Developing Correlation between Dynamic Cone Penetration Index (DCPI) and Unconfined Compression Strength (UCS) of the Soils in Alem Gena Town

By: Alemayehu Dirriba

July, 2017

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Geotechnical Engineering).

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Advisor
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Approved by the board of examiners

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LIST OF ACRONYMS AND SYMBOLS

AASHTO	American Association of State Highway Transportation Officials
AAU	Addis Ababa University
ASTM	American Standards for Testing Materials
BS	British Standard
CBR	California Bearing Ratio
CH	Inorganic High Plastic Clay
Ch.	Church
CL	Inorganic Low Plastic Clay
D	Depth
DCP	Dynamic Cone Penetrometer
DCPI	Dynamic Cone Penetrometer Index
DCP-PR	Dynamic Cone Penetrometer-Penetration Rate
DSN	DCP Structural Number
FS	Free Swell
Gs	Specific Gravity
GL	Ground Level
LI	Liquidity Index
LL	Liquid Limit
MH	Inorganic High Plastic Silt
ML	Inorganic Low Plastic Silt
Mn/DOT	Minnesota Department of Transportation
N	Standard Penetration Resistance Number
NMC	Natural Moisture Content
PI	Plasticity Index
PL	Plastic Limit
q_u	Ultimate bearing capacity
R^2	Coefficient Of Determination
SPSS	Statistical Package for the Social Sciences
SPT	Standard Penetration Test
S_u	Undrained Shear Strength Of Soil
TRRL	Transport Road Research Laboratory
UCS	Unconfined Compression Strength
USCS	Unified Soil Classification System
ε	Axial Strain
γ_b	Bulk Density
σ'	Effective Stress

ABSTRACT

To find the Unconfined Compressive Strength (UCS) of the soil, a time consuming testing procedure of on undisturbed sample is required which demands significant effort. Therefore Correlations Dynamic Cone Penetration Index (DCPI) with Unconfined Compressive Strength (UCS) make it an attractive alternative, due to a fast, very light, versatile and user-friendly property of DCP. To this end, the present research aimed to develop single and multiple correlations of UCS and DCPI for Alem Gena soil.

This research consists of field testing, laboratory testing, and analysis of the results for 30 samples from 14 test pits of Alem Gena Town soils. In the development of a relationship between Dynamic Cone Penetration Index (DCPI) and Unconfined Compressive Strength (UCS), consider a variety of soil properties, natural moisture contents, Atterberg limits, gradation, bulk densities and specific gravities.

Good correlations between Unconfined Compressive Strength (UCS) and Dynamic Cone Penetration Index (DCPI) have been developed with significant coefficient of determination, which revealed that Unconfined Compressive Strength (UCS) can be estimated by using the developed correlation equations for soils of Alem Gena. The reproducibility and repeatability of the current proposed relationships quantified by compared with some previous works and actual measured values. The study will benefit consultants, contractors, researchers and the public at large.

1 INTRODUCTION

1.1 General

The Dynamic Cone Penetrometer (DCP), also known as the Scala penetrometer, was developed in 1956 in South Africa for evaluating pavement layer or underground soils [1]. Due to its economy and simplicity, Dynamic Cone Penetrometer testing reduces significantly the effort and cost involved in the evaluation of pavement and underground soils.

Some applications of the Dynamic Cone Penetrometer (DCP) include correlations with California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). It is also used in performance evaluation of pavement layers and quality control of compaction of fill.

The application of Dynamic Cone Penetrometer (DCP) is a faster and easier way to estimate the strength parameters. Thus this study aims at developing correlations between Dynamic Cone Penetration Index (DCPI) and Unconfined Compression Strength (UCS) in Alem Gena Town.

1.2 Background of the Research

The correlation between DCPI and UCS is quite useful but has to be used according to the soil conditions available in the field. Therefore, it is very much desirable to use the correlations between DCPI and UCS established for local soils instead of depending on the correlations established for soils types of other areas. No published research has been found to relate DCP penetration to UCS, or any other strength parameter in Alem Gena Town. In this study, the author has attempted to establish the correlation equation between DCPI and UCS for the soils Alem Gena Town. The developed correlation equation can be used to retrieve UCS values from DCPI measurements for further application.

1.3 Problem Statement

Characterizing field material properties by using laboratory tests is an ongoing problem in the discipline of geotechnical investigations. It is difficult to collect and test representative samples, and because of this, there is a discrepancy between laboratory test results and in situ soil conditions of environment.

This study focuses on establishing reliable correlations between the results of the UCS and DCP for soils at various locations of Alem Gena Town, regional state of Oromia, Ethiopia.

1.4 Objective of the Study

1.4.1 General Objective

The main objective of the study is to develop correlation between Dynamic Cone Penetration Index (DCPI) and Unconfined Compression Strength (UCS) for the soil samples in Alem Gena Town.

1.4.2 Specific Objectives

The specific objectives of the research are:

- To determine engineering properties of soils samples in Alem Gena Town, such as specific gravity, natural moisture content, Atterberg limits, gradation and classification.
- To introduce Dynamic Cone Penetration (DCP) test device for the soils samples in Alem Gena Town.
- To apply DCP for estimating the unconfined compressive strength of soil found in Alem Gena Town.

1.5 Scope of the study

The following are the scope of this research consists:

- To asses previous researches, including properties and test methods of the soils, application and limitation of correlation results.
- To conduct Dynamic Cone Penetration (DCP) test (field test) on selected sites and take disturbed and undisturbed samples from test pit. This incorporates field visual identification of the soil, ground verification, color, and other geological conditions.
- To conduct laboratory tests to identify engineering properties including Unconfined Compression Strength (UCS) tests results.
- To analysis of the Dynamic Cone Penetration (DCP) test results (field test) using UK DCP software and laboratory tests, including single and multiple regression analysis.
- Finally, proposing a reliable correlation.

1.6 Limitation of the Study

Dynamic Cone Penetration Index (DCPI) is determined at in situ moisture content and density of the soil layers. During laboratory test, USC strength determination taken into consideration in situ Natural Moisture Content and Bulk Density kept.

Although DCP interpretation is a very good indicator of in situ strength and stiffness, Care must also be taken in the choice of equation used to determine the required strength parameter, as the equations are sensitive to material properties and are typically only reliable over the specific area from which they were derived. The relationships developed between DCPI and UCS value should be used for Alem Gena Town.

1.7 Benefits and beneficiaries

The study will benefit consultants, contractors, researchers and the public at large. Dynamic Cone Penetration (DCP) test is versatile, simple, inexpensive, portable, and easy to operate. If a correlation is established one would determine the Unconfined Compression Strength (UCS) of soils found in Alem Gena Town.

1.8 Thesis Outline

The structure of this thesis divided in to seven separated but integrated chapters. The first Chapter presents the general statement, objective and scope of this thesis with limitation and application of the study result. The previous works concerning applications, principles, factors, and relationships of Dynamic Cone Penetrometer (DCP) and undrained shear strength (UCS) are reviewed and discussed in the second Chapter. The third Chapter presents the study area description, the data collection methods and testing methodology for different studied parameters of soil samples. The analyses of all field and laboratory tests results are presented in the fourth chapter. The fifth Chapter presents the single and multiple correlation procedures, results and analysis. Finally, discussion and conclusion of the thesis are presented in chapter six and seven respectively. All field and laboratory test results are presented in the Appendixes parts.

2 LITERATURE REVIEW

2.1 Dynamic Cone Penetrometer (DCP)

In geotechnical and foundation engineering in-situ penetration tests have been widely used for site investigation. The Dynamic Cone Penetrometer (DCP), also known as the Scala penetrometer, was developed in 1956 in South Africa as an in situ pavement evaluation technique consists of about 9kg hammer with a dropping vertical distance of 510mm with a 15.875mm diameter rod. The hammer impact energy is ultimately applied on to a 30 degree angle cone fitted at bottom end of the 762mm guide rod [2], [3].

The DCP has been intended to alleviate many of the deficiencies of systems that are manually pushed into soil or paving materials. The earliest record of a subsoil penetration testing device similar to the DCP is a "ram penetrometer" developed in Germany at the end of 17th century by Nicholaus Goldmann. This device was later standardized in 1964 as the "Light penetrometer", German Standard DIN 4094 [4]. Later, a similar device like DCP was developed by Van Vuuren [5]. It consists of a 10 kg hammer which drops freely from 460 mm height with 30 degree cone tip [2].

Since 1991, the DCP has undergone significant changes at the connection of the upper and lower rods, a threaded simple slip plug change to bolt connection. Other notable modifications make to increase device life and to make a hand safety guard on the anvil [4].

The approach of determining the strength of the soil property involves the determination of property of the medium from known penetration energy and penetration depth. Blow counts with penetration depth can generally be used to identify material strength. The soil strength is measured by the penetration (usually in millimeters or inches) per hammer blow, which is called Dynamic Cone Penetration Index (DCPI).

The DCP consists of a steel rod with a steel cone attached to one end of lower shaft driven into the soil using a sliding hammer on the upper shaft with a diameter of 16 mm. The hammer weighs 8 or 4kg and the cone has an angle of 30 or 60 degrees and a drop height of 575mm. As a reading device, additional measured flat steel is used as an attachment to the lower shaft. The diameter of the cone is slightly larger than that of the rod to ensure the resistance to penetration exerted on the cone [6]. Tests can be performed continuously to the desired depth with an expendable cone, which is left in the ground upon drill rod withdrawal, or they can be performed at specified intervals by using a retractable cone and advancing the hole by auger or other means between tests [7].

The Dynamic Cone Penetrometer (DCP) described in this research is based on the ASTM Standards [8]. As shown in the Fig. 2-1.

Data from a DCP test processed to produce a Dynamic Cone Penetration Index (DCPI), the average penetration of the cone per blow is reported in as an index value and it may be represented in many forms, viz. Dynamic Cone Penetration Index (DCPI), Penetration Rate (PR), Penetration Index (PI), Number of blows required to penetrate a given thickness of layer as Dynamic Cone Penetration Number (DCPN /N_{DCP}/), Blow Rate (BR) and DCP Structural Number (DSN). In this thesis, the cone's average penetration per blow (mm/blow) is denoted as Dynamic Cone Penetration Index (DCPI). The Dynamic Cone Penetration Index (DCPI) can be plotted on a layer strength diagram, or can be correlated directly and indirectly with a number of common subsoil strength parameters.

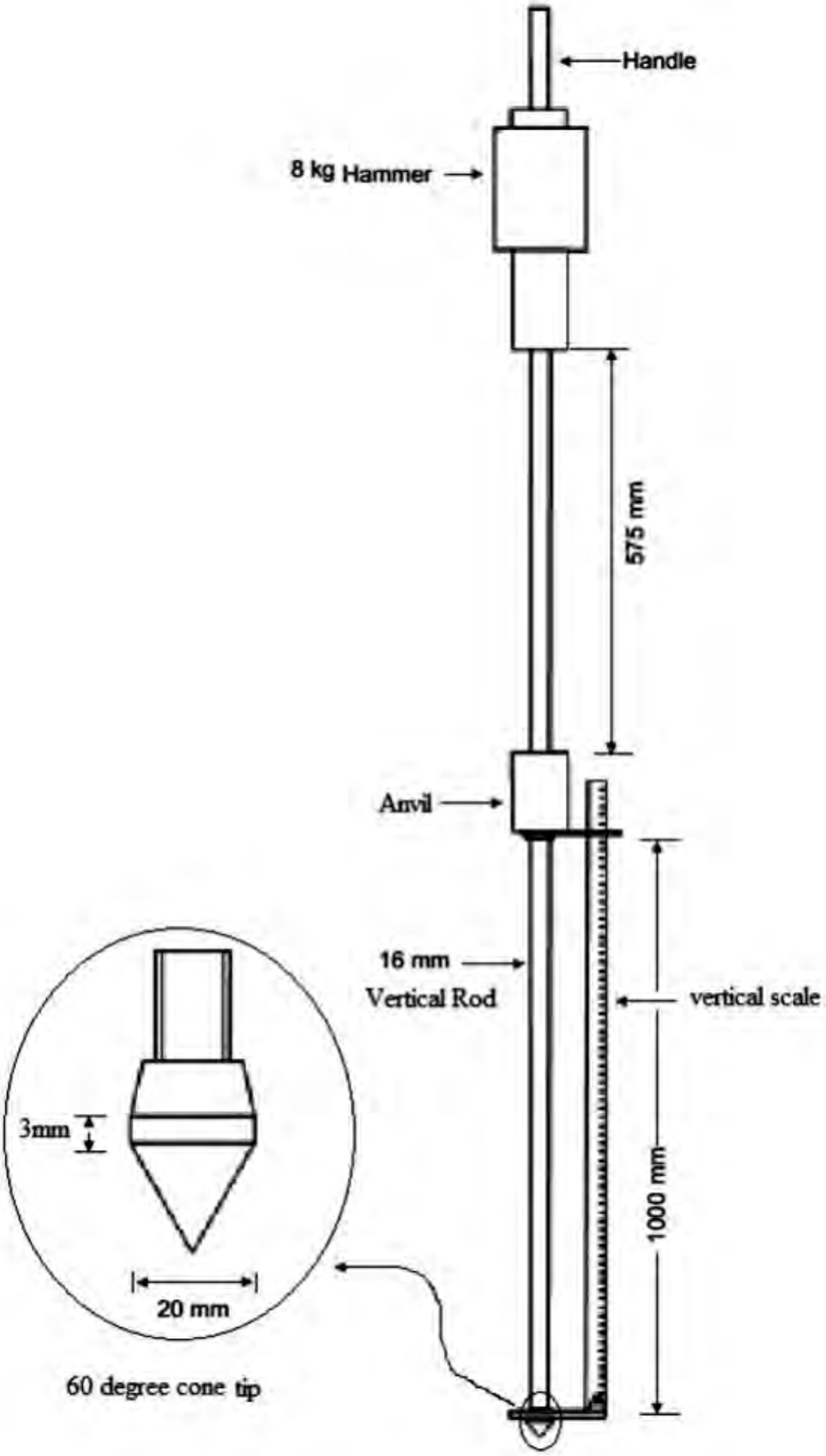

Figure 2-1 Dynamic Cone Penetrometer [7]

2.1.1 Principle and Mathematical Modeling

Characterization of soil strength is usually made by measuring the response of a soil to applied forces. The strength of soil results from cohesive forces between soil particles and their frictional resistance to sliding past or over one another. The dynamic penetrometer uses a calculated amount of kinetic energy to move a cone a certain distance through the soil, which is then converted to penetration resistance using a simple formula. Penetrometers are widely used to measure the soil resistance to penetration, expressed as force per unit cross-sectional area of the cone-base.

DCP is not a direct property test but a convenient field tool, index test based on dynamic impact loading. An 8kg hammer drops over a height of 575mm, which yields a theoretical driving energy of 45J, and drives a 60 degree 20 mm base diameter cone tip vertically into the soil. Not all of the energy from the hammer is transmitted to the soil at the impact because both the hammer and the shaft move downward together into the soil [9].

The penetrometer comprises of a hammer of mass (m) and a shaft mass (m') (which include the rod, the anvil, cone and other parts attached to the penetrometer). The hammer mass (m) is lifted to height (H) and dropped to produce an amount of kinetic energy (W) (in J kg^{-1}), described as:

$$W = mgH \qquad (2-1)$$

The steel rod to which the cone is attached has a smaller diameter than the cone (16mm) to minimize the skin friction.

Acording to the Bowle's modified dynamic formula [10], the relationship between point resistance and penetration depth is given as:

$$R = \frac{E * W_h H}{D}\left(\frac{W_h + n^2 W_d}{W_h + W_d}\right) \qquad (2-2)$$

Where:-

R = Point resitance

W_d = Weight of DCP, excluding hammer

H = Height of hammer freefall

W_h = Weight of Hammer

E = Hammer efficiency

n = Coefficient of restitution [9]

D = Depth of penetration per blow

As shown in the above equation, except penetration depth, the other parameters for one specific typical DCP apparatus are constant. Therefore, the above Eq. 2-2 may be written as follows;

$$R = \frac{k}{D} \tag{2-3}$$

Where: - k is constant value

The above equation assumes an overall system efficiency of. Taking in to account losses due to elastic soil compressibility and other factors, two theoretical relations known as log - log model and inverse model are proposed [11];

Inverse model

$$R = \frac{k}{D^e} \tag{2-4}$$

log - log model

$$log\, R = log\, k - e * \; log\, D \tag{2-5}$$

Where: - *e* is the constant, to account for overall system efficiency.

2.1.2 Relationships of Dynamic Cone Penetrometer

Many useful applications and correlations have been proposed;

I. Relationships Between DCPI and Unconfined Compressive Strength (UCS)

Based on laboratory studies, McElvaney and Djatnika (1991) have concluded that DCPI values can be correlated to the unconfined compressive strength (UCS) [7]. They considered both individual soil material and combined soil- lime mixtures types in their analysis. The developed relationship with 99 percent confidence is presented below.

$$log\, UCS = 3.21 - 0.809 log * (DCPI) \tag{2-6}$$

Where; UCS (unconfined compressive strength) in kPa
DCPI (Dynamic Cone Penetration Index) in inches/blow

Salgado, et al., [12] proposed correlation of the Unconfined Compressive Strength (UCS) with Dynamic Cone Penetration Index (DCPI) that were conducted for clayey sand and well graded sand with in deferent Study area are shown in Fig. 2-2 [12]. The result shows that Unconfined Compressive Strength (UCS) decreases as the Dynamic Cone Penetration Index (DCPI) increases.

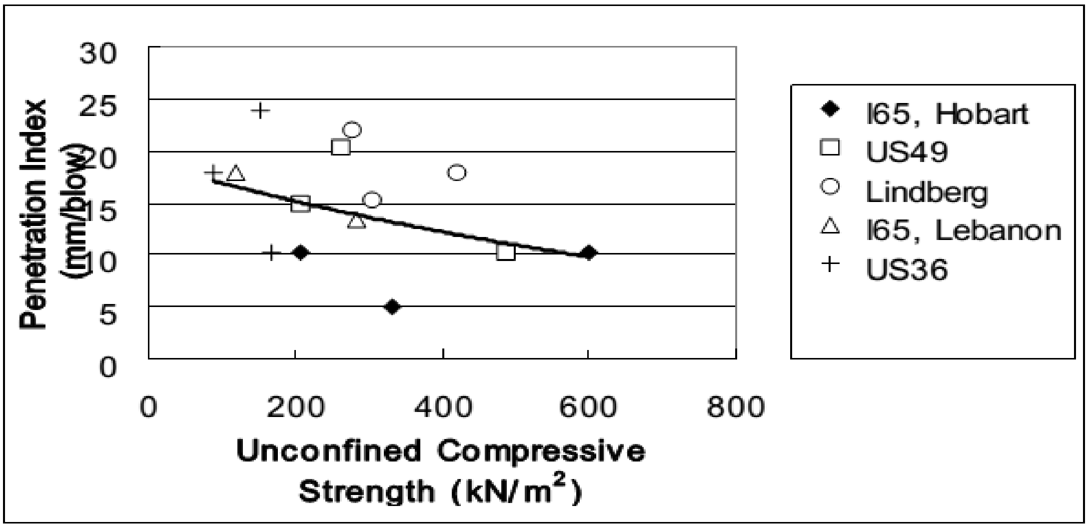

Figure 2-2 Relationships between USC and DCPI after Salgado, et al., [12]

Patel, et al., [13] developed a correlation between Unconfined Compressive Strength (UCS) with Dynamic Cone Penetration Index (DCPI), (eq. 2-7 and fig. 2-3), that was conducted at various locations of Gujarat, India.

$$UCS = 3.1237 * DCPI^{-0.865} \qquad (2-7)$$

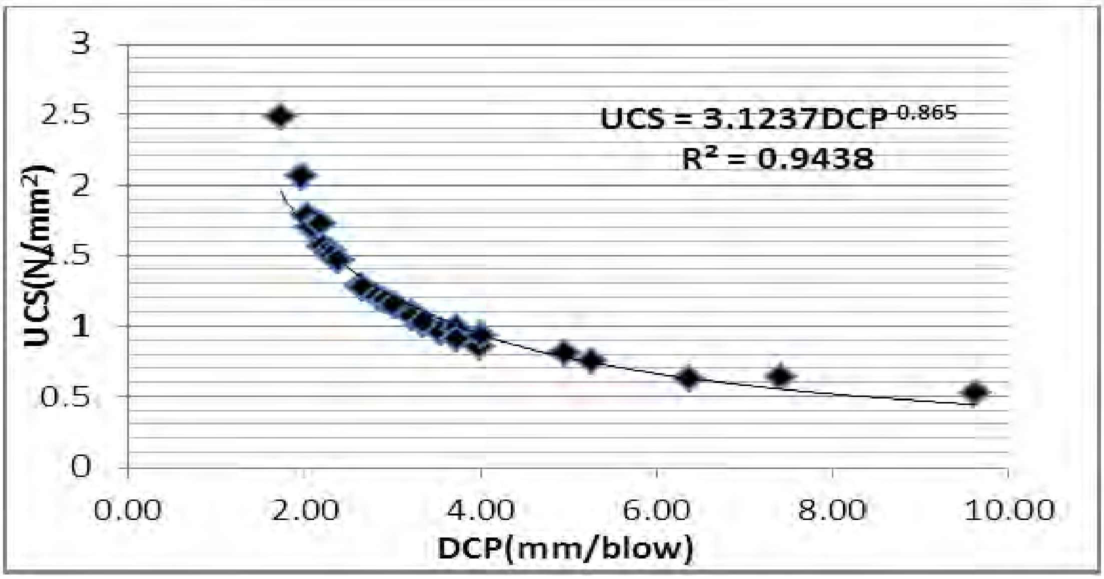

Figure 2-3 relationships between USC and DCPI after Patel, et al., [13]

Temnit Fitsum, [14] developed a correlation between Unconfined Compressive Strength (UCS) with Dynamic Cone Penetration Index (DCPI) for red clay soil samples of Addis Ababa, Ethiopia, (eq. 2-8).

$$UCS = -110.2 * ln[DCPI] + 503.18 \qquad (2-8)$$

II. Relationships Between DCPI and California Bearing Ratio (CBR)

The most common correlation of the Dynamic Cone Penetration Index (DCPI) is with California Bearing Ratio (CBR). The CBR is defined as the ratio of the resistance to penetration developed by a subgrade soil to that developed by a standard material.

By plotting a graph of cumulative Dynamic Cone Penetration Index (DCPI) versus cumulative depth below the testing surface, a user can also observe a profile showing layer, thicknesses, and strength conditions. The soil layer of DCP value is converted to CBR by projecting the corresponding soil layer DCP slope value from its location on the X-axis vertically up to slop deflection and then horizontally over to the Y-axis (Fig. 2-4). This time taking slow process may be eliminated by using a spreadsheet and different developed computer programs (i.e. UK DCP [15] and DCP Research [16]).

