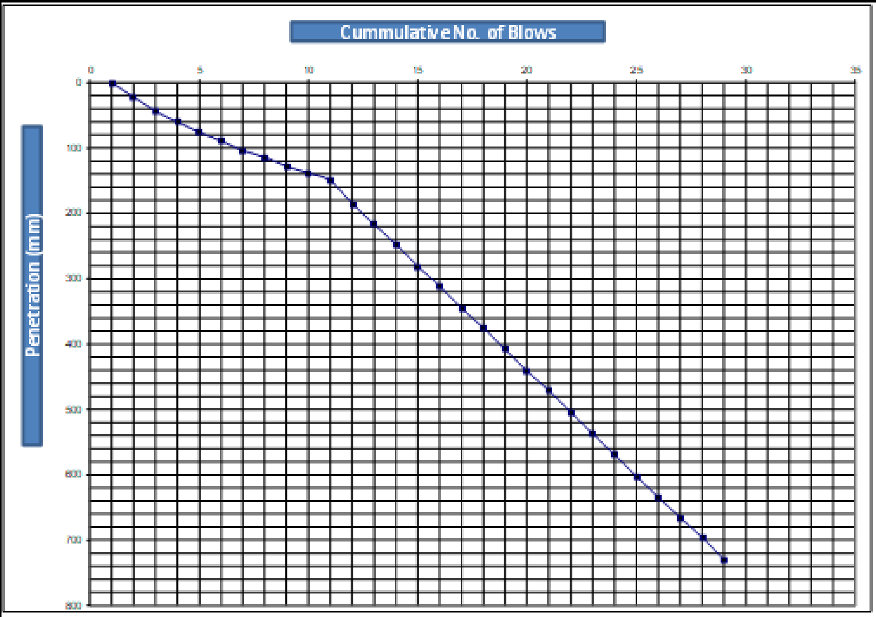
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	194	0	
1	1	219	25	25
1	2	245	51	26
1	3	264	70	19
1	4	286	92	22
1	5	304	110	18
1	6	324	130	20
1	7	339	145	15
1	8	356	162	17
1	9	369	175	13
1	10	387	193	18
1	11	424	230	37
1	12	458	264	34
1	13	494	300	36
1	14	529	335	35
1	15	561	367	32
1	16	598	404	37
1	17	633	439	35
1	18	668	474	35
1	19	703	509	35
1	20	736	542	33
1	21	771	577	35
1	22	806	612	35
1	23	841	647	35
1	24	875	681	34
1	25	910	716	35



DCPI = 19.3 mm/blow (Upper Layer)
DCPI = 34.9 mm/blow (Lower Layer)

Test ID: TR_32

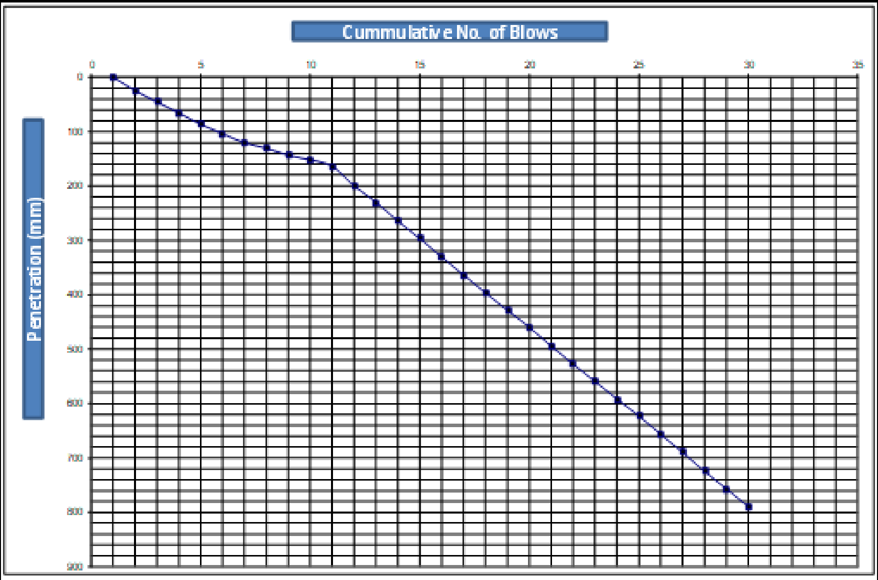
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	192	0	
1	1	214	22	22
1	2	236	44	22
1	3	252	60	16
1	4	268	76	16
1	5	281	89	13
1	6	296	104	15
1	7	306	114	10
1	8	320	128	14
1	9	330	138	10
1	10	342	150	12
1	11	377	185	35
1	12	409	217	32
1	13	439	247	30
1	14	473	281	34
1	15	503	311	30
1	16	537	345	34
1	17	567	375	30
1	18	600	408	33
1	19	633	441	33
1	20	663	471	30
1	21	696	504	33
1	22	729	537	33
1	23	761	569	32
1	24	794	602	33
1	25	826	634	32
1	26	857	665	31
1	27	887	695	30
1	28	921	729	34



DCPI = 15.0 mm/blow (Upper Layer)
DCPI = 32.2 mm/blow (Lower Layer)

Test ID: TR_33

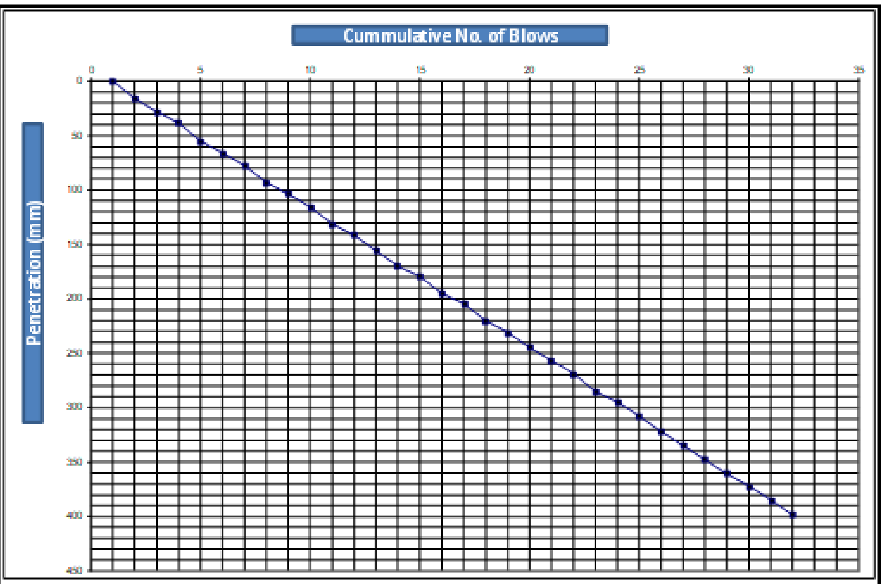
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	222	25	25
1	2	243	46	21
1	3	263	66	20
1	4	284	87	21
1	5	301	104	17
1	6	318	121	17
1	7	328	131	10
1	8	341	144	13
1	9	349	152	8
1	10	361	164	12
1	11	397	200	36
1	12	427	230	30
1	13	462	265	35
1	14	494	297	32
1	15	528	331	34
1	16	561	364	33
1	17	594	397	33
1	18	626	429	32
1	19	657	460	31
1	20	692	495	35
1	21	725	528	33
1	22	757	560	32
1	23	789	592	32
1	24	820	623	31
1	25	854	657	34
1	26	887	690	33
1	27	922	725	35
1	28	954	757	32
1	29	987	790	33



DCPI = 16.4 mm/blow (Upper Layer)
DCPI = 32.9 mm/blow (Lower Layer)

Test ID: TR_34

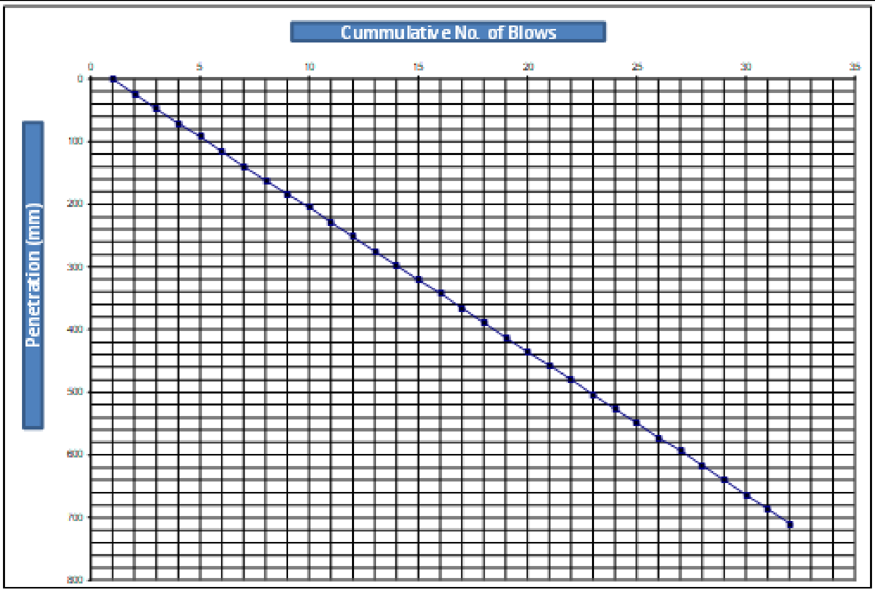
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	211	16	16
1	2	223	28	12
1	3	234	39	11
1	4	250	55	16
1	5	261	66	11
1	6	273	78	12
1	7	288	93	15
1	8	299	104	11
1	9	311	116	12
1	10	326	131	15
1	11	337	142	11
1	12	351	156	14
1	13	365	170	14
1	14	375	180	10
1	15	390	195	15
1	16	400	205	10
1	17	415	220	15
1	18	426	231	11
1	19	440	245	14
1	20	452	257	12
1	21	464	269	12
1	22	480	285	16
1	23	490	295	10
1	24	503	308	13
1	25	517	322	14
1	26	530	335	13
1	27	543	348	13
1	28	556	361	13
1	29	567	372	11
1	30	580	385	13
1	31	594	399	14



DCPI = 12.9 mm/blow

Test ID: TR_35

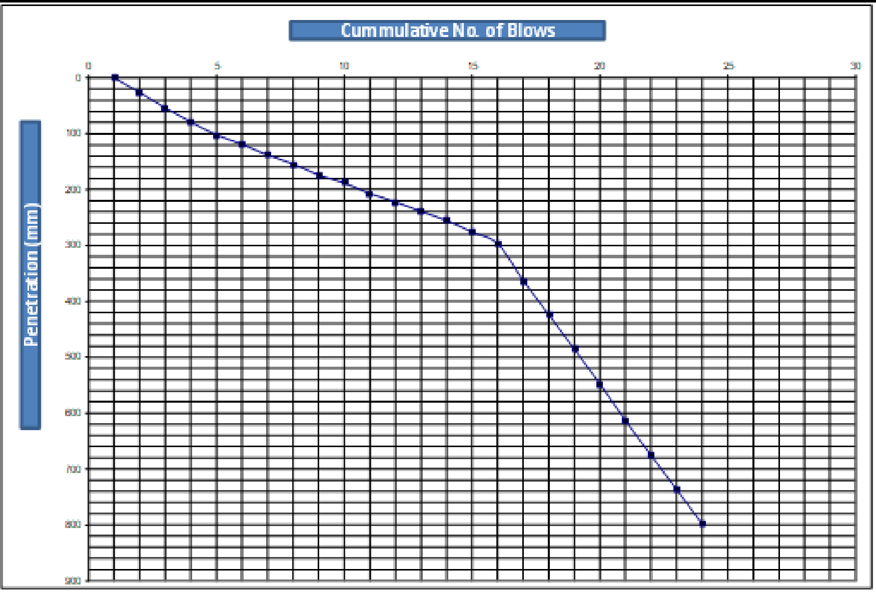
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	193	0	
2	2	217	24	12
2	4	241	48	12
2	6	264	71	11.5
2	8	285	92	10.5
2	10	309	116	12
2	12	333	140	12
2	14	355	162	11
2	16	377	184	11
2	18	398	205	10.5
2	20	422	229	12
2	22	445	252	11.5
2	24	468	275	11.5
2	26	491	298	11.5
2	28	514	321	11.5
2	30	535	342	10.5
2	32	559	366	12
2	34	582	389	11.5
2	36	606	413	12
2	38	629	436	11.5
2	40	650	457	10.5
2	42	673	480	11.5
2	44	697	504	12
2	46	720	527	11.5
2	48	742	549	11
2	50	766	573	12
2	52	786	593	10
2	54	810	617	12
2	56	833	640	11.5
2	58	857	664	12
2	60	879	686	11
2	62	903	710	12



DCPI = 11.5 mm/blow

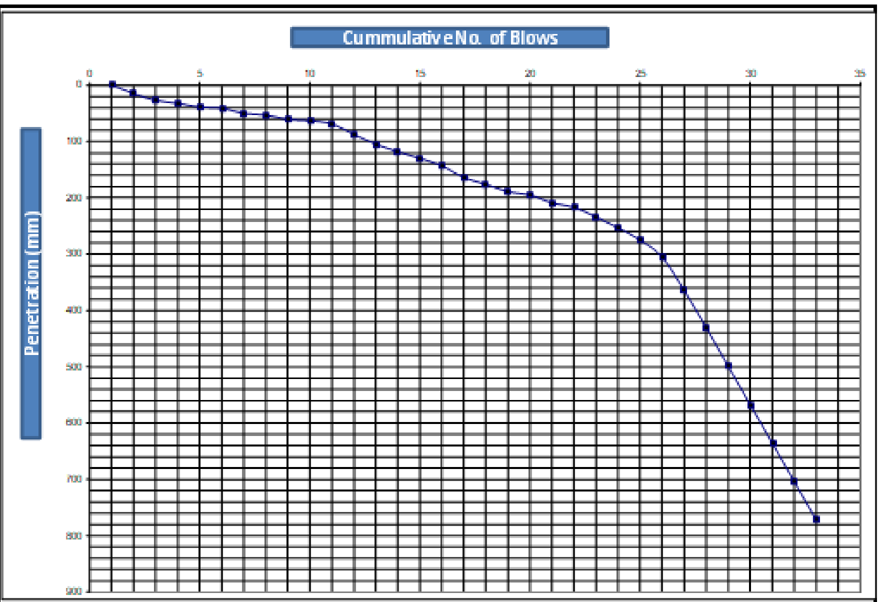
Test ID: TR_36

No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	197	0	
1	1	223	26	26
1	2	251	54	28
1	3	276	79	25
1	4	299	102	23
1	5	316	119	17
1	6	335	138	19
1	7	351	154	16
1	8	371	174	20
1	9	385	188	14
1	10	404	207	19
1	11	419	222	15
1	12	436	239	17
1	13	452	255	16
1	14	473	276	21
1	15	494	297	21
5	20	560	363	13.2
5	25	621	424	12.2
5	30	683	486	12.4
5	35	745	548	12.4
5	40	811	614	13.2
5	45	873	676	12.4
5	50	934	737	12.2
5	55	996	799	12.4



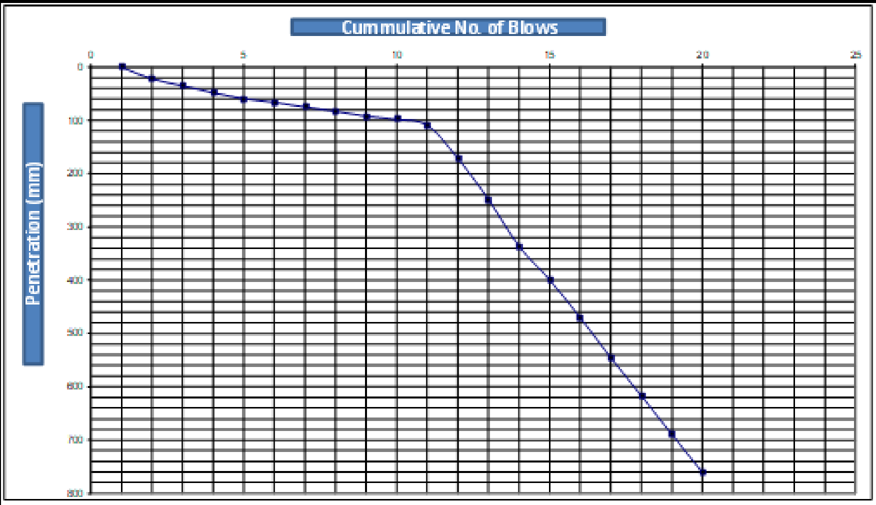
DCPI = 19.8 mm/blow (Upper Layer)
DCPI = 12.6 mm/blow (Lower Layer)

Test ID: TR_37				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	210	15	15
1	2	222	27	12
1	3	227	32	5
1	4	234	39	7
1	5	236	41	2
1	6	245	50	9
1	7	248	53	3
1	8	256	61	8
1	9	258	63	2
1	10	264	69	6
5	15	282	87	3.6
5	20	300	105	3.6
5	25	313	118	2.6
5	30	325	130	2.4
5	35	338	143	2.6
5	40	359	164	4.2
5	45	371	176	2.4
5	50	384	189	2.6
5	55	390	195	1.2
5	60	404	209	2.8
5	65	412	217	1.6
5	70	429	234	3.4
5	75	448	253	3.8
5	80	470	275	4.4
5	85	500	305	6
5	90	559	364	11.8
5	95	625	430	13.2
5	100	694	499	13.8
5	105	762	567	13.6
5	110	830	635	13.6
5	115	898	703	13.6
5	120	967	772	13.8



DCPI = 3.6 mm/blow (Upper Layer)
DCPI = 13.3 mm/blow (Lower Layer)

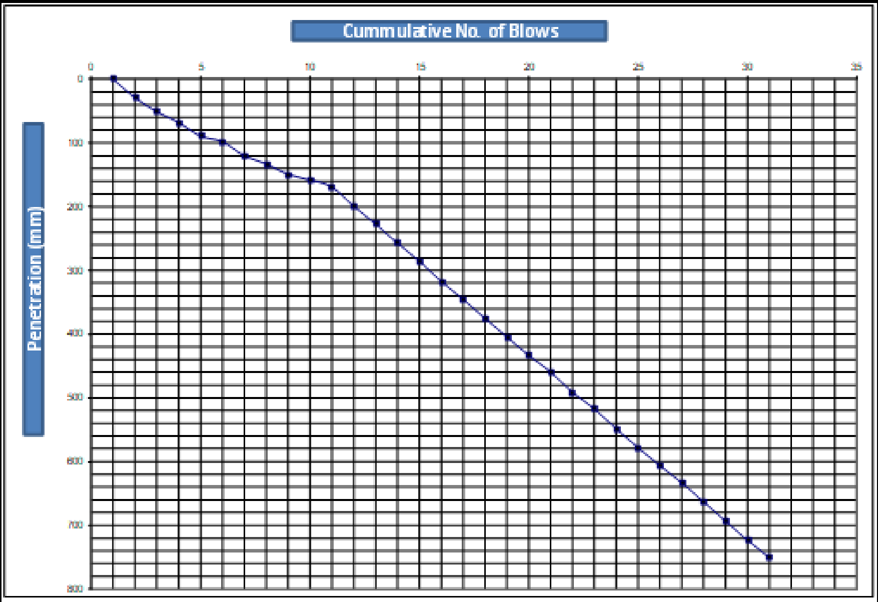
Test ID: TR_38				
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	190	0	
1	1	212	22	22
1	2	225	35	13
1	3	238	48	13
1	4	249	59	11
1	5	256	66	7
1	6	265	75	9
1	7	273	83	8
1	8	282	92	9
1	9	288	98	6
1	10	299	109	11
5	15	361	171	12.4
5	20	438	248	15.4
5	25	526	336	17.6
5	30	589	399	12.6
5	35	660	470	14.2
5	40	735	545	15
5	45	807	617	14.4
5	50	879	689	14.4
5	55	951	761	14.4



DCPI = 10.9 mm/blow (Upper Layer)
DCPI = 14.5 mm/blow (Lower Layer)

Test ID: TR_39

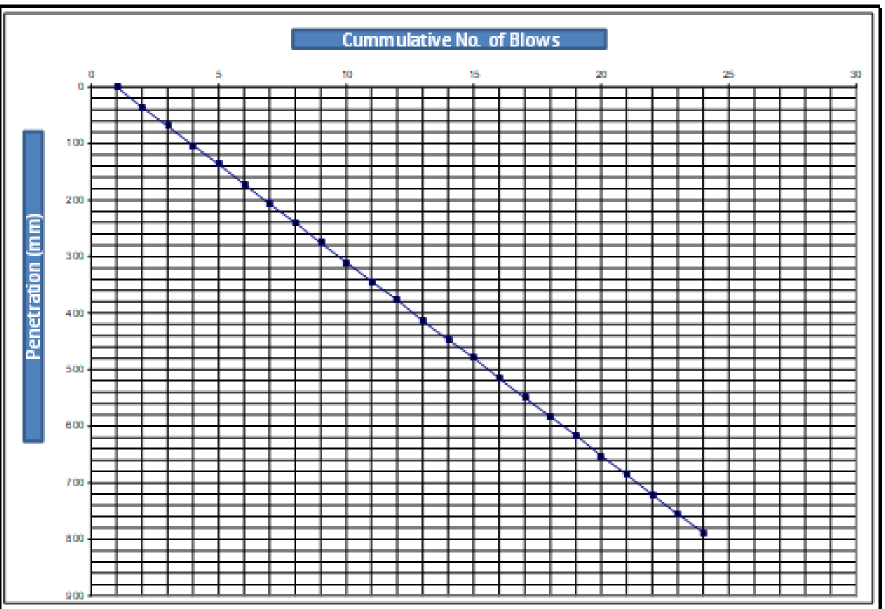
No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	224	29	29
1	2	246	51	22
1	3	263	68	17
1	4	284	89	21
1	5	293	98	9
1	6	315	120	22
1	7	328	133	13
1	8	344	149	16
1	9	353	158	9
1	10	364	169	11
1	11	394	199	30
1	12	422	227	28
1	13	452	257	30
1	14	480	285	28
1	15	512	317	32
1	16	540	345	28
1	17	570	375	30
1	18	599	404	29
1	19	628	433	29
1	20	654	459	26
1	21	686	491	32
1	22	712	517	26
1	23	743	548	31
1	24	773	578	30
1	25	801	606	28
1	26	828	633	27
1	27	858	663	30
1	28	888	693	30
1	29	918	723	30
1	30	945	750	27



DCPI = 16.9 mm/blow (Upper Layer)
DCPI = 29.1 mm/blow (Lower Layer)

Test ID: TR_40

No.of Blows	Cum. No. of blows	Reading (mm)	Penetration (mm)	DCPI (mm/blow)
0	0	195	0	
1	1	231	36	36
1	2	264	69	33
1	3	298	103	34
1	4	332	137	34
1	5	367	172	35
1	6	402	207	35
1	7	435	240	33
1	8	471	276	36
1	9	505	310	34
1	10	539	344	34
1	11	572	377	33
1	12	609	414	37
1	13	642	447	33
1	14	674	479	32
1	15	711	516	37
1	16	745	550	34
1	17	778	583	33
1	18	811	616	33
1	19	848	653	37
1	20	881	686	33
1	21	916	721	35
1	22	951	756	35
1	23	983	788	32



DCPI = 34.2 mm/blow

Appendix 2: Readings of California Bearing Ratio Test

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_01				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	3	0.06		
1.27	11	0.20		
1.96	21	0.39		
2.54	28	0.52	0.52	3.88
3.18	36	0.67		
3.81	44	0.81		
4.45	51	0.94		
5.08	59	1.09	1.09	5.45
7.62	88	1.63		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_02				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	1	0.02		
1.27	6	0.11		
1.96	13	0.24		
2.54	21	0.39	0.39	2.91
3.18	28	0.52		
3.81	37	0.68		
4.45	45	0.83		
5.08	54	1.00	1.00	4.99
7.62	92	1.70		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_03				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	11	0.20		
1.27	37	0.68		
1.96	66	1.22		
2.54	87	1.61	1.61	12.04
3.18	111	2.05		
3.81	135	2.49		
4.45	160	2.96		
5.08	185	3.42	3.42	17.09
7.62	284	5.25		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_04				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	3	0.06		
1.27	7	0.13		
1.96	14	0.26		
2.54	21	0.39	0.39	2.91
3.18	28	0.52		
3.81	37	0.68		
4.45	44	0.81		
5.08	50	0.92	0.92	4.62
7.62	80	1.48		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_05				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	32	0.59		
1.27	64	1.18		
1.96	98	1.81		
2.54	125	2.31	2.31	17.30
3.18	158	2.92		
3.81	192	3.55		
4.45	228	4.21		
5.08	257	4.75	4.75	23.75
7.62	370	6.84		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_06				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	35	0.65		
1.27	72	1.33		
1.96	113	2.09		
2.54	154	2.85	2.85	21.32
3.18	193	3.57		
3.81	238	4.40		
4.45	269	4.97		
5.08	300	5.54	5.54	27.72
7.62	428	7.91		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_07				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	48	0.89		
1.27	95	1.76		
1.96	150	2.77		
2.54	197	3.64	3.64	27.27
3.18	246	4.55		
3.81	290	5.36		
4.45	330	6.10		
5.08	372	6.87	6.87	34.37
7.62	535	9.89		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_08				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	51	0.94		
1.27	110	2.03		
1.96	175	3.23		
2.54	239	4.42	4.42	33.08
3.18	305	5.64		
3.81	370	6.84		
4.45	432	7.98		
5.08	493	9.11	9.11	45.55
7.62		0.00		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_09				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	22	0.41		
1.27	59	1.09		
1.96	107	1.98		
2.54	152	2.81	2.81	21.04
3.18	203	3.75		
3.81	245	4.53		
4.45	283	5.23		
5.08	315	5.82	5.82	29.11
7.62	426	7.87		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_10				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	11	0.20		
1.27	18	0.33		
1.96	25	0.46		
2.54	31	0.57	0.57	4.29
3.18	40	0.74		
3.81	49	0.91		
4.45	59	1.09		
5.08	67	1.24	1.24	6.19
7.62	103	1.90		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_11				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	13	0.24		
1.27	28	0.52		
1.96	45	0.83		
2.54	58	1.07	1.07	8.03
3.18	74	1.37		
3.81	88	1.63		
4.45	102	1.88		
5.08	113	2.09	2.09	10.44
7.62	173	3.20		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_12				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	11	0.20		
1.27	18	0.33		
1.96	27	0.50		
2.54	36	0.67	0.67	4.98
3.18	42	0.78		
3.81	50	0.92		
4.45	57	1.05		
5.08	65	1.20	1.20	6.01
7.62	98	1.81		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_13				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	10	0.18		
1.27	19	0.35		
1.96	28	0.52		
2.54	34	0.63	0.63	4.71
3.18	42	0.78		
3.81	49	0.91		
4.45	57	1.05		
5.08	65	1.20	1.20	6.01
7.62	95	1.76		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_14				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	8	0.15		
1.27	20	0.37		
1.96	33	0.61		
2.54	44	0.81	0.81	6.09
3.18	54	1.00		
3.81	64	1.18		
4.45	75	1.39		
5.08	87	1.61	1.61	8.04
7.62	133	2.46		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_15				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	46	0.85		
1.27	105	1.94		
1.96	183	3.38		
2.54	245	4.53	4.53	33.91
3.18	305	5.64		
3.81	263	4.86		
4.45	418	7.72		
5.08	473	8.74	8.74	43.71
7.62	660	12.20		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_16				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	15	0.28		
1.27	35	0.65		
1.96	57	1.05		
2.54	76	1.40	1.40	10.52
3.18	95	1.76		
3.81	115	2.13		
4.45	136	2.51		
5.08	156	2.88	2.88	14.41
7.62	240	4.44		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_17				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	45	0.83		
1.27	85	1.57		
1.96	147	2.72		
2.54	202	3.73	3.73	27.96
3.18	258	4.77		
3.81	307	5.67		
4.45	352	6.50		
5.08	395	7.30	7.30	36.50
7.62	432	7.98		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_18				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	8	0.15		
1.27	16	0.30		
1.96	23	0.43		
2.54	30	0.55	0.55	4.15
3.18	39	0.72		
3.81	47	0.87		
4.45	55	1.02		
5.08	64	1.18	1.18	5.91
7.62	101	1.87		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_19				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	13	0.24		
1.27	23	0.43		
1.96	32	0.59		
2.54	40	0.74	0.74	5.54
3.18	49	0.91		
3.81	55	1.02		
4.45	64	1.18		
5.08	72	1.33	1.33	6.65
7.62	110	2.03		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_20				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	6	0.11		
1.27	12	0.22		
1.96	20	0.37		
2.54	27	0.50	0.50	3.74
3.18	34	0.63		
3.81	42	0.78		
4.45	50	0.92		
5.08	57	1.05	1.05	5.27
7.62	87	1.61		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_21				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	9	0.17		
1.27	16	0.30		
1.96	24	0.44		
2.54	29	0.54	0.54	4.01
3.18	37	0.68		
3.81	45	0.83		
4.45	52	0.96		
5.08	60	1.11	1.11	5.54
7.62	91	1.68		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_22				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	5	0.09		
1.27	10	0.18		
1.96	16	0.30		
2.54	21	0.39	0.39	2.91
3.18	29	0.54		
3.81	35	0.65		
4.45	42	0.78		
5.08	49	0.91	0.91	4.53
7.62	76	1.40		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_23				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	7	0.13		
1.27	14	0.26		
1.96	21	0.39		
2.54	27	0.50	0.50	3.74
3.18	34	0.63		
3.81	41	0.76		
4.45	48	0.89		
5.08	55	1.02	1.02	5.08
7.62	85	1.57		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_24				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	10	0.18		
1.27	17	0.31		
1.96	24	0.44		
2.54	27	0.50	0.50	3.74
3.18	32	0.59		
3.81	39	0.72		
4.45	43	0.79		
5.08	48	0.89	0.89	4.44
7.62	69	1.28		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_25				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	10	0.18		
1.27	18	0.33		
1.96	29	0.54		
2.54	38	0.70	0.70	5.26
3.18	47	0.87		
3.81	56	1.03		
4.45	65	1.20		
5.08	72	1.33	1.33	6.65
7.62	107	1.98		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_26				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	1	0.02		
1.27	6	0.11		
1.96	13	0.24		
2.54	21	0.39	0.39	2.91
3.18	28	0.52		
3.81	37	0.68		
4.45	45	0.83		
5.08	54	1.00	1.00	4.99
7.62	92	1.70		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_27				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	35	0.65		
1.27	72	1.33		
1.96	113	2.09		
2.54	154	2.85	2.85	21.32
3.18	193	3.57		
3.81	238	4.40		
4.45	269	4.97		
5.08	300	5.54	5.54	27.72
7.62	428	7.91		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_28				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	48	0.89		
1.27	95	1.76		
1.96	150	2.77		
2.54	197	3.64	3.64	27.27
3.18	246	4.55		
3.81	290	5.36		
4.45	330	6.10		
5.08	372	6.87	6.87	34.37
7.62	535	9.89		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_29				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	45	0.83		
1.27	85	1.57		
1.96	147	2.72		
2.54	202	3.73	3.73	27.96
3.18	258	4.77		
3.81	307	5.67		
4.45	352	6.50		
5.08	395	7.30	7.30	36.50
7.62	432	7.98		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_30				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	5	0.09		
1.27	10	0.18		
1.96	16	0.30		
2.54	21	0.39	0.39	2.91
3.18	29	0.54		
3.81	35	0.65		
4.45	42	0.78		
5.08	49	0.91	0.91	4.53
7.62	76	1.40		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_31				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	5	0.09		
1.27	8	0.15		
1.96	13	0.24		
2.54	27	0.50	0.50	3.74
3.18	32	0.59		
3.81	39	0.72		
4.45	47	0.87		
5.08	54	1.00	1.00	4.99
7.62	85	1.57		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_32				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	8	0.15		
1.27	12	0.22		
1.96	19	0.35		
2.54	28	0.52	0.52	3.88
3.18	35	0.65		
3.81	42	0.78		
4.45	57	1.05		
5.08	60	1.11	1.11	5.54
7.62	79	1.46		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_33				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	5	0.09		
1.27	12	0.22		
1.96	23	0.43		
2.54	32	0.59	0.59	4.43
3.18	40	0.74		
3.81	45	0.83		
4.45	52	0.96		
5.08	57	1.05	1.05	5.27
7.62	72	1.33		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_34				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	22	0.41		
1.27	50	0.92		
1.96	93	1.72		
2.54	122	2.25	2.25	16.89
3.18	150	2.77		
3.81	180	3.33		
4.45	209	3.86		
5.08	273	5.05	5.05	25.23
7.62	340	6.28		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_35				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	20	0.37		
1.27	48	0.89		
1.96	90	1.66		
2.54	118	2.18	2.18	16.33
3.18	145	2.68		
3.81	180	3.33		
4.45	210	3.88		
5.08	261	4.82	4.82	24.12
7.62	330	6.10		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_36				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	15	0.28		
1.27	35	0.65		
1.96	60	1.11		
2.54	105	1.94	1.94	14.53
3.18	125	2.31		
3.81	160	2.96		
4.45	185	3.42		
5.08	217	4.01	4.01	20.05
7.62	240	4.44		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_37				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	33	0.61		
1.27	58	1.07		
1.96	82	1.52		
2.54	105	1.94	1.94	14.53
3.18	120	2.22		
3.81	142	2.62		
4.45	178	3.29		
5.08	216	3.99	3.99	19.96
7.62	288	5.32		
10.16				
12.7				