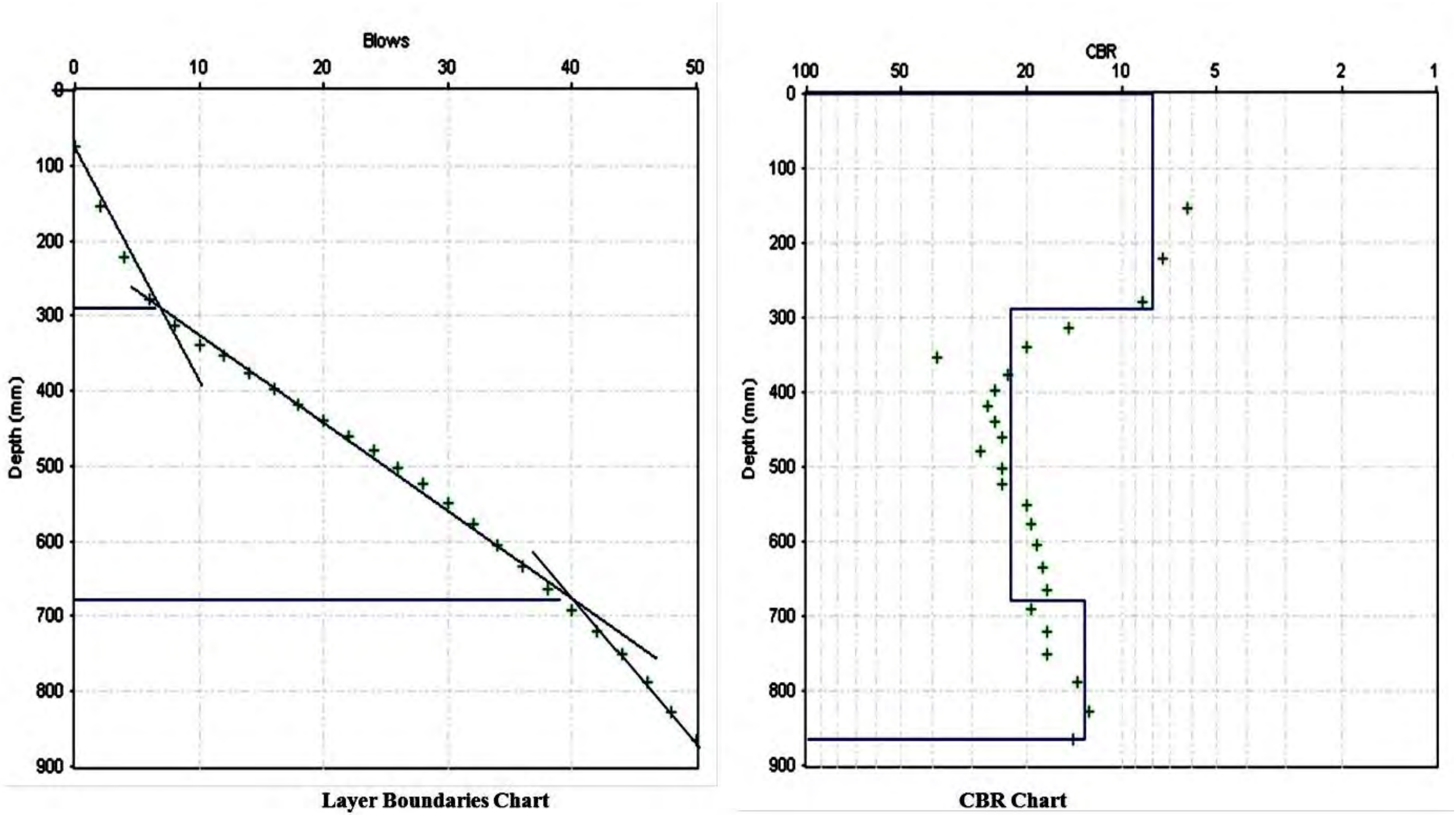

Figure 2-4 Typical DCP soil Layer and CBR Analysis using UK DCP

Extensive researches have been carried out to investigate the relationship between Dynamic Cone Penetration Index (DCPI) and California Bearing Ratio (CBR) [11], [6]. Based on the results of past studies, many of the relationships between DCP and CBR have the following log-log model of the form of Eq. 2-9. A summary of some of these log-log equation correlations is presented in Table 2-1.

$$log(CBR) = A + B * log(DCPI) \qquad (2-9)$$

Where: - DCPI = Dynamic Cone Penetration Index (mm/blow);
CBR = California Bearing Ratio (%)
A and B = constant

Table 2-1 summary of some of log-log equation correlations

Correlation	A	B	Material tested	Reference
log(CBR) = 2.55 - 1.14 log (DCPI)	2.55	1.14	Granular and cohesive	(Harison , 1987) [11]
log(CBR) = 2.45 - 1.12 log (DCPI	2.45	1.12	Granular and cohesive	(Livneh et al. 1992) [17]
log(CBR) = 2.46 - 1.12 log (DCPI	2.46	1.12	Various soil types	(Webster et al. 1992) [6]

Equations using the inverse method have also been proposed by Army Corps of Engineers and Waterways Experiment Station (WES) as presented in Eq. 2-10 and 2-11 respectively [6].

$$CBR = \frac{292}{DCPI^{1.12}} \qquad (2-10)$$

$$CBR = \frac{1}{(0.017019 * DCPI)^2}, \quad If\ CBR < 10\% \qquad (a)$$

$$CBR = \frac{1}{(0.002871 * DCPI)}, \quad If\ soil\ (CH) \qquad (b) \qquad (2-11)$$

Where: - DCPI, Dynamic Cone Penetration Index (mm/blow)
CBR, California Bearing Ratio (%)

Harison [11] concluded that the log-log model equation produces more reliable results than the inverse model equation. Based on statistical analysis, inverse model equations contain more errors and are not suitable to use.

Typical relationships between Dynamic Cone Penetration Index (DCPI), Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) are presented below by Tom and Dave [4].

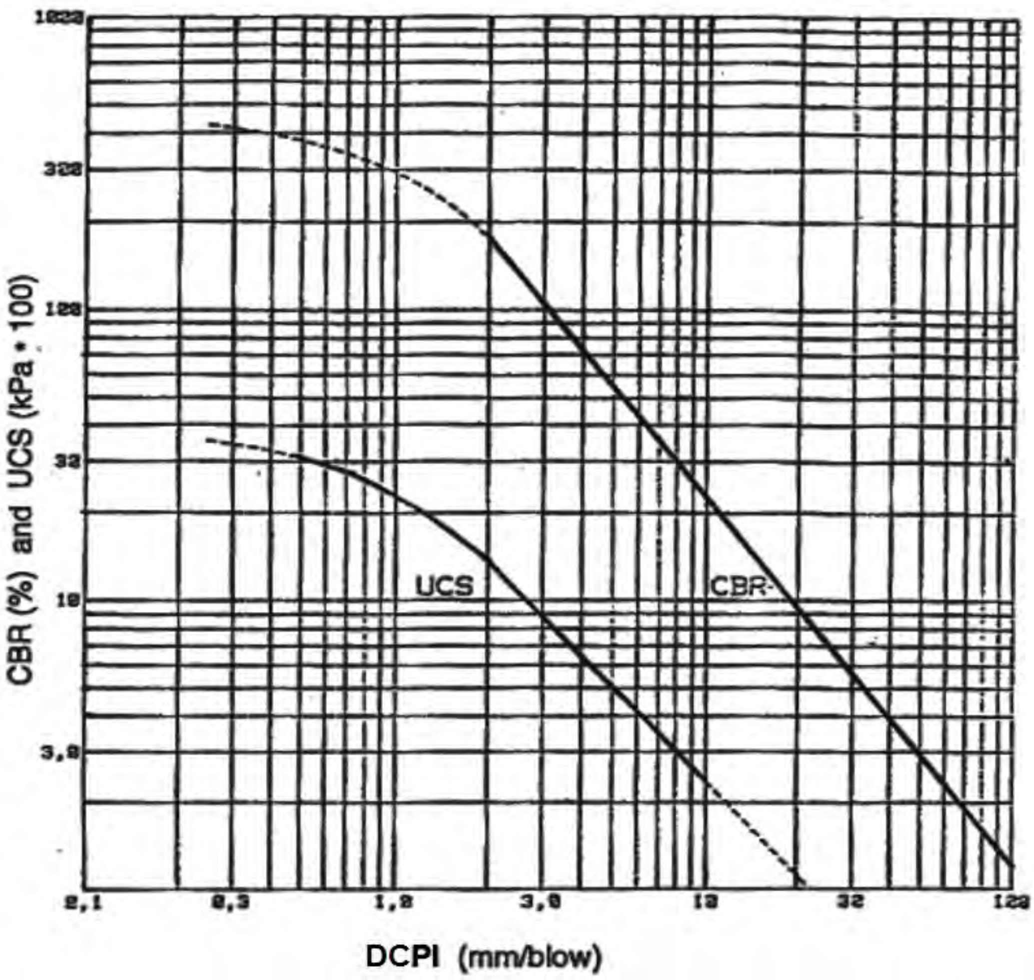

Figure 2-5 Typical relationship between DCPI, UCS and CBR [4]

2.1.3 Factors Affecting DCP Results

Hassan [18] performed a study on the effects of several variables on the determination of DCPI and operation of DCP. He concluded that for fine-grained soils, moisture contents, soil classification, soil density and confining pressures influence the value of DCPI. For coarse-grained soils, coefficient of uniformity and confining pressures were affecting DCPI result [7], [19].

I. Soil Material Properties (Soil Type) and Depth

DCP tests in highly plastic clays are generally accurate for shallow depths. At deeper depths, clay sticking to the lower rod may indicate higher Strength values than the actual values by adding skin friction on cone tip resistance. Many sands occur in a loose state at shallow depths.

Such sands when relatively dry will show no DCP index values for the top few inches and then may show increasing DCP index values with depth. Several investigators indicated that moisture content, gradation, density, and plasticity were important material properties influencing the DCPI [7].

II. Moisture Content and Density

Salgado et al. [12], and Tuncer et al. [20], conclude that Penetration Index affected by Unit Weight and Water Content. They indicate the value of strength index in term of DCPI is more dependent on dry Unit Weight than the Water Content. Salgado et al. [12], studies show the penetration index decreases as the dry density increases and slightly increases as moisture content increases; however, both studies recommended need of additional studies for better understand of the relationships.

Furthermore, Harison [11] conclude that moisture content and dry density do not affect the relationship or correlation of CBR and DCPI. Because, moisture content and dry density are affect both parameters (CBR and DCPI), but they affect in similar ways.

III. Vertical Confinement and Side Friction

Livneh et al. [21], indicated that there is no vertical confinement effect by rigid pavement structure or by upper cohesive layers on the DCP values of lower subgrade layers. Vertical confinement effect may occur at the upper layers in the DCP values of the granular pavement layers. These confinement effects usually result a decrease in the DCP values.

Because of the DCP device is not completely vertical while penetrating through the soil, DCPI value would be apparently very lower due to side friction. This apparent higher resistance may also be caused when penetrating in a collapsible granular material. This effect is usually small in cohesive soils [7].

IV. Damaged DCP Apparatus

The cone should be replaced when its diameter is reduced, when its surface is badly gouged or the tip very blunt. The cone should be examined for wear before any test. A visual comparison to a new cone is a quick way to decide if the test should proceed. Additionally, the rod leave its vertical alignment, no attempt should be made to correct this, as contact between the bottom rod and the sides of the hole lead to erroneous results and may the rod bend.

2.2 Unconfined Compressive Strength (UCS)

The maximum load that can be transmitted to the subsoil depends upon the resistance of the underlying soil. The unconfined compression strength of soil is a load per unit area at which an unconfined cylindrical specimen of soil will fail in simple compression test. It used to calculate the unconsolidated undrained shear strength of the soil under unconfined conditions.

The choice between total and effective stress analysis depends on the load application, which is by considering and comparing the soil response during and after construction, after construction effective stresses or shear strength increased due to excess pore pressures dissipated as of the soil consolidated. Thus, the immediate total stress response of the soil during construction is most critical. This is the justification for the use of quick undrained shear strength tests rather than effective stress analysis for foundation design.

To measure the resistance of the soil by compressibility or shearing deformation, UCS test gives the shear strength of the soil that is useful parameters for computing safe bearing capacity of soil as well as strength of soil. The undrained shear strength is necessary for the determination of the bearing capacity of foundations, dams, etc. It is basically equal to the cohesion, hence the soil angle of internal friction zero, which represent the most critical condition for the soil usually occurs immediately after construction, undrained conditions.

The UCS is a measure of the cohesive strength of a soil, but it is lengthy and need experienced engineer to conduct. The test can be conducted only on intact (non- fissured) soil specimen, which can stand without confinement [22].

Determine the Unconfined Compressive Strength (UCS) of undisturbed soil specimen and the test is a special case of a triaxial compression test, especially for cohesive soils only which can stand alone without confinement. A simple compression axial load is applied quickly in the soil specimen in which the all-round pressure (confined pressure) is equal to zero. The test is an undrained test and is based on the assumption that there is no moisture loss during the test. The soil specimen is sheared by applying an axial load of major principal stress ($\sigma 1$) and failure is reached. The Deviator stress ($\sigma 1$-$\sigma 3$) is equal to the major principal stress and minor principal stress ($\sigma 3$) is equal to zero.

2.2.1 Predicting Undrained Shear Strength

Using the consistency of molded clay soil physical property, one may predict the undrained shear strength of clay soils in the field simply by using one's finger. Table 2-2 shows general relationship of consistency and Unconfined Compression Strength (UCS) of clays [9], [23].

Table 2-2 Table General Relationship of Consistency and UCS of Clays [9]

Consistency	q_u(kN/m^2)	Remark
Very Soft	0-25	Squishes between finger when squeezed
Soft	25-50	Very easily deformed by squeezing
Medium Stiff (firm)	50-100	Thumb makes impression to deform
Stiff	100-200	Hard to deform by hand squeezing
Very Stiff	200-400	Very hard to deform by hand
Hard	>400	Nearly impossible to deform by hand

Table 2-3 shows a summary of Terzaghi and Peck [24] study to determine the relationship between q_u and Standard Penetration Test (SPT) N- value with considering consistency. In Fig. 2-6 the NAVFAC, [25] relationships between the Standard Penetration Test (SPT) N-value and the unconfined compressive strength are presented.

Table 2-3 Correlation between q_u andN(SPT) [24]

Consistency	q_u(kN/m^2)	SPT-N
Very Soft	0-25	< 2
Soft	25-50	2-4
Medium Stiff (firm)	50-100	4-8
Stiff	100-200	8-15
Very Stiff	200-400	15-30
Hard	>400	>30

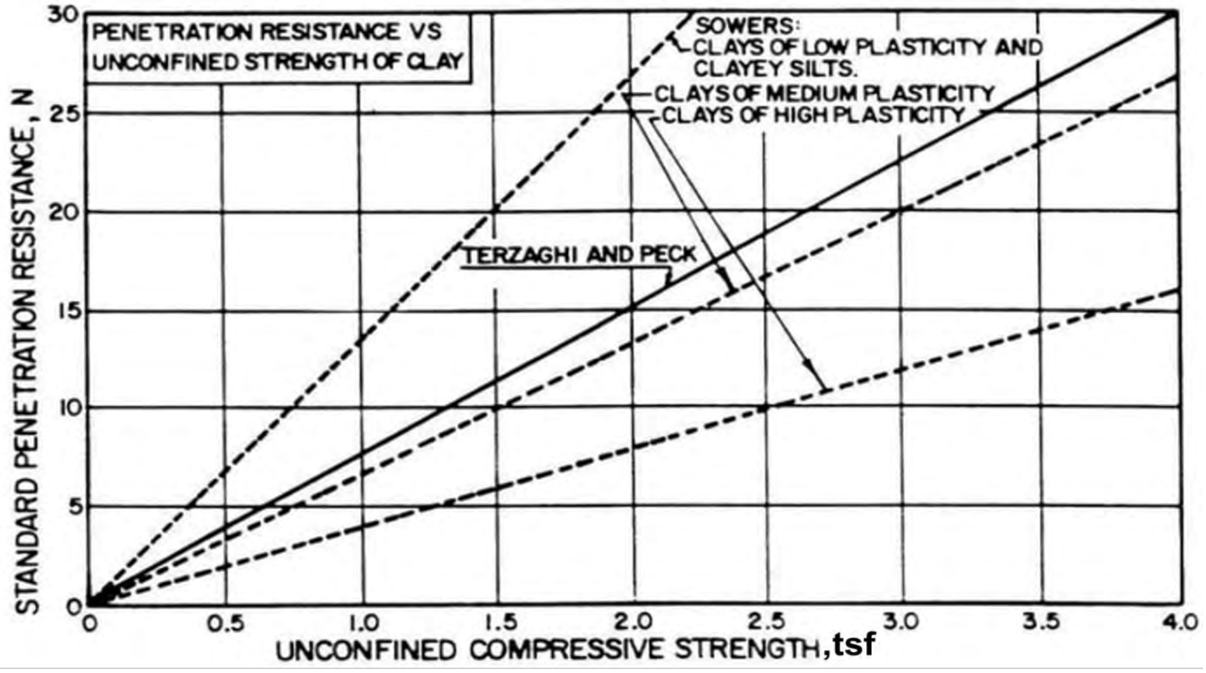

Figure 2-6 Relationship between SPT N-value and UCS [25]

The ratio of undrained shear strength of clay to overburden stress or effective stress by many researchers has been correlated to Atterberg limits. In Fig. 2-7, data are presented showing the relationship between values of undrained strengths and plasticity index for normally to lightly overconsolidated fine-grained soils by Bjerrum [26].

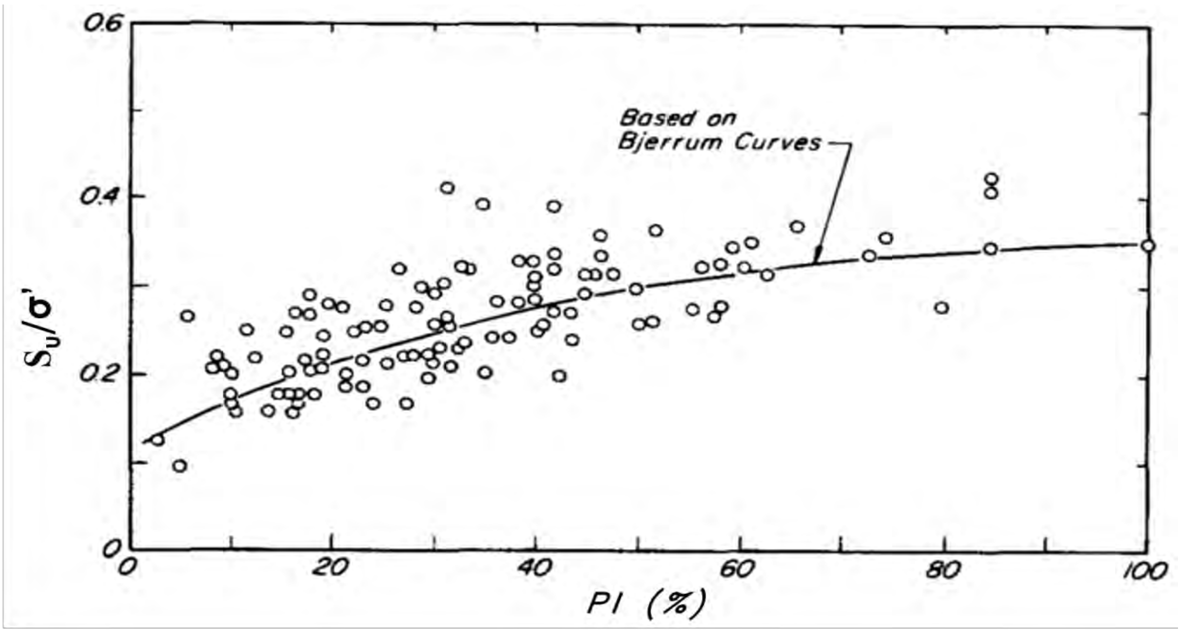

Figure 2-7 Relationship between s_u/σ' and plasticity index [26]

2.3 Grain Size Distribution

Based on the ASTM D1140-97 [27] wash method or wet sieve analysis is conducted to determine the percentage material finer than 75μm more efficiently and accurately. The material retained on the 75 μm (No.200) sieve is collected and dried in oven for 24 hours. The dried soil sample is weighed accurately to determine the grain size distributions of coarser than 75μm materials by using the dry sieve technique. The distribution of particle sizes smaller than 75 μm is determined by a sedimentation process based on D 422-98 [28]. The distribution of particle sizes in soil samples determined after plotting the distribution curve by combining above three test result.

2.4 Atterberg Limits and Free Swell Test

The objective of the Atterberg Limits test is to obtain basic index information about plasticity of the soil. Fine-grained soils are tested to determine the liquid and plastic limits, and plastic index which are moisture contents that define boundaries between material consistency states as per ASTM D 4318-98 [28], which used for soil identification, classification and correlations to other properties.

The free swell test is conducted by placing 10 ml of dry soil passing the No. 40 sieve into a graduated cylinder filled with 100 ml water. According to Holtz and Gibbs (1956), swelled volume of the soil in water is measured after 24 hours and by comparing the initial volume of soil samples (Appendix – B4), can be compute the free swell as follows formula (Eq. 4-1) [29];

$$FS = \frac{V - V_o}{V_o} * 100\% \qquad (2\text{–}12)$$

Where:-

- FS is free swell in %
- V is final volume (Swelled volume) of the soil
- V_o is initial volume of soil

The free swell value increases with plasticity index. It is also indicate an amount of clays present in the soil sample [29].

$$PI = LL - PL \tag{2-13}$$

$$LI = \frac{(NMC - PL)}{PI} \tag{2-14}$$

Where:-

PI is plastic index in %

PL is plastic limit in %

LI is liquidity index in

LL is plastic limit in %

NMC is Natural Moisture Content in %

2.5 Specific Gravity (Gs) and Natural Moisture Content (NMC)

The term specific gravity is defined as the ratio of the weight of a given volume of material to the weight of an equal volume of water. It used to determine the unit weights or density of the soil grain. The specific gravity value can be used in calculations of the hydrometer portion and used to in the determination of soil identification, classification and correlation to other properties [9].

For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior, its index properties and the phase relationships of air, water, and solids in a given volume of materials. Natural moisture content refers to the water content of the soil under insitu natural condition. The Specific Gravity and the Natural Moisture Content (NMC) of soil samples presented in this research are determined according to ASTM D 854-98 and ASTM D 2216-98a standard respectively.

3 METHODS OF DATA COLLECTING AND TESTING

3.1 Description of the Study Area

The geographical location of Alem Gena Town is 8°55′N latitude and 38°39′E longitude with an elevation range between 2128 to 2554m above sea level. The town is located in Oromia Special Zone at about 18km west of Addis Ababa and it lies in an area characterized by variable topographic features such as flat terrain, rugged, hill and mountainous (Fig. 3-1).

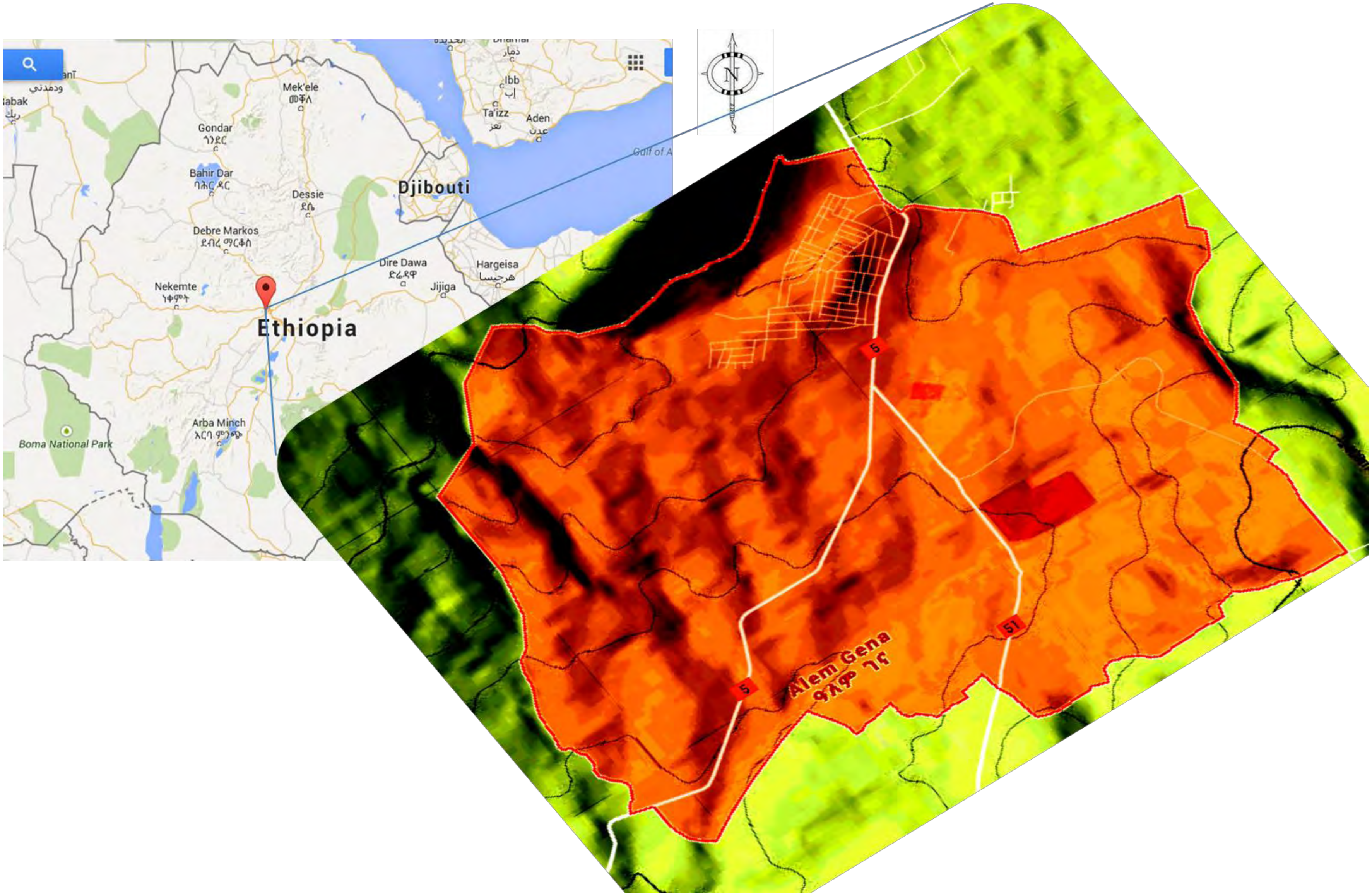

Figure 3-1 Map of Alem Gena Town [Source: Google Map®]

3.2 Data Collection

The data collection stage consists of gathering relevant information from google map, Alem Gena Town Municipality and collection of soil samples and in situ field test during site visits. Sampling locations were selected within and outskirt of Alem Gena Town using stratified random sampling technique. After completing the DCP test, the cone-rod is removed and soil samples are collected. The collected soil samples from the field are further analysed in the laboratory to classify and categorize the soil type and detrmine UCS strength.

Fourteen test pits are excavated usig local labor and samples were collected from each test pits at different depth in different parts of Alem Gena Town (Fig. 3-2). The number of samples taken from one pit mainly depend on the penetration resistance or strength dictated by the DCP test and observed changes in color and moisture conditions of the soil. Up to three soil samples are taken from one test pit, in total thirty disturbed and undisturbed samples collected for further labrotory investigations.

Disturbed and undisturbed soil samples were collected from test pits to determine index properties, soil classification, Unconfined Compression Strength (UCS), etc. Tube sampling techniques used to extract undisturbed soil as per ASTM D1587-94 specification in different area of Alem Gena Town. Polythene bag, due to its very minimum degree of disturbance, is used for sampling and transporting representative disturbed soil samples at different layers of test pits according to ASTM D 4220-95.

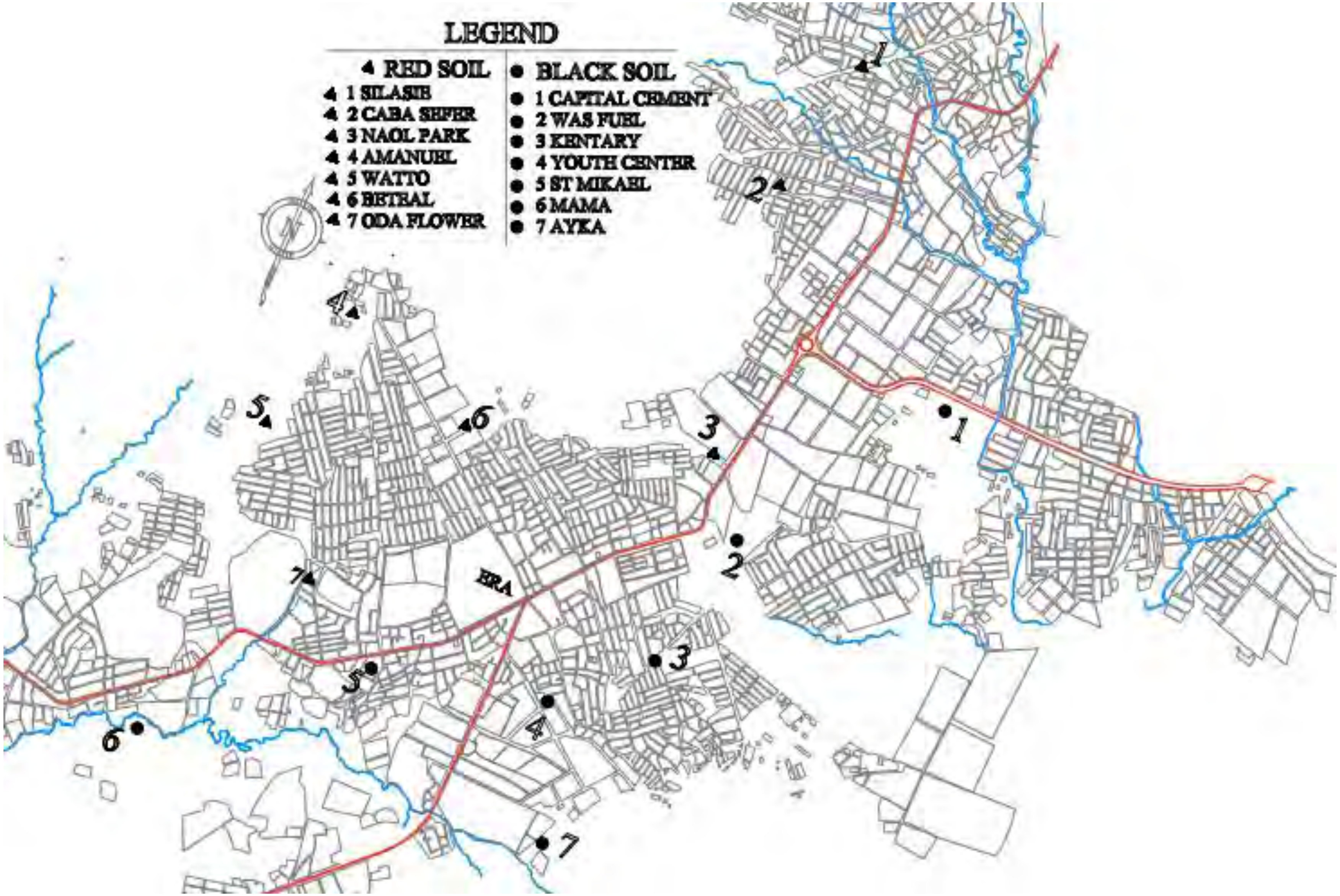

Figure 3-2 Location of Sample Taken [Source: Sebeta City Manucipality]

3.3 Testing Metedology

3.3.1 DCP/Field Test

The DCP test is to be conducted according to new standard test method, ASTM D6951/ D6951M-09 [8].

Before using the DCP apparatus, Webster et al. [6], recommended that, for each and every test the equipment should be inspected for any fatigue or damaged parts, and that all connections are securely tightened. Operating the DCP with loose joints will reduce the life of the instrument.

Operation of the DCP requires two persons, one dropping the hammer and the other recording the depth of penetration. The entire apparatus is then held by the handle perpendicular to the surface by the operator. Before any blow, the recorder observes the reading on the ruler at the bottom of the anvil in reference to the ground and records this as the Zero Reading of DCP [15].

It should be notable (Fig. 3-3a) that initial penetration depth of the first few blows is not representative of the actual penetration index. Additionally the initial reading is not usually equal to zero due to the disturbed loose state of the ground surface and the self-weight of the testing equipment. Place the DCP cone tip rest on top of the layer to be tested and the tip seated such that the top of the widest part of the tipis flush with the surface. Record the reading value, Thus value of the initial reading counted as initial penetration reading corresponding to zero value blow. Therefore, as shown in the (Fig. 3-3b) the first few blow excluded (or consider zero) the initial penetration can represent the actual conditions.

Piouslin et al. [15], recommended that the penetration of the cone should be measured at increments of about 10 mm. However, it is difficult to blow the desire penetration depth. Therefore the operator should lift the hammer to its predetermined or maximum height (i.e. 575 mm) and allow it to drop freely on to the anvil either one or more times depending upon the strength of the soil at a test location. Following each hammer drop, a penetration reading is taken (for soft material, 20mm or more/blow) using the DCP penetration data recording sheet (Appendixes D). If after 10 blows, the device has not penetrated more than 2 mm, it is considered as refusal [14].

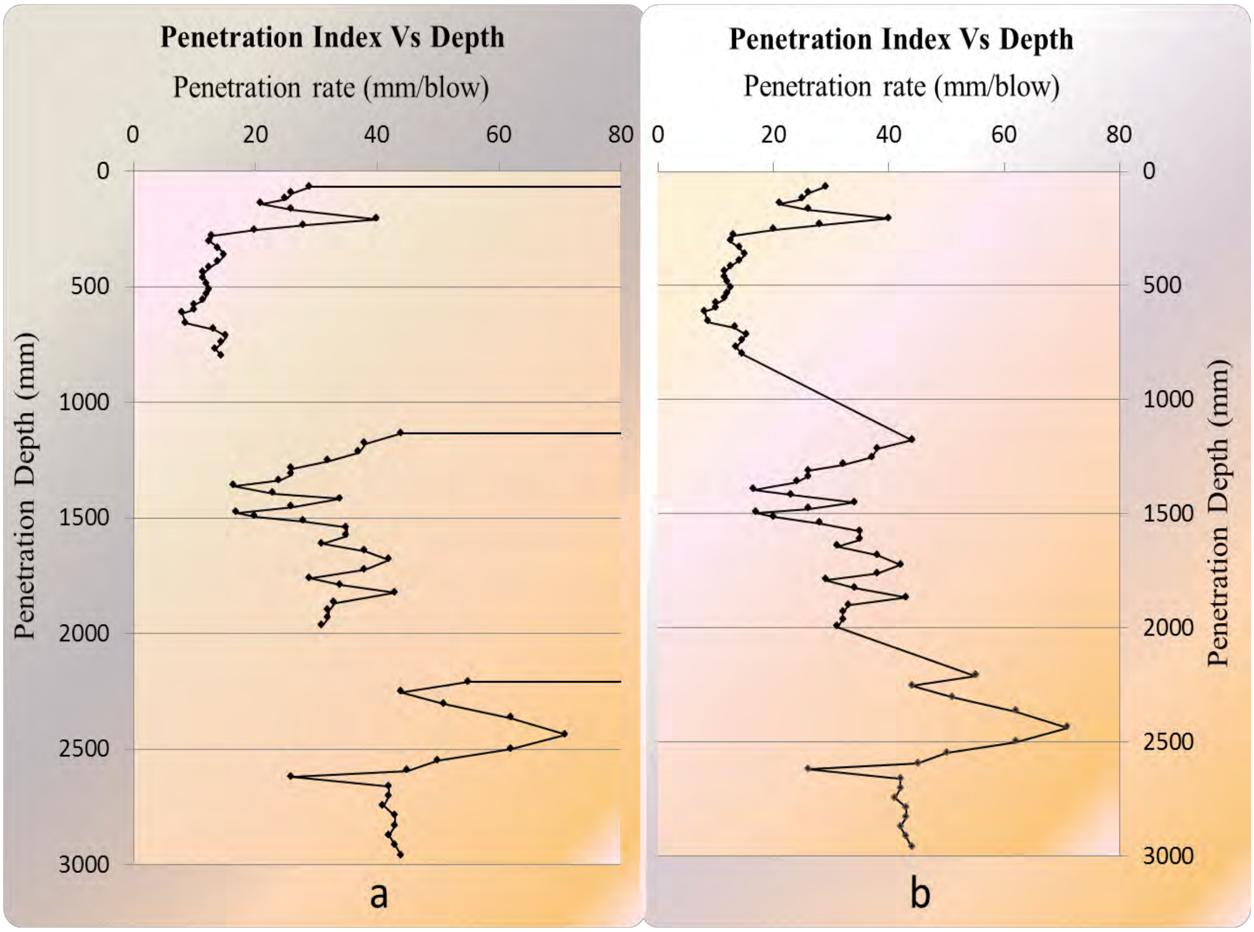

Figure 3-3 Initial setting conditons

3.3.2 Laboratory Tests

The entire laboratory tests are performed in Addis Ababa Institute of Technology Geotechnical Laboratory using the following standard testing procedures, (Table 3-1).

Table 3-1 Summary of laboratory testing procedure standards

Test Description	Standard Testing Procedure	Reference
Grain Size Distribution Analysis	ASTM D 1140-97 and D 422-98	[27], [28]
Natural Moisture Content	ASTM D 2216-98a	[28]
Atterberg Limits	ASTM D 4318-98	[28]
Specific Gravity	ASTM D 854-98	[28]
Free Swell Test	Holtz and Gibbs (1956)	[29]
Unconfined Compressive Strength	ASTM D2166-98a	[28]

4 RESULTS AND DISCUSSIONS

4.1 Field / DCP Test Results

As DCP testing is basically a measure of penetration resistance, expressed as Dynamic Cone Penetration Index (DCPI), the analysis of the DCP data must be interpreted, following a standardized procedure, to generate a representative value of penetration per blow for the material being tested. This representative value can be obtained by arithmetic averaging the DPI across the entire penetration depth at each test location.

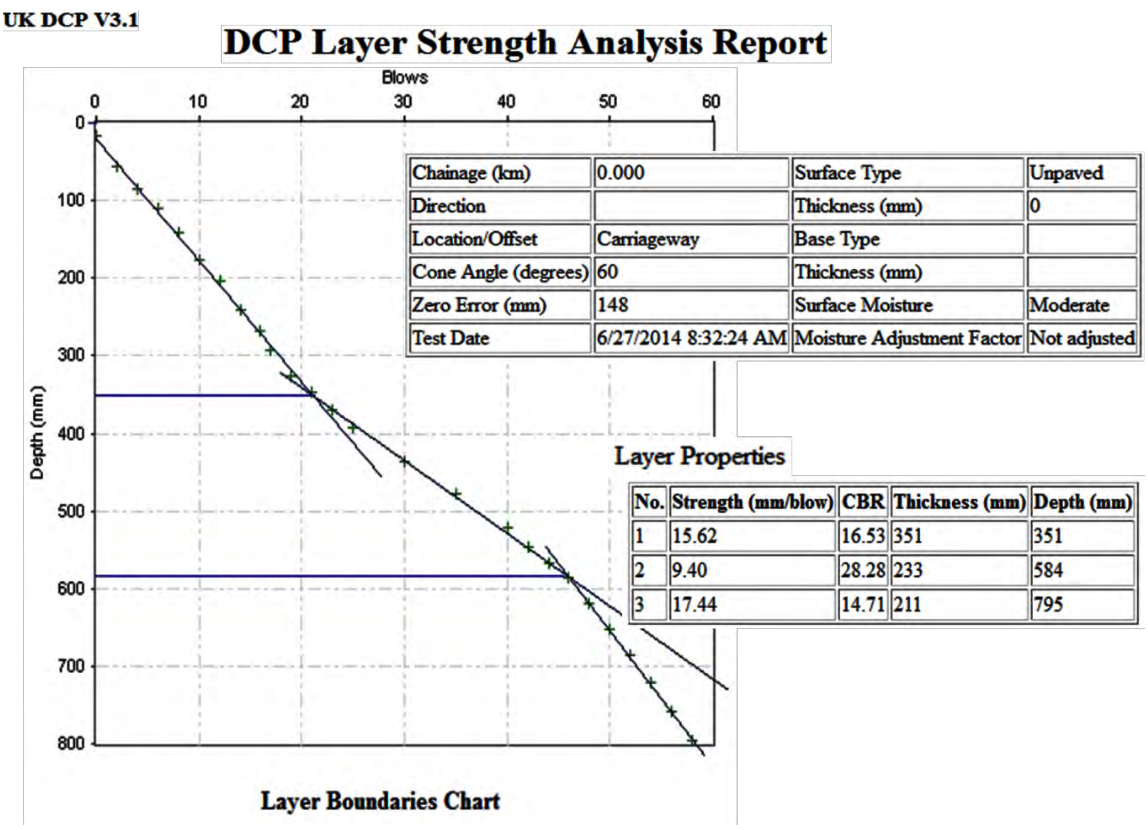

Figure 4-1 Typical results of DCP Layers and DCPI determination

In the current research, the data is analyzed using simple software called UK DCP [Version 3.1] [15]. Using this software one can input depth of penetration and number of blows to get penetration index and layers of in situ characteristics in an enhanced way. The exact interface of layer is difficult to define, because a transition zone exists between layers. But the user can define the interface layer manually or automatically with in the computer program. If the user identified the layer transition zone by excavating test pit, manual layer analysis is better and accurate techniques. Depending on the soil structure and environmental conditions the plot is divided into "best fit" straight lines. The slope values are then calculated by the change in penetration versus the change in the number of blows observed over the range for that particular straight line section - expressed as mm/blow (Fig. 4-1 and Appendix - A).

Stiffer or stronger soils require a higher number of blows or drops of the hammer to achieve a given penetration, as could be seen in the summary of the tabulated test results Table 4-1.

4.2 Laboratory Test Results

The distribution of particle sizes in soil samples determined after plotting the distribution curve (Fig. 4-2 and Fig 4-3).

Atterberg Limits and Free Swell, Natural Moisture Content (NMC), Unconfined Compression Strength (UCS) and Specific Gravity (Gs) test results are summarized in Table 4-1. Detail test data and results tabulated in Appendix – B.

4.3 Summary of Test Results

The Unified Soil Classification System (USCS) is used to classify soils of the study area. According to the USCS classification method both black expansive and red soils in Alem Gena Town are classified in CH, CL, MH and ML groups (Fig. 4-4). The results and further relationship or correlation investigation were done using two categories (i.e. Category -1(Black Expansive Soil) and Category -2 (Red Soil)).

Table 4-1 Summary of test results

Sample No	Sample Designation	Sample Depth	DCPI	NMC	Gs	Unit Weight	UCS	Clay fraction	LL	PL	PI	LI	Free Swell	Activity	USCS
		mm	mm/blow	%		KG/M^3	Kpa	%	%	%	%		%		
1	Amanuel I	750	17.44	33	2.78	1956	141	20	54	38	16	-0.3	34	0.8	ML
2	Amanuel II	1500	9.66	22	2.66	1657	181	18	59	46	13	-1.9	32	0.7	ML
3	Amanuel III	2400	12.72	26	2.71	1763	166	27	69	47	22	-0.9	42	0.8	MH
4	Ayka I*	800	22.78	27	2.77	2106	143.5	41	89	33	56	-0.1	70	1.4	CH
5	Ayka II*	1600	15.48	38	2.71	1866	156	22	62	30	32	0.3	50	1.5	CH
6	Ayka III*	2200	8.05	18	2.65	1626	166.5	22	57	28	29	-0.3	51	1.3	CH
7	betel I	720	9.38	22	2.71	1645	182	27	47	24	23	-0.1	40	0.8	MH
8	betel II	1400	12.84	23	2.74	1775	172	28	41	17	24	0.3	39	0.9	CL
9	betel III	2400	14.54	27	2.78	1836	160	30	48	23	25	0.2	42	0.8	CL
10	caba	750	35.18	56	2.78	2069	102	19	50	32	18	1.3	30	0.9	MH
11	capital cement I*	1200	22.3	39	2.76	2008	144	31	92	39	53	0	57	1.7	CH
12	capital cement II*	1800	37.56	44	2.75	2258	143	40	91	35	56	0.2	65	1.4	CH
13	capital cement III*	2700	48.1	49	2.82	2320	119.5	41	91	37	54	0.2	63	1.3	CH
14	kentari I*	630	11.69	19	2.67	1781	177.5	24	72	32	40	-0.3	53	1.7	CH
15	kentari II*	1500	19.56	40	2.72	1763	150	32	76	33	43	0.2	51	1.3	CH
16	kentari III*	2850	16.73	34	2.78	1754	148.3	39	81	34	47	0	63	1.2	CH
17	mama I*	720	7.94	22	2.72	1888	167	38	81	32	49	-0.2	58	1.3	CH
18	mama II*	1400	14.72	29	2.78	1932	159	32	70	30	40	0	51	1.2	CH
19	mama III*	2800	21.6	34	2.76	2338	148	31	70	28	42	0.1	51	1.4	CH
20	Naol Park I	700	8.69	27	2.69	1612	171	27	40	15	25	0.5	40	0.9	ML
21	Naol Park II	1200	7.51	31	2.67	1554	185	21	40	22	18	0.5	37	0.9	ML

Sample No	Sample Designation	Sample Depth	DCPI	NMC	Gs	Unit Weight	UCS	Clay fraction	LL	PL	PI	LI	Free Swell	Activity	USCS
		mm	mm/blow	%		KG/M^3	Kpa	%	%	%	%		%		
22	Oda Flower I	720	19.17	41	2.81	2028	120	34	72	38	34	0.1	49	1	MH
23	Oda Flower II	1400	15.08	29	2.74	1837	154	28	71	42	29	-0.4	39	1	MH
24	Oda Flower III	2440	7.28	19	2.63	1538	192	21	49	31	18	-0.7	40	0.9	ML
25	silasie	700	14.63	26	2.74	2024	160	27	56	31	25	-0.2	41	0.9	MH
26	St. Mikael Ch. I*	1100	14.3	23	2.67	1781	159.8	27	67	31	36	-0.2	51	1.3	CH
27	St. Mikael Ch. III	2900	9.43	38	2.71	1754	142	14	49	29	20	45	30	1.4	ML
28	Was Fuel*	800	13.4	26	2.69	1760	157.5	36	92	37	55	-0.2	64	1.5	CH
29	watto	1100	14.32	30	2.79	2014	124.8	23	56	33	23	-0.2	37	1	CL
30	Youth Center*	750	22.04	32	2.75	1998	150.5	35	82	30	52	0	52	1.5	CH