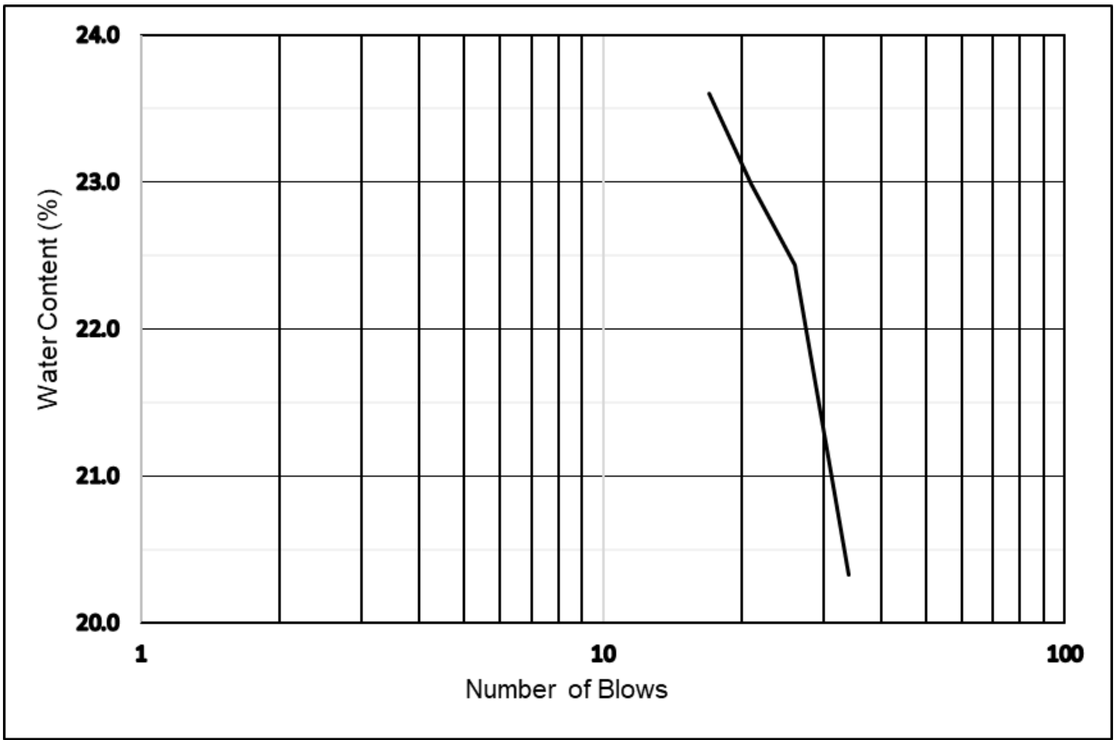
Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_38				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	27	0.50		
1.27	51	0.94		
1.96	77	1.42		
2.54	102	1.88	1.88	14.12
3.18	130	2.40		
3.81	155	2.86		
4.45	180	3.33		
5.08	206	3.81	3.81	19.03
7.62	268	4.95		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_39				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	13	0.24		
1.27	22	0.41		
1.96	32	0.59		
2.54	40	0.74	0.74	5.54
3.18	47	0.87		
3.81	55	1.02		
4.45	64	1.18		
5.08	73	1.35	1.35	6.75
7.62	110	2.03		
10.16				
12.7				

Ring factor (kN/div.)=		0.01848		
TEST ID: - TR_40				
Plunger Penetration (mm)	Dial Reading	Load (kN)	Corrected Load (kN)	CBR %
0	0	0.00		
0.64	6	0.11		
1.27	11	0.20		
1.96	20	0.37		
2.54	27	0.50	0.50	3.74
3.18	34	0.63		
3.81	43	0.79		
4.45	50	0.92		
5.08	60	1.11	1.11	5.54
7.62	87	1.61		
10.16				
12.7				

Appendix 3: Atterberg Limits (PL, LL, PI) Test Results

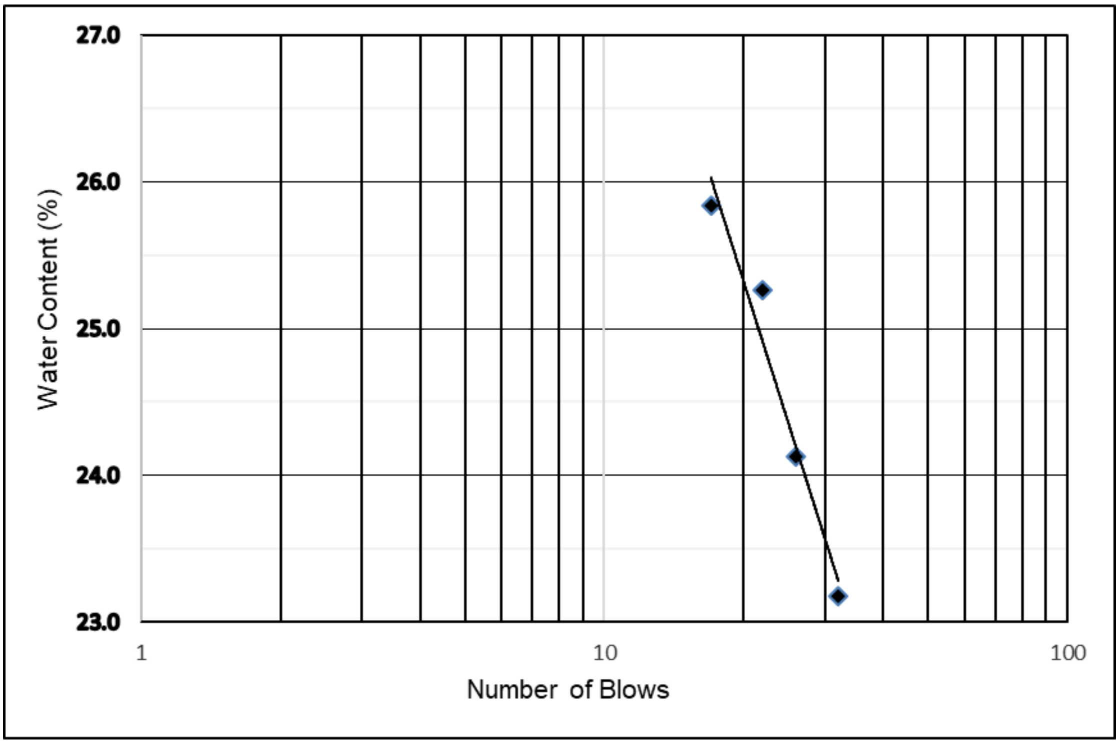
TEST ID: TR_01				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-64	A-60	A-18	A-25
Wt of wet soil + container (gm)	47.40	47.36	44.05	45.30
Wt of dry soil + container (gm)	42.79	42.23	39.44	40.41
Wt of water (gm)	4.61	5.13	4.61	4.89
Wt of container (gm)	20.11	19.36	19.38	19.69
Wt of dry soil (gm)	22.68	22.87	20.06	20.72
Water content, %	20.3	22.4	23.0	23.6
No. of blows	34	26	21	17



Liquid Limit (%)	22.1
Plastic Limit (%)	15.6
Plasticity Index	6.5

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-17	A-26	
Wt of wet soil + container (gm)	21.29	22.61	15.6
Wt of dry soil + container (gm)	20.99	22.3	
Wt of water (gm)	0.30	0.31	
Wt of container (gm)	19.25	20.07	
Wt of dry soil (gm)	1.74	2.23	
Water content, %	17.2	13.9	

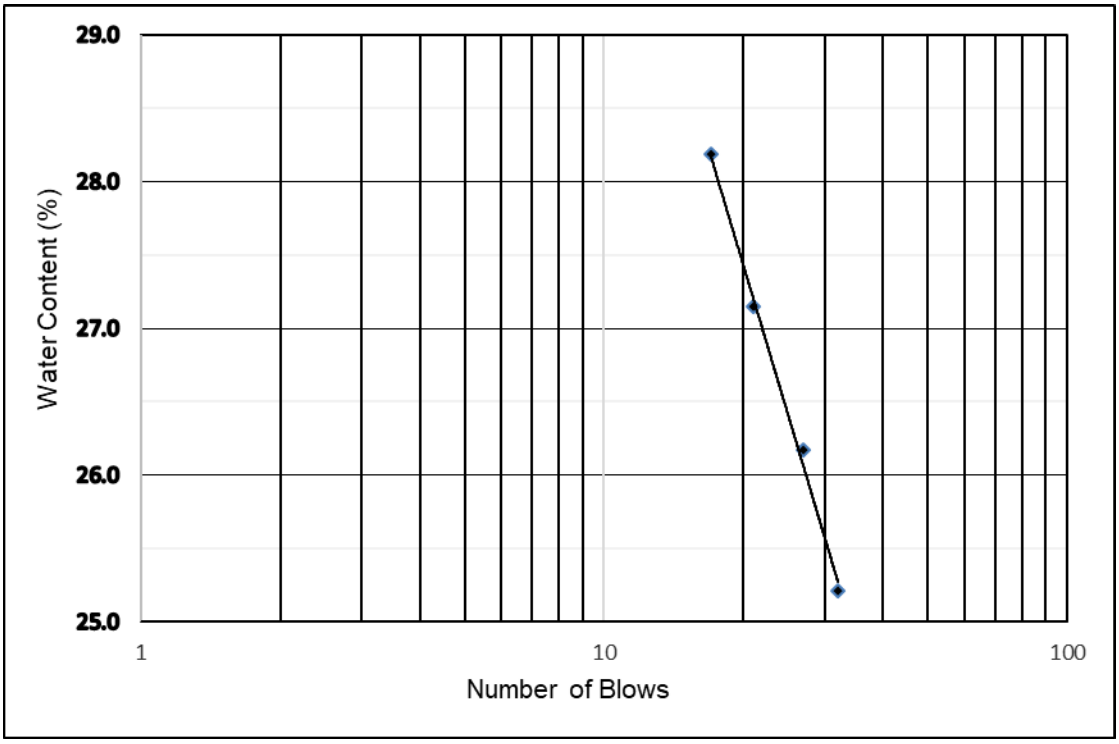
TEST ID: TR_02				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-22	A-3	A-27	A-8
Wt of wet soil + container (gm)	45.67	39.38	42.79	41.90
Wt of dry soil + container (gm)	40.73	35.10	38.22	37.11
Wt of water (gm)	4.94	4.28	4.57	4.79
Wt of container (gm)	19.42	17.36	20.13	18.57
Wt of dry soil (gm)	21.31	17.74	18.09	18.54
Water content, %	23.2	24.1	25.3	25.8
No. of blows	32	26	22	17



Liquid Limit (%)	24.4
Plastic Limit (%)	12.4
Plasticity Index	12.0

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	9	2	
Wt of wet soil + container (gm)	67.03	67.56	
Wt of dry soil + container (gm)	66.55	67.11	
Wt of water (gm)	0.48	0.45	12.4
Wt of container (gm)	62.49	63.62	
Wt of dry soil (gm)	4.06	3.49	
Water content, %	11.8	12.9	

TEST ID: TR_03				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	10	8	2	6
Wt of wet soil + container (gm)	86.32	83.37	87.22	83.37
Wt of dry soil + container (gm)	81.50	78.96	82.20	78.28
Wt of water (gm)	4.82	4.41	5.02	5.09
Wt of container (gm)	62.38	62.11	63.71	60.22
Wt of dry soil (gm)	19.12	16.85	18.49	18.06
Water content, %	25.2	26.2	27.1	28.2
No. of blows	32	27	21	17



Liquid Limit (%)	26.4
Plastic Limit (%)	16.1
Plasticity Index	10.3

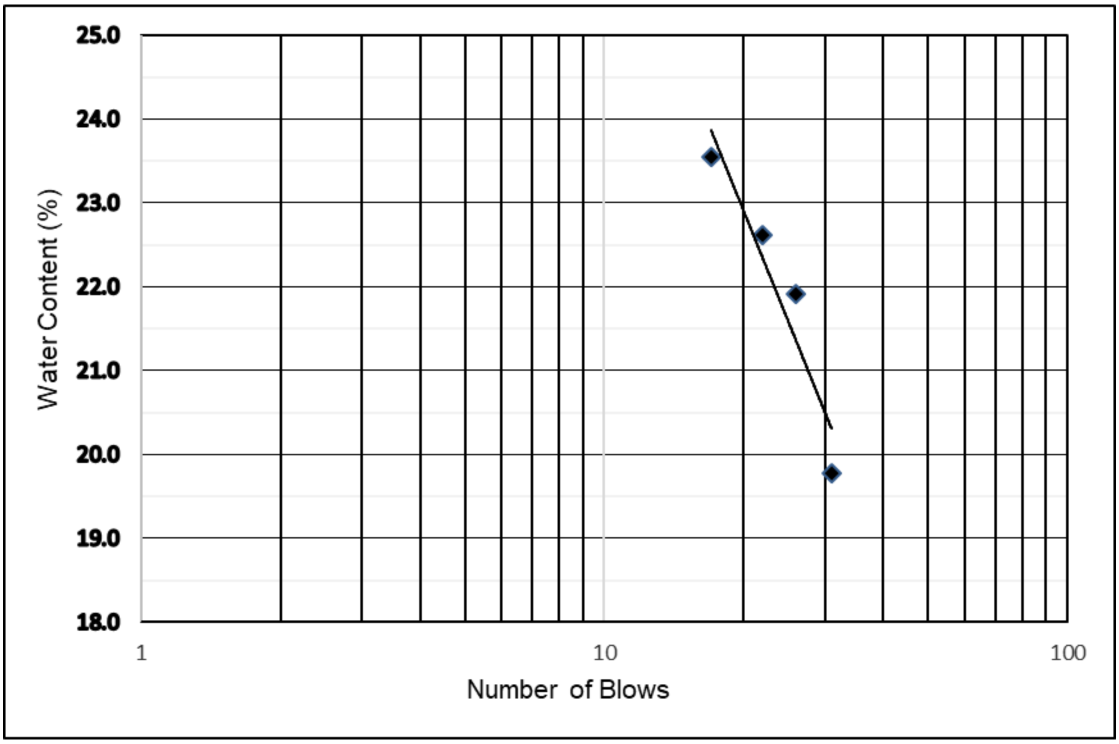
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	11	12	
Wt of wet soil + container (gm)	63.56	65.14	16.1
Wt of dry soil + container (gm)	63.17	64.76	
Wt of water (gm)	0.39	0.38	
Wt of container (gm)	60.79	62.36	
Wt of dry soil (gm)	2.38	2.40	
Water content, %	16.4	15.8	

TEST ID: TR_04				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-20	A-17	A-65	A-66
Wt of wet soil + container (gm)	41.57	40.81	44.87	53.76
Wt of dry soil + container (gm)	36.82	36.15	39.13	48.49
Wt of water (gm)	4.75	4.66	5.74	5.27
Wt of container (gm)	18.87	19.15	18.99	30.52
Wt of dry soil (gm)	17.95	17.00	20.14	17.97
Water content, %	26.5	27.4	28.5	29.3
No. of blows	31	27	23	17

Liquid Limit (%)	27.7
Plastic Limit (%)	15.5
Plasticity Index	12.2

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-14	A-21	
Wt of wet soil + container (gm)	21.40	21.93	15.5
Wt of dry soil + container (gm)	21.07	21.54	
Wt of water (gm)	0.33	0.39	
Wt of container (gm)	18.98	18.99	
Wt of dry soil (gm)	2.09	2.55	
Water content, %	15.8	15.3	

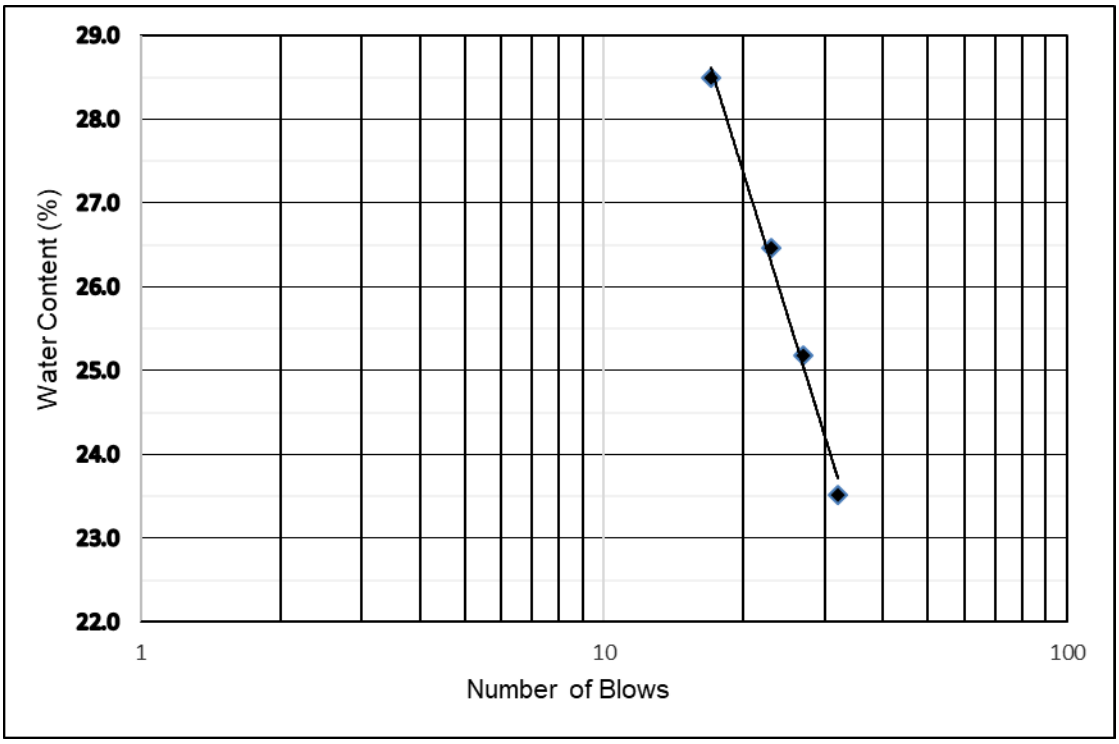
TEST ID: TR_05				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-16	A-61	A-5	A-13
Wt of wet soil + container (gm)	28.71	31.75	34.90	36.70
Wt of dry soil + container (gm)	27.07	29.46	32.05	33.26
Wt of water (gm)	1.64	2.29	2.85	3.44
Wt of container (gm)	18.78	19.01	19.45	18.65
Wt of dry soil (gm)	8.29	10.45	12.60	14.61
Water content, %	19.8	21.9	22.6	23.5
No. of blows	31	26	22	17



Liquid Limit (%)	21.6
Plastic Limit (%)	12.2
Plasticity Index	9.3

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	1	11	
Wt of wet soil + container (gm)	65.88	64.57	12.2
Wt of dry soil + container (gm)	65.50	64.15	
Wt of water (gm)	0.38	0.42	
Wt of container (gm)	62.39	60.72	
Wt of dry soil (gm)	3.11	3.43	
Water content, %	12.2	12.2	

TEST ID: TR_06				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-11	A-60	A-18	A-23
Wt of wet soil + container (gm)	46.24	43.66	40.77	40.81
Wt of dry soil + container (gm)	40.84	38.77	36.30	36.03
Wt of water (gm)	5.40	4.89	4.47	4.78
Wt of container (gm)	17.88	19.35	19.41	19.25
Wt of dry soil (gm)	22.96	19.42	16.89	16.78
Water content, %	23.5	25.2	26.5	28.5
No. of blows	32	27	23	17



Liquid Limit (%)	25.6
Plastic Limit (%)	16.2
Plasticity Index	9.4

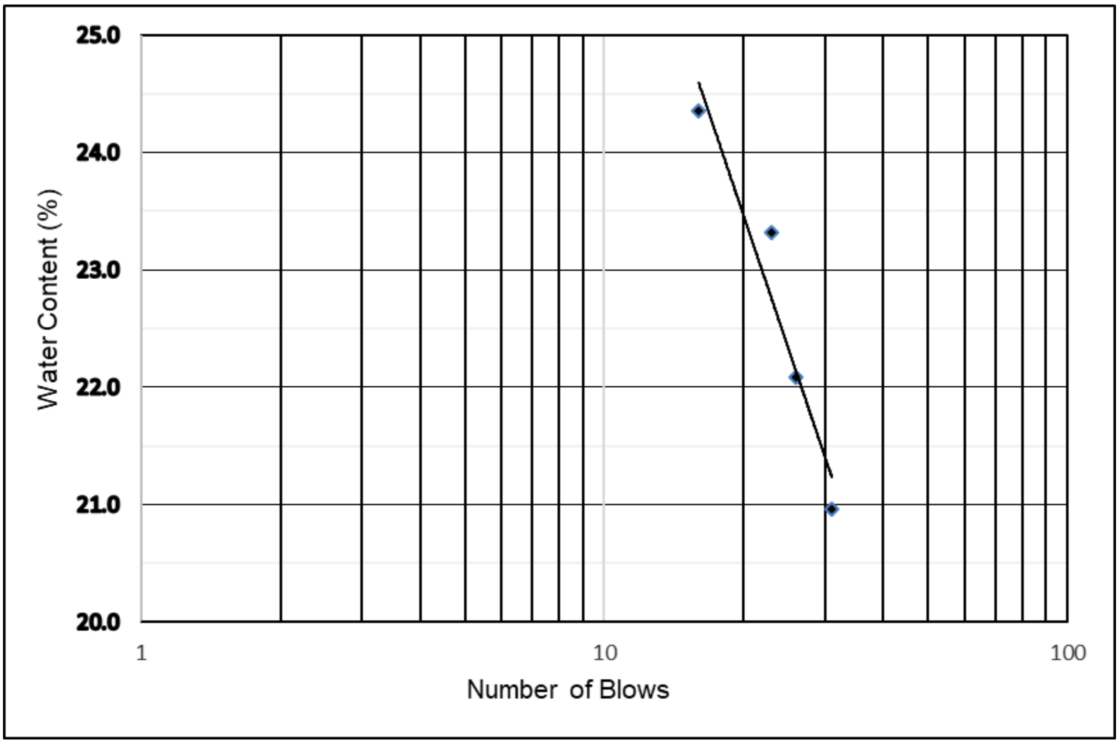
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-3	A-26	
Wt of wet soil + container (gm)	20.59	23.62	
Wt of dry soil + container (gm)	20.14	23.12	
Wt of water (gm)	0.45	0.50	16.2
Wt of container (gm)	17.37	20.04	
Wt of dry soil (gm)	2.77	3.08	
Water content, %	16.2	16.2	

TEST ID: TR_07				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-60	A-6	A-26	A-21
Wt of wet soil + container (gm)	43.99	50.18	47.90	43.79
Wt of dry soil + container (gm)	39.19	44.10	42.15	38.49
Wt of water (gm)	4.80	6.08	5.75	5.30
Wt of container (gm)	19.35	19.84	20.09	19.00
Wt of dry soil (gm)	19.84	24.26	22.06	19.49
Water content, %	24.2	25.1	26.1	27.2
No. of blows	33	27	23	16

Liquid Limit (%)	25.4
Plastic Limit (%)	15.5
Plasticity Index	9.9

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-13	A-23	
Wt of wet soil + container (gm)	20.95	21.36	15.5
Wt of dry soil + container (gm)	20.64	21.08	
Wt of water (gm)	0.31	0.28	
Wt of container (gm)	18.65	19.27	
Wt of dry soil (gm)	1.99	1.81	
Water content, %	15.6	15.5	

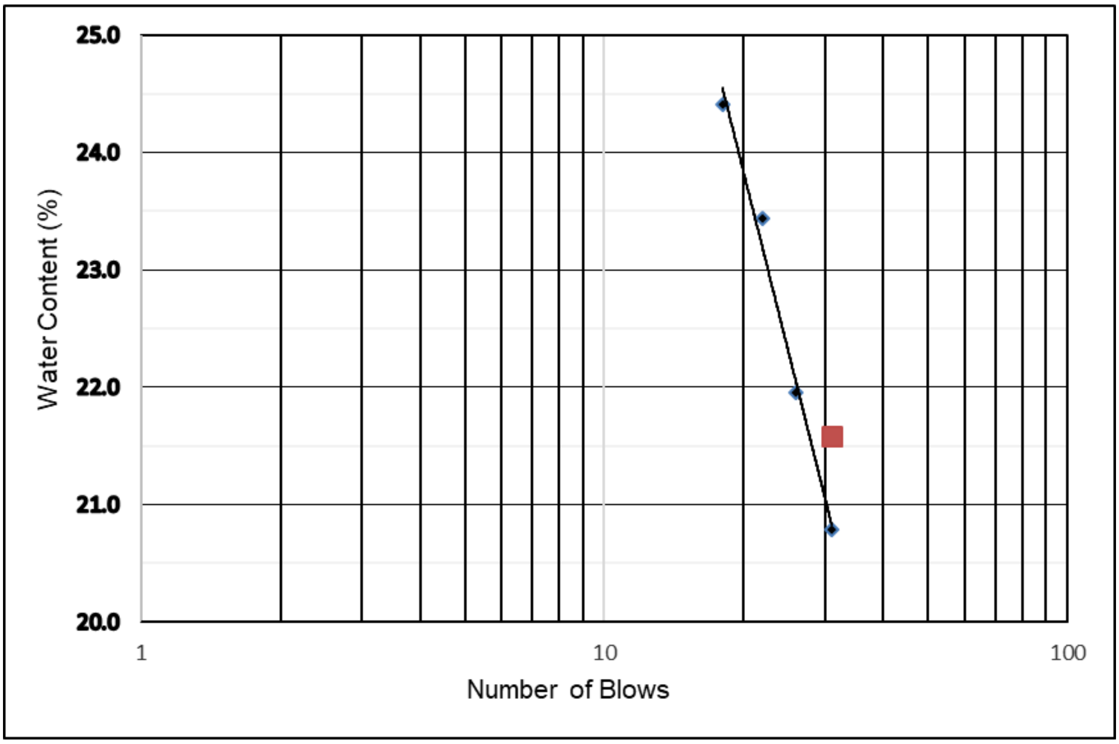
TEST ID: TR_08				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-80	A-27	A-61	A-17
Wt of wet soil + container (gm)	44.30	40.75	45.08	40.29
Wt of dry soil + container (gm)	40.02	37.02	40.15	36.15
Wt of water (gm)	4.28	3.73	4.93	4.14
Wt of container (gm)	19.60	20.13	19.01	19.15
Wt of dry soil (gm)	20.42	16.89	21.14	17.00
Water content, %	21.0	22.1	23.3	24.4
No. of blows	31	26	23	16