Note:- * Black expansive clay soils

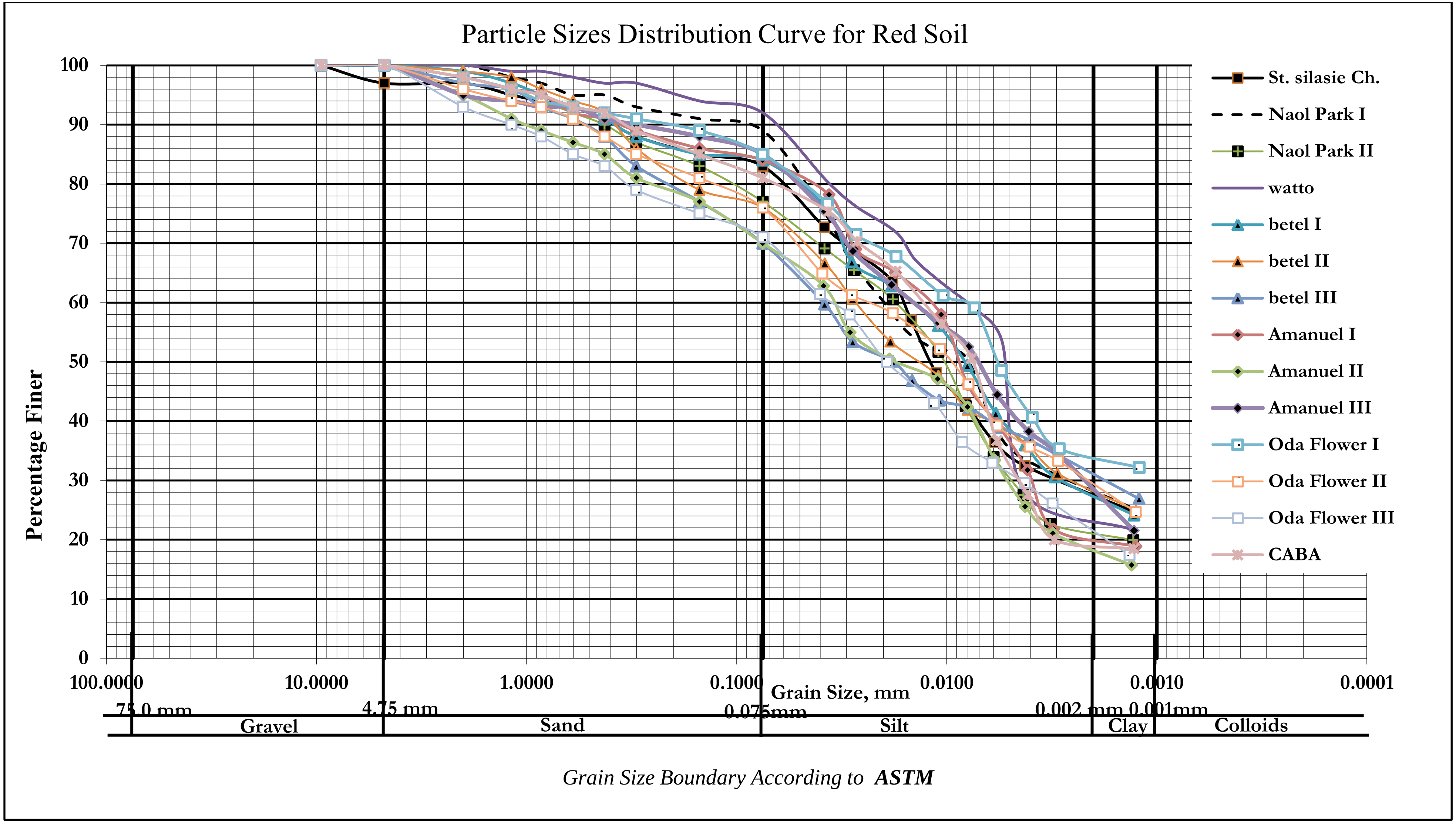

Figure 4-2 Particle Sizes Distribution Curve for Red Soil

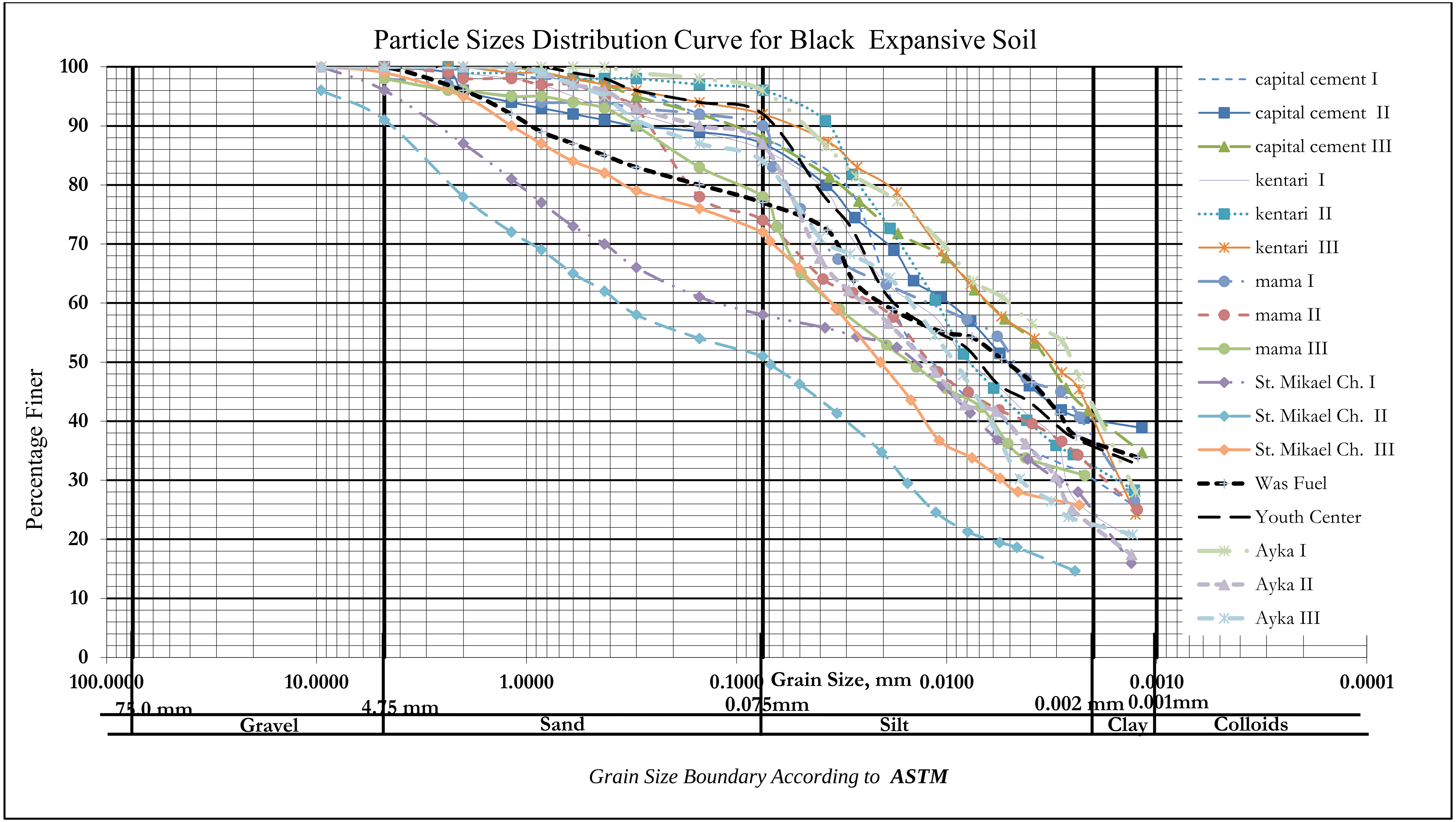

Figure 4-3 Particle Sizes Distribution Curve for Black Expansive Soil

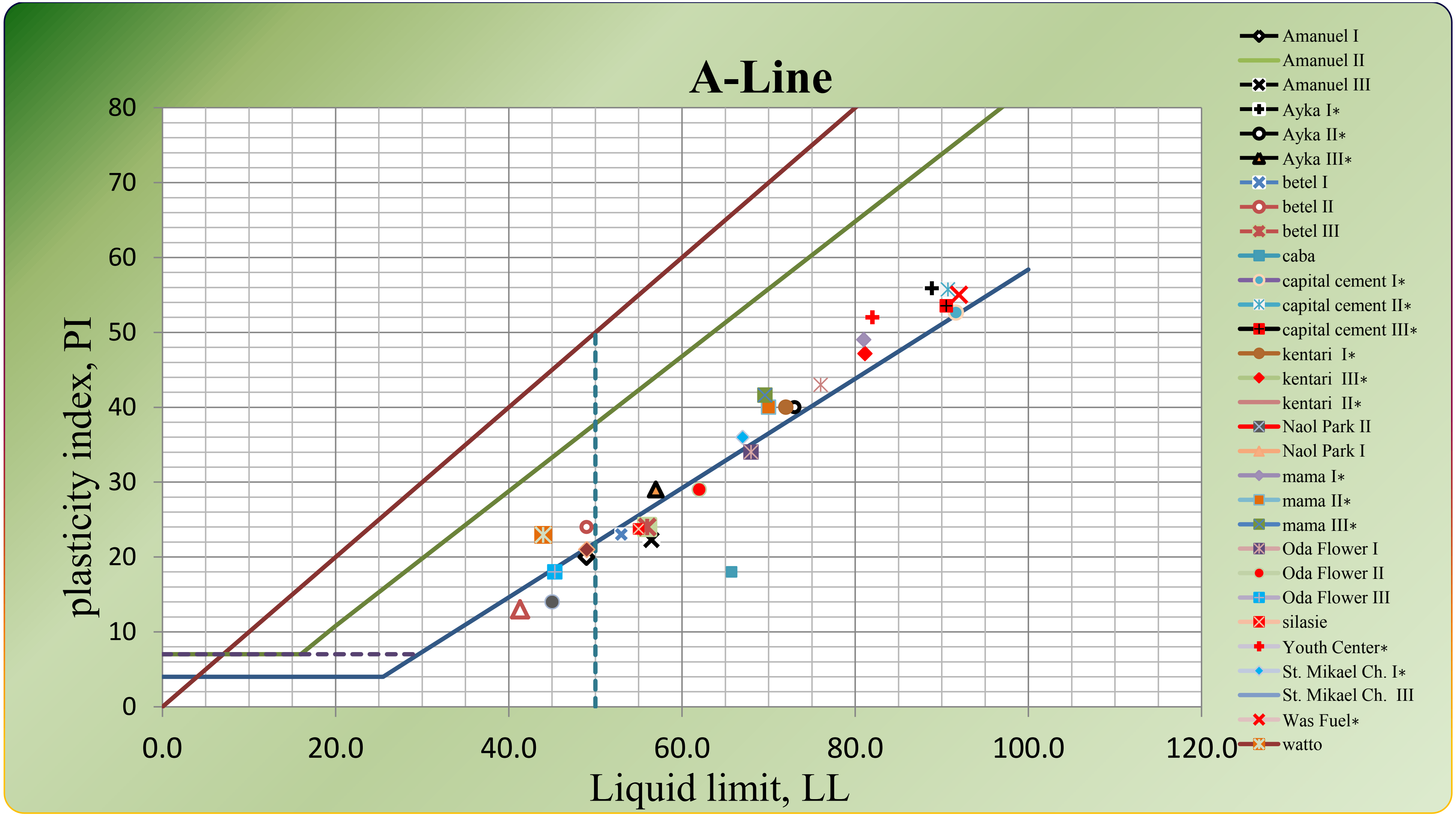

Figure 4-4 USCS Soil classification chart result

5 SINGLE AND MULTIPLE CORRELATIONS

Regression analysis is used to establish correlations between dependent and independent parameters. A correlation function, which is most suited to the data collected, is selected for the analysis. Correlation functions were determined for both categories of soil separately.

Different models are used for the correlation and those models with a higher coefficient of determination (R^2) are accepted as significant relationships. Single and multiple correlation are carried out.

5.1 Single Correlations

The correlation is done for the two soil categories separately. For each categorized group an individual combined single correlation data is plotted in the best fit paper (linear, semi-log or log-log) to identify the best model equation using Microsoft excel spreadsheet.

Single correlation is done by considering Unconfined Compression Strength (UCS) dependent parameter and the independent variables are Natural Moisture Content (NMC), Specific Gravity (Gs), and Liquidity Index (LI).

In single mathematical model analysis, the following general model equations are more preferable or give higher coefficient of determination (R^2) (Table 5-1 and Table 5-2).

i. Linear,

$$UCS = Ax + B \qquad (5-1)$$

ii. Power,

$$UCS = A * e^{Bx} \qquad (5-2)$$

iii. Logarithmic,

$$UCS = A * \ln[x] + B \qquad (5-3)$$

Where: - UCS = Unconfined Compression Strength (UCS)
x = independent variable
A and B = Constant

5.1.1 Category -1 (Black Expansive Soil)

In Table 5-1, it may be observed that the Unconfined Compression Strength (UCS) is related to Dynamic Cone Penetration Index (DCPI), Natural Moisture Content (NMC), Specific Gravity (Gs) and also Liquid Limit (LL). (Fig. 5-1 and 5-2)

Table 5-1 Summary of correlation equations and R^2 of category-1(Black soil)

Dependable Item	Variable Item	Equation	R^2
UCS	DCPI	UCS =-24.56*ln[DCPI]+223.05	0.805
	NMC	UCS=-1.233(NMC)+191.62	0.727
	Gs	UCS=-217.39(Gs)+746.55	0.621
	LI	UCS=-54.841(LI)+150.8	0.632

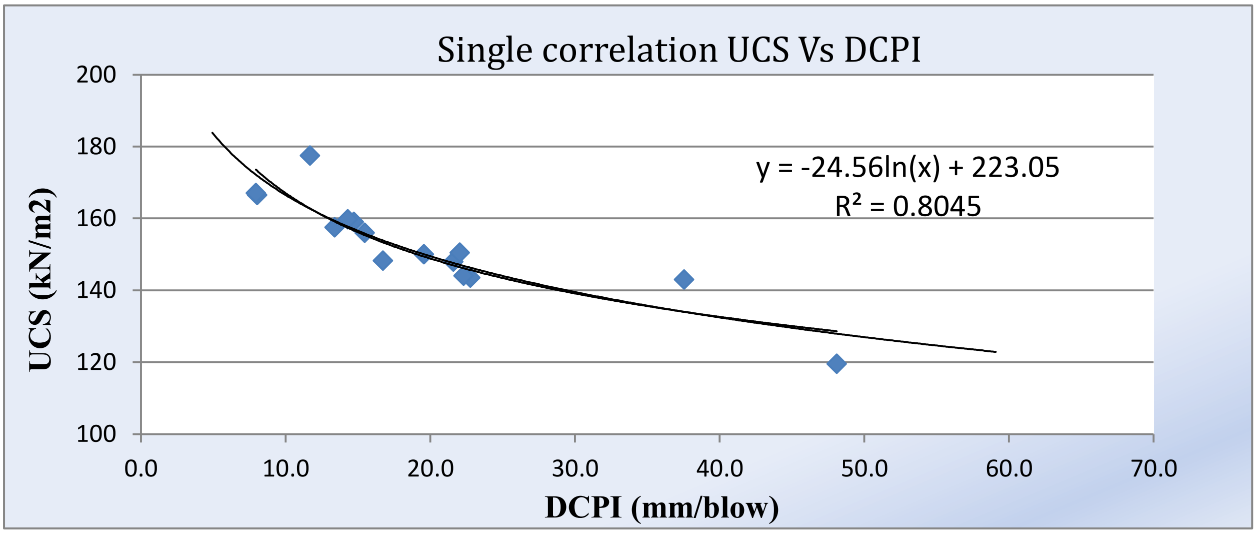

Figure 5-1 Single correlation of DCPI with USC for black expansive soil

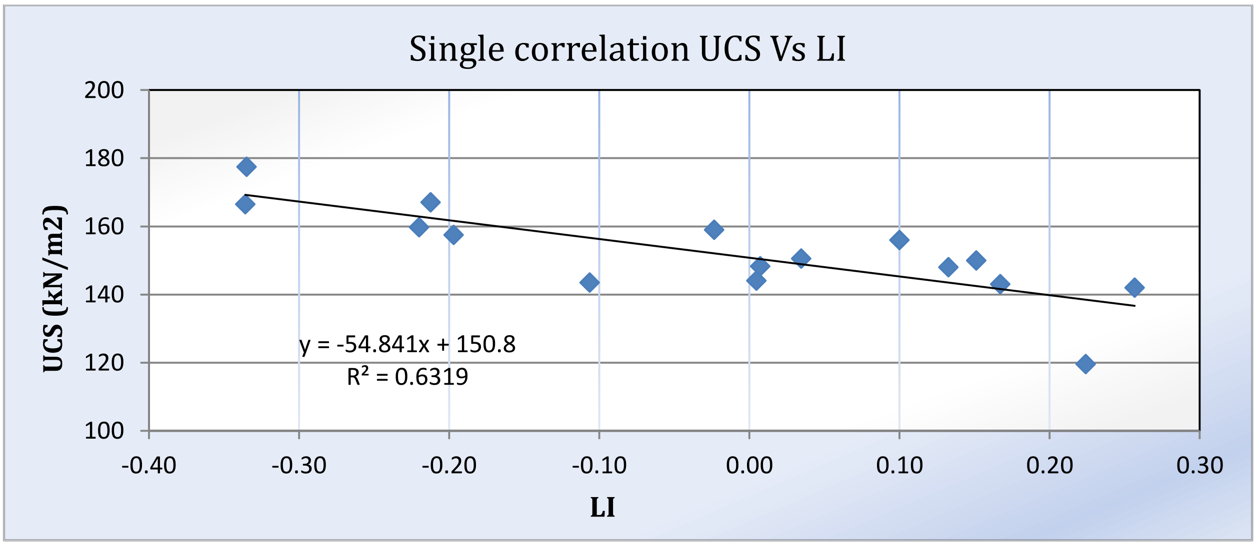

Figure 5-2 Single correlation of USC with Liquidity Index for black expansive soil

5.1.2 Category -2 (Red Soil)

In Table 5-2, it may be observed that the Unconfined Compression Strength (UCS) is related to Dynamic Cone Penetration Index (DCPI), Natural Moisture Content (NMC), Specific Gravity (Gs) and also Liquid Limit (LL).

Table 5-2 Summary of correlation equations and R^2 of category 2 (Red soil)

Dependable Item	Variable Item	Equation	R^2
UCS	DCPI	UCS =-58.59*ln[DCPI]+308.04	0.831
	NMC	UCS=-2.45(NMC)+229.83	0.729
	Gs	UCS=-424.98(Gs)+1318.5	0.749
	LI	UCS=-76.48(LI)+151.56	0.725

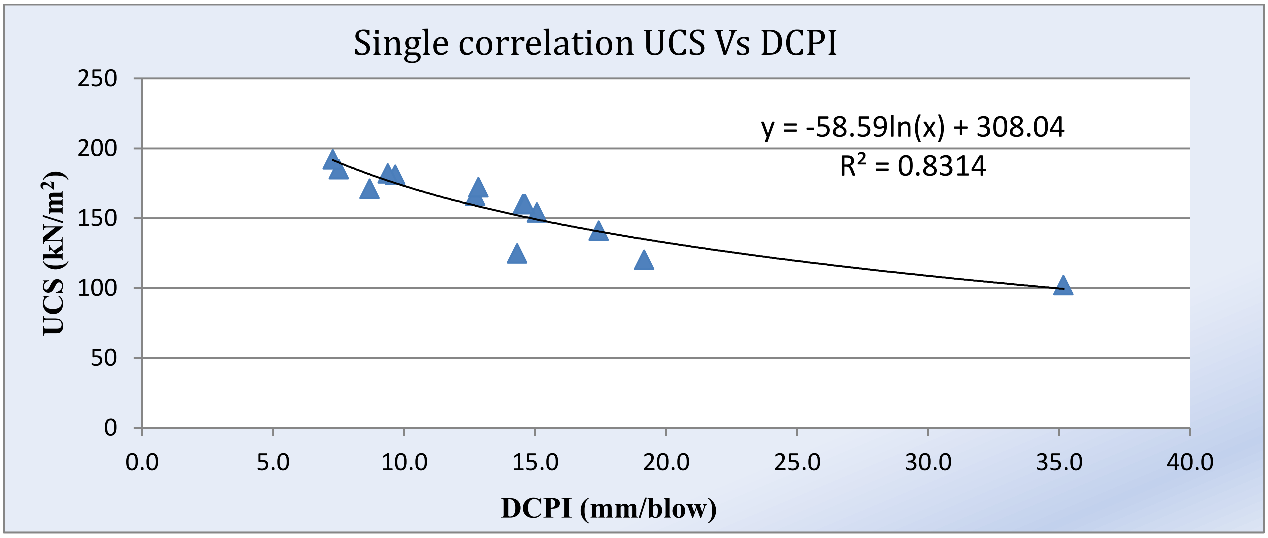

Figure 5-3 Single correlation of DCPI with USC for Red soil

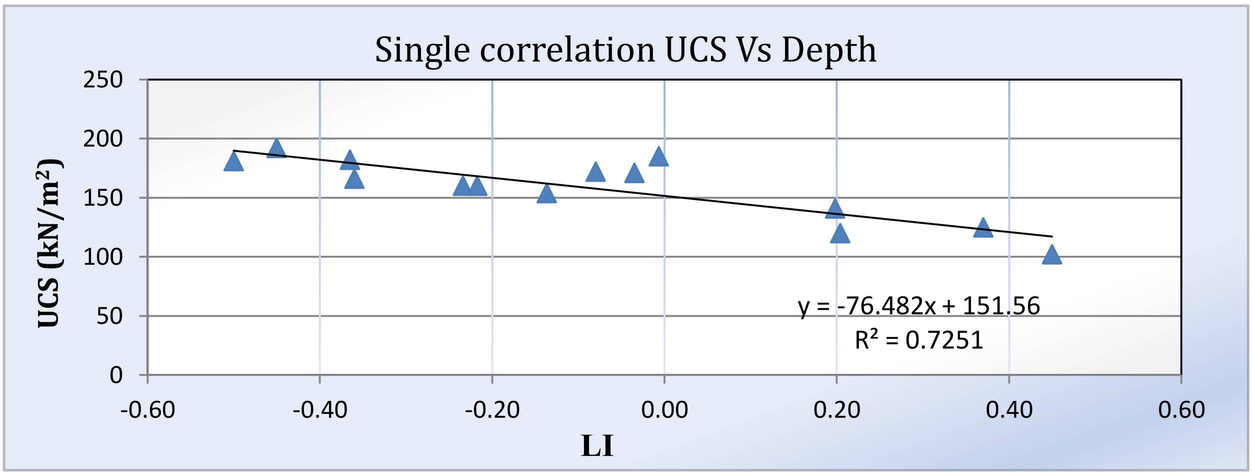

Figure 5-4 Single correlation of USC with Liquidity Index for Red soil

5.2 Multiple Correlations

Multiple Correlations is a technique that allows additional factors to enter the analysis separately so that the effect of each can be estimated using one model equations. It is valuable for quantifying the impact of various simultaneous influences upon a single dependent variable. Furthermore, because of omitted variables bias with single regression, multiple regression is often essential even when the investigator is only interested in the effects of one of the independent variables.

In SPSS, adjusted R^2 is applied [30]. The mathematical model used for multiple regression due to the limitation of SPSS is linear. The independent variables that are introduced to this model are Dynamic Cone Penetration Index (DCPI), and Liquidity Index (LI).

5.2.1 Multiple Regression of Category -1 (Black Expansive Soil)

When developing this equation using linear regression models, the significance of the parameter and the Adjusted R Square is analyzed. After Analysis those variables that have significant contribution to Unconfined Compression Strength (UCS) are Dynamic Cone Penetration Index (DCPI), and Liquid Index(LI), as presented in Eq. 5-4.

For best model of SPSS multiple linear correlation analysis has been done using the ENTER data input method. The following significant model indicator emerged in the developed correlation equation;

$$UCS=-0.99*DCPI - 12.06*LI + 171.89 \qquad (5-4)$$

The ANOVA Table reports a significant F statistic $F_{2,12}=26.78$, $Sig<0.0005$;

The Regression sum of the square is much greater than residual sum of the square;

R square = 0.817; The Adjusted R square = 0.786. (Appendix – C2)

5.2.2 Multiple Regression of Category -2 (Red Soil)

When developing this equation using linear regression models, the significance of the parameter and the Adjusted R Square is analyzed. After Analysis those variables that have significant contribution to Unconfined Compression Strength (UCS) are Dynamic Cone Penetration Index (DCPI), and Liquid Index(LI), as presented in Eq. 5-4.

For best model of SPSS multiple linear correlation analysis has been done using the ENTER data input method. The following significant model indicator emerged in the developed correlation equation;

$$UCS=-3.35*DCPI - 0.2*LI + 205.46 \quad (5-5)$$

The ANOVA Table reports a significant F statistic $F_{2,12}=18.18$, $Sig<0.0005$;

The Regression sum of the square is much greater than residual sum of the square;

R square = 0.768; The Adjusted R square = 0.725. (Appendix – C2)

6 DISCUSSION AND COMPARISON

6.1 Discussion

By referring the single regression equations in Table 5-1 and 5-2 the end user can estimate the Unconfined Compression Strength (UCS) simply from field test of Dynamic Cone Penetration Index (DCPI) of category -1 Black expansive soil and category -2 Red soils respectively.

From SPSS Statistical software analysis, using multiple linear regression model, it has been found out that Dynamic Cone Penetration Index (DCPI), and Liquid Index (LI) contribute for target dependent parameter Unconfined Compression Strength (UCS) for both categories. Additionally the above independent parameters give higher Adjusted R Square (Coefficient of determination) and have significance value (Appendix C2).

Very small researches are conducted in developing relationship between Unconfined Compression Strength (UCS) and Dynamic Cone Penetration Index (DCPI). The relationships developed are based on small samples that have significant variation from the actual condition. A statistically valid relationship between Dynamic Cone Penetration Index (DCPI) and Unconfined Compression Strength (UCS) is feasible for the specific area.

6.2 Comparison

To evaluate the capabilities of the proposed correlations in this research, predicted Unconfined Compression Strength (UCS) values were plotted against measured Actual Unconfined Compression Strength (UCS) values.

6.2.1 Comparison with pervious similar studies

Correlations developed by Patel, et al. [13], Temnit [14], and Salgado, et al. [12] were selected for comparison of present proposed single correlation relationships. Figure 6-1 compares the suggested correlations by above stated studies to the proposed correlations in this study between the Unconfined Compression Strength (UCS) and Dynamic Cone Penetration Index (DCPI).

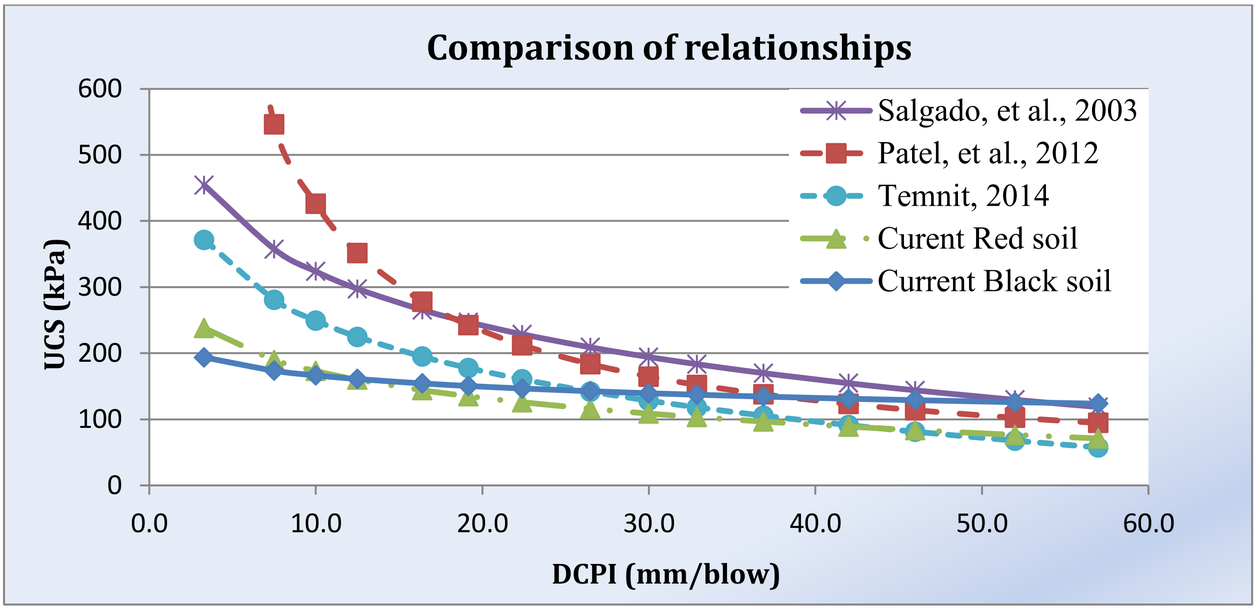

Figure 6-1 Comparison of perivious and current studies

As shown in the Fig. 6-1 the single correlation of current studies seems similar trend, but not in equal position. This is the reason due to the geographical deference and the type of soil of the studied area is different.

The index properties of Alem Gena soils from current research and previous researches are presented in Table 6-1 for comparison purpose.

Table 6-1 Index properties of Alem Gena soil from previous and current researches

Researches	**Clay Content (%)**	**LL (%)**	**PI (%)**	**Gs**
Selamawit Mekbib **[31]**	33.22-69.78	38-103	17-70	2.65-2.86
Current Research	14.08-41.28	41-92	13-56	2.63-2.82

From Table 6-1 one can see that the test results of the current research is different from the previously conducted research this is due to the amount of sample taken in the current research is higher than the previous one.

6.2.2 Comparison of Measured and Predicted Results

The predicted Unconfined Compression Strength (UCS) results using the proposed equations are compared with the actual measured in laboratory for validation.

Fig. 6-2 and 6-3 show the actual measured versus current predicted Unconfined Compression Strength (UCS) value including 95% confidence limit lines. The Figures confirm the developed multiple correlation equation can predict the actual value of Unconfined Compression Strength (UCS) with excellent potential and quality within 95% confidence limits.

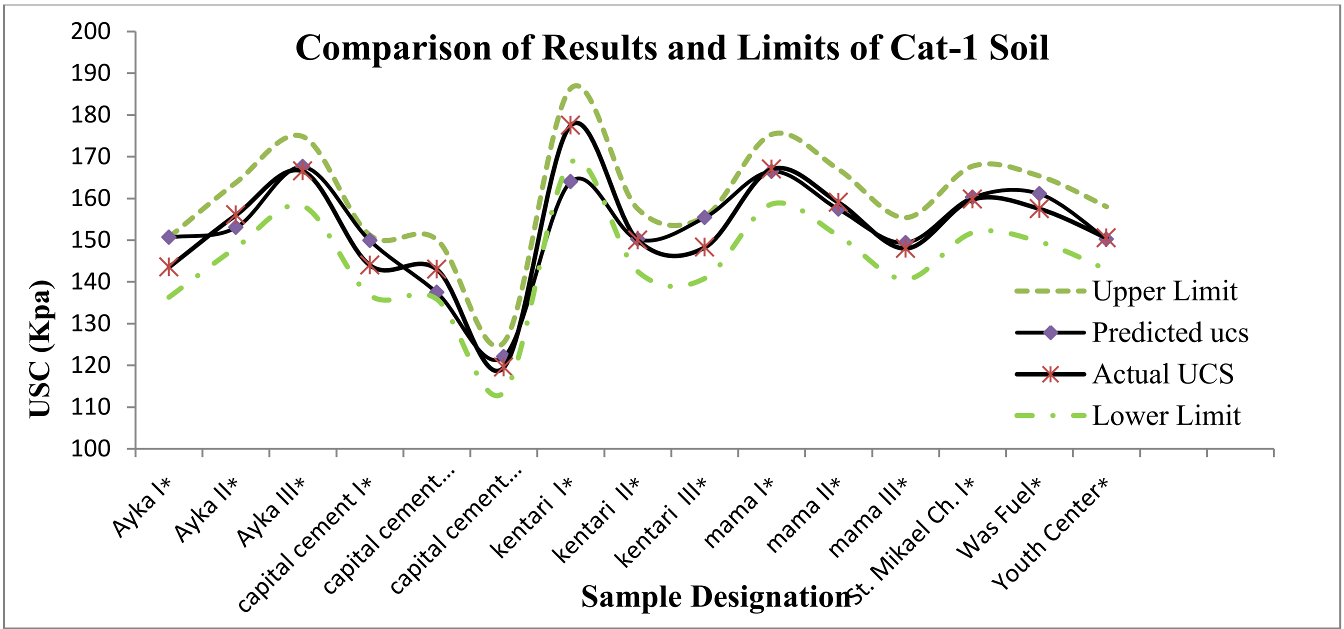

Figure 6-2 Actual measured versus Current predicted UCS Value of cat -1 Black Expansive Soil

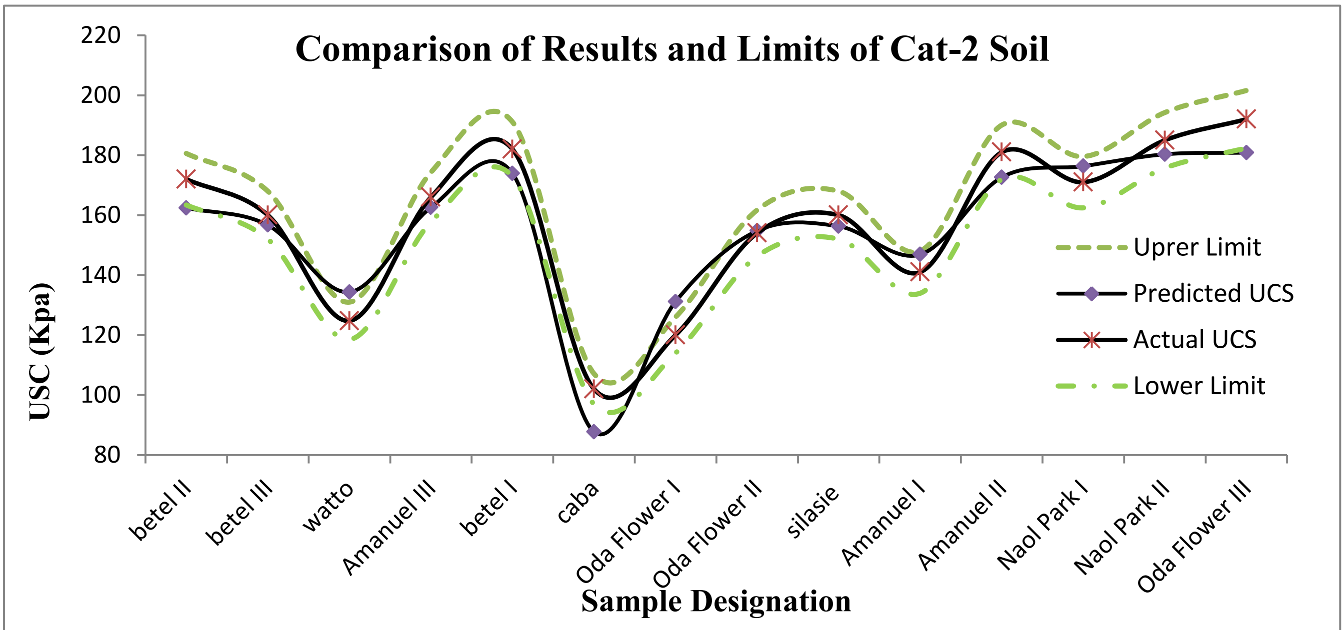

Figure 6-3 Actual measured versus Current predicted UCS Value of cat -2 Red soil

7 CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Unconfined Compression Strength (UCS) depends on Dynamic Cone Penetration Index (DCPI), Natural Moisture Content (NMC), Liquidity Index (LI), and Specific Gravity (Gs). The following single regression equations have been developed to estimate the Unconfined Compression Strength (UCS) from field test of Dynamic Cone Penetration Index (DCPI) for both categories.

From the Comparison made between the newly developed equation and previous developed equation of sample made outside the study area one can see that the newly developed equations are acceptable. But applicability of the result will be limited to the study area. Therefore the results should only be applied to the study area.

From the current research unconfined compression strength (UCS) is highly influenced by DCPI and Liquidity Index (LI). Therefore, for multiple regression analysis Unconfined Compression Strength (UCS) is better estimated when Dynamic Cone Penetration Index (DCPI) and Liquidity Index (LI) are introduced as independent variables.

7.2 Recommendation

i. From the developed single correlation equation Unconfined Compression Strength (UCS) can be calculated from the Dynamic Cone Penetration Index (DCPI) test result. However, the prediction can be improved if multiple regression equation used.

ii. Relationships developed based on small samples should be strengthened by increasing the number of samples for each category thus producing a more reliable relationship.

iii. Even though, a good correlation between Dynamic Cone Penetration Index (DCPI) and Unconfined Compression Strength (UCS) has been developed, since these are dependent on material properties, they should be used with caution. Additionally, these relationships cannot be considered as perfect substitute of the laboratory values and their use requires experience and engineering judgments.

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DECLARATION

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

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Signature:

Date: July, 2017

Place: Addis Ababa institute of Technology
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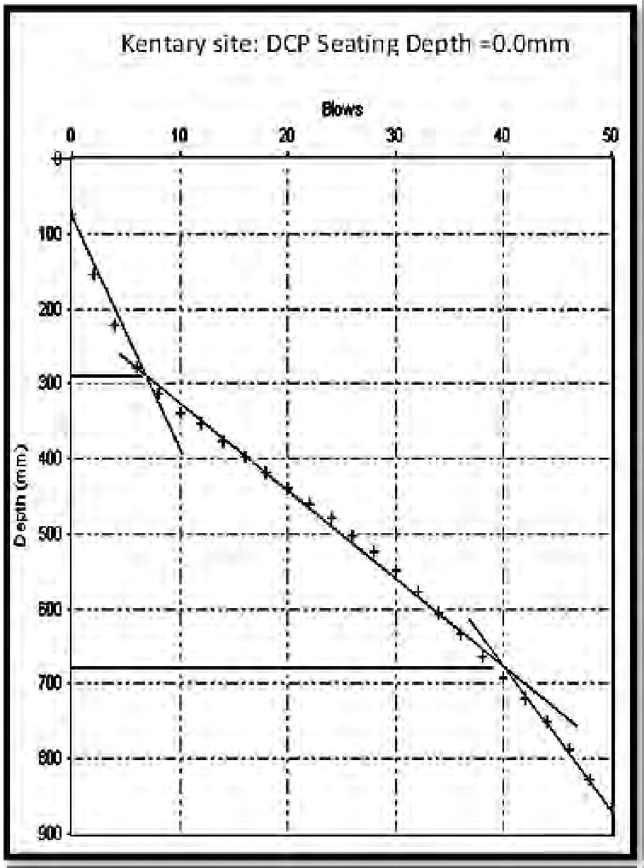
APPENDICES