Liquid Limit (%)	22.3
Plastic Limit (%)	15.1
Plasticity Index	7.2

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-22	A-25	
Wt of wet soil + container (gm)	20.49	33.08	15.1
Wt of dry soil + container (gm)	20.27	32.74	
Wt of water (gm)	0.22	0.34	
Wt of container (gm)	18.80	30.52	
Wt of dry soil (gm)	1.47	2.22	
Water content, %	15.0	15.3	

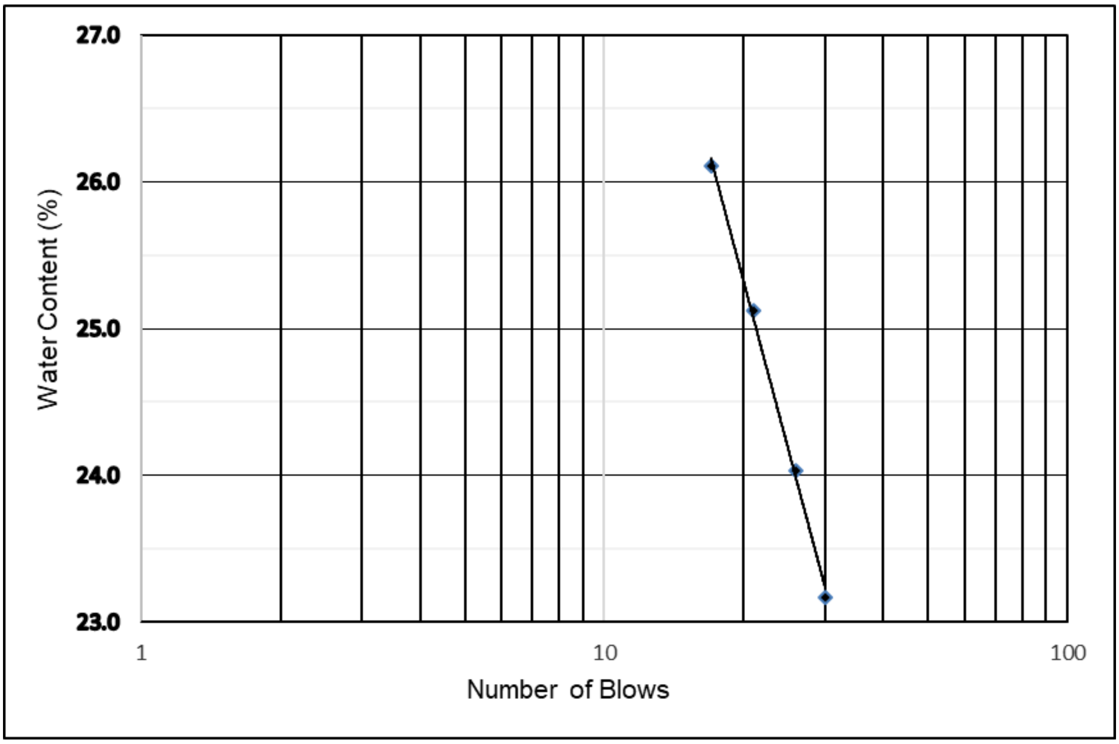
TEST ID: TR_09				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-25	A-65	A-6	A-23
Wt of wet soil + container (gm)	41.50	42.1	39.99	43.45
Wt of dry soil + container (gm)	37.75	37.94	36.15	38.77
Wt of water (gm)	3.75	4.16	3.84	4.68
Wt of container (gm)	19.71	18.99	19.77	19.60
Wt of dry soil (gm)	18.04	18.95	16.38	19.17
Water content, %	20.8	22.0	23.4	24.4
No. of blows	31	26	22	18



Liquid Limit (%)	22.3
Plastic Limit (%)	14.5
Plasticity Index	7.8

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-22	A-25	
Wt of wet soil + container (gm)	21.66	22.18	14.5
Wt of dry soil + container (gm)	21.38	21.85	
Wt of water (gm)	0.28	0.33	
Wt of container (gm)	19.43	19.6	
Wt of dry soil (gm)	1.95	2.25	
Water content, %	14.4	14.7	

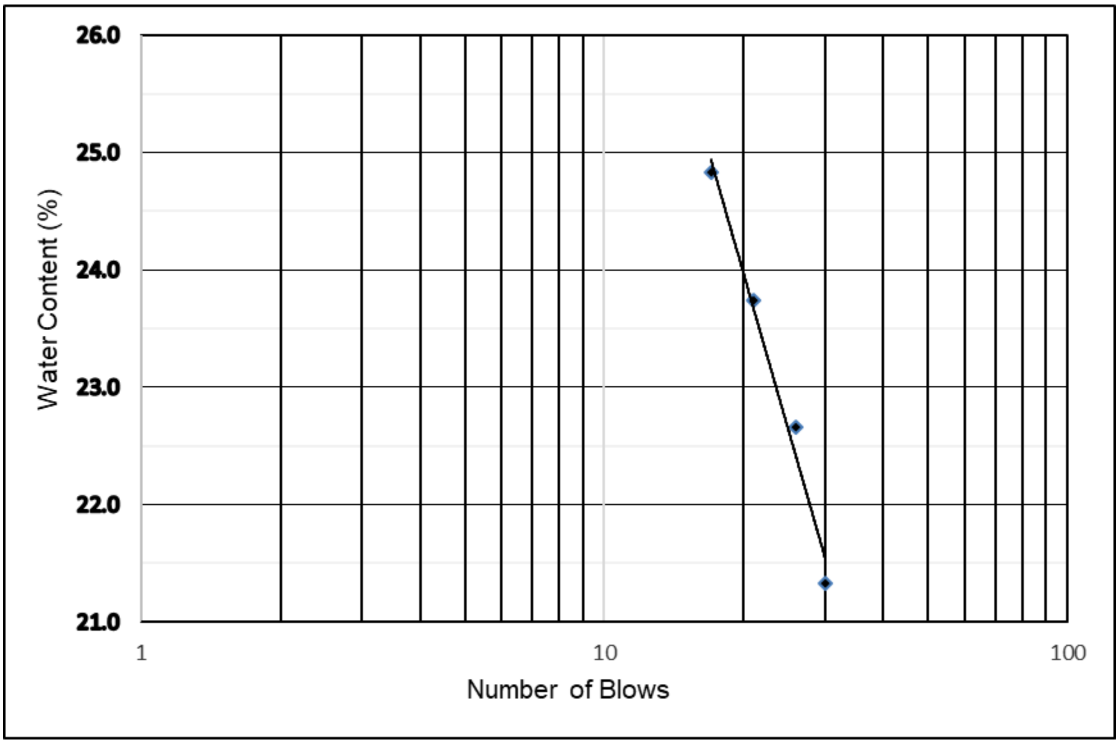
TEST ID: TR_10				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-11	A-2	A-9	A-3
Wt of wet soil + container (gm)	87.73	90.32	83.01	90.20
Wt of dry soil + container (gm)	82.66	85.15	78.90	84.50
Wt of water (gm)	5.07	5.17	4.11	5.70
Wt of container (gm)	60.78	63.64	62.54	62.67
Wt of dry soil (gm)	21.88	21.51	16.36	21.83
Water content, %	23.2	24.0	25.1	26.1
No. of blows	30	26	21	17



Liquid Limit (%)	24.2
Plastic Limit (%)	16.5
Plasticity Index	7.7

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-5	A-4	
Wt of wet soil + container (gm)	64.60	67.12	16.5
Wt of dry soil + container (gm)	64.27	66.7	
Wt of water (gm)	0.33	0.42	
Wt of container (gm)	62.24	64.18	
Wt of dry soil (gm)	2.03	2.52	
Water content, %	16.3	16.7	

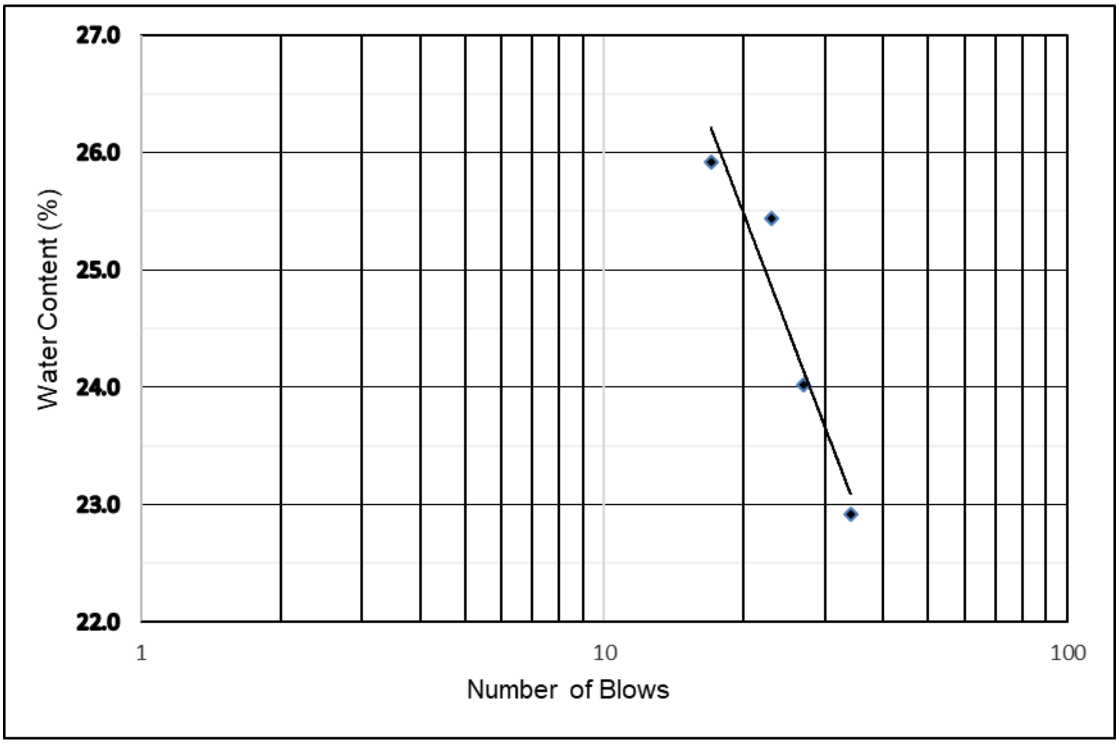
TEST ID: TR_11				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-18	A-63	A-29	A-22
Wt of wet soil + container (gm)	44.50	43.52	41.32	44.58
Wt of dry soil + container (gm)	39.99	39.00	36.85	39.70
Wt of water (gm)	4.51	4.52	4.47	4.88
Wt of container (gm)	18.85	19.05	18.02	20.05
Wt of dry soil (gm)	21.14	19.95	18.83	19.65
Water content, %	21.3	22.7	23.7	24.8
No. of blows	30	26	21	17



Liquid Limit (%)	22.6
Plastic Limit (%)	14.1
Plasticity Index	8.5

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-9	A-4	
Wt of wet soil + container (gm)	23.45	22.95	14.1
Wt of dry soil + container (gm)	22.98	22.45	
Wt of water (gm)	0.47	0.50	
Wt of container (gm)	19.65	18.92	
Wt of dry soil (gm)	3.33	3.53	
Water content, %	14.1	14.2	

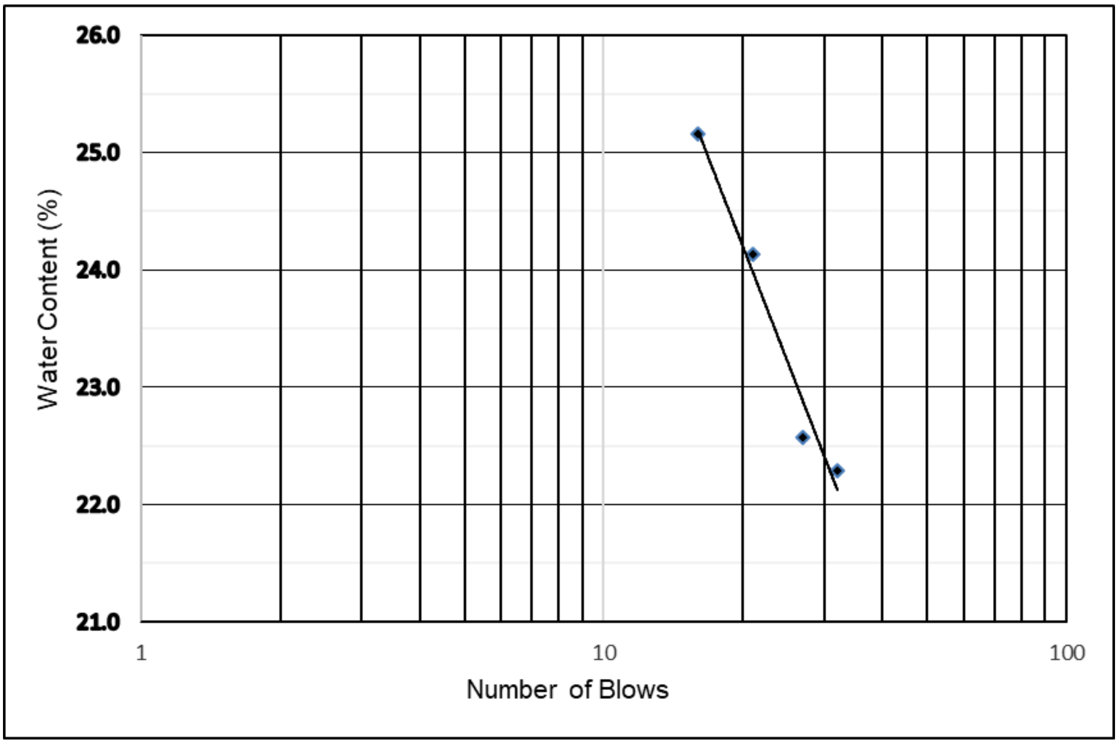
TEST ID: TR_12				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-5	A-6	A-25	A-60
Wt of wet soil + container (gm)	36.14	39.15	42.03	36.79
Wt of dry soil + container (gm)	33.03	35.41	37.50	33.20
Wt of water (gm)	3.11	3.74	4.53	3.59
Wt of container (gm)	19.46	19.84	19.69	19.35
Wt of dry soil (gm)	13.57	15.57	17.81	13.85
Water content, %	22.9	24.0	25.4	25.9
No. of blows	34	27	23	17



Liquid Limit (%)	24.5
Plastic Limit (%)	15.4
Plasticity Index	9.0

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-66	A-8	
Wt of wet soil + container (gm)	34.94	22.11	15.4
Wt of dry soil + container (gm)	34.35	21.64	
Wt of water (gm)	0.59	0.47	
Wt of container (gm)	30.52	18.6	
Wt of dry soil (gm)	3.83	3.04	
Water content, %	15.4	15.5	

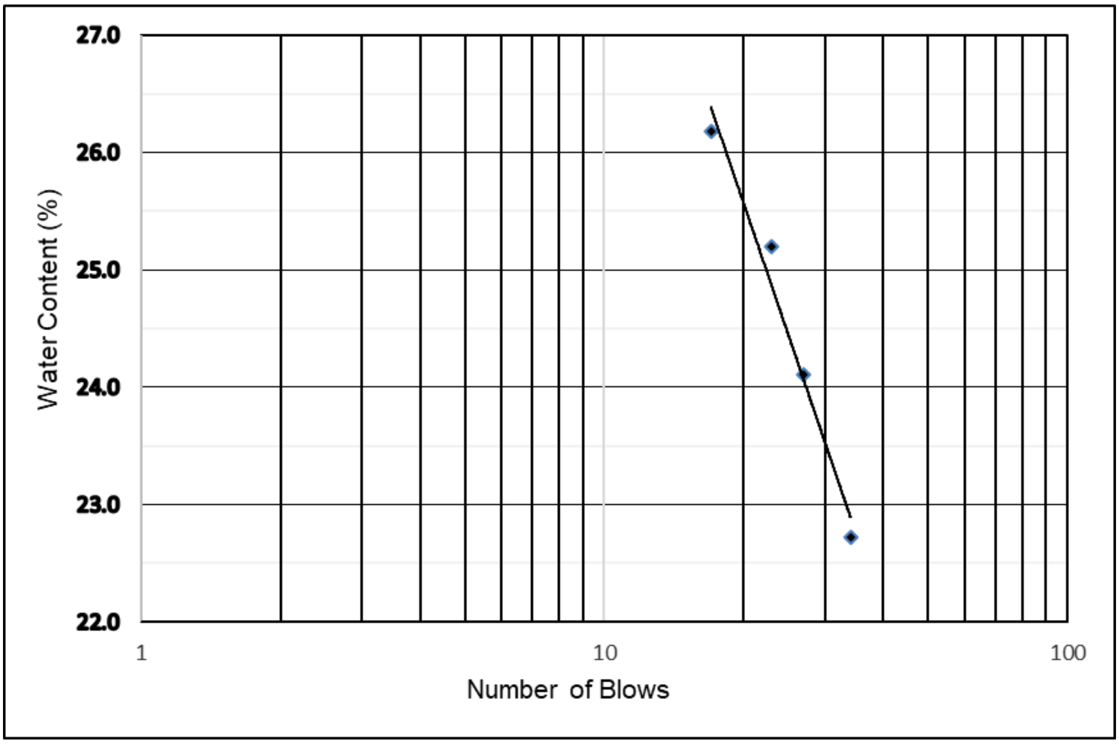
TEST ID: TR_13				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-11	A-6	A-3	A-8
Wt of wet soil + container (gm)	82.05	77.81	81.68	83.07
Wt of dry soil + container (gm)	78.18	74.57	77.99	78.85
Wt of water (gm)	3.87	3.24	3.69	4.22
Wt of container (gm)	60.82	60.22	62.70	62.08
Wt of dry soil (gm)	17.36	14.35	15.29	16.77
Water content, %	22.3	22.6	24.1	25.2
No. of blows	32	27	21	16



Liquid Limit (%)	23.2
Plastic Limit (%)	16.3
Plasticity Index	6.9

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-1	A-9	
Wt of wet soil + container (gm)	65.25	65.03	16.3
Wt of dry soil + container (gm)	64.85	64.68	
Wt of water (gm)	0.40	0.35	
Wt of container (gm)	62.38	62.55	
Wt of dry soil (gm)	2.47	2.13	
Water content, %	16.2	16.4	

TEST ID: TR_14				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-64	A-21	A-3	A-65
Wt of wet soil + container (gm)	43.14	39.1	36.01	31.30
Wt of dry soil + container (gm)	38.88	35.20	32.27	28.75
Wt of water (gm)	4.26	3.90	3.74	2.55
Wt of container (gm)	20.13	19.02	17.43	19.01
Wt of dry soil (gm)	18.75	16.18	14.84	9.74
Water content, %	22.7	24.1	25.2	26.2
No. of blows	34	27	23	17



Liquid Limit (%)	24.4
Plastic Limit (%)	15.1
Plasticity Index	9.3

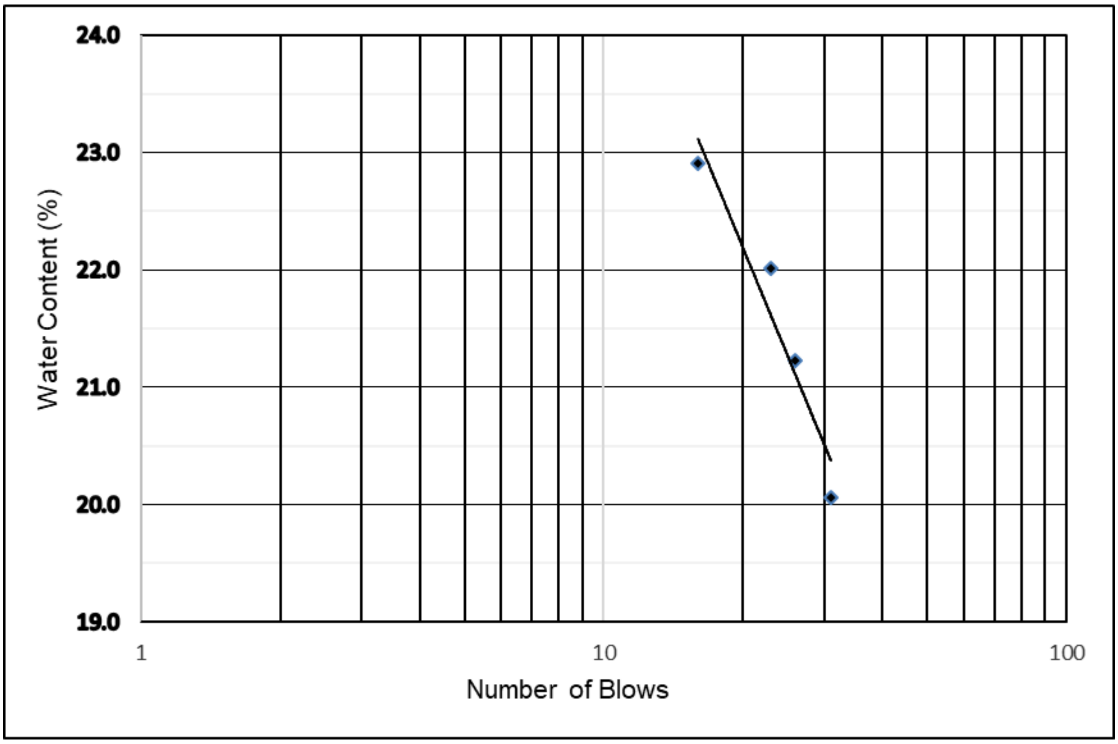
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-26	A-13	
Wt of wet soil + container (gm)	23.48	21.96	15.1
Wt of dry soil + container (gm)	23.03	21.53	
Wt of water (gm)	0.45	0.43	
Wt of container (gm)	20.09	18.66	
Wt of dry soil (gm)	2.94	2.87	
Water content, %	15.3	15.0	

TEST ID: TR_15				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-14	A-21	A-13	A-5
Wt of wet soil + container (gm)	47.16	42.7	43.23	41.42
Wt of dry soil + container (gm)	42.41	38.56	38.76	37.27
Wt of water (gm)	4.75	4.14	4.47	4.15
Wt of container (gm)	18.95	18.98	18.64	19.45
Wt of dry soil (gm)	23.46	19.58	20.12	17.82
Water content, %	20.2	21.1	22.2	23.3
No. of blows	31	28	23	17

Liquid Limit (%)	21.6
Plastic Limit (%)	15.2
Plasticity Index	6.4

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-8	A-64	
Wt of wet soil + container (gm)	23.11	23.75	15.2
Wt of dry soil + container (gm)	22.51	23.28	
Wt of water (gm)	0.60	0.47	
Wt of container (gm)	18.62	20.13	
Wt of dry soil (gm)	3.89	3.15	
Water content, %	15.4	14.9	

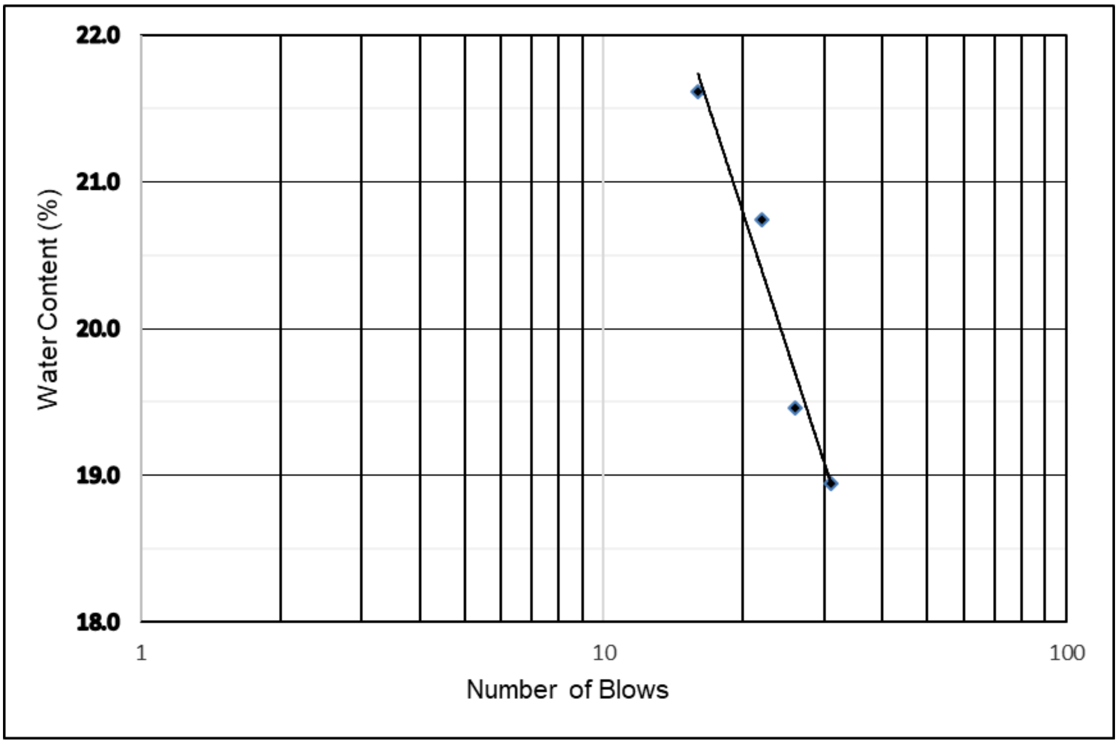
TEST ID: TR_16				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-1	A-6	A-7	A-12
Wt of wet soil + container (gm)	87.88	83	89.28	86.30
Wt of dry soil + container (gm)	83.63	79.01	84.75	81.82
Wt of water (gm)	4.25	3.99	4.53	4.48
Wt of container (gm)	62.45	60.21	64.17	62.26
Wt of dry soil (gm)	21.18	18.80	20.58	19.56
Water content, %	20.1	21.2	22.0	22.9
No. of blows	31	26	23	16



Liquid Limit (%)	21.3
Plastic Limit (%)	14.0
Plasticity Index	7.3

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-10	A-8	
Wt of wet soil + container (gm)	65.11	64.91	
Wt of dry soil + container (gm)	64.77	64.57	
Wt of water (gm)	0.34	0.34	14.0
Wt of container (gm)	62.38	62.09	
Wt of dry soil (gm)	2.39	2.48	
Water content, %	14.2	13.7	

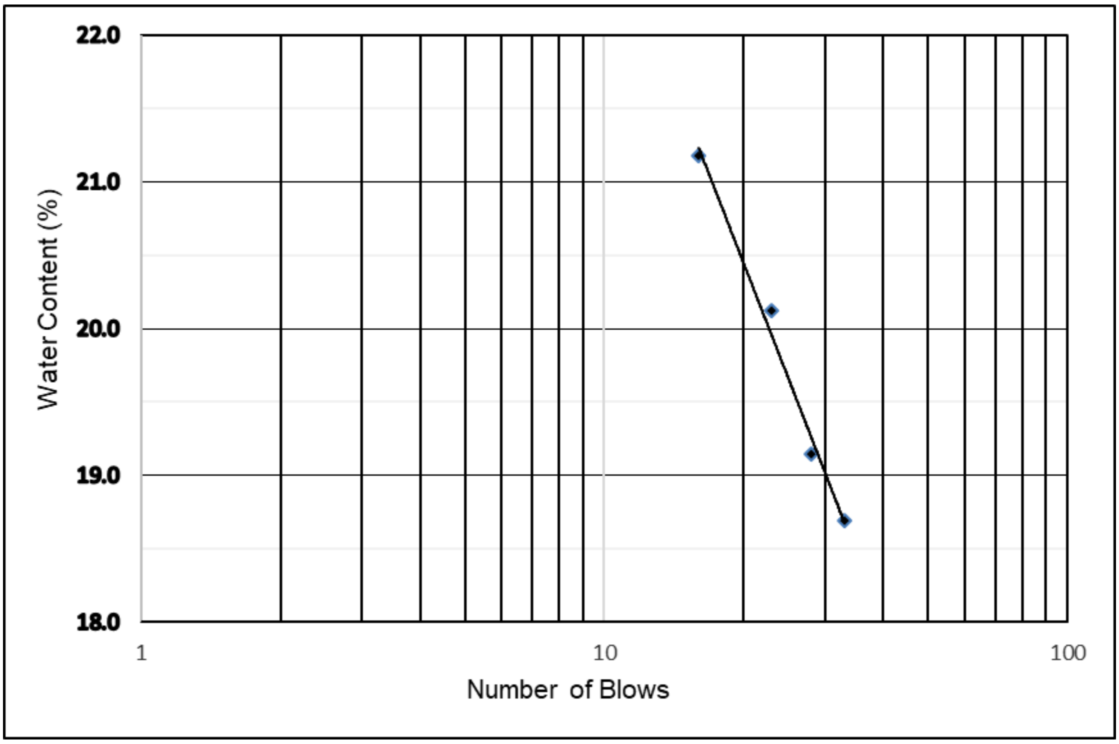
TEST ID: TR_17				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-7	A-4	A-12	A-2
Wt of wet soil + container (gm)	86.63	88.95	84.25	91.13
Wt of dry soil + container (gm)	83.05	84.91	80.47	86.25
Wt of water (gm)	3.58	4.04	3.78	4.88
Wt of container (gm)	64.15	64.15	62.25	63.67
Wt of dry soil (gm)	18.90	20.76	18.22	22.58
Water content, %	18.9	19.5	20.7	21.6
No. of blows	31	26	22	16



Liquid Limit (%)	19.9
Plastic Limit (%)	12.9
Plasticity Index	6.9

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-1	A-10	
Wt of wet soil + container (gm)	63.90	64.76	12.9
Wt of dry soil + container (gm)	63.74	64.48	
Wt of water (gm)	0.16	0.28	
Wt of container (gm)	62.46	62.38	
Wt of dry soil (gm)	1.28	2.10	
Water content, %	12.5	13.3	

TEST ID: TR_18				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-17	A-5	A-23	A-25
Wt of wet soil + container (gm)	43.02	47.27	48.50	42.99
Wt of dry soil + container (gm)	39.26	42.80	43.60	38.92
Wt of water (gm)	3.76	4.47	4.90	4.07
Wt of container (gm)	19.14	19.45	19.25	19.70
Wt of dry soil (gm)	20.12	23.35	24.35	19.22
Water content, %	18.7	19.1	20.1	21.2
No. of blows	33	28	23	16



Liquid Limit (%)	19.7
Plastic Limit (%)	14.1
Plasticity Index	5.6

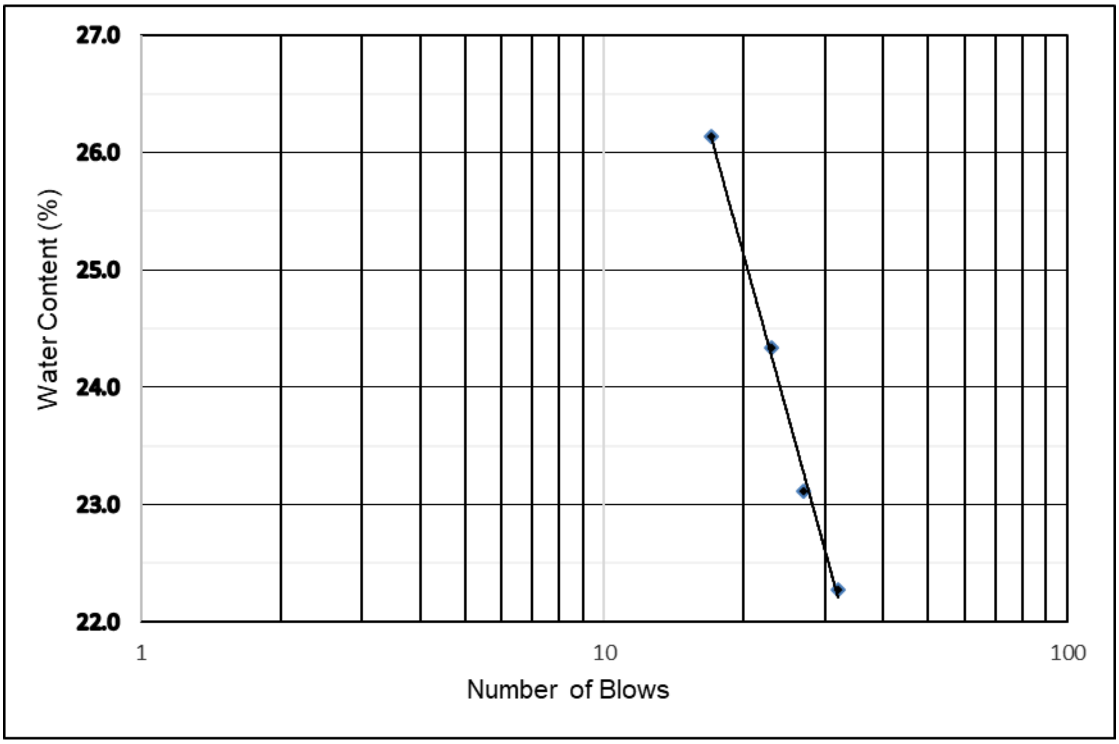
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-65	A-64	
Wt of wet soil + container (gm)	21.60	22.27	14.1
Wt of dry soil + container (gm)	21.28	21.86	
Wt of water (gm)	0.32	0.41	
Wt of container (gm)	18.99	18.97	
Wt of dry soil (gm)	2.29	2.89	
Water content, %	14.0	14.2	

TEST ID: TR_19				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-25	A-6	A-8	A-65
Wt of wet soil + container (gm)	55.35	44.35	52.23	48.50
Wt of dry soil + container (gm)	50.01	42.18	46.70	43.42
Wt of water (gm)	5.34	2.17	5.53	5.08
Wt of container (gm)	19.69	30.52	18.60	19.01
Wt of dry soil (gm)	30.32	11.66	28.10	24.41
Water content, %	17.6	18.6	19.7	20.8
No. of blows	31	26	22	16

Liquid Limit (%)	18.8
Plastic Limit (%)	12.3
Plasticity Index	6.5

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-64	A-5	
Wt of wet soil + container (gm)	22.78	21.98	12.3
Wt of dry soil + container (gm)	22.49	21.7	
Wt of water (gm)	0.29	0.28	
Wt of container (gm)	20.09	19.46	
Wt of dry soil (gm)	2.40	2.24	
Water content, %	12.1	12.5	

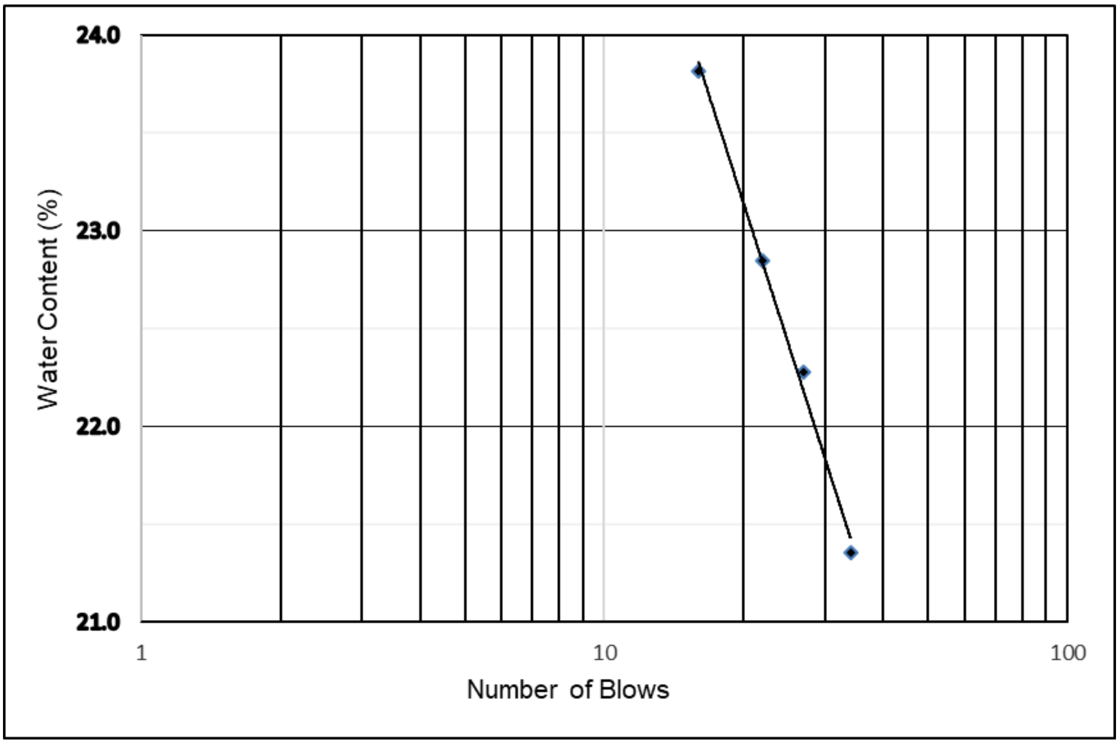
TEST ID: TR_20				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	4	3	5	1
Wt of wet soil + container (gm)	88.21	82.83	90.22	86.48
Wt of dry soil + container (gm)	83.83	79.05	84.74	81.50
Wt of water (gm)	4.38	3.78	5.48	4.98
Wt of container (gm)	64.17	62.70	62.22	62.45
Wt of dry soil (gm)	19.66	16.35	22.52	19.05
Water content, %	22.3	23.1	24.3	26.1
No. of blows	32	27	23	17



Liquid Limit (%)	23.7
Plastic Limit (%)	15.2
Plasticity Index	8.5

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	7	9	
Wt of wet soil + container (gm)	67.02	64.73	
Wt of dry soil + container (gm)	66.64	64.44	
Wt of water (gm)	0.38	0.29	15.2
Wt of container (gm)	64.15	62.53	
Wt of dry soil (gm)	2.49	1.91	
Water content, %	15.3	15.2	

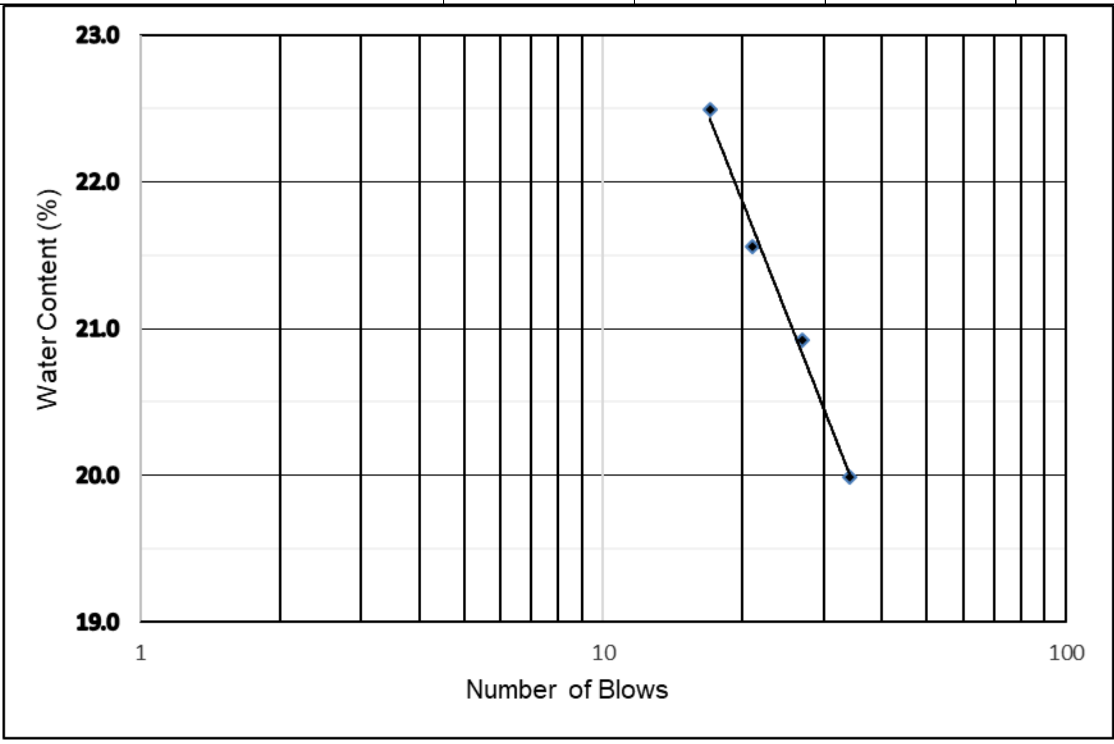
TEST ID: TR_21				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-20	A-21	A-27	A-23
Wt of wet soil + container (gm)	39.02	46.61	49.97	45.56
Wt of dry soil + container (gm)	35.46	41.58	44.42	40.57
Wt of water (gm)	3.56	5.03	5.55	4.99
Wt of container (gm)	18.79	19.00	20.13	19.62
Wt of dry soil (gm)	16.67	22.58	24.29	20.95
Water content, %	21.4	22.3	22.8	23.8
No. of blows	34	27	22	16



Liquid Limit (%)	22.4
Plastic Limit (%)	15.5
Plasticity Index	6.9

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-60	A-14	
Wt of wet soil + container (gm)	21.83	22.06	15.5
Wt of dry soil + container (gm)	21.50	21.8	
Wt of water (gm)	0.33	0.26	
Wt of container (gm)	19.36	20.14	
Wt of dry soil (gm)	2.14	1.66	
Water content, %	15.4	15.7	

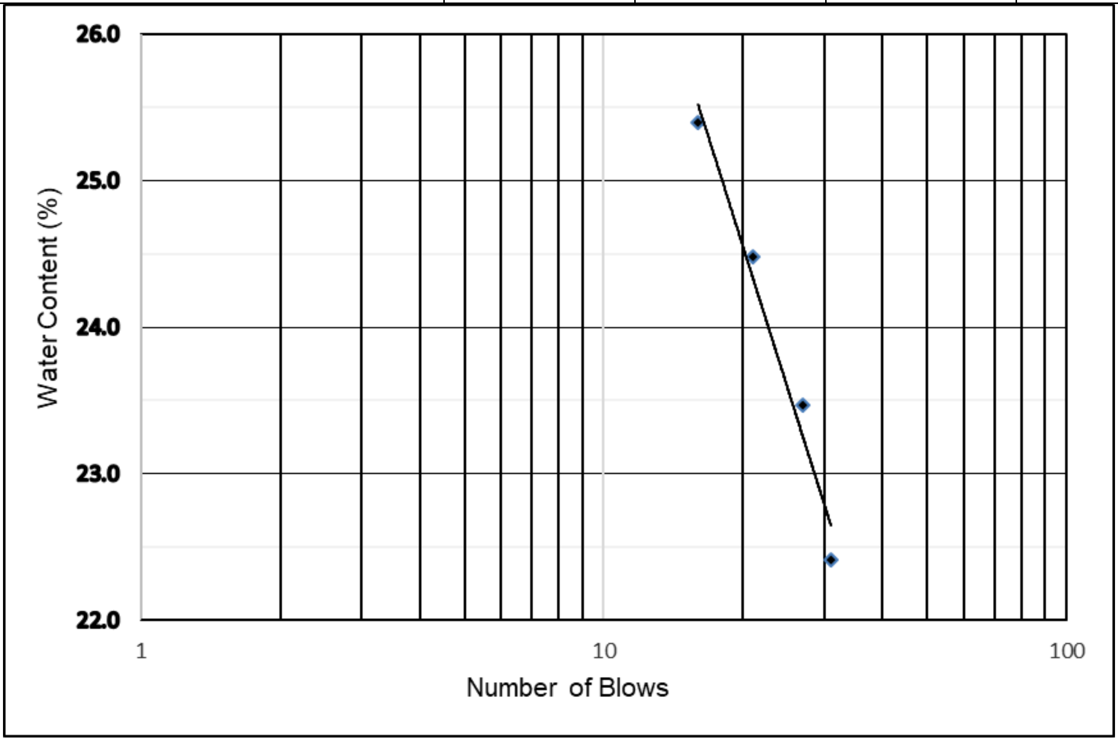
TEST ID: TR_22				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	2	11	1	9
Wt of wet soil + container (gm)	89.84	86.93	88.91	87.66
Wt of dry soil + container (gm)	85.47	82.40	84.21	83.04
Wt of water (gm)	4.37	4.53	4.70	4.62
Wt of container (gm)	63.61	60.75	62.41	62.50
Wt of dry soil (gm)	21.86	21.65	21.80	20.54
Water content, %	20.0	20.9	21.6	22.5
No. of blows	34	27	21	17



Liquid Limit (%)	21.1
Plastic Limit (%)	13.1
Plasticity Index	8.0

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	7	3	
Wt of wet soil + container (gm)	66.26	64.96	13.1
Wt of dry soil + container (gm)	66.00	64.7	
Wt of water (gm)	0.26	0.26	
Wt of container (gm)	64.09	62.64	
Wt of dry soil (gm)	1.91	2.06	
Water content, %	13.6	12.6	

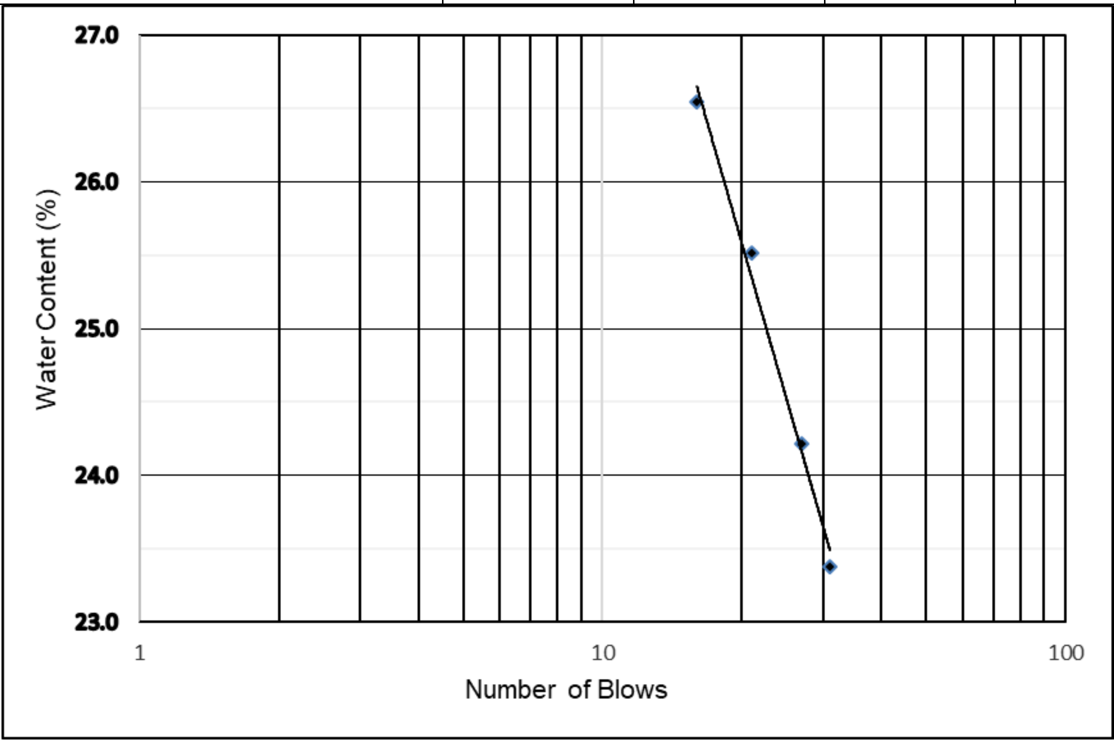
TEST ID: TR_23				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	12	9	15	12
Wt of wet soil + container (gm)	88.24	85.65	89.31	83.24
Wt of dry soil + container (gm)	83.50	81.20	84.60	79.20
Wt of water (gm)	4.74	4.45	4.71	4.04
Wt of container (gm)	62.35	62.24	65.36	63.29
Wt of dry soil (gm)	21.15	18.96	19.24	15.91
Water content, %	22.4	23.5	24.5	25.4
No. of blows	31	27	21	16



Liquid Limit (%)	23.6
Plastic Limit (%)	15.5
Plasticity Index	8.1

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	7	5	
Wt of wet soil + container (gm)	63.25	64.11	15.5
Wt of dry soil + container (gm)	62.84	63.9	
Wt of water (gm)	0.41	0.21	
Wt of container (gm)	60.18	62.55	
Wt of dry soil (gm)	2.66	1.35	
Water content, %	15.4	15.6	

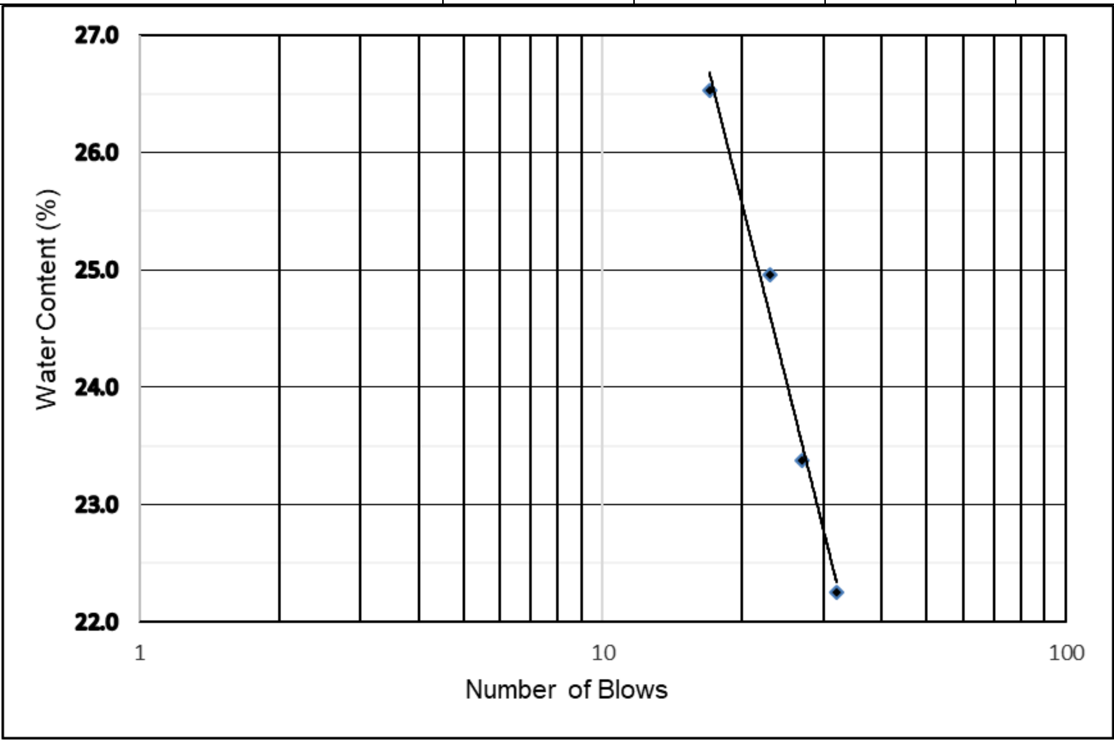
TEST ID: TR_24				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	10	5	4	12
Wt of wet soil + container (gm)	87.62	86.26	90.87	89.37
Wt of dry soil + container (gm)	82.83	81.57	85.44	83.69
Wt of water (gm)	4.79	4.69	5.43	5.68
Wt of container (gm)	62.34	62.20	64.16	62.29
Wt of dry soil (gm)	20.49	19.37	21.28	21.40
Water content, %	23.4	24.2	25.5	26.5
No. of blows	31	27	21	16



Liquid Limit (%)	24.5
Plastic Limit (%)	16.3
Plasticity Index	8.2

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	6	8	
Wt of wet soil + container (gm)	62.89	65.18	16.3
Wt of dry soil + container (gm)	62.51	64.74	
Wt of water (gm)	0.38	0.44	
Wt of container (gm)	60.17	62.06	
Wt of dry soil (gm)	2.34	2.68	
Water content, %	16.2	16.4	

TEST ID: TR_25				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-13	A-20	A-3	A-6
Wt of wet soil + container (gm)	44.30	41.3	41.51	46.29
Wt of dry soil + container (gm)	39.63	37.04	36.69	40.73
Wt of water (gm)	4.67	4.26	4.82	5.56
Wt of container (gm)	18.65	18.82	17.38	19.77
Wt of dry soil (gm)	20.98	18.22	19.31	20.96
Water content, %	22.3	23.4	25.0	26.5
No. of blows	32	27	23	17



Liquid Limit (%)	24.0
Plastic Limit (%)	15.3
Plasticity Index	8.7

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-66	A-11	
Wt of wet soil + container (gm)	33.14	20.31	15.3
Wt of dry soil + container (gm)	32.79	19.99	
Wt of water (gm)	0.35	0.32	
Wt of container (gm)	30.53	17.87	
Wt of dry soil (gm)	2.26	2.12	
Water content, %	15.5	15.1	

TEST ID: TR_26				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-22	A-3	A-27	A-8
Wt of wet soil + container (gm)	45.57	39.28	42.69	41.80
Wt of dry soil + container (gm)	40.63	35.00	38.12	37.01
Wt of water (gm)	4.94	4.28	4.57	4.79
Wt of container (gm)	19.42	17.36	20.13	18.57
Wt of dry soil (gm)	21.21	17.64	17.99	18.44
Water content, %	23.3	24.3	25.4	26.0
No. of blows	32	27	23	17

Liquid Limit (%)	24.6
Plastic Limit (%)	12.5
Plasticity Index	12.1

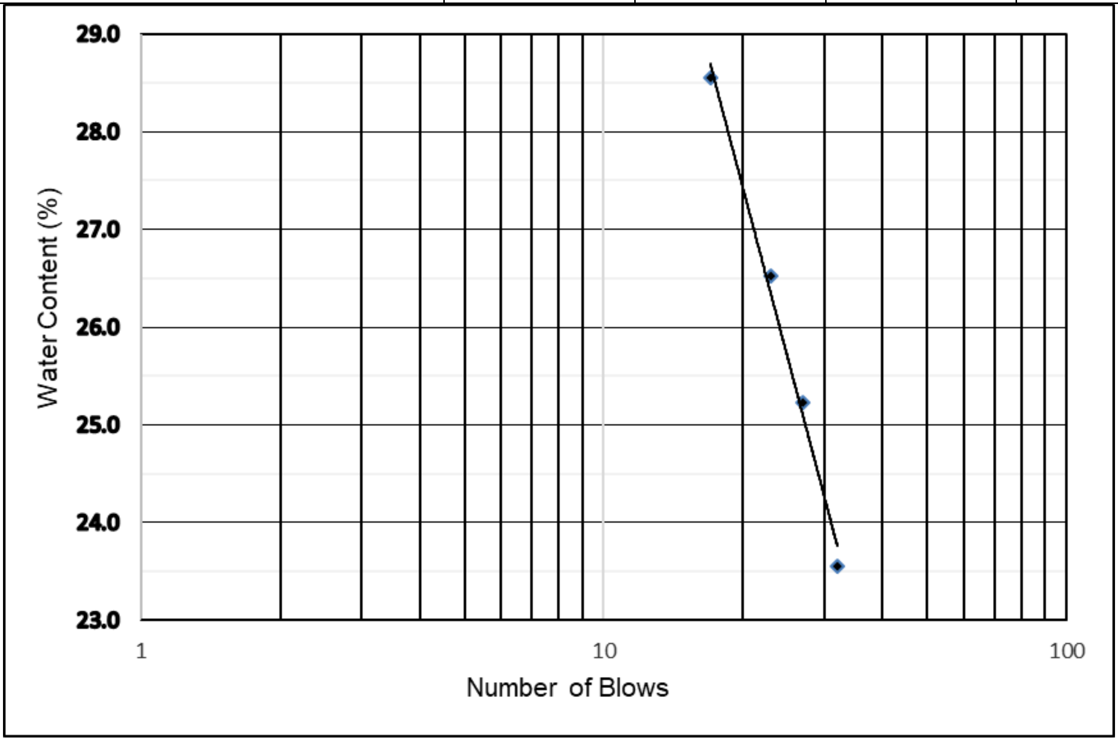
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	9	2	
Wt of wet soil + container (gm)	67.51	66.98	12.5
Wt of dry soil + container (gm)	67.06	66.50	
Wt of water (gm)	0.45	0.48	
Wt of container (gm)	63.62	62.49	
Wt of dry soil (gm)	3.44	4.01	
Water content, %	13.1	12.0	

TEST ID: TR_26				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-22	A-3	A-27	A-8
Wt of wet soil + container (gm)	45.57	39.28	42.69	41.80
Wt of dry soil + container (gm)	40.63	35.00	38.12	37.01
Wt of water (gm)	4.94	4.28	4.57	4.79
Wt of container (gm)	19.42	17.36	20.13	18.57
Wt of dry soil (gm)	21.21	17.64	17.99	18.44
Water content, %	23.3	24.3	25.4	26.0
No. of blows	32	27	23	17

Liquid Limit (%)	24.6
Plastic Limit (%)	12.5
Plasticity Index	12.1

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	9	2	
Wt of wet soil + container (gm)	67.51	66.98	
Wt of dry soil + container (gm)	67.06	66.50	
Wt of water (gm)	0.45	0.48	12.5
Wt of container (gm)	63.62	62.49	
Wt of dry soil (gm)	3.44	4.01	
Water content, %	13.1	12.0	