APPENDIX– A

DCP LAYER /SAMPLE/ STRENGTH ANALYSIS REPORT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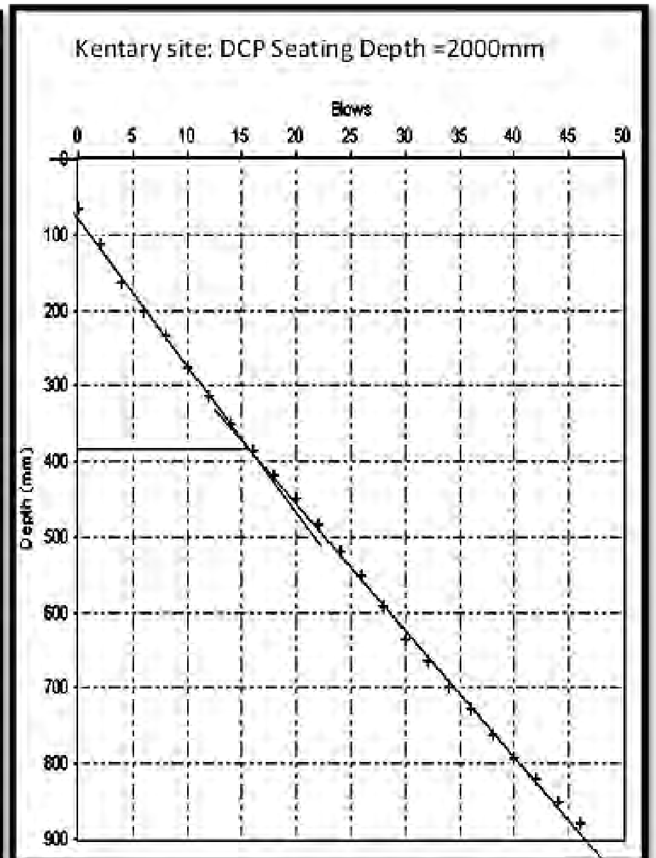
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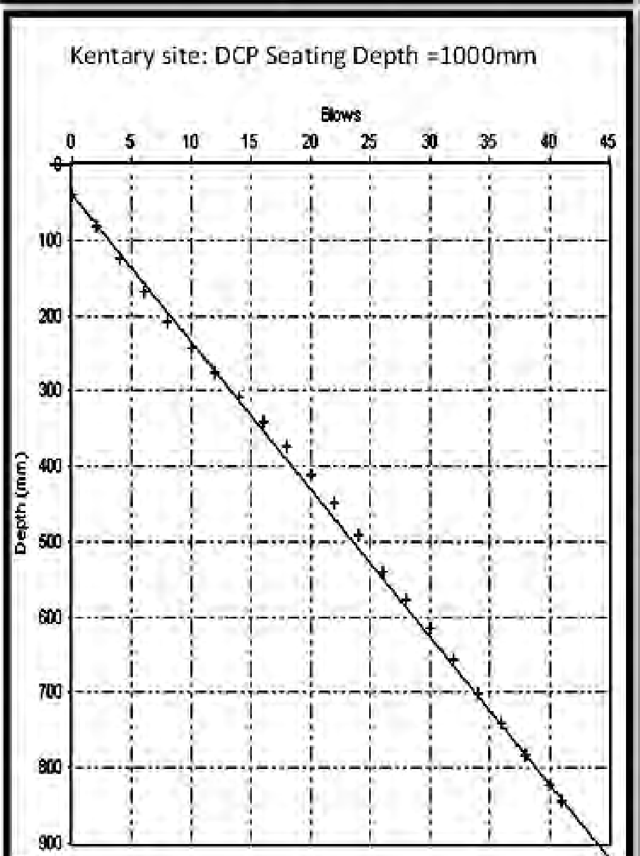
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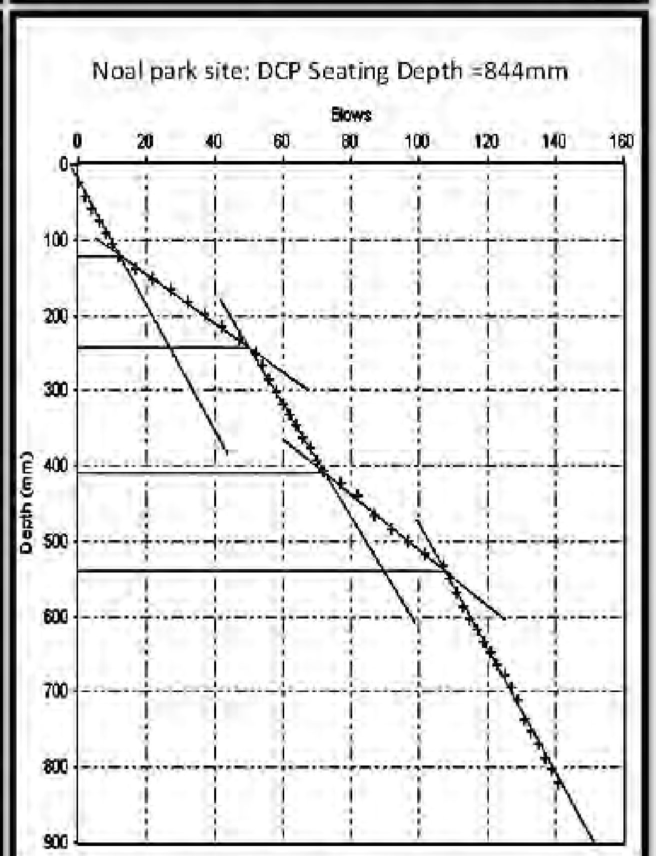
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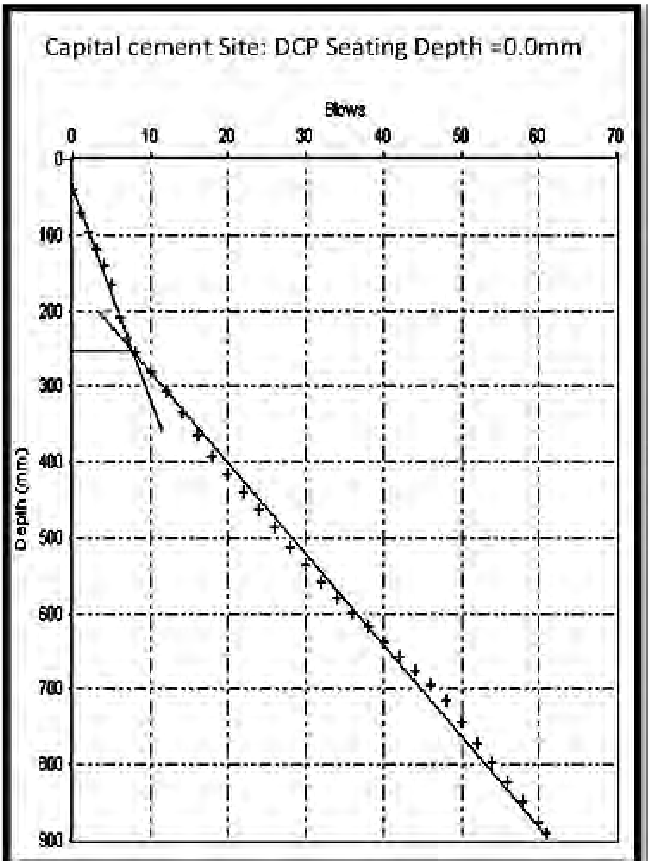
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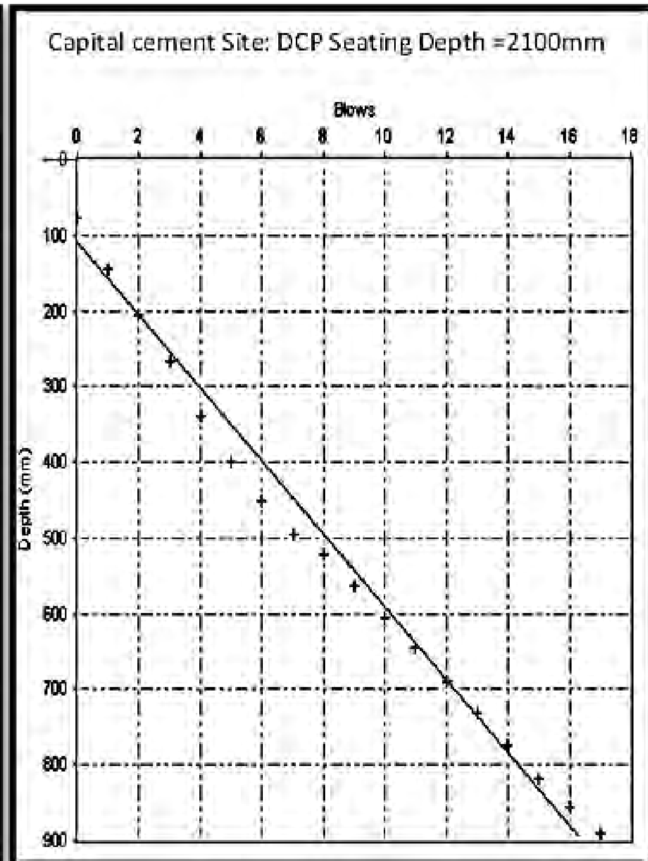
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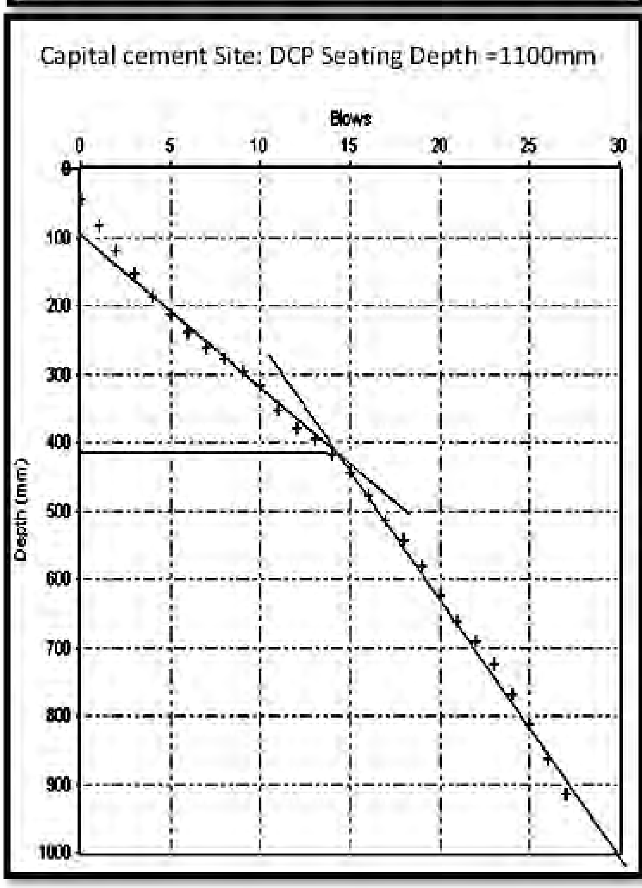
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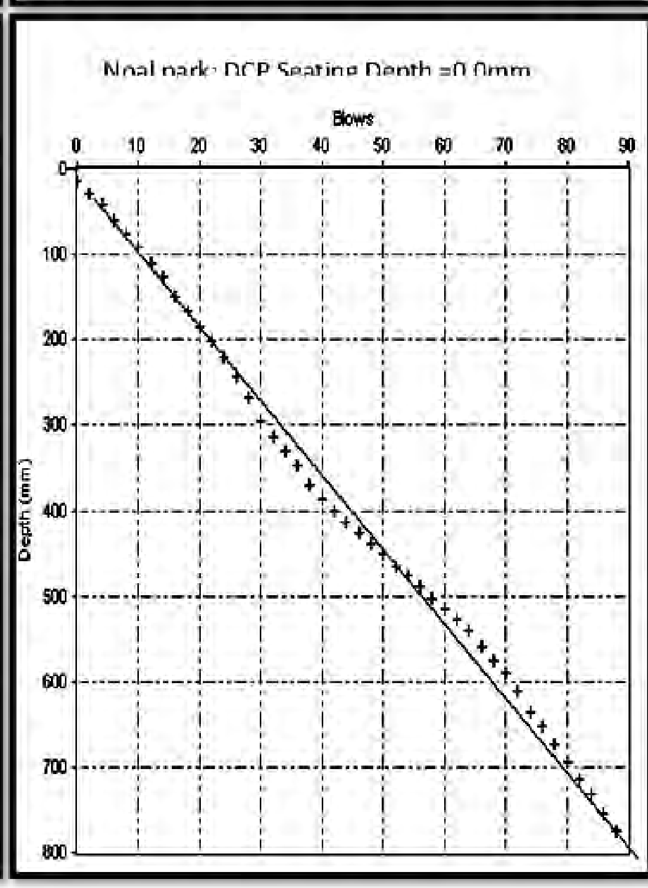
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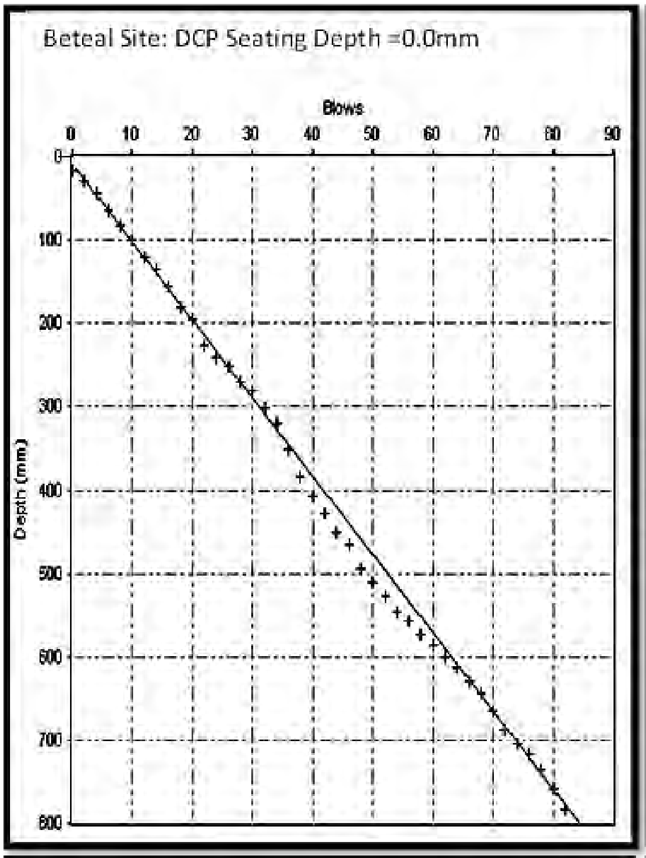
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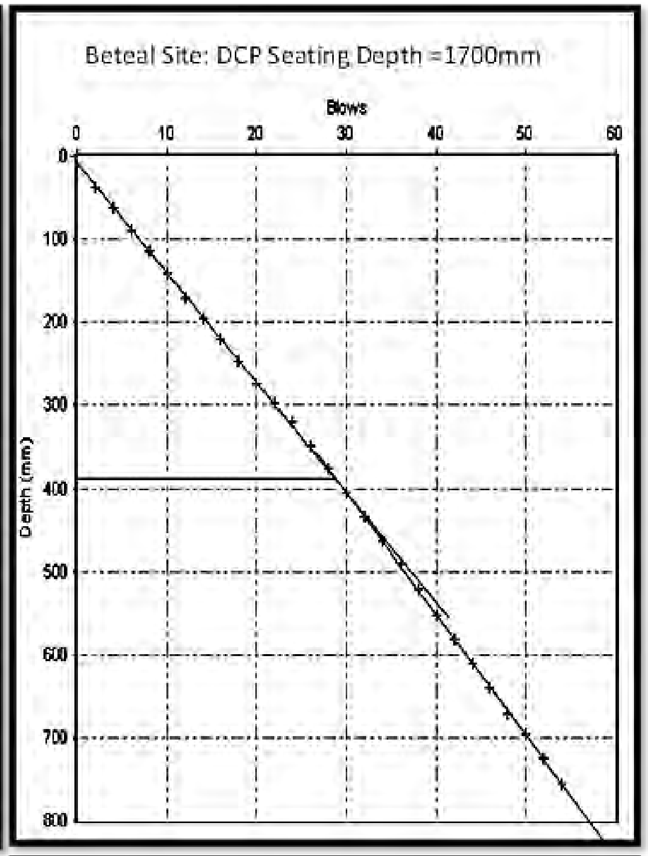
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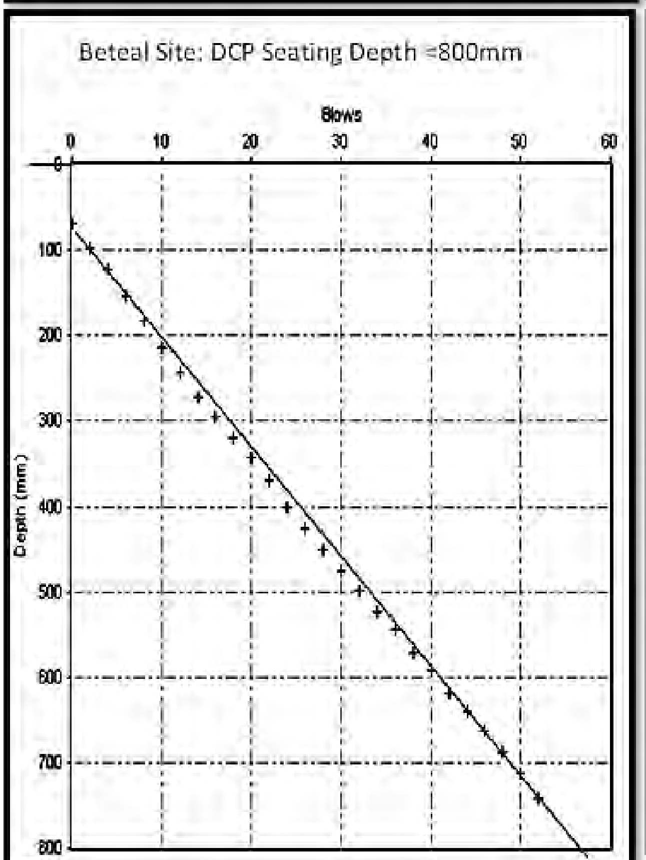
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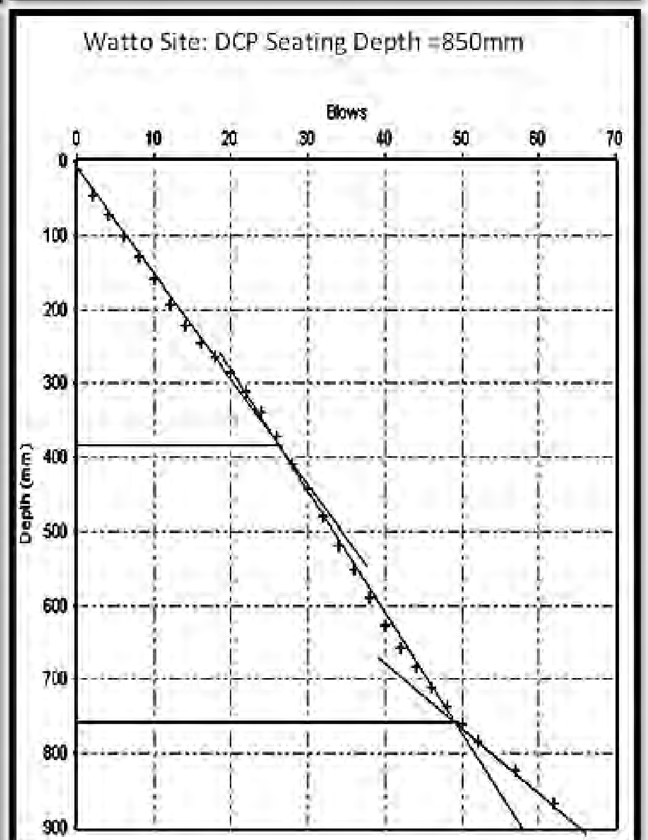
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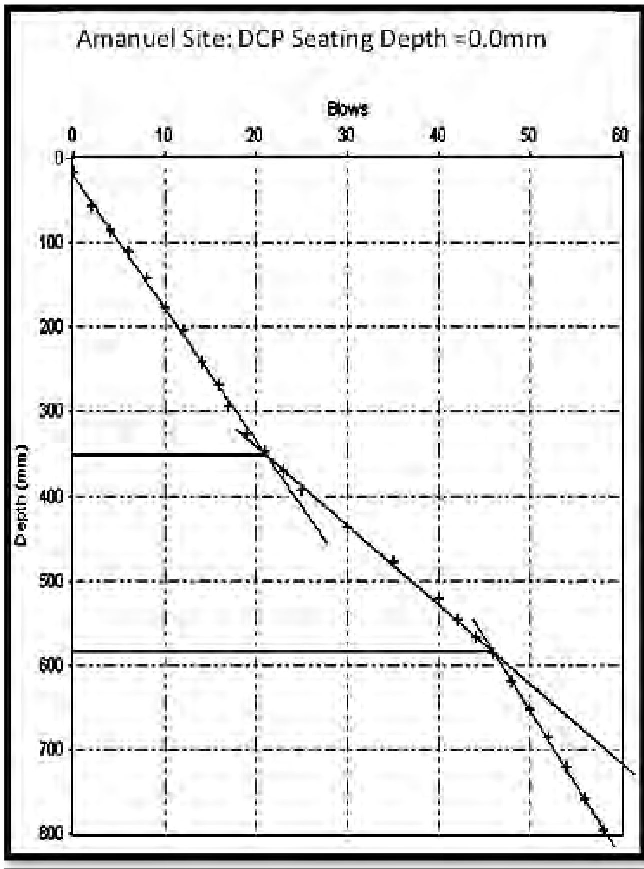
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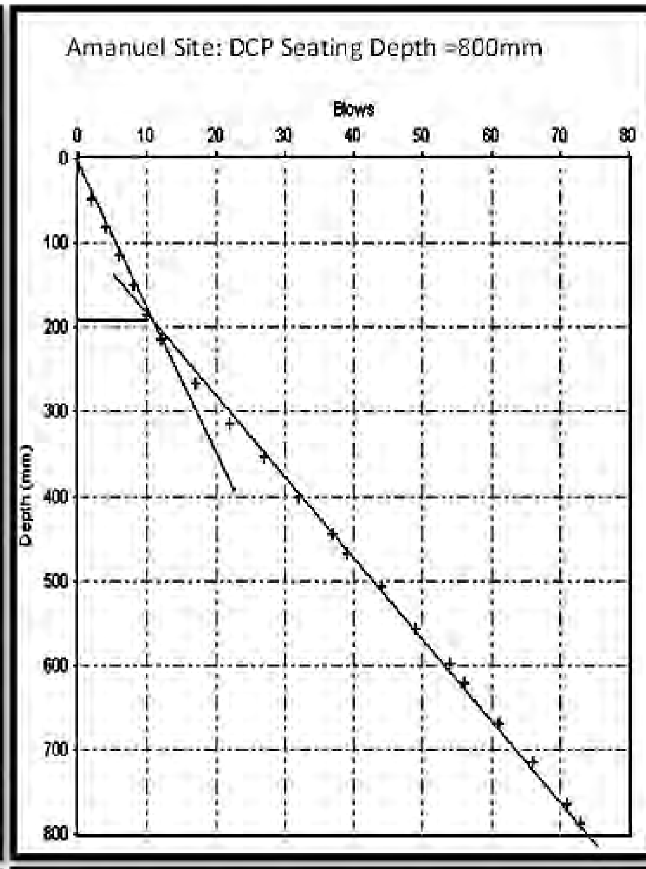
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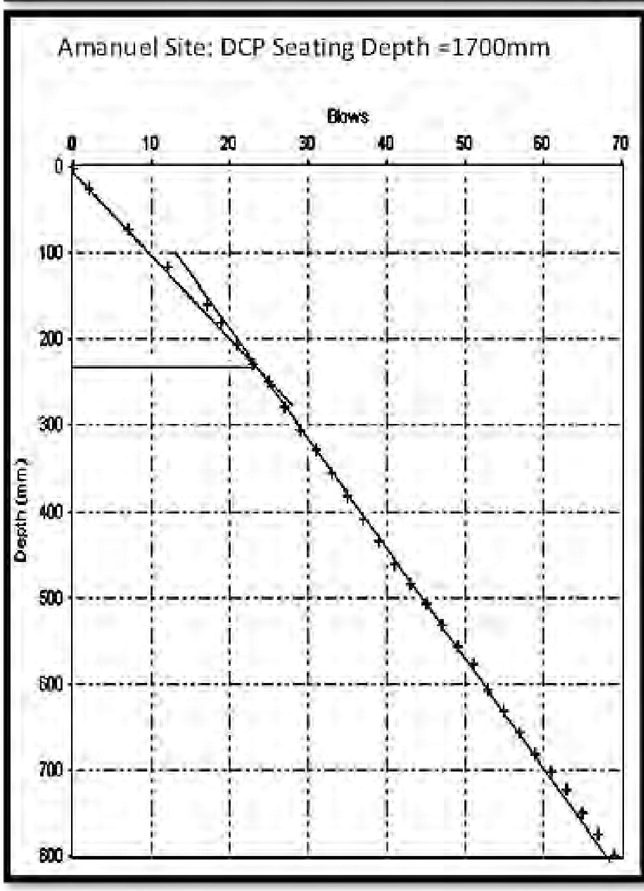
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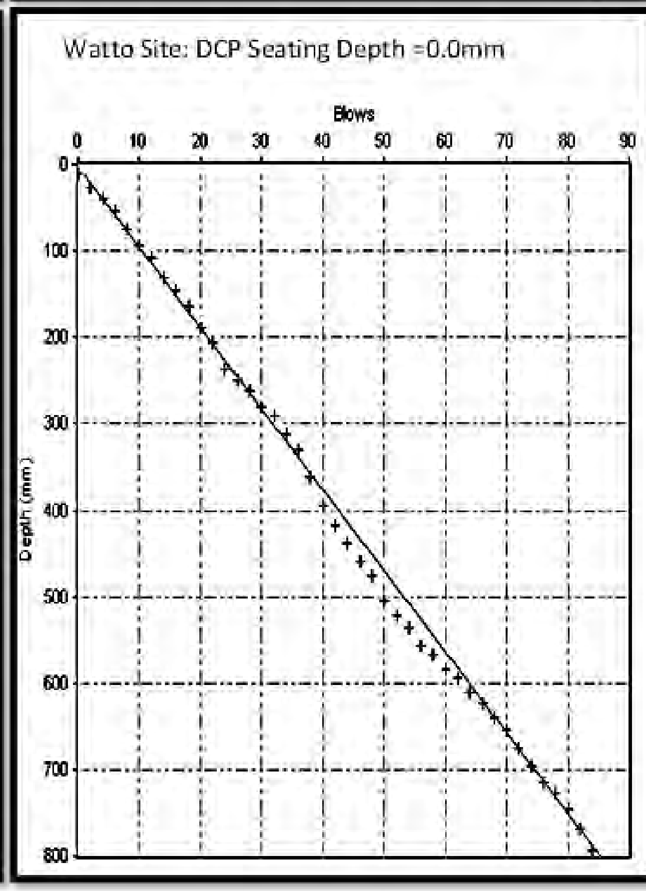
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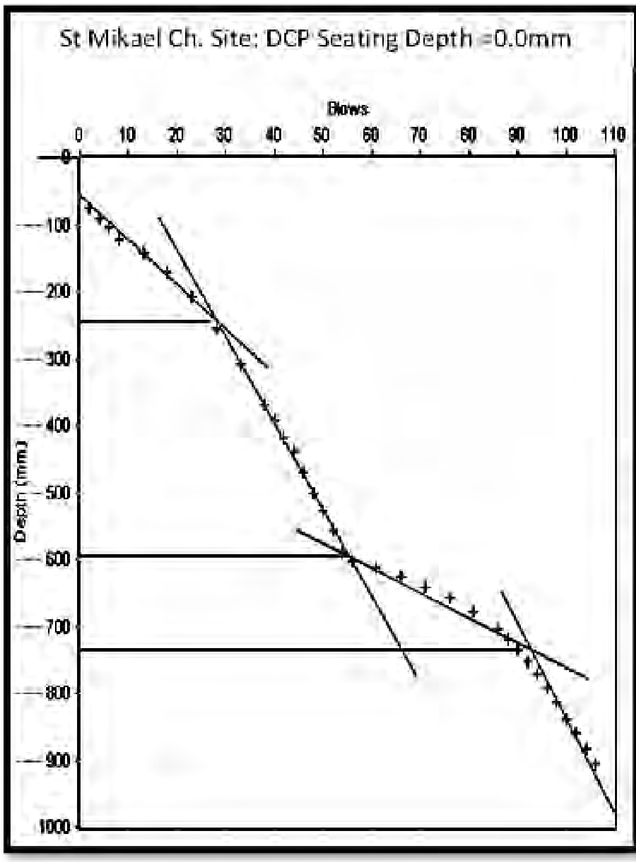
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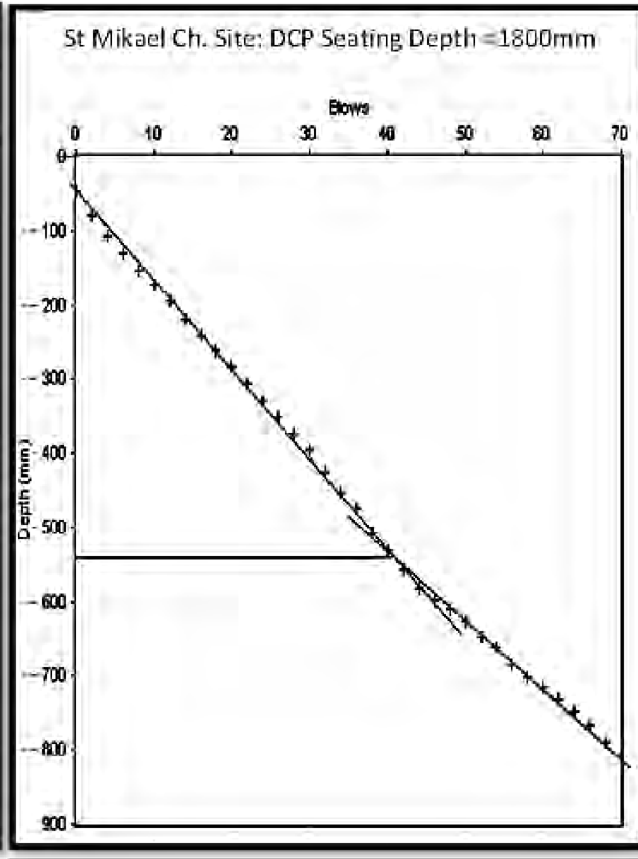
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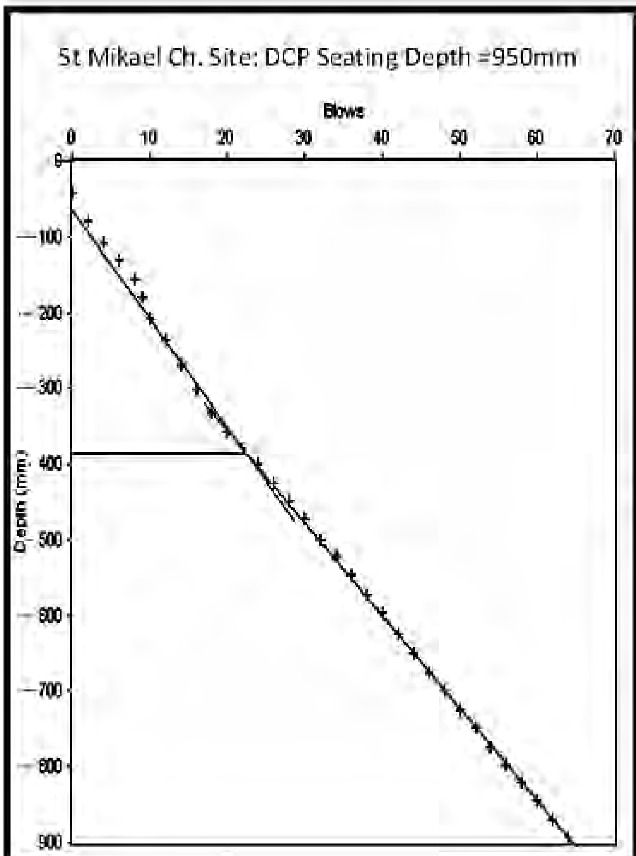
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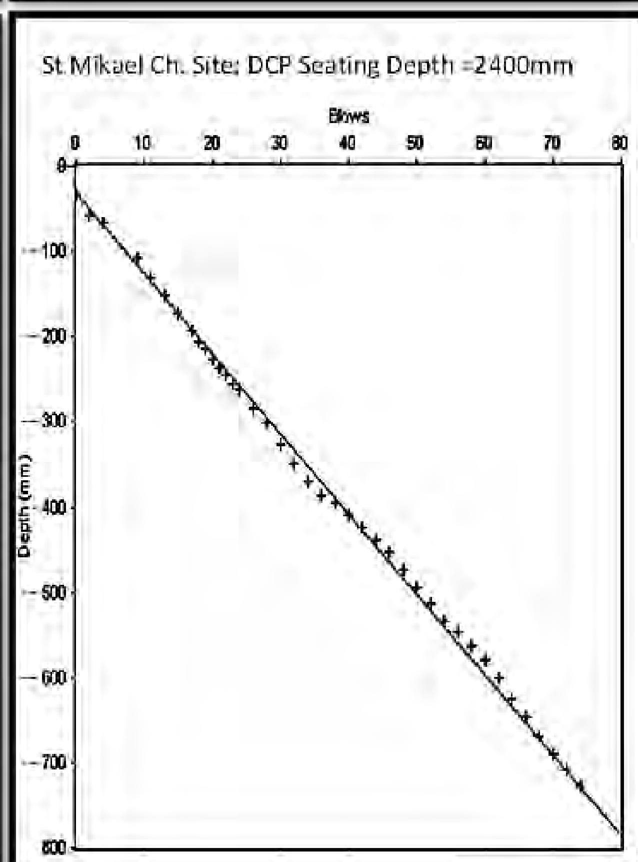
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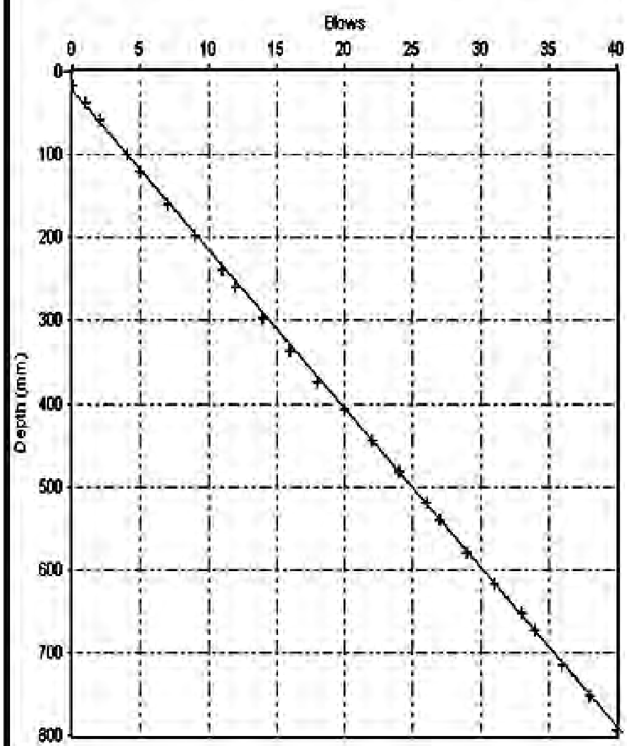

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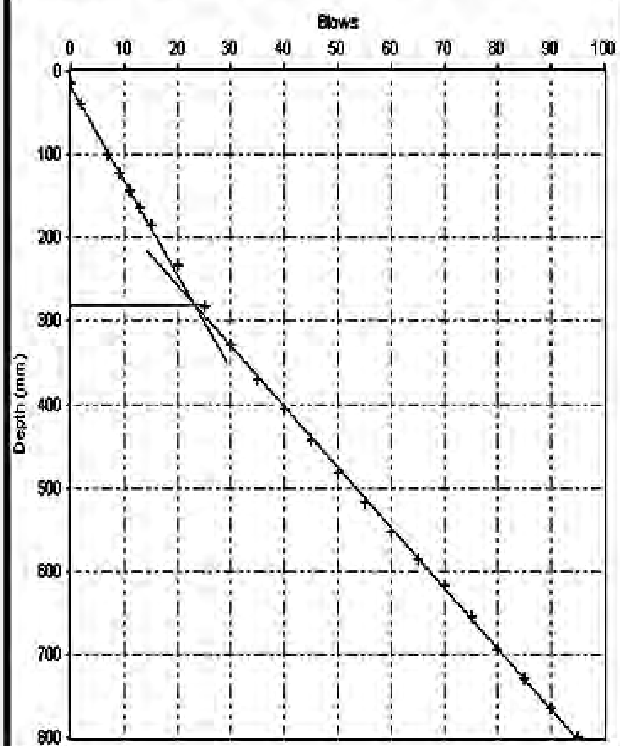