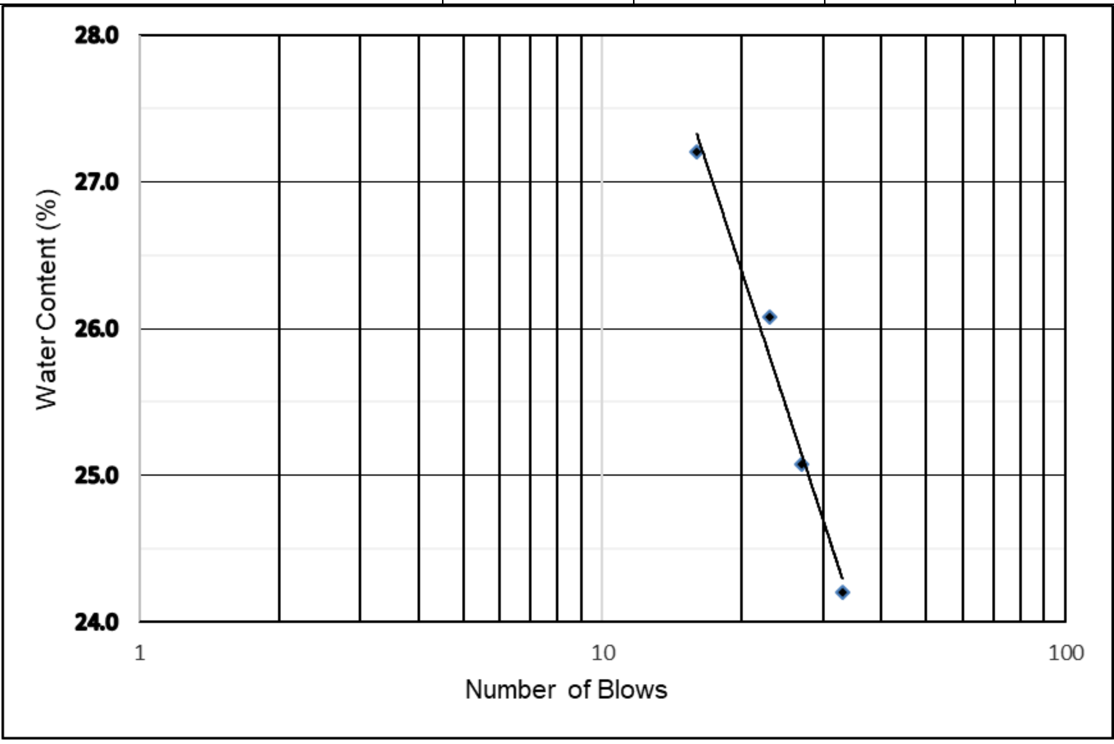
TEST ID: TR_27				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-11	A-60	A-18	A-23
Wt of wet soil + container (gm)	46.20	43.62	40.73	40.77
Wt of dry soil + container (gm)	40.80	38.73	36.26	35.99
Wt of water (gm)	5.40	4.89	4.47	4.78
Wt of container (gm)	17.88	19.35	19.41	19.25
Wt of dry soil (gm)	22.92	19.38	16.85	16.74
Water content, %	23.6	25.2	26.5	28.6
No. of blows	32	27	23	17



Liquid Limit (%)	25.7
Plastic Limit (%)	16.3
Plasticity Index	9.4

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-3	A-26	
Wt of wet soil + container (gm)	20.58	23.61	16.3
Wt of dry soil + container (gm)	20.13	23.11	
Wt of water (gm)	0.45	0.50	
Wt of container (gm)	17.37	20.04	
Wt of dry soil (gm)	2.76	3.07	
Water content, %	16.3	16.3	

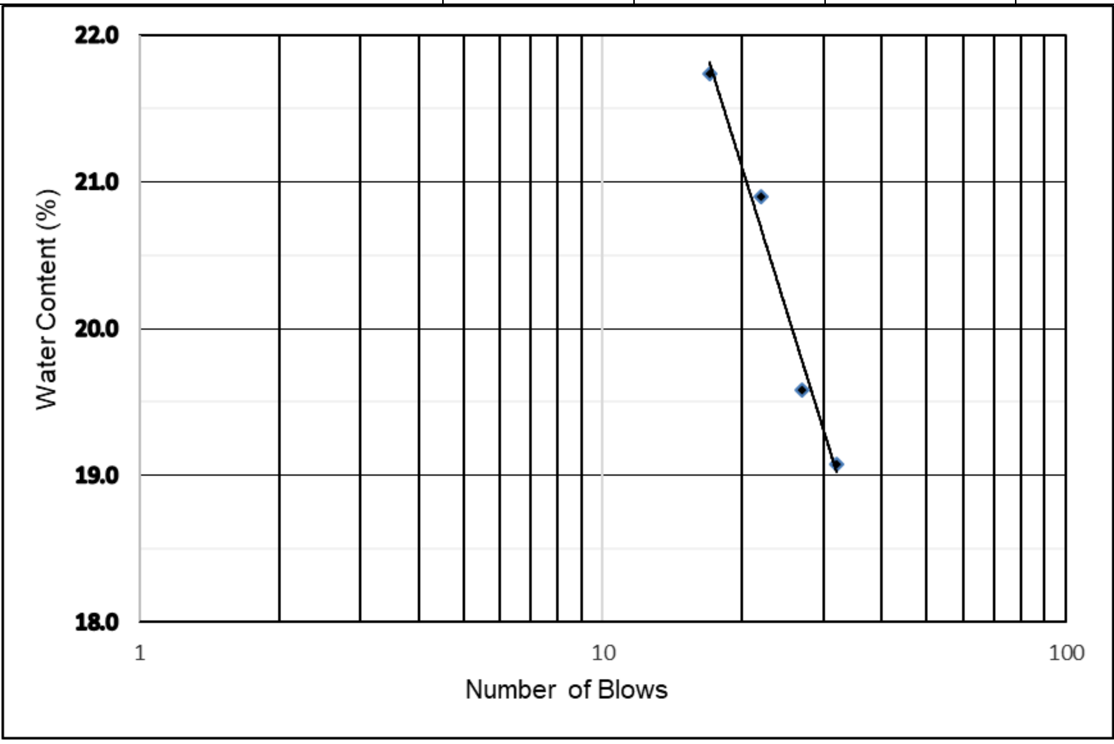
TEST ID: TR_28				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-60	A-6	A-26	A-21
Wt of wet soil + container (gm)	43.98	50.17	47.89	43.78
Wt of dry soil + container (gm)	39.18	44.09	42.14	38.48
Wt of water (gm)	4.80	6.08	5.75	5.30
Wt of container (gm)	19.35	19.84	20.09	19.00
Wt of dry soil (gm)	19.83	24.25	22.05	19.48
Water content, %	24.2	25.1	26.1	27.2
No. of blows	33	27	23	16



Liquid Limit (%)	25.5
Plastic Limit (%)	15.3
Plasticity Index	10.1

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-22	A-25	
Wt of wet soil + container (gm)	20.47	33.06	
Wt of dry soil + container (gm)	20.25	32.72	
Wt of water (gm)	0.22	0.34	15.3
Wt of container (gm)	18.80	30.52	
Wt of dry soil (gm)	1.45	2.20	
Water content, %	15.2	15.5	

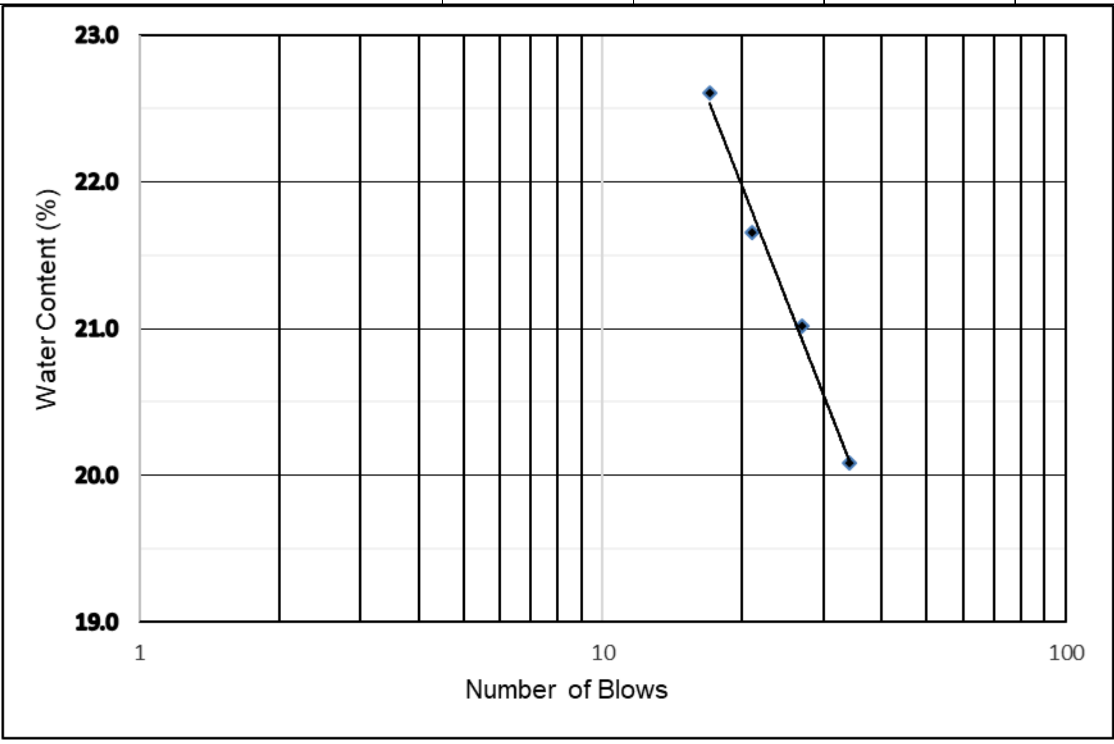
TEST ID: TR_29				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-7	A-4	A-12	A-2
Wt of wet soil + container (gm)	86.50	88.82	84.12	91.00
Wt of dry soil + container (gm)	82.92	84.78	80.34	86.12
Wt of water (gm)	3.58	4.04	3.78	4.88
Wt of container (gm)	64.15	64.15	62.25	63.67
Wt of dry soil (gm)	18.77	20.63	18.09	22.45
Water content, %	19.1	19.6	20.9	21.7
No. of blows	32	27	22	17



Liquid Limit (%)	20.1
Plastic Limit (%)	13.0
Plasticity Index	7.1

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-1	A-10	
Wt of wet soil + container (gm)	63.89	64.75	13.0
Wt of dry soil + container (gm)	63.73	64.47	
Wt of water (gm)	0.16	0.28	
Wt of container (gm)	62.46	62.38	
Wt of dry soil (gm)	1.27	2.09	
Water content, %	12.6	13.4	

TEST ID: TR_30				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	2	11	1	9
Wt of wet soil + container (gm)	89.74	86.83	88.81	87.56
Wt of dry soil + container (gm)	85.37	82.30	84.11	82.94
Wt of water (gm)	4.37	4.53	4.70	4.62
Wt of container (gm)	63.61	60.75	62.41	62.50
Wt of dry soil (gm)	21.76	21.55	21.70	20.44
Water content, %	20.1	21.0	21.7	22.6
No. of blows	34	27	21	17



Liquid Limit (%)	21.2
Plastic Limit (%)	13.2
Plasticity Index	8.0

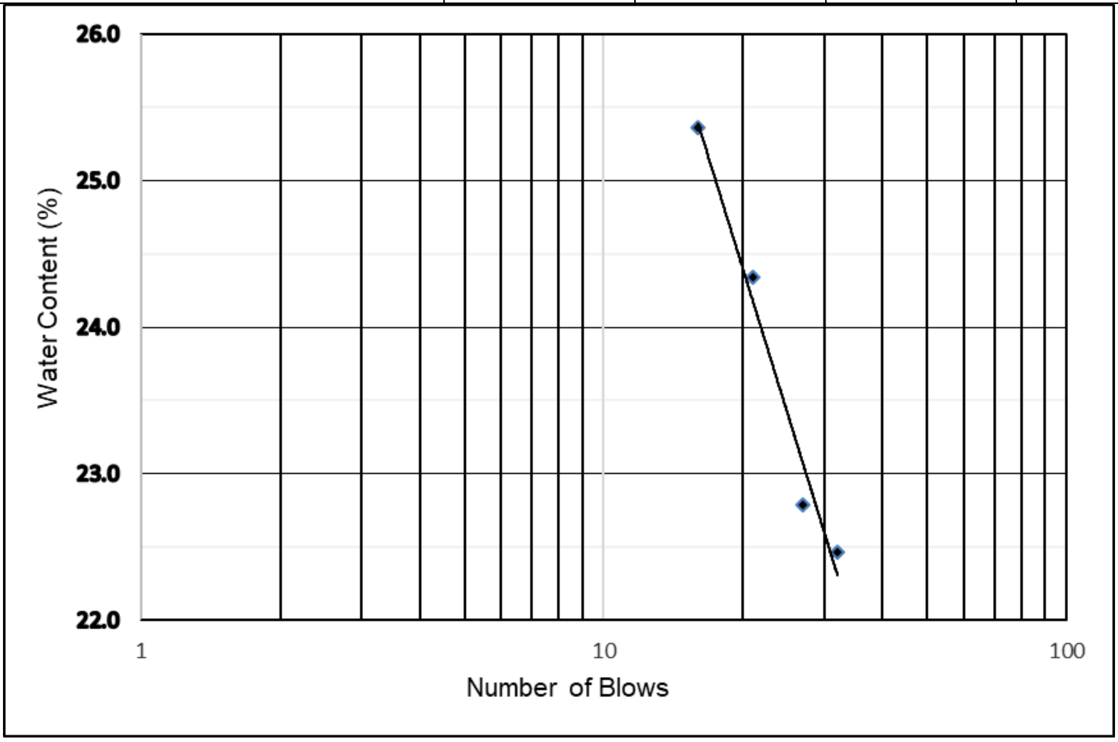
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	7	3	
Wt of wet soil + container (gm)	66.25	64.95	13.2
Wt of dry soil + container (gm)	65.99	64.69	
Wt of water (gm)	0.26	0.26	
Wt of container (gm)	64.09	62.64	
Wt of dry soil (gm)	1.90	2.05	
Water content, %	13.7	12.7	

TEST ID: TR_31				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-5	A-6	A-25	A-60
Wt of wet soil + container (gm)	36.01	39.02	41.90	36.66
Wt of dry soil + container (gm)	32.90	35.28	37.37	33.07
Wt of water (gm)	3.11	3.74	4.53	3.59
Wt of container (gm)	19.46	19.84	19.69	19.35
Wt of dry soil (gm)	13.44	15.44	17.68	13.72
Water content, %	23.1	24.2	25.6	26.2
No. of blows	34	27	23	17

Liquid Limit (%)	23.7
Plastic Limit (%)	15.4
Plasticity Index	8.3

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-8	A-66	
Wt of wet soil + container (gm)	22.17	34.87	15.4
Wt of dry soil + container (gm)	21.7	34.28	
Wt of water (gm)	0.47	0.59	
Wt of container (gm)	18.6	30.52	
Wt of dry soil (gm)	3.10	3.76	
Water content, %	15.2	15.7	

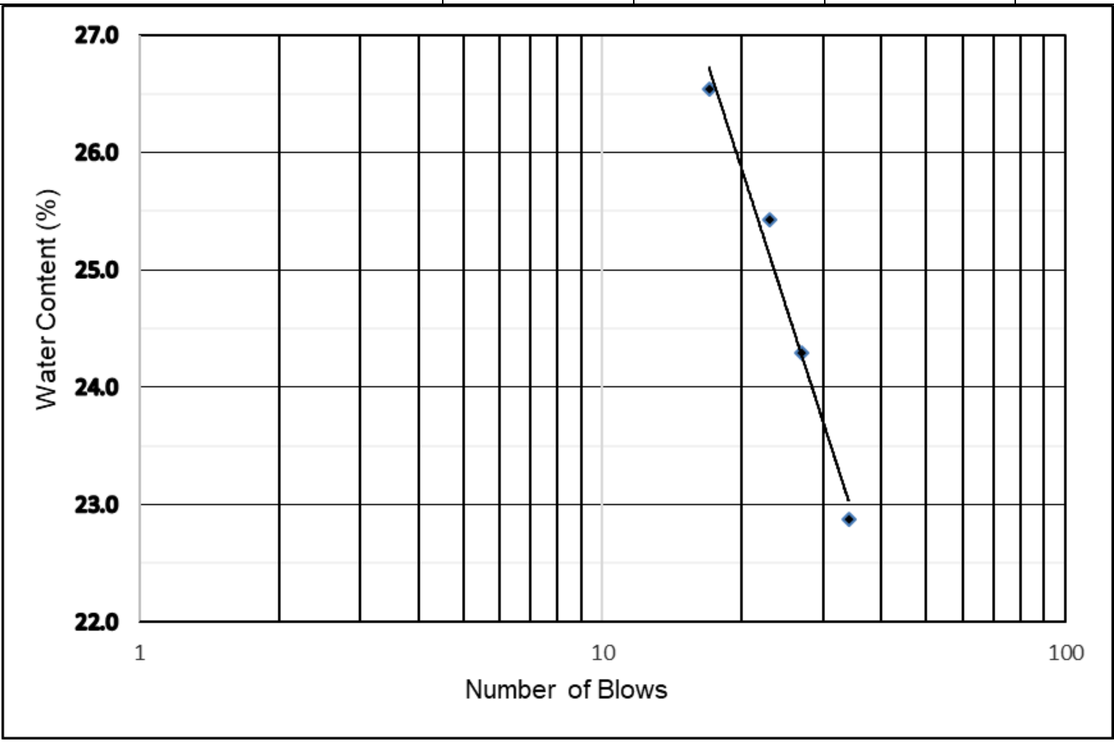
TEST ID: TR_32				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-11	A-6	A-3	A-8
Wt of wet soil + container (gm)	81.92	77.68	81.55	82.94
Wt of dry soil + container (gm)	78.05	74.44	77.86	78.72
Wt of water (gm)	3.87	3.24	3.69	4.22
Wt of container (gm)	60.82	60.22	62.70	62.08
Wt of dry soil (gm)	17.23	14.22	15.16	16.64
Water content, %	22.5	22.8	24.3	25.4
No. of blows	32	27	21	16



Liquid Limit (%)	23.4
Plastic Limit (%)	16.2
Plasticity Index	7.2

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-1	A-9	
Wt of wet soil + container (gm)	65.20	65.11	
Wt of dry soil + container (gm)	64.80	64.76	
Wt of water (gm)	0.40	0.35	16.2
Wt of container (gm)	62.38	62.55	
Wt of dry soil (gm)	2.42	2.21	
Water content, %	16.5	15.8	

TEST ID: TR_33				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-64	A-21	A-3	A-65
Wt of wet soil + container (gm)	43.01	38.97	35.88	31.17
Wt of dry soil + container (gm)	38.75	35.07	32.14	28.62
Wt of water (gm)	4.26	3.90	3.74	2.55
Wt of container (gm)	20.13	19.02	17.43	19.01
Wt of dry soil (gm)	18.62	16.05	14.71	9.61
Water content, %	22.9	24.3	25.4	26.5
No. of blows	34	27	23	17



Liquid Limit (%)	24.7
Plastic Limit (%)	15.0
Plasticity Index	9.6

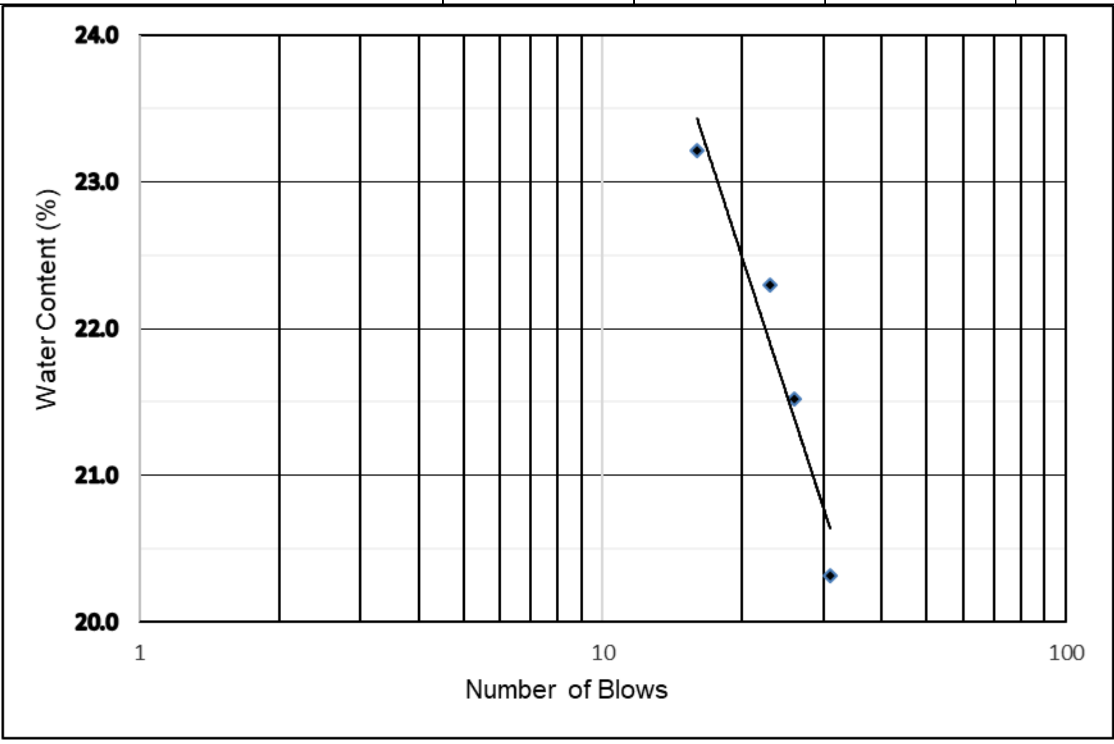
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-26	A-13	
Wt of wet soil + container (gm)	23.44	22.05	15.0
Wt of dry soil + container (gm)	22.99	21.62	
Wt of water (gm)	0.45	0.43	
Wt of container (gm)	20.09	18.66	
Wt of dry soil (gm)	2.90	2.96	
Water content, %	15.5	14.5	

TEST ID: TR_34				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	4	3	5	1
Wt of wet soil + container (gm)	47.03	42.57	43.10	41.29
Wt of dry soil + container (gm)	42.28	38.43	38.63	37.14
Wt of water (gm)	4.75	4.14	4.47	4.15
Wt of container (gm)	18.95	18.98	18.64	19.45
Wt of dry soil (gm)	23.33	19.45	19.99	17.69
Water content, %	20.4	21.3	22.4	23.5
No. of blows	31	28	23	17

Liquid Limit (%)	21.7
Plastic Limit (%)	15.1
Plasticity Index	6.6

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	7	9	
Wt of wet soil + container (gm)	23.06	23.83	15.1
Wt of dry soil + container (gm)	22.46	23.36	
Wt of water (gm)	0.60	0.47	
Wt of container (gm)	18.62	20.13	
Wt of dry soil (gm)	3.84	3.23	
Water content, %	15.6	14.6	

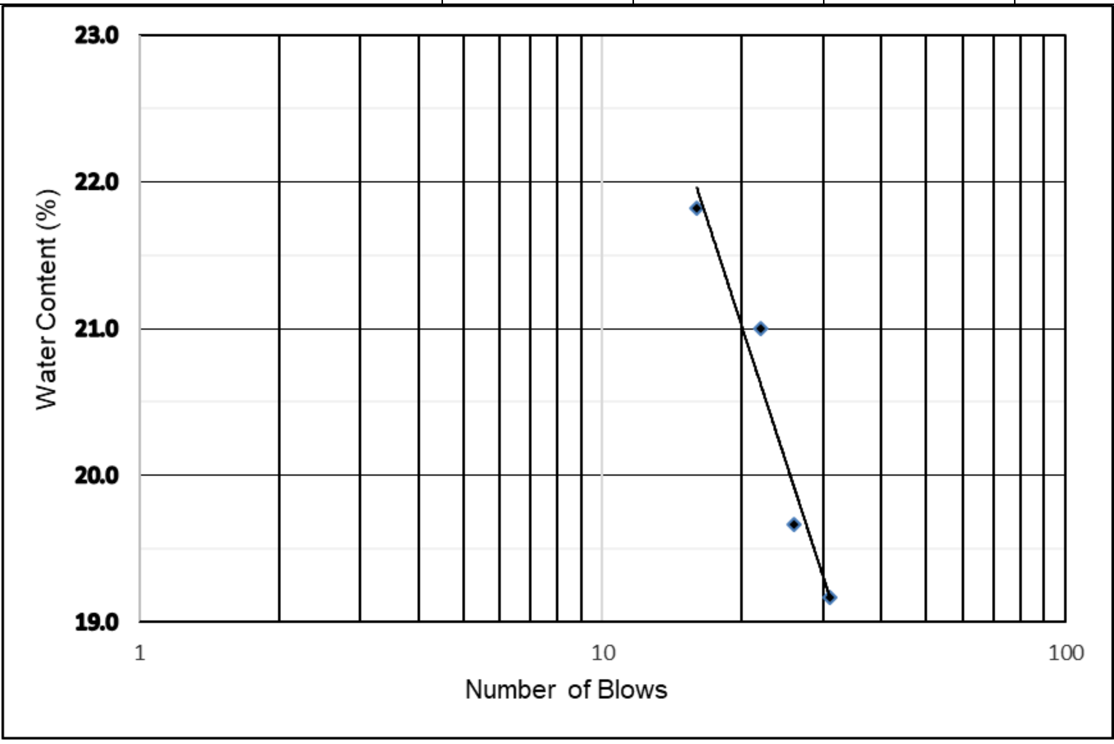
TEST ID: TR_35				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-1	A-6	A-7	A-12
Wt of wet soil + container (gm)	87.62	82.74	89.02	86.04
Wt of dry soil + container (gm)	83.37	78.75	84.49	81.56
Wt of water (gm)	4.25	3.99	4.53	4.48
Wt of container (gm)	62.45	60.21	64.17	62.26
Wt of dry soil (gm)	20.92	18.54	20.32	19.30
Water content, %	20.3	21.5	22.3	23.2
No. of blows	31	26	23	16



Liquid Limit (%)	21.5
Plastic Limit (%)	13.9
Plasticity Index	7.6

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-8	A-10	
Wt of wet soil + container (gm)	64.99	65.06	
Wt of dry soil + container (gm)	64.65	64.72	
Wt of water (gm)	0.34	0.34	13.3
Wt of container (gm)	62.09	62.38	
Wt of dry soil (gm)	2.56	2.34	
Water content, %	13.3	14.5	

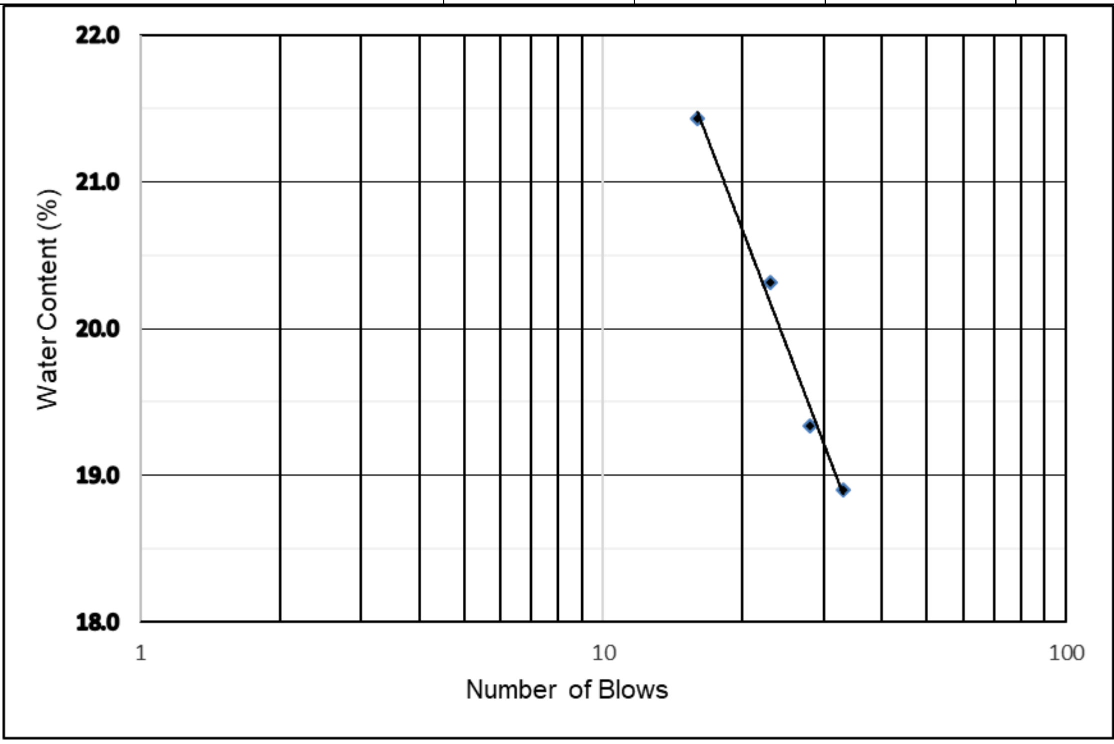
TEST ID: TR_36				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-7	A-4	A-12	A-2
Wt of wet soil + container (gm)	86.41	88.73	84.03	90.91
Wt of dry soil + container (gm)	82.83	84.69	80.25	86.03
Wt of water (gm)	3.58	4.04	3.78	4.88
Wt of container (gm)	64.15	64.15	62.25	63.67
Wt of dry soil (gm)	18.68	20.54	18.00	22.36
Water content, %	19.2	19.7	21.0	21.8
No. of blows	31	26	22	16



Liquid Limit (%)	20.1
Plastic Limit (%)	12.8
Plasticity Index	7.2

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-1	A-10	
Wt of wet soil + container (gm)	63.86	64.85	12.8
Wt of dry soil + container (gm)	63.70	64.57	
Wt of water (gm)	0.16	0.28	
Wt of container (gm)	62.46	62.38	
Wt of dry soil (gm)	1.24	2.19	
Water content, %	12.9	12.8	

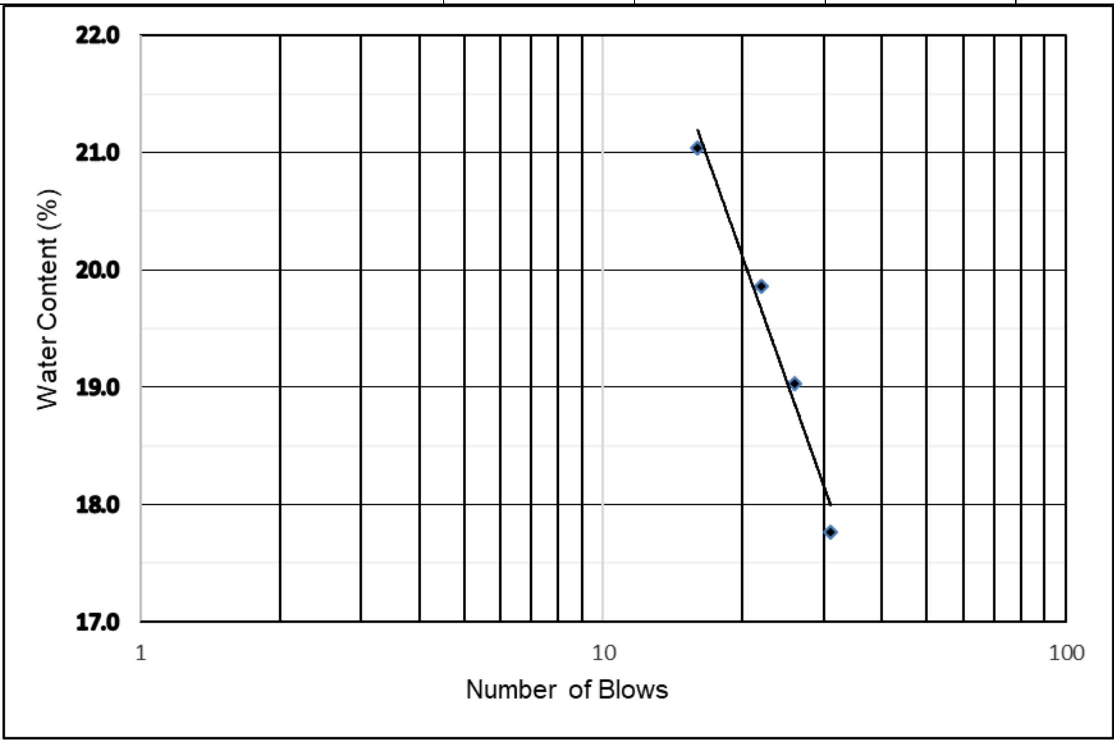
TEST ID: TR_37				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-17	A-5	A-23	A-25
Wt of wet soil + container (gm)	42.79	47.04	48.27	42.76
Wt of dry soil + container (gm)	39.03	42.57	43.37	38.69
Wt of water (gm)	3.76	4.47	4.90	4.07
Wt of container (gm)	19.14	19.45	19.25	19.70
Wt of dry soil (gm)	19.89	23.12	24.12	18.99
Water content, %	18.9	19.3	20.3	21.4
No. of blows	33	28	23	16



Liquid Limit (%)	19.9
Plastic Limit (%)	14.0
Plasticity Index	5.8

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-64	A-65	
Wt of wet soil + container (gm)	22.01	21.34	14.0
Wt of dry soil + container (gm)	21.65	21.04	
Wt of water (gm)	0.36	0.30	
Wt of container (gm)	18.97	18.99	
Wt of dry soil (gm)	2.68	2.05	
Water content, %	13.4	14.6	

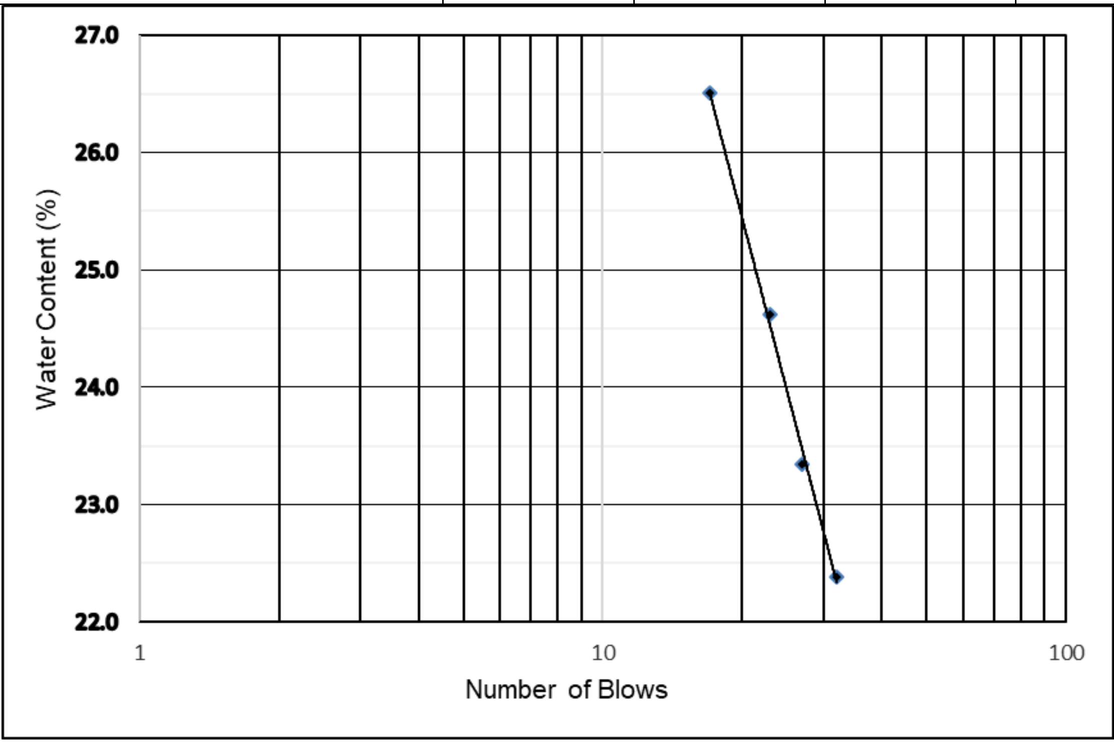
TEST ID: TR_38				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-25	A-6	A-8	A-65
Wt of wet soil + container (gm)	55.09	44.09	51.97	48.24
Wt of dry soil + container (gm)	49.75	41.92	46.44	43.16
Wt of water (gm)	5.34	2.17	5.53	5.08
Wt of container (gm)	19.69	30.52	18.60	19.01
Wt of dry soil (gm)	30.06	11.40	27.84	24.15
Water content, %	17.8	19.0	19.9	21.0
No. of blows	31	26	22	16



Liquid Limit (%)	19.0
Plastic Limit (%)	12.2
Plasticity Index	6.9

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-64	A-5	
Wt of wet soil + container (gm)	22.80	22	12.2
Wt of dry soil + container (gm)	22.51	21.72	
Wt of water (gm)	0.29	0.28	
Wt of container (gm)	20.09	19.46	
Wt of dry soil (gm)	2.42	2.26	
Water content, %	12.0	12.4	

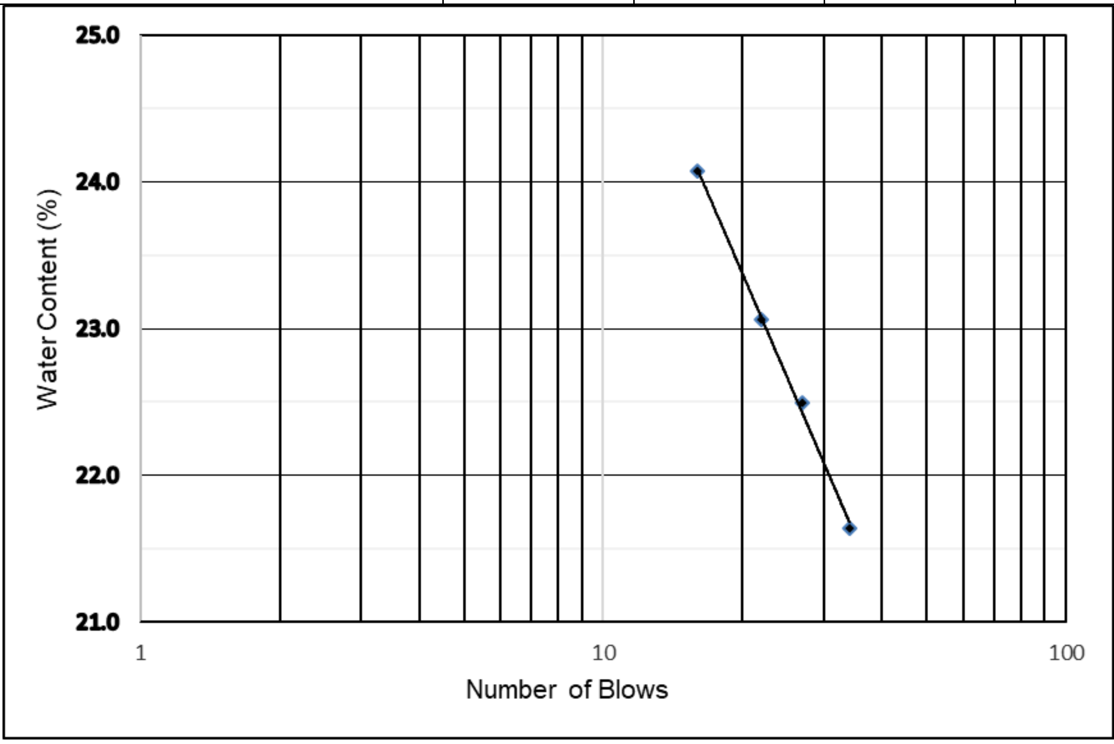
TEST ID: TR_39				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	4	3	5	1
Wt of wet soil + container (gm)	87.95	82.57	89.96	86.22
Wt of dry soil + container (gm)	83.60	78.81	84.48	81.24
Wt of water (gm)	4.35	3.76	5.48	4.98
Wt of container (gm)	64.17	62.70	62.22	62.45
Wt of dry soil (gm)	19.43	16.11	22.26	18.79
Water content, %	22.4	23.3	24.6	26.5
No. of blows	32	27	23	17



Liquid Limit (%)	24.0
Plastic Limit (%)	15.2
Plasticity Index	8.8

PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	7	9	
Wt of wet soil + container (gm)	67.02	64.73	15.2
Wt of dry soil + container (gm)	66.64	64.44	
Wt of water (gm)	0.38	0.29	
Wt of container (gm)	64.15	62.53	
Wt of dry soil (gm)	2.49	1.91	
Water content, %	15.3	15.2	

TEST ID: TR_40				
LIQUID LIMIT				
Test No,	1	2	3	4
Container No.	A-20	A-21	A-27	A-23
Wt of wet soil + container (gm)	38.80	46.39	49.75	45.34
Wt of dry soil + container (gm)	35.24	41.36	44.20	40.35
Wt of water (gm)	3.56	5.03	5.55	4.99
Wt of container (gm)	18.79	19.00	20.13	19.62
Wt of dry soil (gm)	16.45	22.36	24.07	20.73
Water content, %	21.6	22.5	23.1	24.1
No. of blows	34	27	22	16

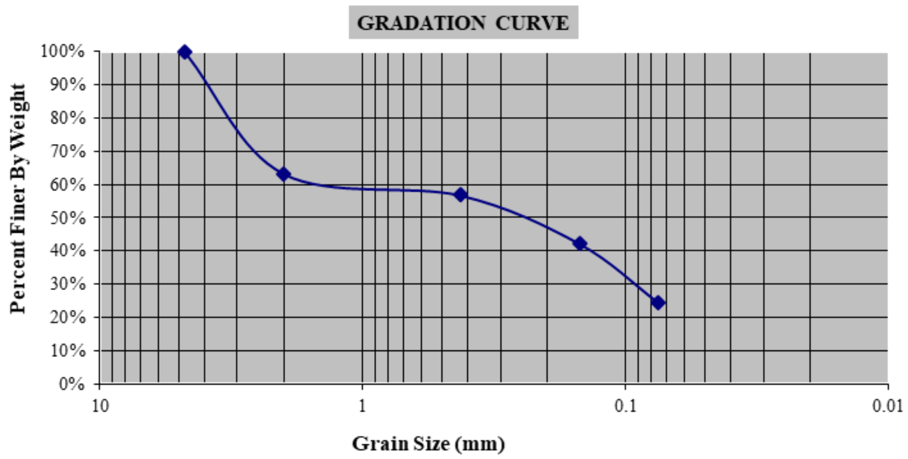


Liquid Limit (%)	22.7
Plastic Limit (%)	15.4
Plasticity Index	7.3

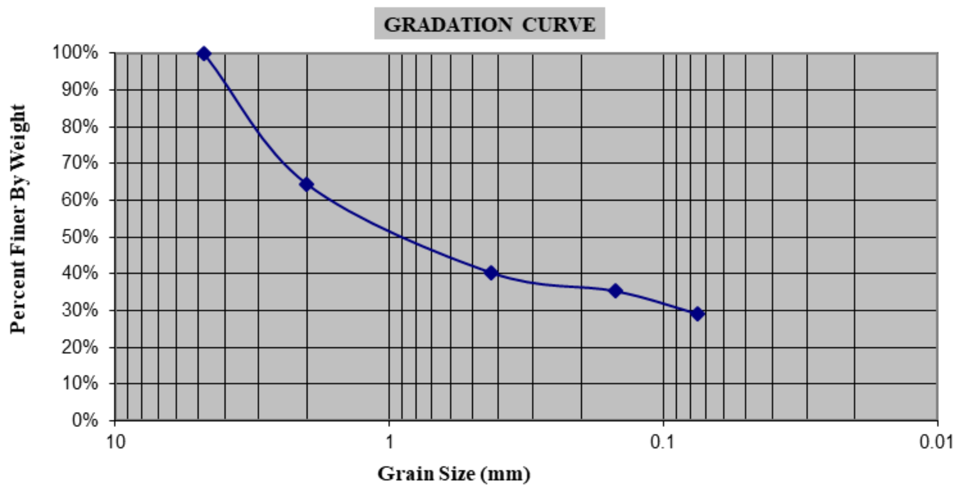
PLASTIC LIMIT			
Test No,	1	2	PL
Container No.	A-60	A-14	
Wt of wet soil + container (gm)	21.85	22.08	15.4
Wt of dry soil + container (gm)	21.52	21.82	
Wt of water (gm)	0.33	0.26	
Wt of container (gm)	19.36	20.14	
Wt of dry soil (gm)	2.16	1.68	
Water content, %	15.3	15.5	

Appendix 4: Sieve Analysis

Test ID: TR_01					
SIEVE ANALYSIS					
Weight of sample = 1000gm					
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative % Retained	% Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	367.0	36.7%	36.7%	63.3%
40	0.425	65.0	6.5%	43.2%	56.8%
100	0.15	145.0	14.5%	57.7%	42.3%
200	0.075	177.0	17.7%	75.4%	24.6%
Pan		246.00	24.60%	100.00%	0.00%



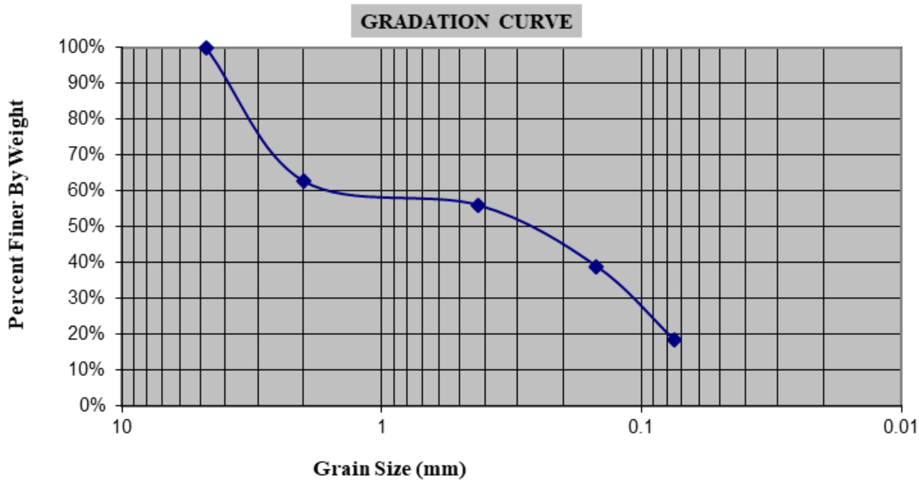
Test ID: TR_02					
SIEVE ANALYSIS					
Weight of sample = 1000gm					
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	355.0	35.5%	35.5%	64.5%
40	0.425	241.0	24.1%	59.6%	40.4%
100	0.15	50.0	5.0%	64.6%	35.4%
200	0.075	62.0	6.2%	70.8%	29.2%
Pan		292.00	29.20%	100.00%	0.00%



Test ID: TR_03
SIEVE ANALYSIS

Weight of sample = 1000gm

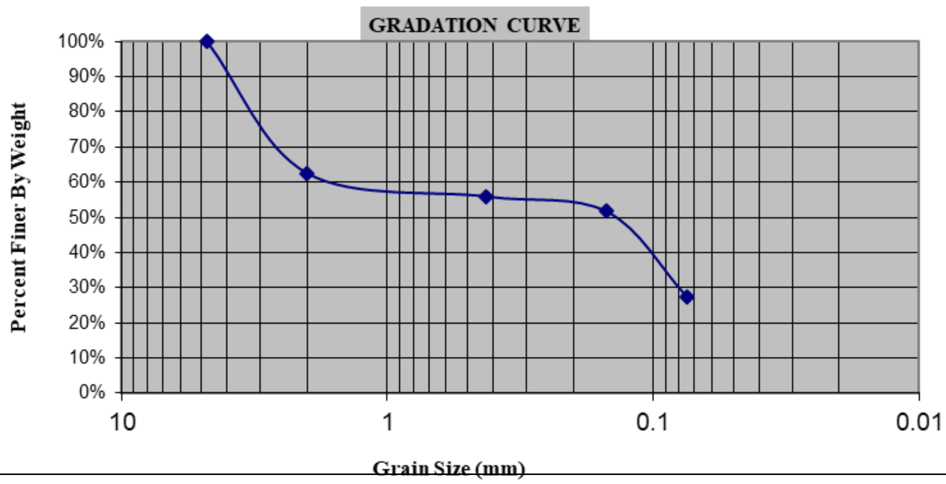
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	373.0	37.3%	37.3%	62.7%
40	0.425	67.0	6.7%	44.0%	56.0%
100	0.15	170.0	17.0%	61.0%	39.0%
200	0.075	207.0	20.7%	81.7%	18.3%
Pan		183.00	18.30%	100.00%	0.00%



Test ID: TR_04
SIEVE ANALYSIS

Weight of sample = 1000gm

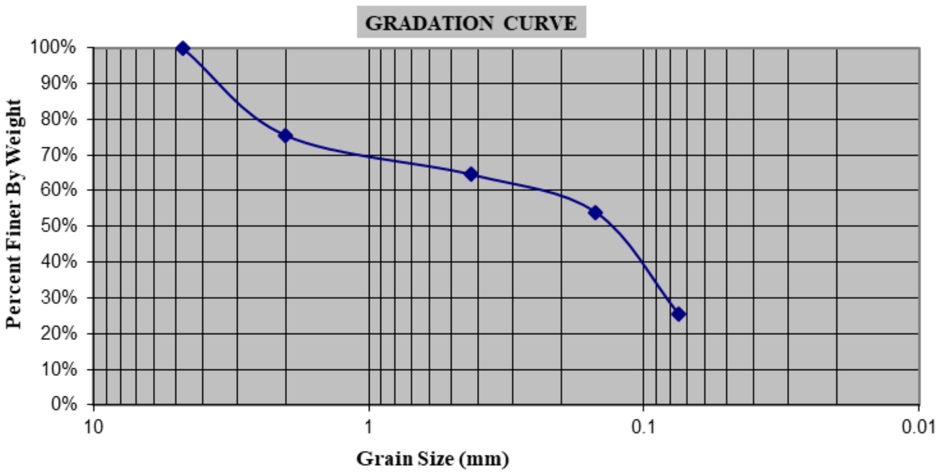
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	374.0	37.4%	37.4%	62.6%
40	0.425	66.0	6.6%	44.0%	56.0%
100	0.15	43.0	4.3%	48.3%	51.7%
200	0.075	242.0	24.2%	72.5%	27.5%
Pan		275.00	27.50%	100.00%	0.00%



Test ID: TR_05
SIEVE ANALYSIS

Weight of sample = 1000gm

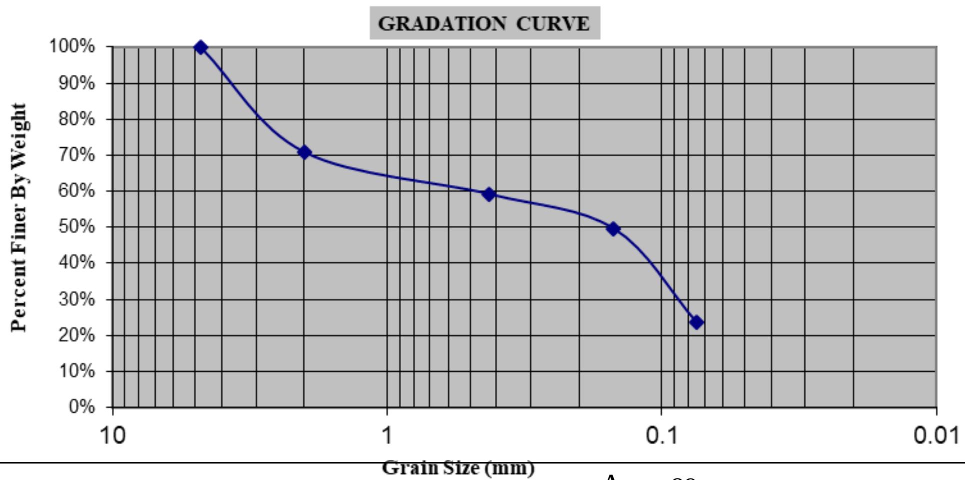
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	245.0	24.5%	24.5%	75.5%
40	0.425	109.0	10.9%	35.4%	64.6%
100	0.15	106.0	10.6%	46.0%	54.0%
200	0.075	285.0	28.5%	74.5%	25.5%
Pan		255.00	25.50%	100.00%	0.00%



Test ID: TR_06
SIEVE ANALYSIS

Weight of sample = 1000gm

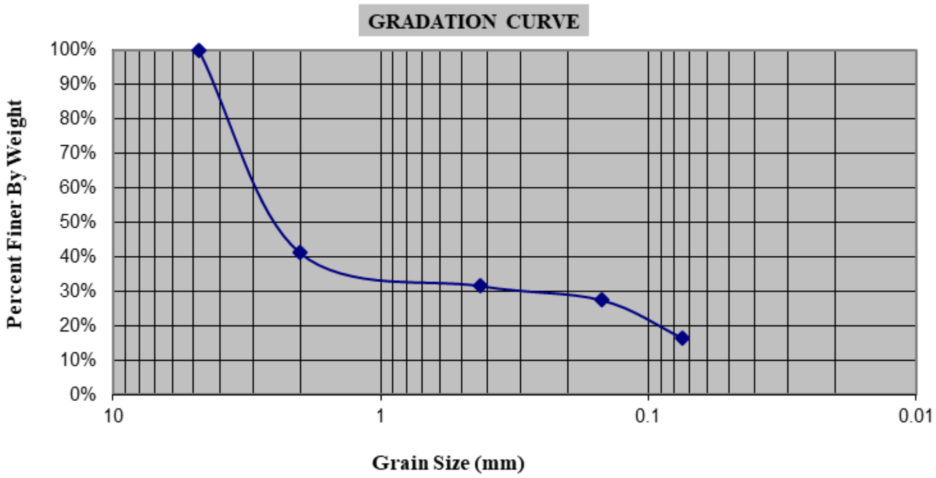
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	291.0	29.1%	29.1%	70.9%
40	0.425	117.0	11.7%	40.8%	59.2%
100	0.15	96.0	9.6%	50.4%	49.6%
200	0.075	261.0	26.1%	76.5%	23.5%
Pan		235.00	23.50%	100.00%	0.00%



Test ID: TR_07
SIEVE ANALYSIS

Weight of sample = 1000gm

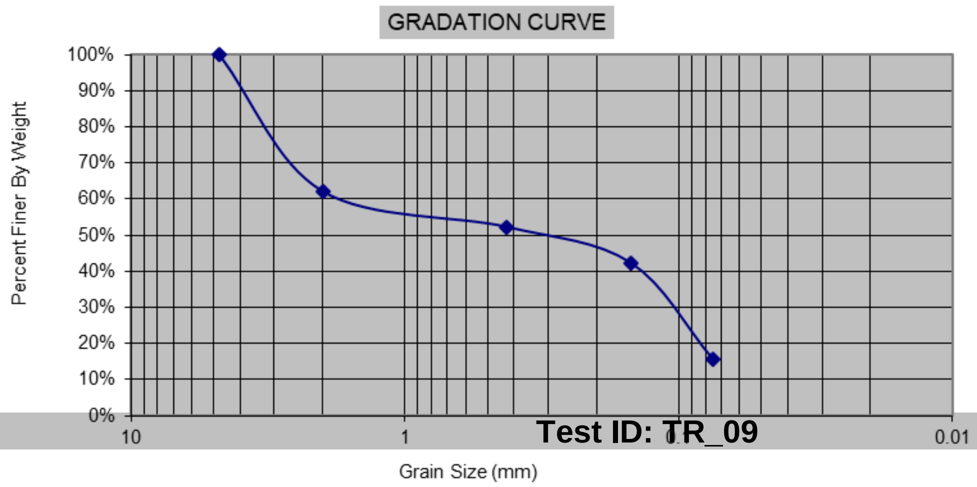
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	588.0	58.8%	58.8%	41.2%
40	0.425	97.0	9.7%	68.5%	31.5%
100	0.15	41.0	4.1%	72.6%	27.4%
200	0.075	110.0	11.0%	83.6%	16.4%
Pan		164.00	16.40%	100.00%	0.00%



Test ID: TR_08
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	378.0	37.8%	37.8%	62.2%
40	0.425	99.0	9.9%	47.7%	52.3%
100	0.15	99.0	9.9%	57.6%	42.4%
200	0.075	268.0	26.8%	84.4%	15.6%
Pan		156.00	15.60%	100.00%	0.00%

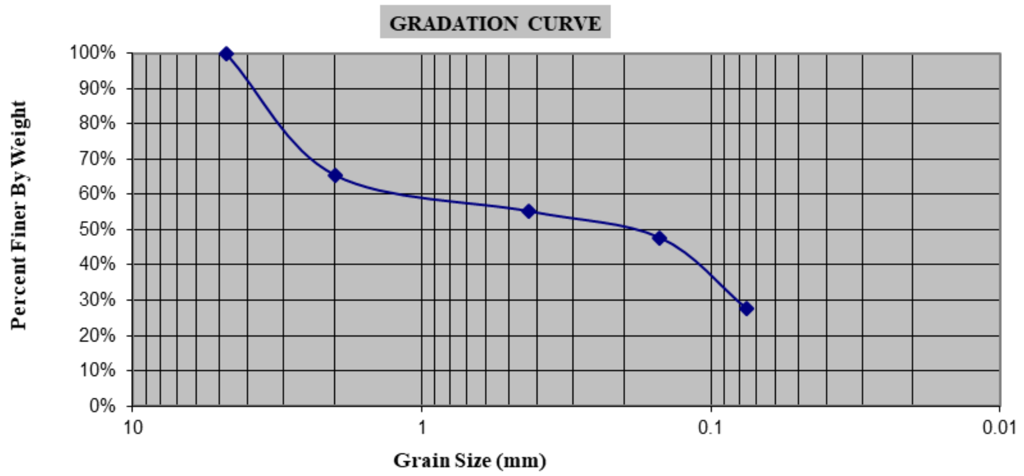


Test ID: TR_09

SIEVE ANALYSIS

Weight of sample = 1000gm

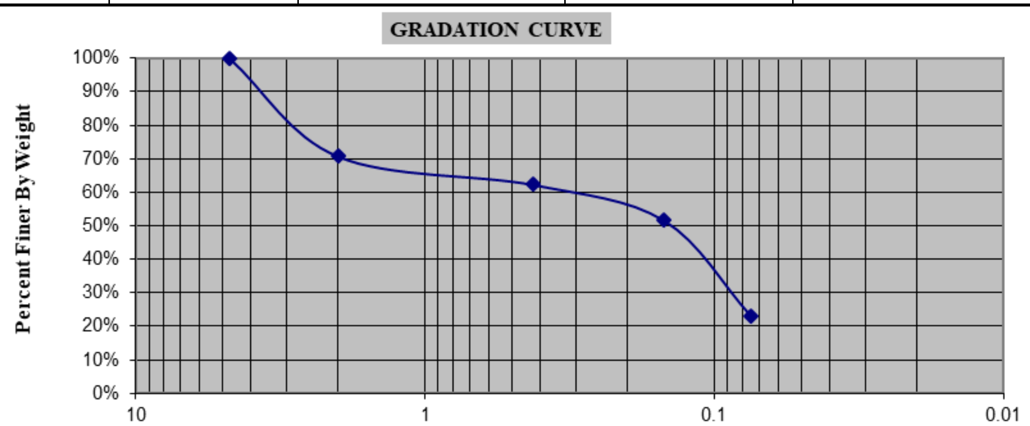
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	345.0	34.5%	34.5%	65.5%
40	0.425	103.0	10.3%	44.8%	55.2%
100	0.15	75.0	7.5%	52.3%	47.7%
200	0.075	202.0	20.2%	72.5%	27.5%
Pan		275.00	27.50%	100.00%	0.00%