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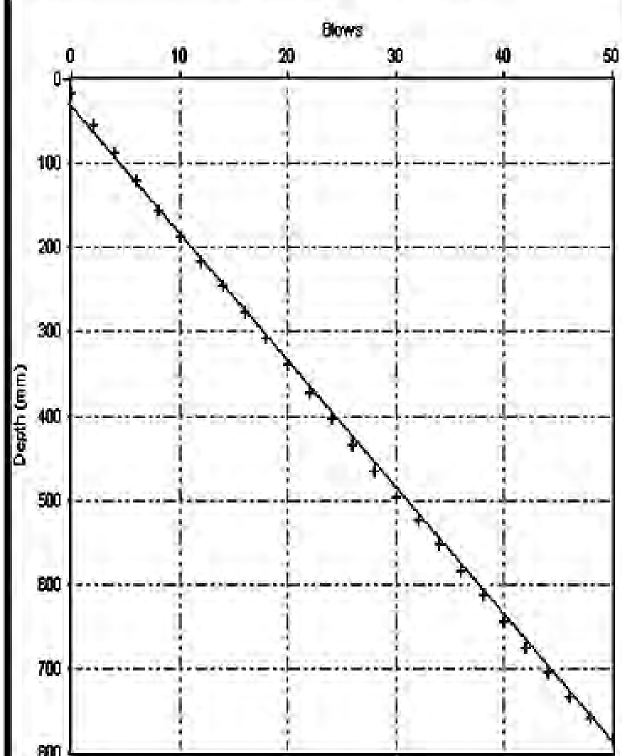

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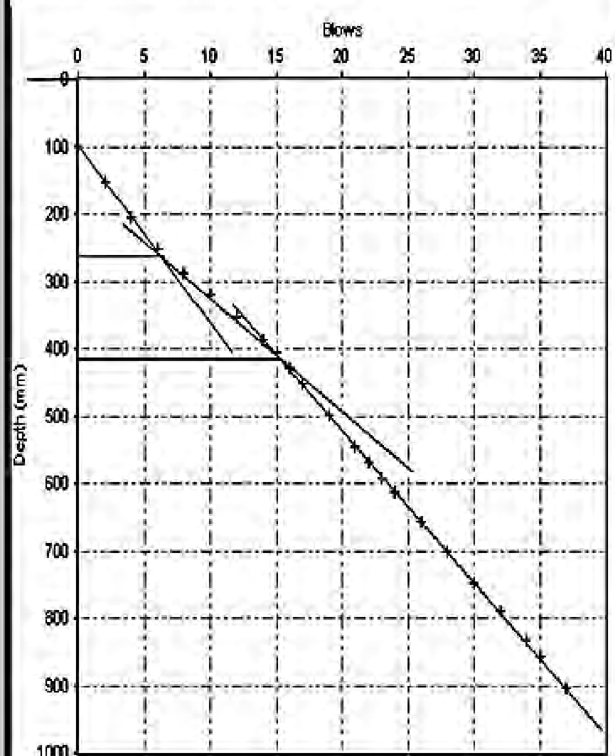

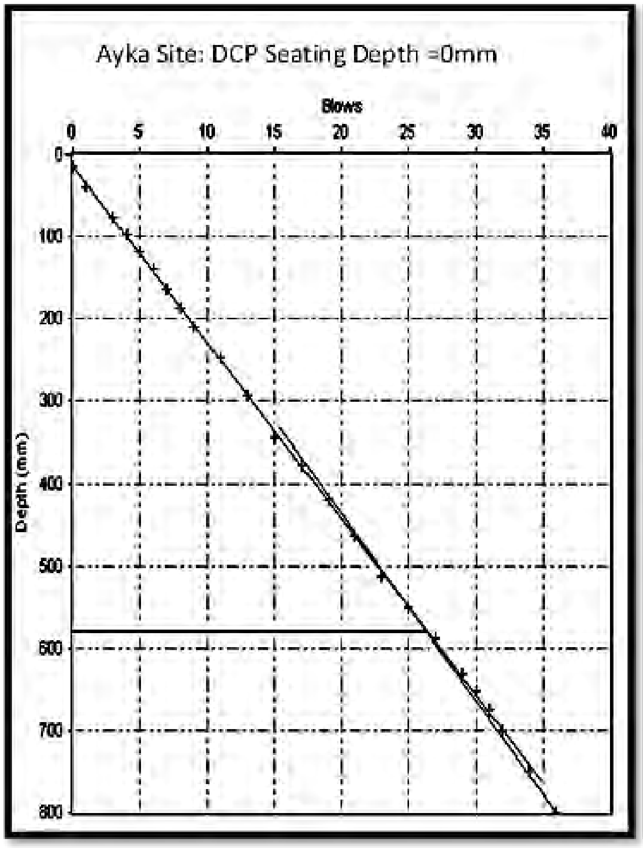
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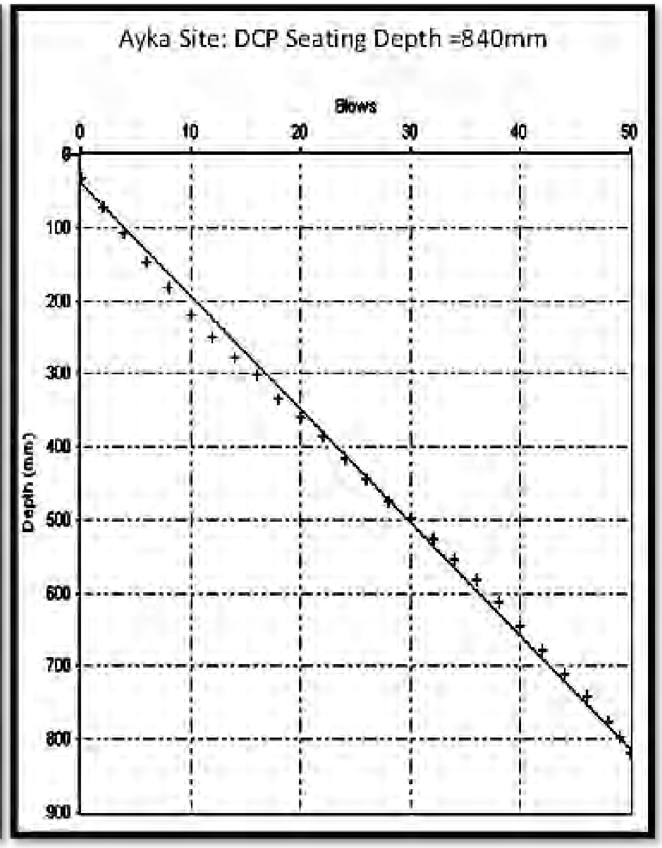
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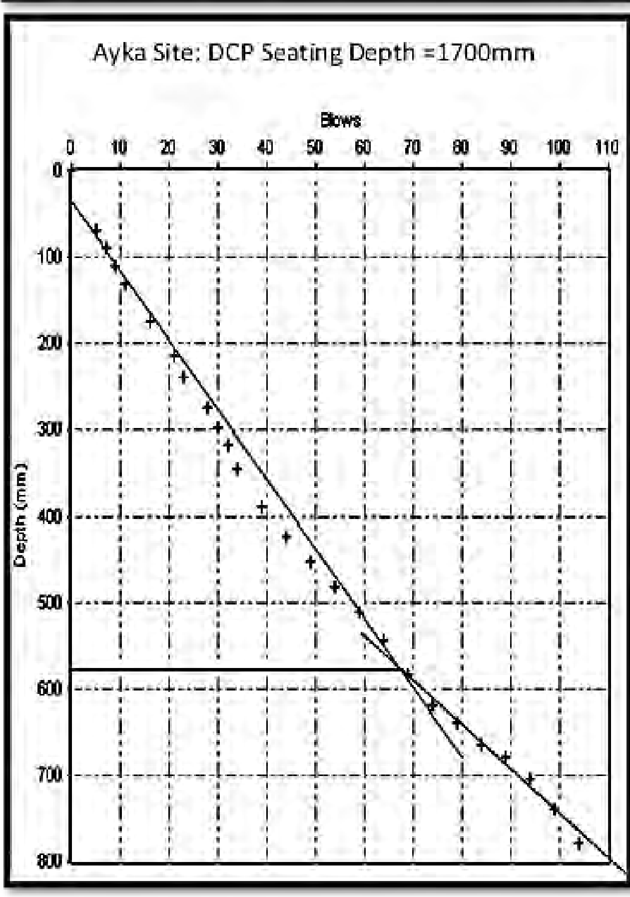
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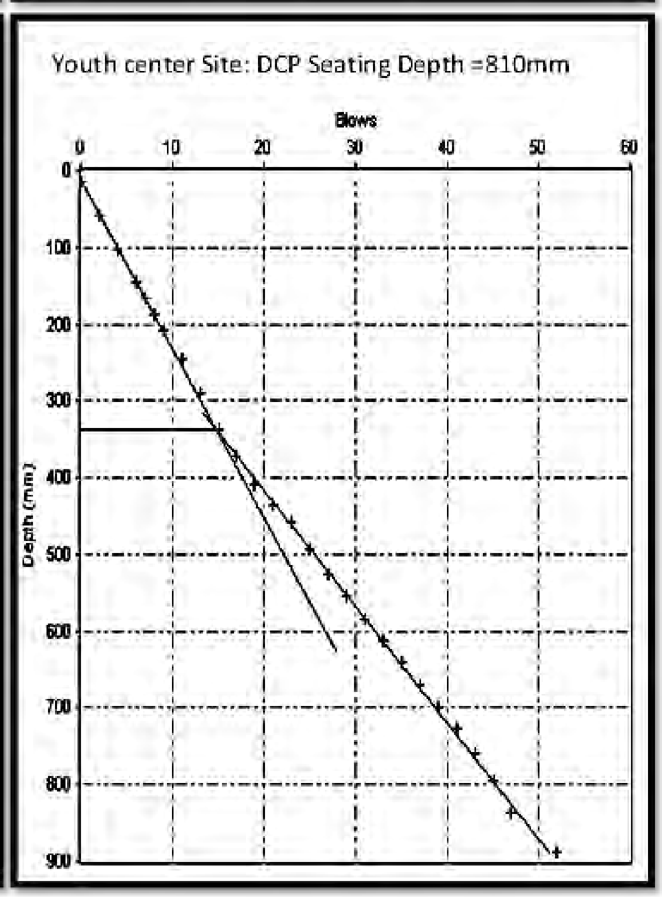
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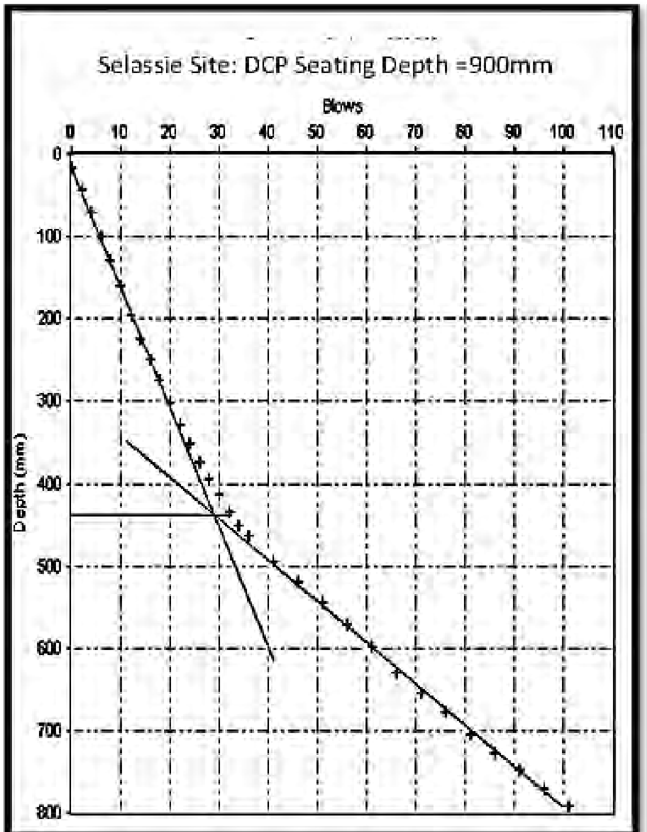
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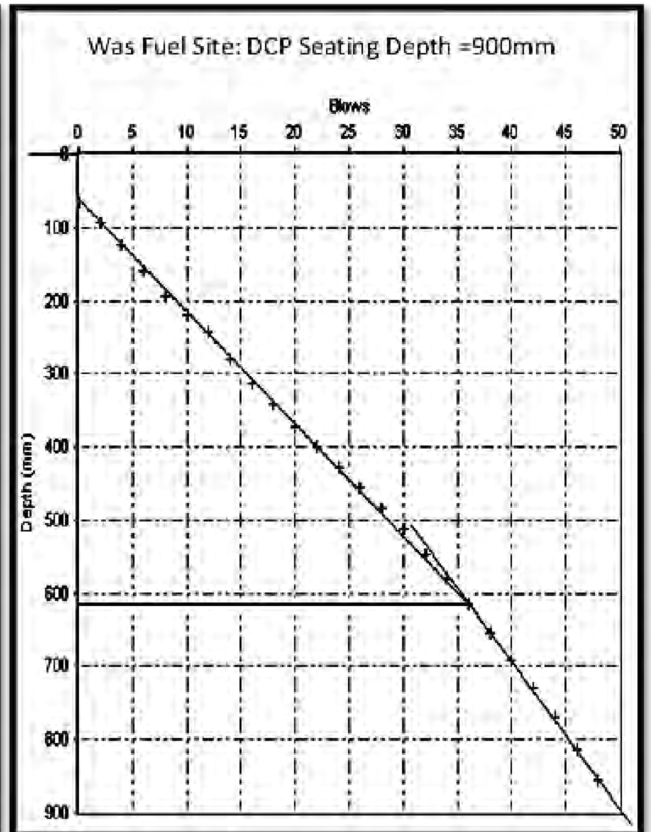
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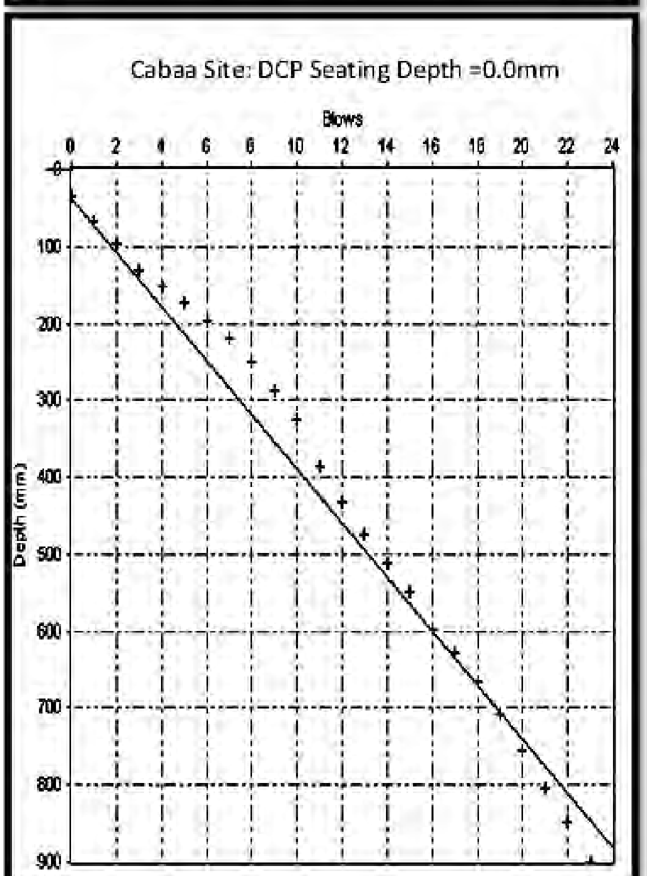
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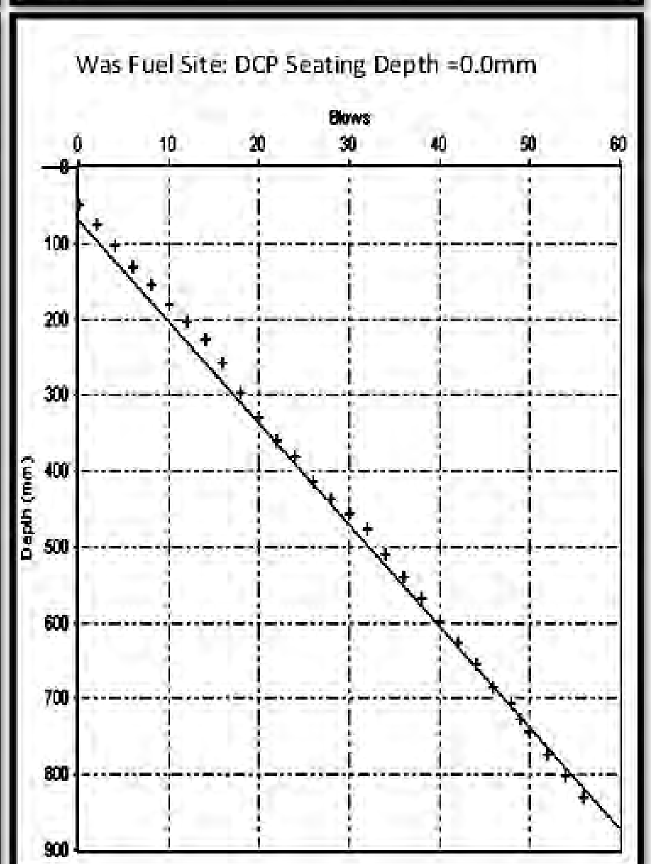
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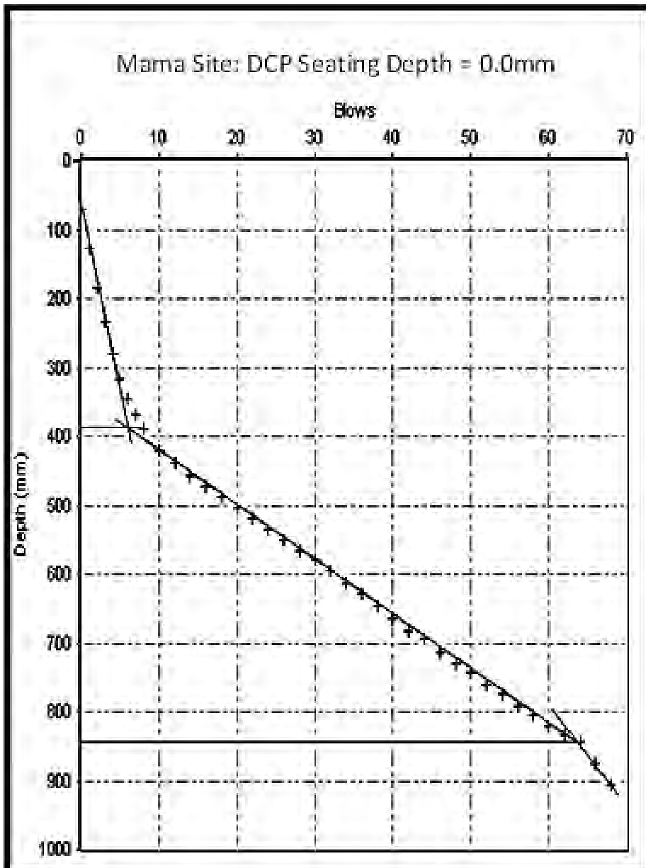
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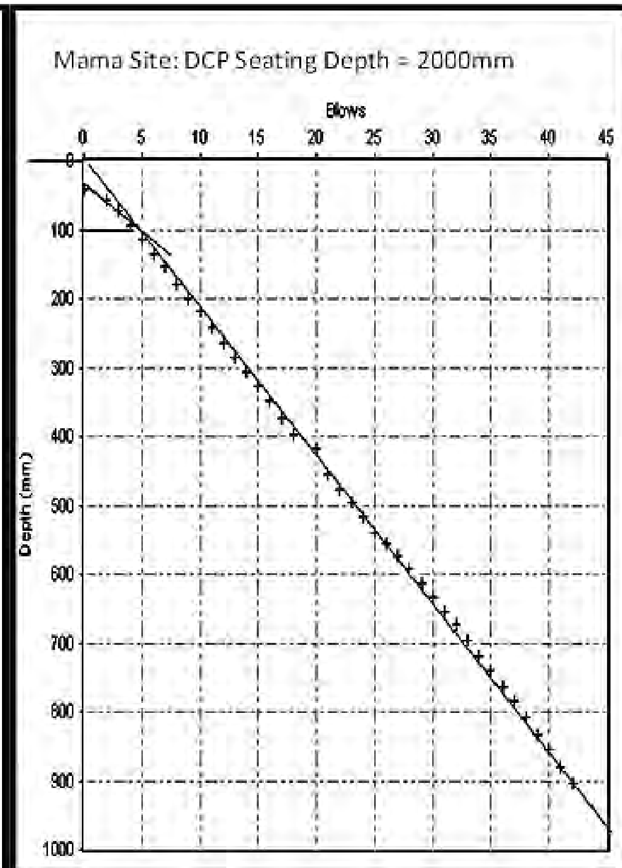
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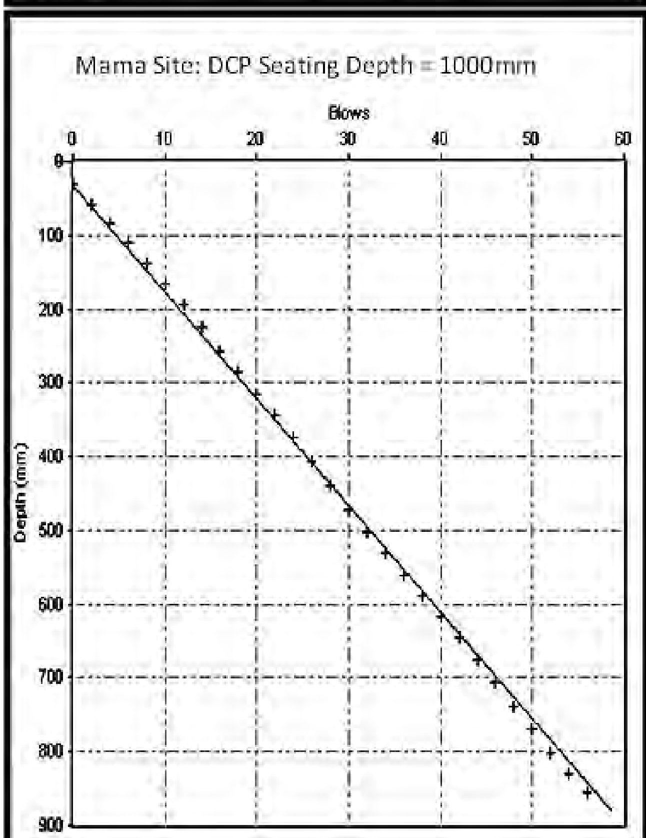
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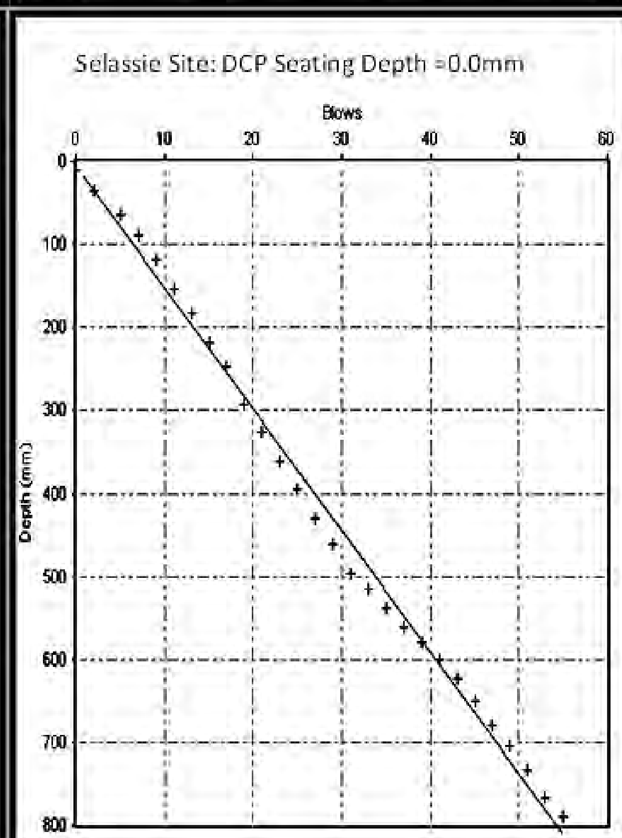
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APPENDIX – B