Test ID: TR_10
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	293.0	29.3%	29.3%	70.7%
40	0.425	84.0	8.4%	37.7%	62.3%
100	0.15	106.0	10.6%	48.3%	51.7%
200	0.075	285.0	28.5%	76.8%	23.2%
Pan		232.00	23.20%	100.00%	0.00%

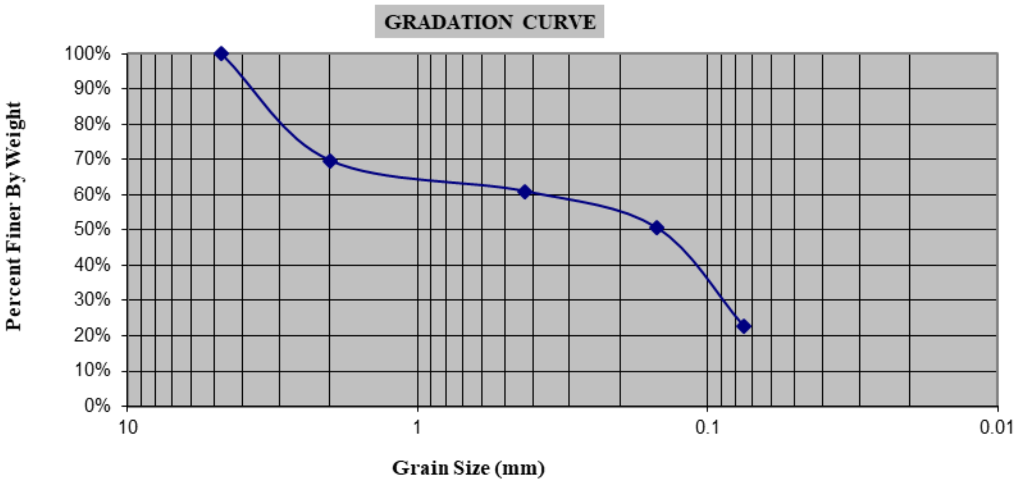


Test ID: TR_11

SIEVE ANALYSIS

Weight of sample = 1000gm

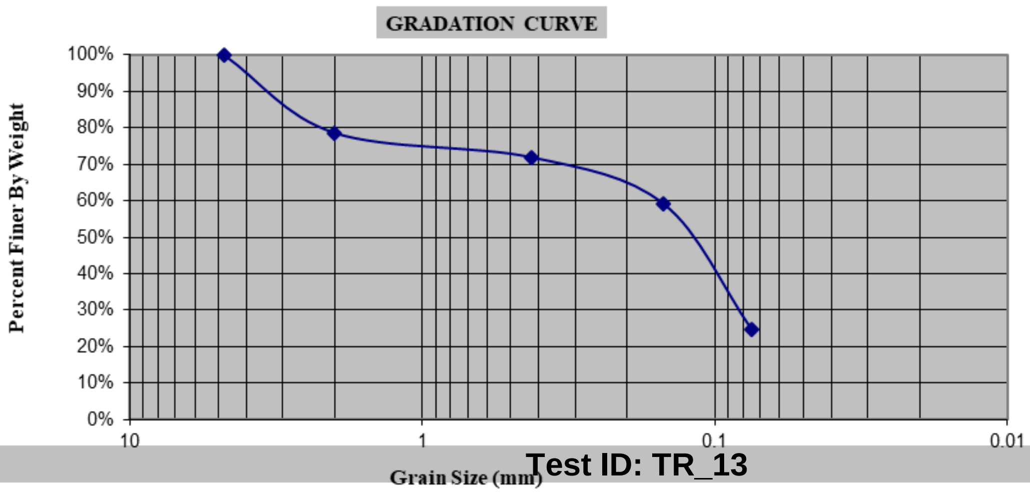
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	303.0	30.3%	30.3%	69.7%
40	0.425	87.0	8.7%	39.0%	61.0%
100	0.15	103.0	10.3%	49.3%	50.7%
200	0.075	280.0	28.0%	77.3%	22.7%
Pan		227.00	22.70%	100.00%	0.00%



Test ID: TR_12
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	213.0	21.3%	21.3%	78.7%
40	0.425	67.0	6.7%	28.0%	72.0%
100	0.15	128.0	12.8%	40.8%	59.2%
200	0.075	345.0	34.5%	75.3%	24.7%
Pan		247.00	24.70%	100.00%	0.00%



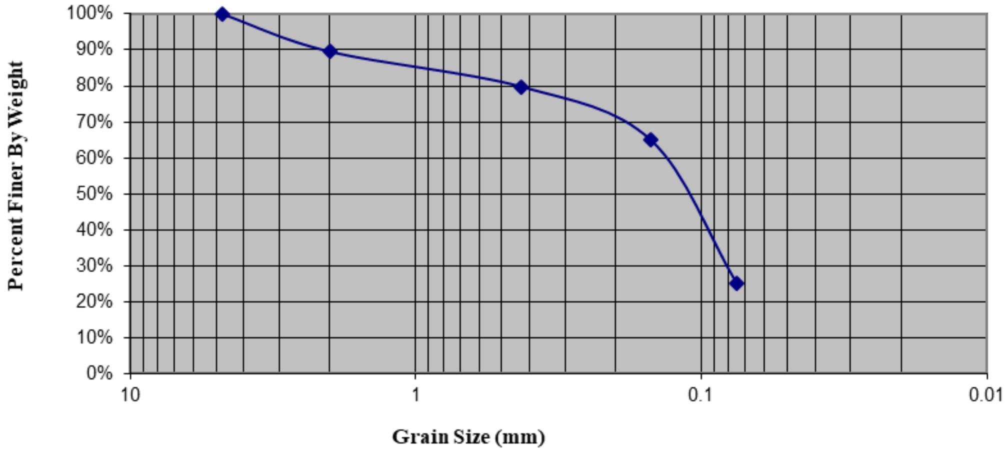
Test ID: TR_13

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	104.0	10.4%	10.4%	89.6%
40	0.425	98.0	9.8%	20.2%	79.8%
100	0.15	148.0	14.8%	35.0%	65.0%
200	0.075	399.0	39.9%	74.9%	25.1%
Pan		251.00	25.10%	100.00%	0.00%

GRADATION CURVE



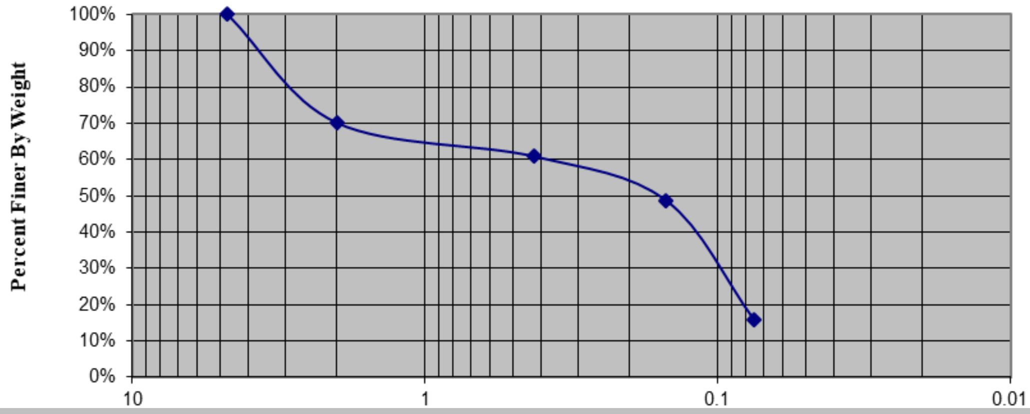
Test ID: TR_14

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	299.0	29.9%	29.9%	70.1%
40	0.425	92.0	9.2%	39.1%	60.9%
100	0.15	121.0	12.1%	51.2%	48.8%
200	0.075	328.0	32.8%	84.0%	16.0%
Pan		160.00	16.00%	100.00%	0.00%

GRADATION CURVE

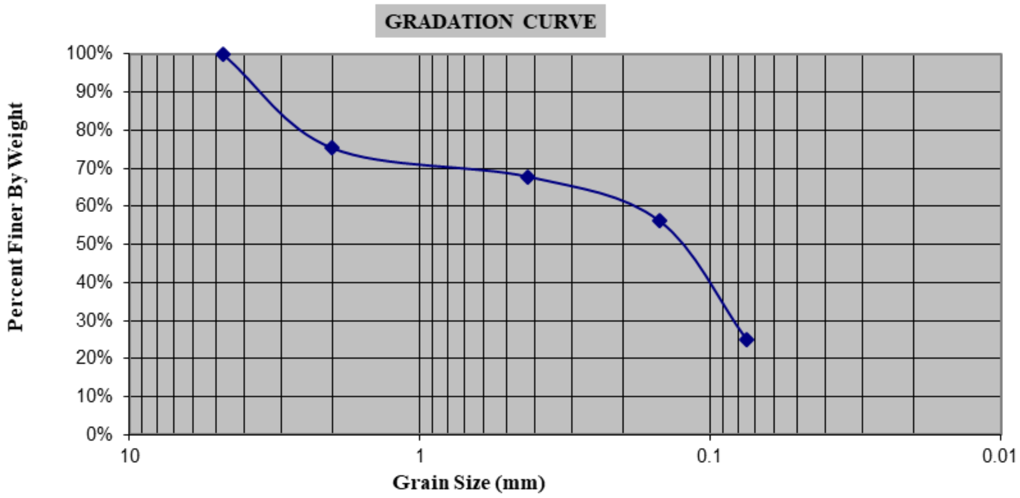


Test ID: TR_15

SIEVE ANALYSIS

Weight of sample = 1000gm

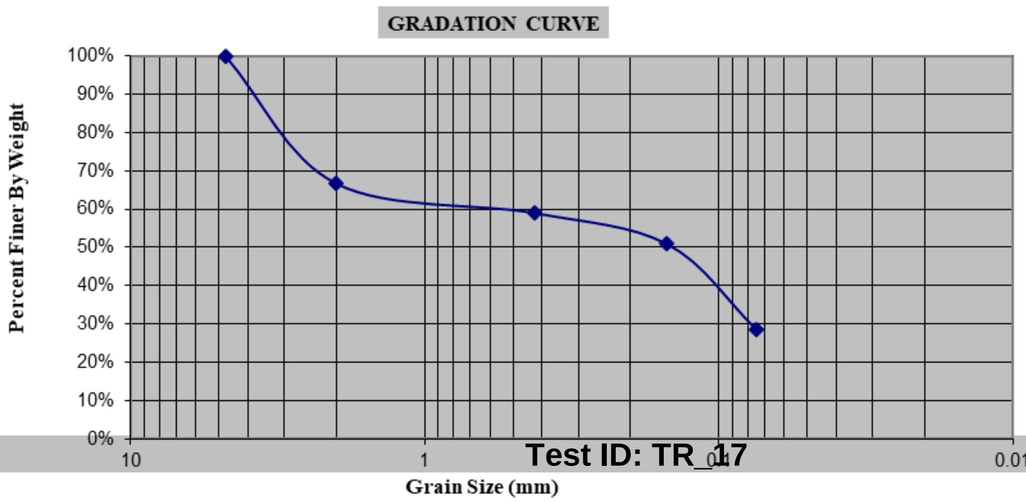
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	247.0	24.7%	24.7%	75.3%
40	0.425	75.0	7.5%	32.2%	67.8%
100	0.15	116.0	11.6%	43.8%	56.2%
200	0.075	313.0	31.3%	75.1%	24.9%
Pan		249.00	24.90%	100.00%	0.00%



Test ID: TR_16
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	333.0	33.3%	33.3%	66.7%
40	0.425	77.0	7.7%	41.0%	59.0%
100	0.15	82.0	8.2%	49.2%	50.8%
200	0.075	223.0	22.3%	71.5%	28.5%
Pan		285.00	28.50%	100.00%	0.00%

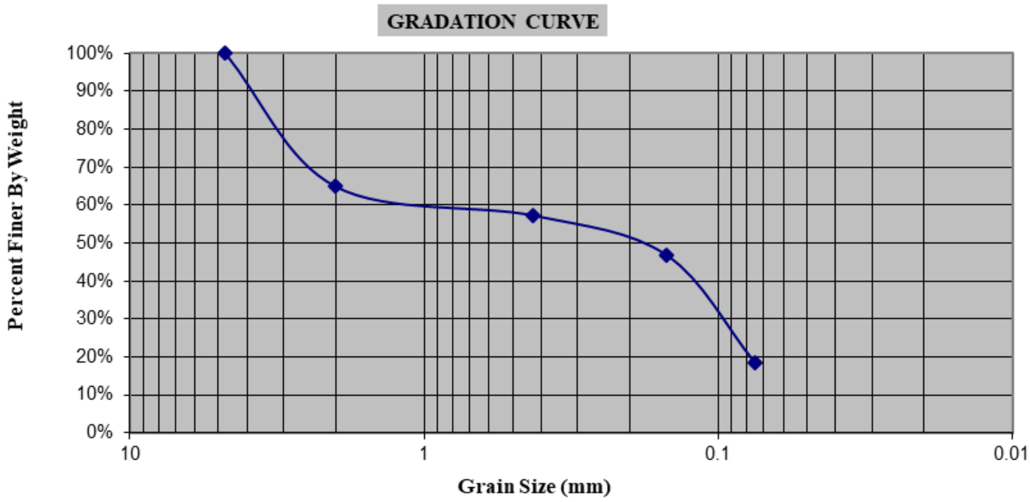


Test ID: TR_17

SIEVE ANALYSIS

Weight of sample = 1000gm

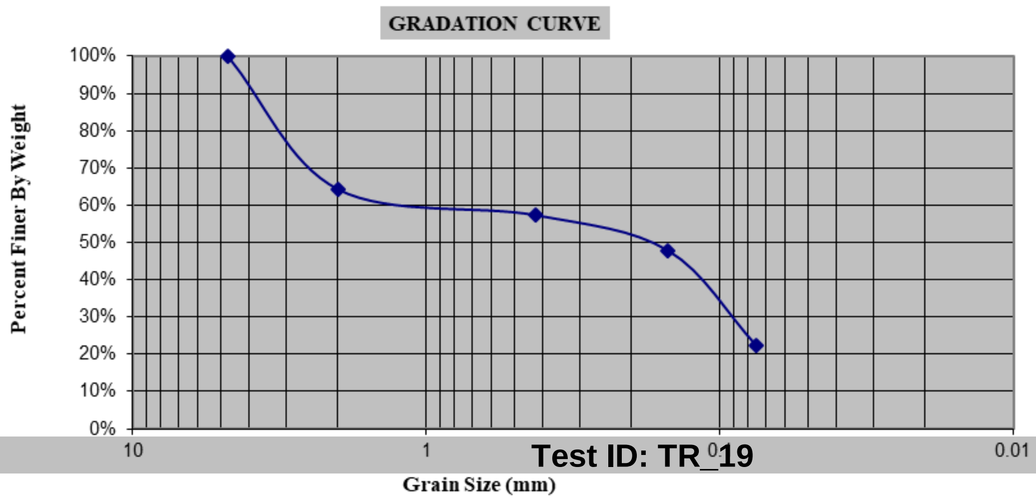
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	351.0	35.1%	35.1%	64.9%
40	0.425	76.0	7.6%	42.7%	57.3%
100	0.15	104.0	10.4%	53.1%	46.9%
200	0.075	283.0	28.3%	81.4%	18.6%
Pan		186.00	18.60%	100.00%	0.00%



Test ID: TR_18
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	357.0	35.7%	35.7%	64.3%
40	0.425	69.0	6.9%	42.6%	57.4%
100	0.15	95.0	9.5%	52.1%	47.9%
200	0.075	255.0	25.5%	77.6%	22.4%
Pan		224.00	22.40%	100.00%	0.00%

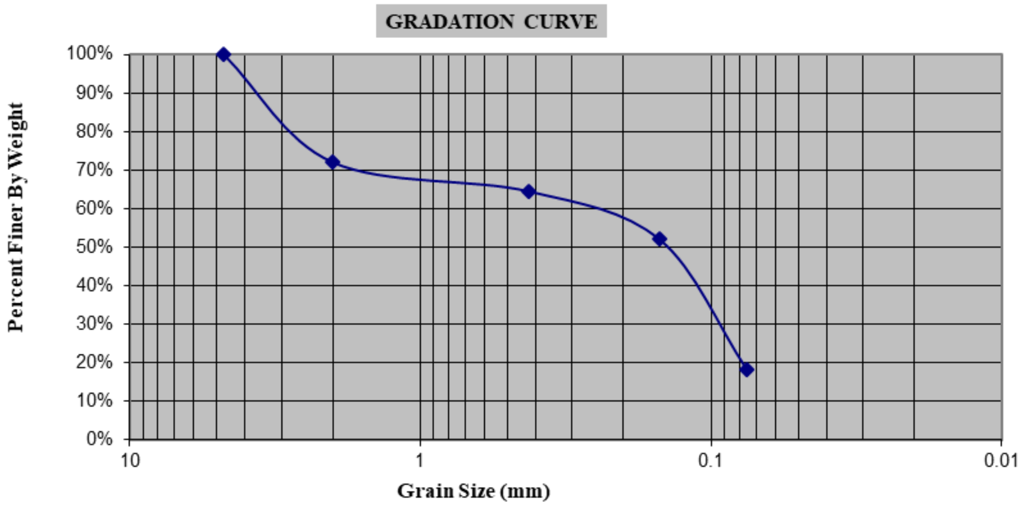


Test ID: TR_19

SIEVE ANALYSIS

Weight of sample = 1000gm

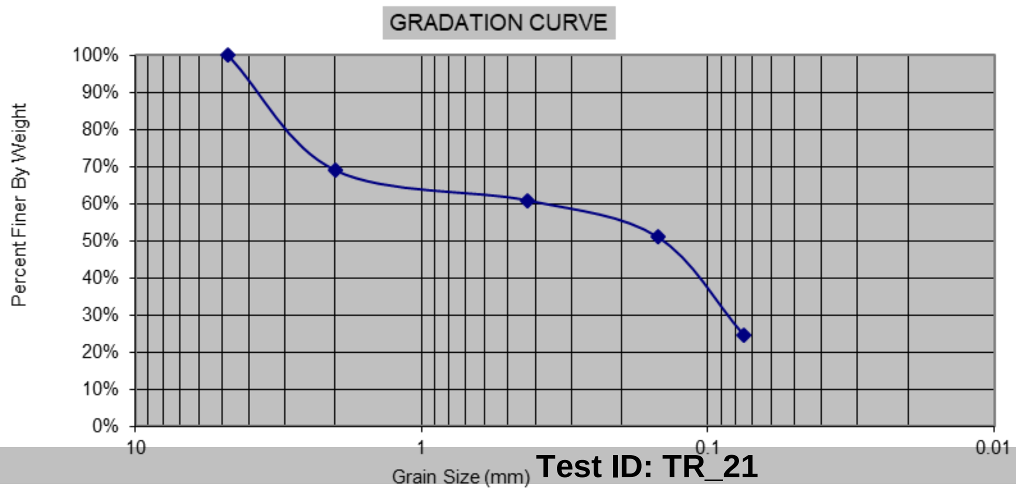
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	280.0	28.0%	28.0%	72.0%
40	0.425	75.0	7.5%	35.5%	64.5%
100	0.15	125.0	12.5%	48.0%	52.0%
200	0.075	338.0	33.8%	81.8%	18.2%
Pan		182.00	18.20%	100.00%	0.00%



Test ID: TR_20
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	310.0	31.0%	31.0%	69.0%
40	0.425	81.0	8.1%	39.1%	60.9%
100	0.15	98.0	9.8%	48.9%	51.1%
200	0.075	264.0	26.4%	75.3%	24.7%
Pan		247.00	24.70%	100.00%	0.00%

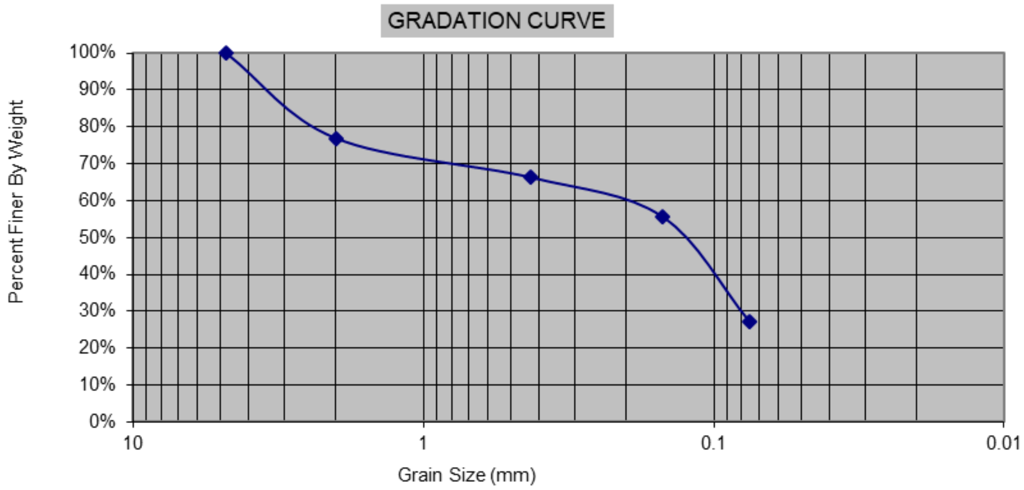


Test ID: TR_21

SIEVE ANALYSIS

Weight of sample = 1000gm

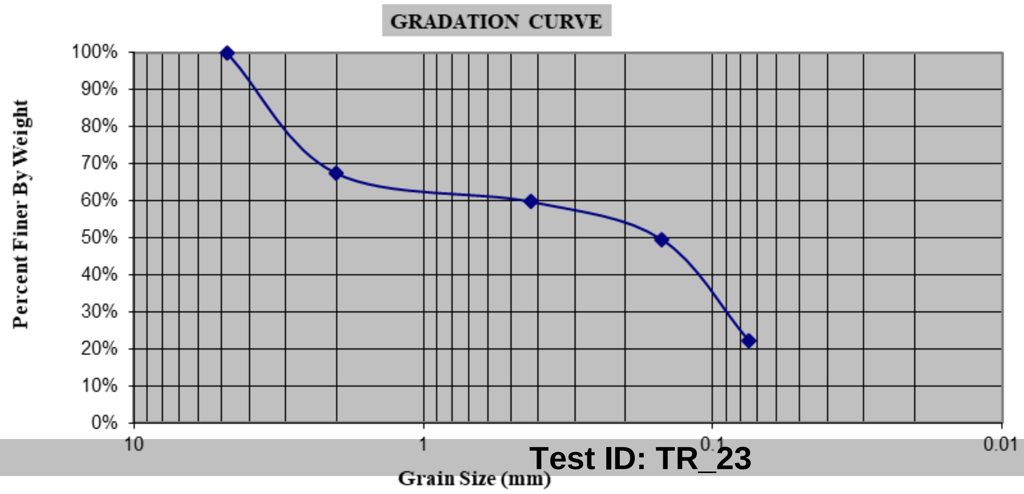
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	231.0	23.1%	23.1%	76.9%
40	0.425	107.0	10.7%	33.8%	66.2%
100	0.15	106.0	10.6%	44.4%	55.6%
200	0.075	286.0	28.6%	73.0%	27.0%
Pan		270.00	27.00%	100.00%	0.00%



Test ID: TR_22
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	325.0	32.5%	32.5%	67.5%
40	0.425	77.0	7.7%	40.2%	59.8%
100	0.15	102.0	10.2%	50.4%	49.6%
200	0.075	274.0	27.4%	77.8%	22.2%
Pan		222.00	22.20%	100.00%	0.00%

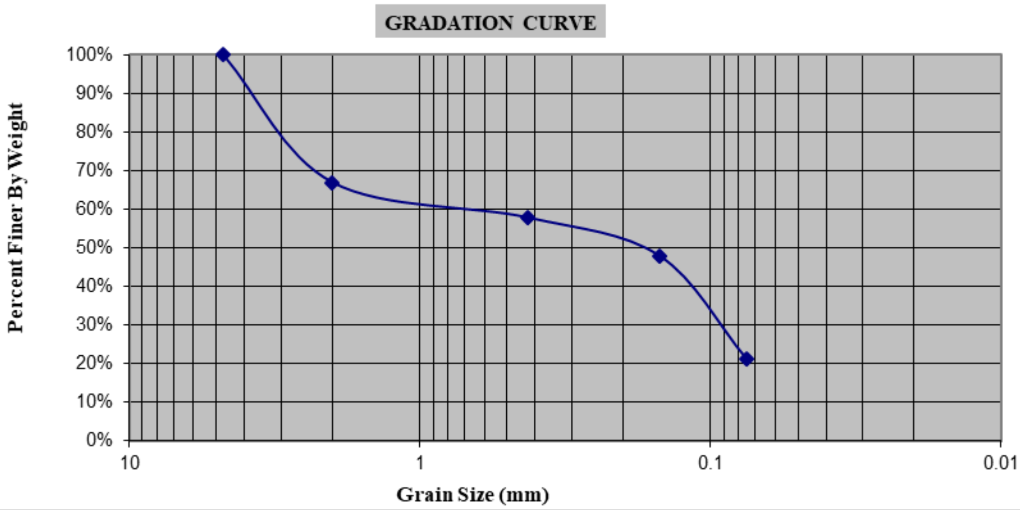


Test ID: TR_23

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	331.0	33.1%	33.1%	66.9%
40	0.425	91.0	9.1%	42.2%	57.8%
100	0.15	99.0	9.9%	52.1%	47.9%
200	0.075	268.0	26.8%	78.9%	21.1%
Pan		211.00	21.10%	100.00%	0.00%

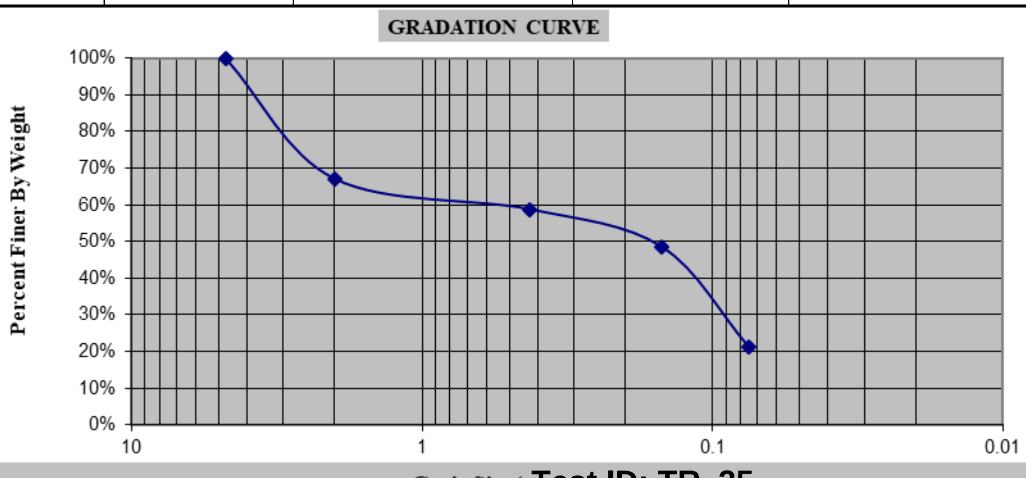


Test ID: TR_24

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	329.0	32.9%	32.9%	67.1%
40	0.425	83.0	8.3%	41.2%	58.8%
100	0.15	102.0	10.2%	51.4%	48.6%
200	0.075	275.0	27.5%	78.9%	21.1%
Pan		211.00	21.10%	100.00%	0.00%

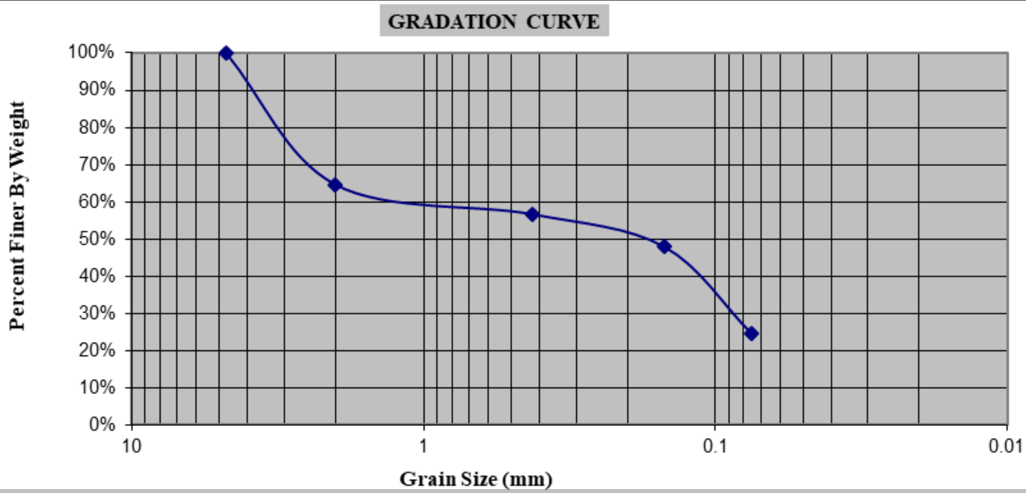


Test ID: TR_25

SIEVE ANALYSIS

Weight of sample = 1000gm

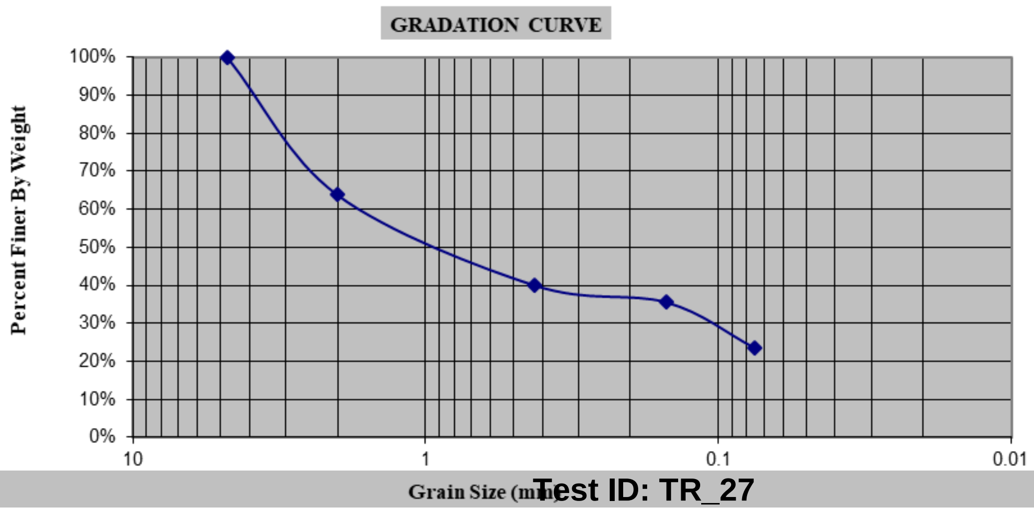
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	354.0	35.4%	35.4%	64.6%
40	0.425	79.0	7.9%	43.3%	56.7%
100	0.15	87.0	8.7%	52.0%	48.0%
200	0.075	234.0	23.4%	75.4%	24.6%
Pan		246.00	24.60%	100.00%	0.00%



Test ID: TR_26
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	362.0	36.2%	36.2%	63.8%
40	0.425	238.0	23.8%	60.0%	40.0%
100	0.15	45.0	4.5%	64.5%	35.5%
200	0.075	120.0	12.0%	76.5%	23.5%
Pan		235.00	23.50%	100.00%	0.00%



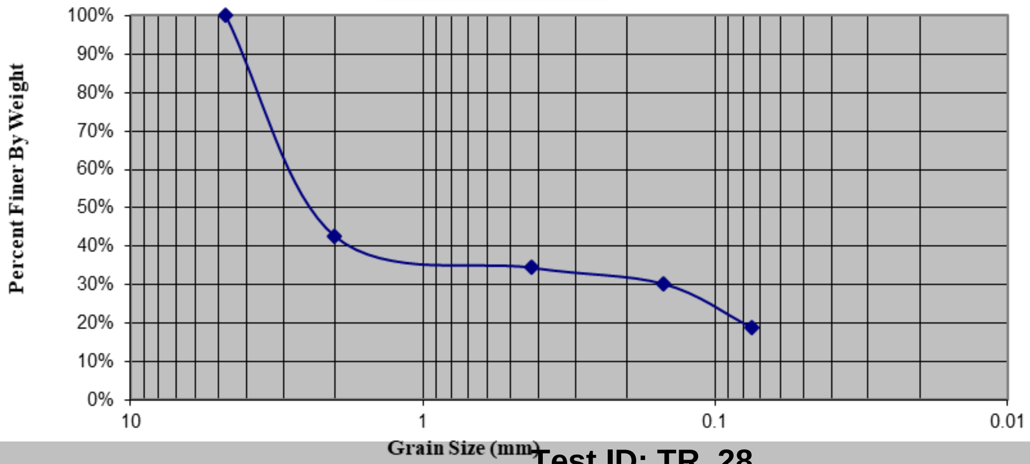
Test ID: TR_27

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	574.0	57.4%	57.4%	42.6%
40	0.425	81.0	8.1%	65.5%	34.5%
100	0.15	42.0	4.2%	69.7%	30.3%
200	0.075	113.0	11.3%	81.0%	19.0%
Pan		190.00	19.00%	100.00%	0.00%

GRADATION CURVE



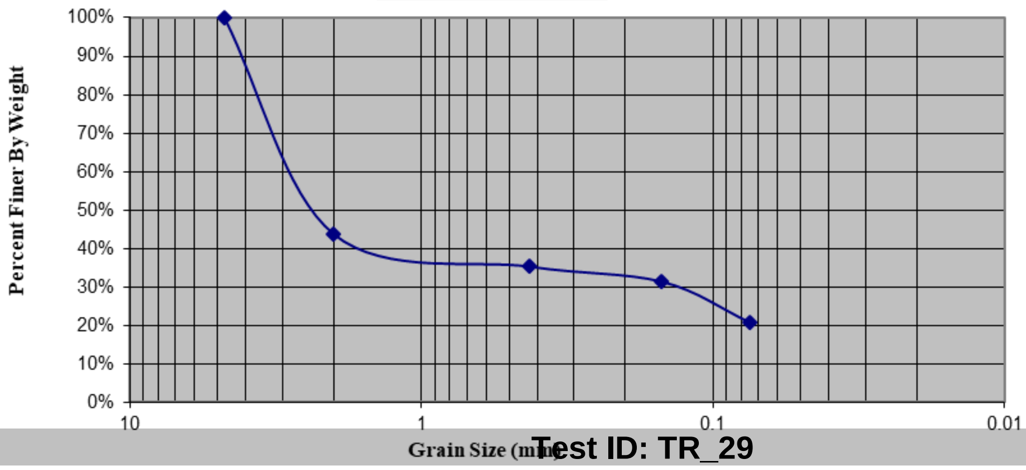
Test ID: TR_28

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	563.0	56.3%	56.3%	43.7%
40	0.425	84.0	8.4%	64.7%	35.3%
100	0.15	39.0	3.9%	68.6%	31.4%
200	0.075	106.0	10.6%	79.2%	20.8%
Pan		208.00	20.80%	100.00%	0.00%

GRADATION CURVE

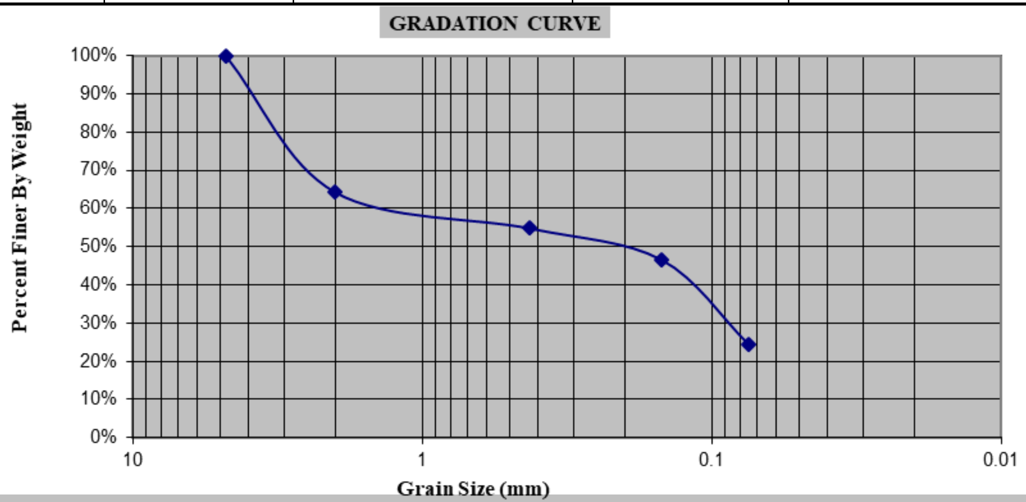


Test ID: TR_29

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	357.0	35.7%	35.7%	64.3%
40	0.425	95.0	9.5%	45.2%	54.8%
100	0.15	82.0	8.2%	53.4%	46.6%
200	0.075	222.0	22.2%	75.6%	24.4%
Pan		244.00	24.40%	100.00%	0.00%

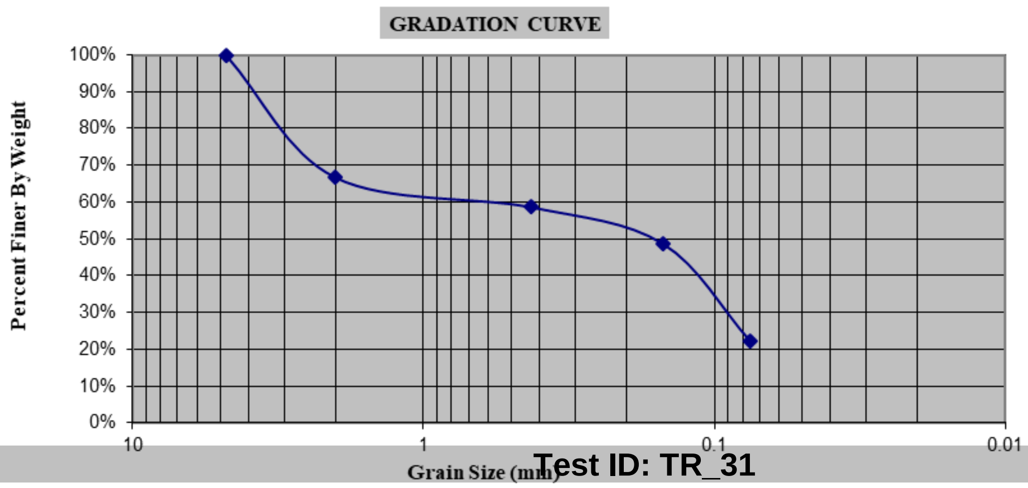


Test ID: TR_30

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	333.0	33.3%	33.3%	66.7%
40	0.425	81.0	8.1%	41.4%	58.6%
100	0.15	99.0	9.9%	51.3%	48.7%
200	0.075	266.0	26.6%	77.9%	22.1%
Pan		221.00	22.10%	100.00%	0.00%

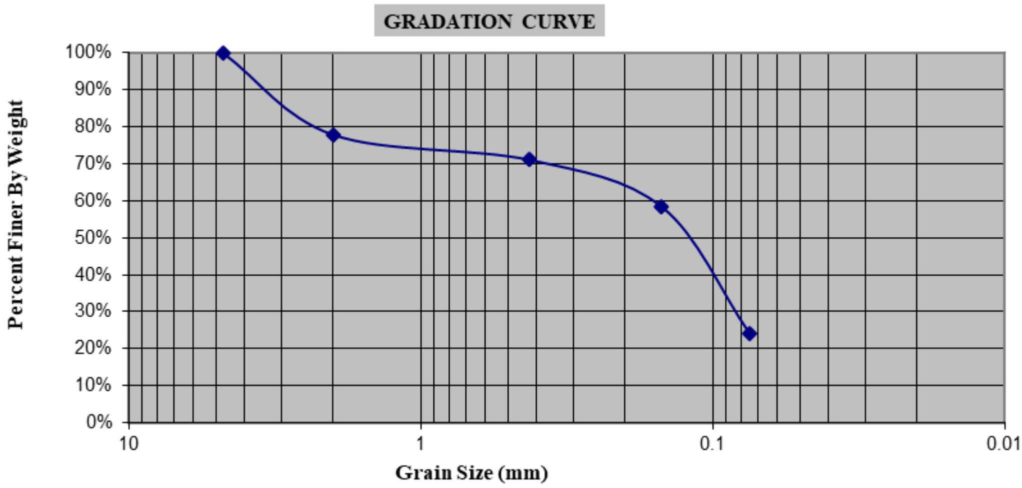


Test ID: TR_31

SIEVE ANALYSIS

Weight of sample = 1000gm

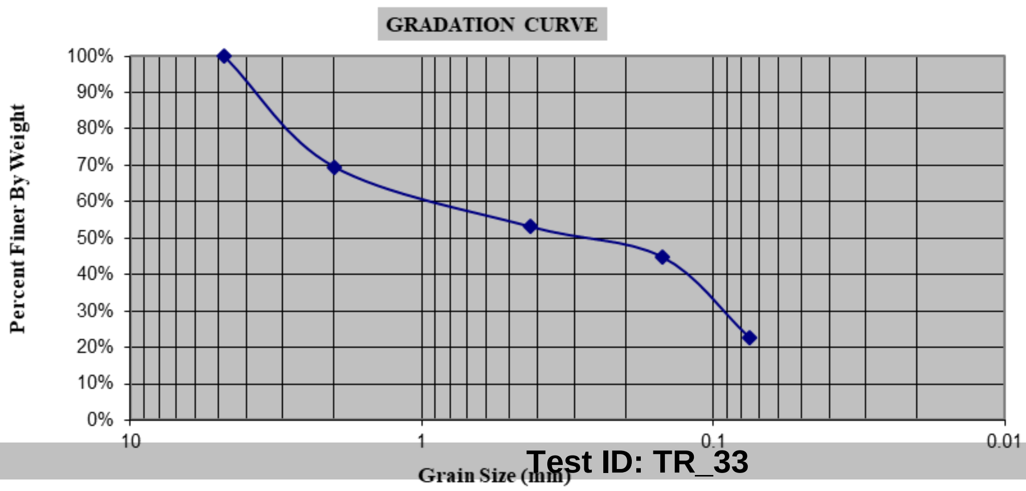
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	221.0	22.1%	22.1%	77.9%
40	0.425	68.0	6.8%	28.9%	71.1%
100	0.15	127.0	12.7%	41.6%	58.4%
200	0.075	343.0	34.3%	75.9%	24.1%
Pan		241.00	24.10%	100.00%	0.00%



Test ID: TR_32
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	304.0	30.4%	30.4%	69.6%
40	0.425	165.0	16.5%	46.9%	53.1%
100	0.15	83.0	8.3%	55.2%	44.8%
200	0.075	223.0	22.3%	77.5%	22.5%
Pan		225.00	22.50%	100.00%	0.00%

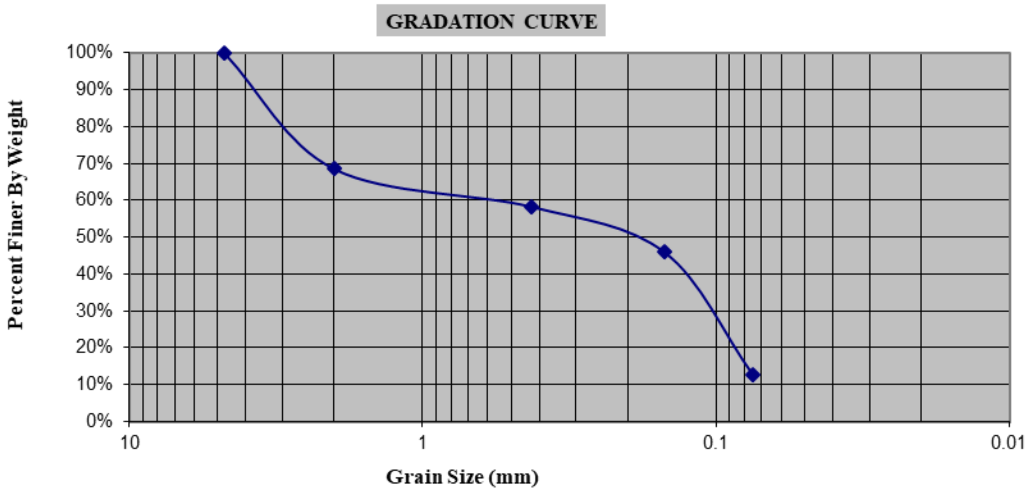


Test ID: TR_33

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	315.0	31.5%	31.5%	68.5%
40	0.425	102.0	10.2%	41.7%	58.3%
100	0.15	123.0	12.3%	54.0%	46.0%
200	0.075	332.0	33.2%	87.2%	12.8%
Pan		128.00	12.80%	100.00%	0.00%

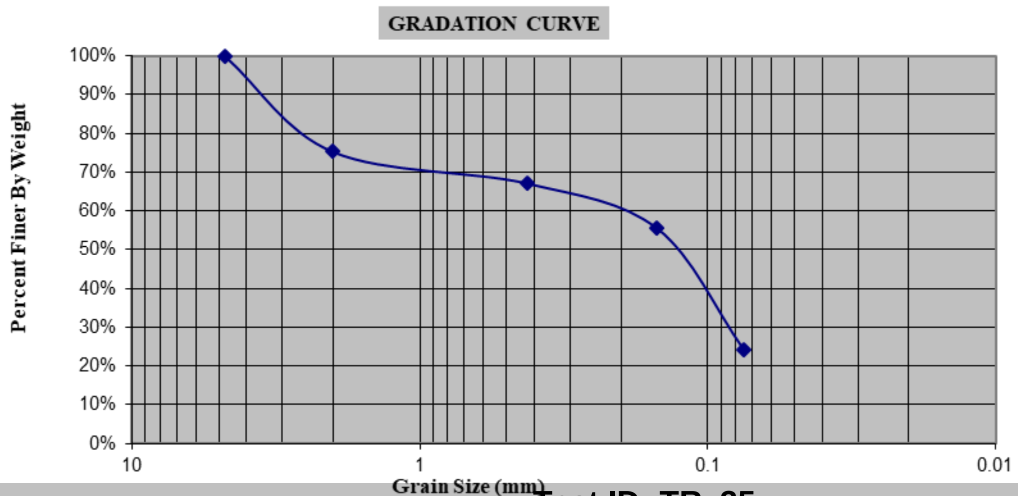


Test ID: TR_34

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	247.0	24.7%	24.7%	75.3%
40	0.425	81.0	8.1%	32.8%	67.2%
100	0.15	116.0	11.6%	44.4%	55.6%
200	0.075	313.0	31.3%	75.7%	24.3%
Pan		243.00	24.30%	100.00%	0.00%

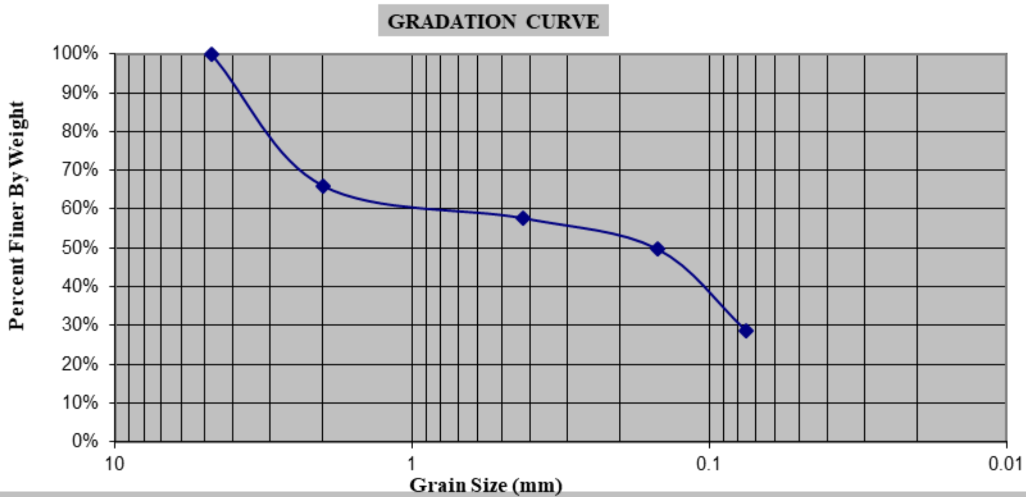


Test ID: TR_35

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	340.0	34.0%	34.0%	66.0%
40	0.425	83.0	8.3%	42.3%	57.7%
100	0.15	79.0	7.9%	50.2%	49.8%
200	0.075	212.0	21.2%	71.4%	28.6%
Pan		286.00	28.60%	100.00%	0.00%

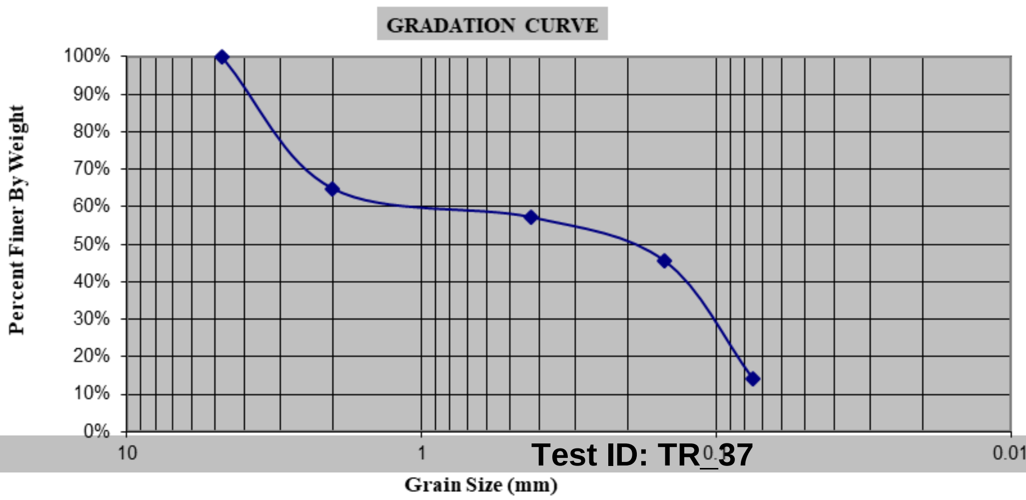


Test ID: TR_36

SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	351.0	35.1%	35.1%	64.9%
40	0.425	76.0	7.6%	42.7%	57.3%
100	0.15	116.0	11.6%	54.3%	45.7%
200	0.075	315.0	31.5%	85.8%	14.2%
Pan		142.00	14.20%	100.00%	0.00%

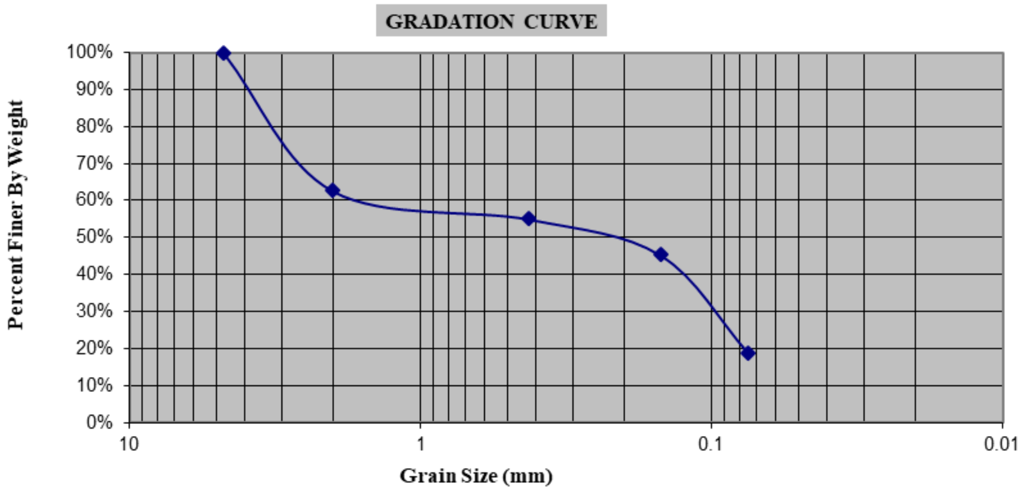


Test ID: TR_37

SIEVE ANALYSIS

Weight of sample = 1000gm

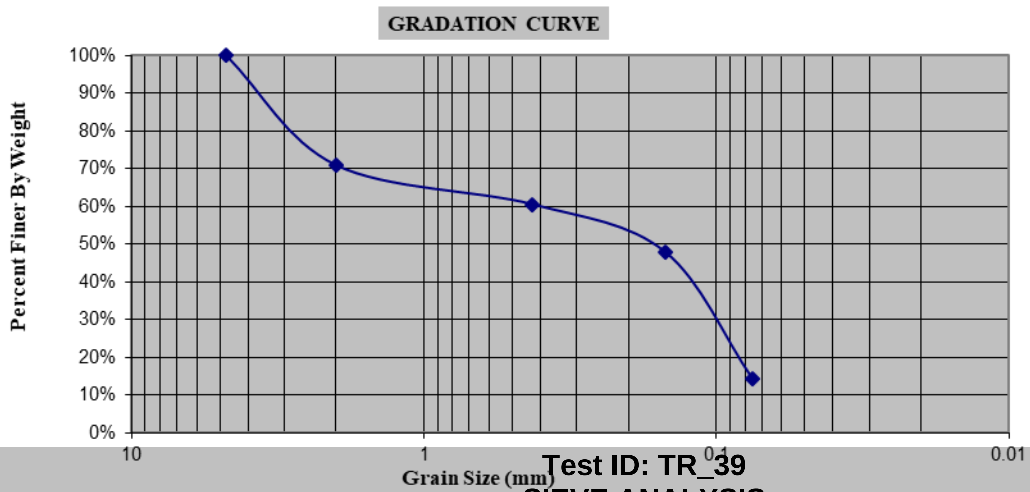
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	374.0	37.4%	37.4%	62.6%
40	0.425	76.0	7.6%	45.0%	55.0%
100	0.15	97.0	9.7%	54.7%	45.3%
200	0.075	264.0	26.4%	81.1%	18.9%
Pan		189.00	18.90%	100.00%	0.00%



Test ID: TR_38
SIEVE ANALYSIS

Weight of sample = 1000gm

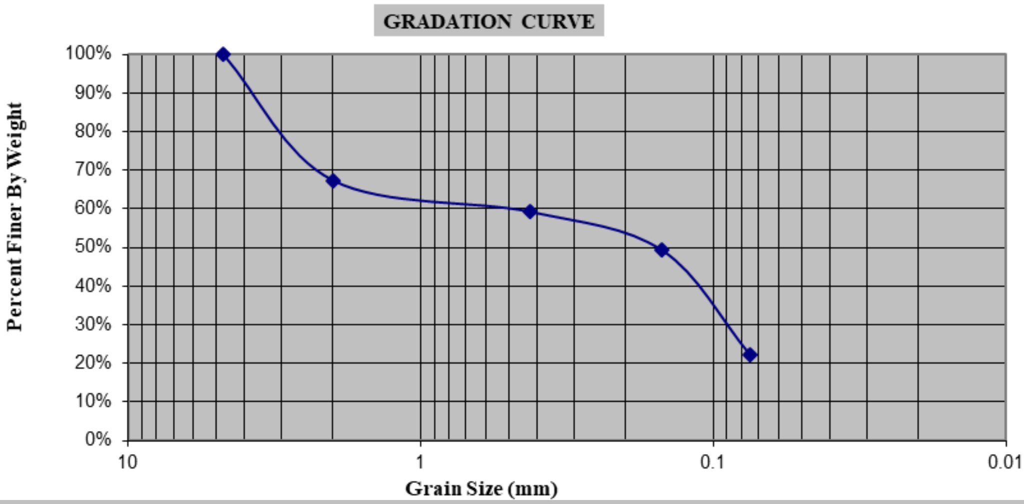
Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	291.0	29.1%	29.1%	70.9%
40	0.425	104.0	10.4%	39.5%	60.5%
100	0.15	125.0	12.5%	52.0%	48.0%
200	0.075	338.0	33.8%	85.8%	14.2%
Pan		142.00	14.20%	100.00%	0.00%



Test ID: TR_39
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	327.0	32.7%	32.7%	67.3%
40	0.425	81.0	8.1%	40.8%	59.2%
100	0.15	100.0	10.0%	50.8%	49.2%
200	0.075	271.0	27.1%	77.9%	22.1%
Pan		221.00	22.10%	100.00%	0.00%



Test ID: TR_40
SIEVE ANALYSIS

Weight of sample = 1000gm

Sieve No.	Diameter (mm)	Wt. of Soil Retained (gm)	% Weight retained	Cumulative Percent Retained	Percent Passing
3/4	50	0.0	0.0%	0.0%	100.0%
3/8	37.5	0.0	0.0%	0.0%	100.0%
4	4.75	0.0	0.0%	0.0%	100.0%
10	2	225.0	22.5%	22.5%	77.5%
40	0.425	94.0	9.4%	31.9%	68.1%
100	0.15	104.0	10.4%	42.3%	57.7%
200	0.075	283.0	28.3%	70.6%	29.4%
Pan		294.00	29.40%	100.00%	0.00%