LABORATORY TEST RESULTS

APPENDIX – B1

NATURAL MOISTURE CONTENT

Specimen Location	Kentary NMC					
Depth from the ground surface (m)	0.63		1.5		2.85	
Specimen trial	1	2	1	2	1	2
Moisture can	N9	D25	MA1B	E4	Z4	C28
Mc =Mass of empty & clean can (grams)	15.5	15.9	15.7	15.7	10.9	14
M_1 =Mass of can and moist soil (grams)	32.9	32.3	30.9	31.6	24.3	25.6
M_2 =Mass of can and dry soil (grams)	30.2	29.7	26.5	27.2	20.8	22.7
Ms =Mass of dry soil (grams)	14.7	13.8	10.8	11.5	9.9	8.7
M_w =Mass of pore water (grams)	2.7	2.6	4.4	4.4	3.5	2.9
Natural moisture content, (%)	18%	19%	41%	38%	35%	33%
ɯ = average natural moisture content, (%)	19		40		34	

Specimen Location	St. Mikael Ch. NMC					
Depth from the ground surface (m)	1.1		2.2		2.9	
Specimen trial	1	2	1	2	1	2 .
Moisture can	A	T12	RL1	IT1	MA18	
Mc =Mass of empty & clean can (grams)	15.6	15.6	15.8	15.5	15.7	
M_1 =Mass of can and moist soil (grams)	35.2	31.7	33.6	28.6	33.5	
M_2 =Mass of can and dry soil (grams)	32.3	28.1	28.3	25.5	28.6	
Ms =Mass of dry soil (grams)	16.7	12.5	12.5	10	12.9	
M_w =Mass of pore water (grams)	2.9	3.6	5.3	3.1	4.9	
Natural moisture content, (%)	17%	29%	42%	31%	38%	
ɯ = average natural moisture content, (%)	23		37		38	

Specimen Location	Mama NMC					
Depth from the ground surface (m)	0.72		1.4		2.8	
Specimen trial	1	2	1	2	1	2
Moisture can	IT1	A	T12	B2	MA18	RL
Mc =Mass of empty & clean can (grams)	15.5	15.6	15.6	15.7	15.7	15.9
M_1 =Mass of can and moist soil (grams)	36.9	35.2	31.7	35.1	30.6	36
M_2 =Mass of can and dry soil (grams)	32.8	32	28.1	30.7	26.9	30.9
Ms =Mass of dry soil (grams)	17.3	16.4	12.5	15	11.2	15
M_w =Mass of pore water (grams)	4.1	3.2	3.6	4.4	3.7	5.1
Natural moisture content, (%)	24%	20%	29%	29%	33%	34%
ɯ = average natural moisture content, (%)	22		29		34	

Specimen Location	Capital Cement NMC					
Depth from the ground surface (m)	1.2		1.8		2.7	
Specimen trial	1	2	1	2	1	2
Moisture can	MA33	LL1	LL3	MA17	IT6	L5
Mc =Mass of empty & clean can (grams)	15.4	15.7	15.5	15.5	15.5	15.7
M_1 =Mass of can and moist soil (grams)	37.1	34.1	33.8	34	33.8	34.2
M_2 =Mass of can and dry soil (grams)	31	28.9	28.1	28.4	27.7	28.2
Ms =Mass of dry soil (grams)	15.6	13.2	12.6	12.9	12.2	12.5
M_w =Mass of pore water (grams)	6.1	5.2	5.7	5.6	6.1	6
Natural moisture content, (%)	39%	39%	45%	43%	50%	48%
ɯ = average natural moisture content, (%)	39		44		49	

Specimen Location	Was Fuel station NMC		Youth Center			
Depth from the ground surface (m)	0.8		0.75			
Specimen trial	1	2	1	2	1 .	2 .
Moisture can	Mk33	MA11	L33	A17		
Mc =Mass of empty & clean can (grams)	15.6	15.7	15.6	15.5		
M_1 =Mass of can and moist soil (grams)	36.3	37.4	33.8	32.5		
M_2 =Mass of can and dry soil (grams)	32.1	32.8	29.2	28.6		
Ms =Mass of dry soil (grams)	16.5	17.1	13.6	13.1		
M_w =Mass of pore water (grams)	4.2	4.6	4.6	3.9		
Natural moisture content, (%)	25%	27%	34%	30%		
ɯ= average natural moisture content, (%)	26		32			

Specimen Location	Ayka NMC					
Depth from the ground surface (m)	0.8		1.6		2.2	
Specimen trial	1	2	1	2	1	2
Moisture can	MA15	PL1	TR6	PL5	PL3	TR17
Mc =Mass of empty & clean can (grams)	15.5	15.6	15.4	15.5	15.6	15.5
M_1 =Mass of can and moist soil (grams)	32.1	33.7	33.8	37.5	33.8	34.2
M_2 =Mass of can and dry soil (grams)	28.7	29.7	28.5	31.7	31.1	31.2
Ms =Mass of dry soil (grams)	13.2	14.1	13.1	16.2	15.5	15.7
M_w =Mass of pore water (grams)	3.4	4	5.3	5.8	2.7	3
Natural moisture content, (%)	26%	28%	40%	36%	17%	19%
ɯ = average natural moisture content, (%)	27		38		18	

Specimen Location	Caba NMC		WATTO NMC			
Depth from the ground surface (m)	1m		1m			
Specimen trial	1	2	1	2		
Moisture can	MA18	L5	2 (12)	2L6		
Mc =Mass of empty & clean can (grams)	15.6	15.7	15.7	15.6		
M_1 =Mass of can and moist soil (grams)	34.5	34.2	43.5	43.1		
M_2 =Mass of can and dry soil (grams)	27.6	27.7	37.2	36.8		
Ms =Mass of dry soil (grams)	12	12	21.5	21.2		
M_w =Mass of pore water (grams)	6.9	6.5	6.3	6.3		
Natural moisture content, (%)	58%	54%	29%	30%		
ɯ = average natural moisture content, (%)	56		30			

Specimen Location	St. Silasea NMC		Naol Park NMC			
Depth from the ground surface (m)	1m		0.7m		1.2m	
Specimen trial	1	2	1	2	1	2
Moisture can	M1 (6)	H10	11(20)	2L6	T12	CB2
Mc =Mass of empty & clean can (grams)	15.7	15.4	15.6	15.6	15.6	15.7
M_1 =Mass of can and moist soil (grams)	54	44.5	55.8	58	31.7	35.1
M_2 =Mass of can and dry soil (grams)	46.1	38.6	47.2	48.9	28	30.4
Ms =Mass of dry soil (grams)	30.4	23.2	31.6	33.3	12.4	14.7
M_w =Mass of pore water (grams)	7.9	5.9	8.6	9.1	3.7	4.7
Natural moisture content, (%)	26%	25%	27%	27%	30%	32%
ɯ= average natural moisture content, (%)	26		27		31	

Specimen Location	Beteal NMC					
Depth from the ground surface	0.72m		1.4m		2.4m	
Specimen trial	1	2	1	2	1	2
Moisture can	IT1	A	AA	T12	11 (20)	2L6
Mc =Mass of empty & clean can (grams)	15.5	15.6	15.6	15.6	15.9	15.6
M_1 =Mass of can and moist soil (grams)	36.9	35.2	35.2	31.7	46.2	52.7
M_2 =Mass of can and dry soil (grams)	32.8	32	32.3	28.1	40.1	44.5
Ms =Mass of dry soil (grams)	17.3	16.4	16.7	12.5	24.2	28.9
M_w =Mass of pore water (grams)	4.1	3.2	2.9	3.6	6.1	8.2
Natural moisture content, (%)	24%	20%	17%	29%	25%	28%
ɯ = average natural moisture content, (%)	22		23		27	

Specimen Location	Amanual NMC					
Depth from the ground surface (m)	0.75		1.5		2.4	
Specimen trial	1	2	1	2	1	2
Moisture can	PT1	AA	PT12	BC	MA18	TRL
Mc =Mass of empty & clean can (grams)	15.6	15.6	15.6	15.7	15.7	15.9
M_1 =Mass of can and moist soil (grams)	37.1	35.2	33.1	35.1	33.2	36
M_2 =Mass of can and dry soil (grams)	31.6	30.5	29.9	31.7	29.5	31.9
Ms =Mass of dry soil (grams)	16	14.9	14.3	16	13.8	16
M_w =Mass of pore water (grams)	5.5	4.7	3.2	3.4	3.7	4.1
Natural moisture content, (%)	34%	32%	22%	21%	27%	26%
ɯ = average natural moisture content, (%)	33		22		26	

Specimen Location	Oda Flower NMC					
Depth from the ground surface (m)	0.7		1.4		2.44	
Specimen trial	1	2	1	2	1	2
Moisture can	MN	D24	MA18	DE4	Z4	C28
Mc =Mass of empty & clean can (grams)	15.5	16.5	15.7	15.7	11.1	14.7
M_1 =Mass of can and moist soil (grams)	33.4	32.3	30.9	31.6	24.7	25.9
M_2 =Mass of can and dry soil (grams)	28.1	27.8	27.5	28	22.5	24.1
Ms =Mass of dry soil (grams)	12.6	11.3	11.8	12.3	11.4	9.4
M_w =Mass of pore water (grams)	5.3	4.5	3.4	3.6	2.2	1.8
Natural moisture content, (%)	42%	40%	29%	29%	19%	19%
ɯ = average natural moisture content, (%)	41		29		19	

APPENDIX – B2

SPECIFIC GRAVITY

Specific Gravity of	Capital Cement I		Capital Cement II		Capital Cement III	
Specimen depth from the ground surface (m)	1.2		1.8		2.7	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A2	B1	B2	A1	A2
Wp = Mass of empty, clean pycnometer (grams)	49.6	49.7	76.6	48.6	48.7	49.5
Wsp = Mass of empty pycnometer + dry soil (grams)	69.7	69.7	96.7	68.6	68.7	69.5
Ws =dry soil mass	20.1	20	20.1	20	20	20
Wspw = Mass of pycnometer + dry soil + water (grams)	161.9	161.9	188.6	160.6	162.1	160.8
Wpw = Mass of pycnometer + water (grams)	149.1	149.1	175.8	147.9	149.2	147.9
measured Temperature, T (^{o}c)	22	24	23	21.5	23	21.5
G_T = Specific Gravity at T^{o}C temperature	2.753	2.778	2.753	2.74	2.817	2.817
Conversion factor , K for T^{o}C temperature	0.99 96	0.999 1	0.999 3	0.999 7	0.999 3	0.999 7
G_{20} = Specific Gravity at 20^{o}c temperature	2.75	2.78	2.75	2.74	2.81	2.82
Average Specific Gravity at 20^{o}c temperature	**2.76**		**2.75**		**2.82**	

Specific Gravity of	Mama I		Mama II		Mama III	
Specimen depth from the ground surface (m)	0.72		1.4		2.8	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A2	B1	B2	A1	A2
Wp = Mass of empty, clean pycnometer (grams)	49.7	76.9	48.5	49.7	49.7	48.7
Wsp = Mass of empty pycnometer + dry soil (grams)	74.7	102	73.6	74.6	75.4	73.8
Ws =dry soil mass	25	25.1	25.1	24.9	25.7	25.1
Wspw = Mass of pycnometer + dry soil + water (grams)	164.8	191.5	164	164.9	165.4	164
Wpw = Mass of pycnometer + water (grams)	149.1	175.5	147.9	149	149.1	147.9
measured Temperature, T (^{o}c)	21.5	22.5	22.5	22.5	22.5	20.5
G_T = Specific Gravity at T^{o}C temperature	2.688	2.758	2.789	2.767	2.734	2.789
Conversion factor , K for T^{o}C temperature	0.999 7	0.999 5	0.999 5	0.999 5	0.999 5	0.999 9
G_{20} = Specific Gravity at 20^{o}c temperature	2.69	2.76	2.79	2.77	2.73	2.79
Average Specific Gravity at 20^{o}c temperature	**2.72**		**2.78**		**2.76**	

Specific Gravity of	**Kentary I**		**Kentary II**		**Kentary III**		**St. Silasie Church**	
Specimen depth from the ground surface (m)	0.63		1.5		2.85		0.7	
Specimen number	1	2	1	1	2	2	1	2
Pycnometer bottle number	A1	A2	B1	A1	A1	B2	A1	A2
Wp = Mass of empty, clean pycnometer (grams)	49.4	49.5	49.5	45.3	45.6	49.6	49.4	49.5
Wsp = Mass of empty pycnometer + dry soil (grams)	75	75.1	74.7	70.3	70.7	75.2	74.2	74
Ws =dry soil mass	25.6	25.6	25.2	25	25.1	25.6	24.8	24.5
Wspw = Mass of pycnometer + dry soil + water (grams)	165.2	164.9	165.1	160.1	160.4	165.4	165	164.9
Wpw = Mass of pycnometer + water (grams)	149.1	149	149.2	144.3	144.4	149.2	149.1	149.2
measured Temperature, T (^{o}c)	20.5	22.5	22.5	21	21	22.5	25	23
G_T = Specific Gravity at T^{o}C temperature	2.695	2.639	2.71	2.717	2.758	2.723	2.787	2.784
Conversion factor , K for T^{o}C temperature	0.9999	0.9995	0.9995	0.99950	0.9988	0.9993	0.999	0.999
G_{20} = Specific Gravity at 20^{o}c temperature	2.69	2.64	2.71	2.71	2.75	2.72	2.78	2.78
Average Specific Gravity at 20^{o}c temperature	**2.67**		**2.72**		**2.78**		**2.73**	

Specific Gravity of	**St. Mikael Ch. I**		**St. Mikael Ch. II**		**St. Mikael Ch. III**	
Specimen depth from the ground surface (m)	1.1		2.2		2.9	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A2	B1	B2	A1	A2
Wp = Mass of empty, clean pycnometer (grams)	49.5	49.6	49.5	49.6	49.7	48.7
Wsp = Mass of empty pycnometer + dry soil (grams)	74.6	75	75	75.1	74.8	73.8
Ws =dry soil mass	25.1	25.4	25.5	25.5	25.1	25.1
Wspw = Mass of pycnometer + dry soil + water (grams)	165	165.1	165	165.4	164.9	163.8
Wpw = Mass of pycnometer + water (grams)	149.3	149.2	149.2	149.6	149.1	147.9
measured Temperature, T (^{o}c)	20.5	22.5	22.5	22.5	22.5	20.5
G_T = Specific Gravity at T^{o}C temperature	2.67	2.674	2.629	2.629	2.699	2.728
Conversion factor , K for T^{o}C temperature	0.9999	0.9995	0.9995	0.9995	0.9995	0.9999
G_{20} = Specific Gravity at 20^{o}c temperature	2.67	2.67	2.63	2.63	2.70	2.73
Average Specific Gravity at 20^{o}c temperature	**2.67**		**2.63**		**2.71**	

Specific Gravity of	Was Fuel		Youth Center		Caba	
Specimen depth from the ground surface (m)	0.8		0.75		0.75M	
Specimen number	1	1	1	2	2	2
Pycnometer bottle number	A1	A1	A1	A2	A1	A2
Wp = Mass of empty, clean pycnometer (grams)	49.5	45.3	49.4	49.5	45.6	49.6
Wsp = Mass of empty pycnometer + dry soil (grams)	74.6	70.3	74.4	74.6	70.7	74.8
Ws =dry soil mass	25.1	25	25	25.1	25.1	25.2
Wspw = Mass of pycnometer + dry soil + water (grams)	165	160.2	165	165.4	160.4	165.1
Wpw = Mass of pycnometer + water (grams)	149.3	144.3	149.1	149.2	144.4	149.2
measured Temperature, T (^{o}c)	20.5	21	25	23	21	22.5
G_T = Specific Gravity at T^{o}C temperature	2.67	2.747	2.747	2.82	2.758	2.71
Conversion factor , K for T^{o}C temperature	0.9999	0.9995	0.9980	0.9998	0.9997	0.9996
G_{20} = Specific Gravity at 20^{o}c temperature	2.67	2.74	2.75	2.82	2.75	2.71
Average Specific Gravity at 20^{o}c temperature	**2.69**		**2.75**		**2.78**	

Specific Gravity of	Ayka I		Ayka II		Ayka III	
Specimen depth from the ground surface (m)	0.8		1.6		2.2	
Specimen number	3	4	3	4	3	4
Pycnometer bottle number	A1	A1	A1	A1	A1	A1
Wp = Mass of empty, clean pycnometer (grams)	45.4	45.3	45.3	45.3	45.3	45.4
Wsp = Mass of empty pycnometer + dry soil (grams)	70.5	70.4	70.4	70.3	70.6	70.4
Ws =dry soil mass	25.1	25.1	25.1	25	25.3	25
Wspw = Mass of pycnometer + dry soil + water (grams)	160.4	160.5	160.1	160.1	160	159.9
Wpw = Mass of pycnometer + water (grams)	144.4	144.4	144.3	144.3	144.3	144.3
measured Temperature, T (^{o}c)	25	23	22	23	22	23
G_T = Specific Gravity at T^{o}C temperature	2.758	2.789	2.699	2.717	2.635	2.66
Conversion factor , K for ToC temperature	0.9997	0.99757	0.9996	0.9993	0.9996	0.9993
G_{20} = Specific Gravity at 20^{o}c temperature	2.76	2.78	2.70	2.72	2.63	2.66
Average Specific Gravity at 20^{o}c temperature	**2.77**		**2.71**		**2.65**	

Specific Gravity of	Beteal I		Beteal II		Beteal III	
Specimen depth from the ground surface (m)	0.72m		1.4m		2.4m	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A1	A1	A1	A1	A1
Wp = Mass of empty, clean pycnometer (grams)	45.3	45.4	45.4	45.3	45.3	45.3
Wsp = Mass of empty pycnometer + dry soil (grams)	70.4	70.4	70.4	70.4	70.6	70.3
Ws =dry soil mass	25.1	25	25	25.1	25.3	25
Wspw = Mass of pycnometer + dry soil + water (grams)	160.3	160.2	160.3	160.5	160.6	160.5
Wpw = Mass of pycnometer + water (grams)	144.5	144.4	144.5	144.5	144.4	144.5
measured Temperature, T (^{o}c)	21.5	22	23	22.5	20.5	22.5
G_T = Specific Gravity at T^{o}C temperature	2.699	2.717	2.717	2.758	2.78	2.778
Conversion factor , K for T^{o}C temperature	0.9997	0.9996	0.9993	0.9995	0.9999	0.9995
G_{20} = Specific Gravity at 20^{o}c temperature	2.70	2.72	2.72	2.76	2.78	2.78
Average Specific Gravity at 20^{o}c temperature	**2.71**		**2.74**		**2.78**	

Specific Gravity of	Naol Park I		Naol Park II		Watto	
Specimen depth from the ground surface (m)	0.7		1.2		1.1	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A1	A1	A1	A1	A1
Wp = Mass of empty, clean pycnometer (grams)	45.4	45.3	45.3	45.3	45.3	45.3
Wsp = Mass of empty pycnometer + dry soil (grams)	70.6	70.4	70.3	70.3	70.6	70.3
Ws =dry soil mass	25.2	25.1	25	25	25.3	25
Wspw = Mass of pycnometer + dry soil + water (grams)	160.6	159.9	160.6	160.5	160.1	160
Wpw = Mass of pycnometer + water (grams)	144.5	144.4	144.5	144.5	144.3	144.3
measured Temperature, T (^{o}c)	22	23	23	23	22	23
G_T = Specific Gravity at T^{o}C temperature	2.769	2.615	2.809	2.778	2.663	2.688
Conversion factor , K for T^{o}C temperature	0.9978	0.9993	0.9996	0.9993	0.9993	0.9993
G_{20} = Specific Gravity at 20^{o}c temperature	2.76	2.61	2.81	2.78	2.66	2.69
Average Specific Gravity at 20^{o}c temperature	**2.69**		**2.67**		**2.79**	

Specific Gravity of	Amanuel I		Amanuel II		Amanuel III	
Specimen depth from the ground surface (m)	0.75		1.5		2.4	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A1	A1	A1	A1	A1
Wp = Mass of empty, clean pycnometer (grams)	45.3	45.4	45.4	45.3	45.4	45.3
Wsp = Mass of empty pycnometer + dry soil (grams)	70.4	70.4	70.6	70.4	70.6	70.3
Ws =dry soil mass	25.1	25	25.2	25.1	25.2	25
Wspw = Mass of pycnometer + dry soil + water (grams)	160.2	160.4	160	160.2	160.3	160.3
Wpw = Mass of pycnometer + water (grams)	144.1	144.4	144.3	144.5	144.4	144.5
measured Temperature, T (^{o}c)	22.5	22	22.5	20.5	20.5	22.5
G_T = Specific Gravity at T^{o}C temperature	2.789	2.778	2.653	2.67	2.71	2.717
Conversion factor , K for T^{o}C temperature	0.999 5	0.999 6	0.999 5	0.999 9	0.999 9	0.999 5
G_{20} = Specific Gravity at 20^{o}c temperature	2.79	2.78	2.65	2.67	2.71	2.72
Average Specific Gravity at 20^{o}c temperature	**2.78**		**2.66**		**2.71**	

Specific Gravity of	Oda Flower I		Oda Flower II		Oda Flower III	
Specimen depth from the ground surface (m)	0.75		1.5		2.4	
Specimen number	1	2	1	2	1	2
Pycnometer bottle number	A1	A2	B1	B2	B1	B2
Wp = Mass of empty, clean pycnometer (grams)	48.5	49.7	49.7	48.7	49.5	49.6
Wsp = Mass of empty pycnometer + dry soil (grams)	73.6	74.7	74.2	73.8	74.7	75.2
Ws =dry soil mass	25.1	25	24.5	25.1	25.2	25.6
Wspw = Mass of pycnometer + dry soil + water (grams)	164.1	165.1	164.7	163.8	164.8	165.1
Wpw = Mass of pycnometer + water (grams)	147.9	149	149.1	147.9	149.2	149.2
measured Temperature, T (^{o}c)	22.5	22.5	22.5	20.5	22.5	22.5
G_T = Specific Gravity at T^{o}C temperature	2.82	2.809	2.753	2.728	2.625	2.639
Conversion factor , K for T^{o}C temperature	0.999 5	0.999 5	0.999 5	0.999 9	0.999 5	0.999 5
G_{20} = Specific Gravity at 20^{o}c temperature	2.82	2.81	2.75	2.73	2.62	2.64
Average Specific Gravity at 20^{o}c temperature	**2.81**		**2.74**		**2.63**	

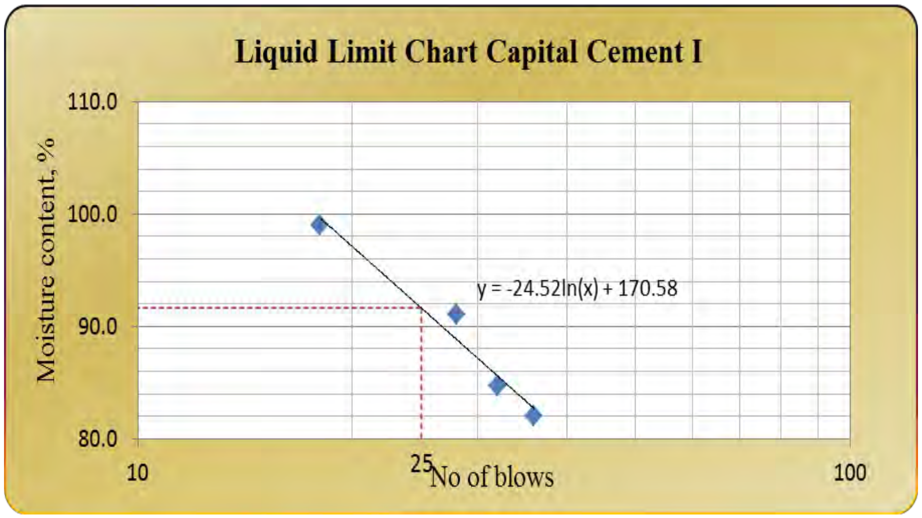
APPENDIX – B3

ATTERBERG LIMITS

Sample Capital Cement I
Depth, m: 1.20 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	36	32	18	28	-	-
Can No	A8	A8	H10	PL3	IT6	IT5
Mass of can, g	15.9	15.9	15.7	15.6	15.6	15.7
Mass of can + Wet soil, g	39.2	34	36.6	34.9	22	21.5
Mass of can +Oven Dry soil, g	28.7	25.7	26.2	25.7	20.2	19.9
Moisture content, %	82.0	84.7	99.0	91.1	39.1	38.1

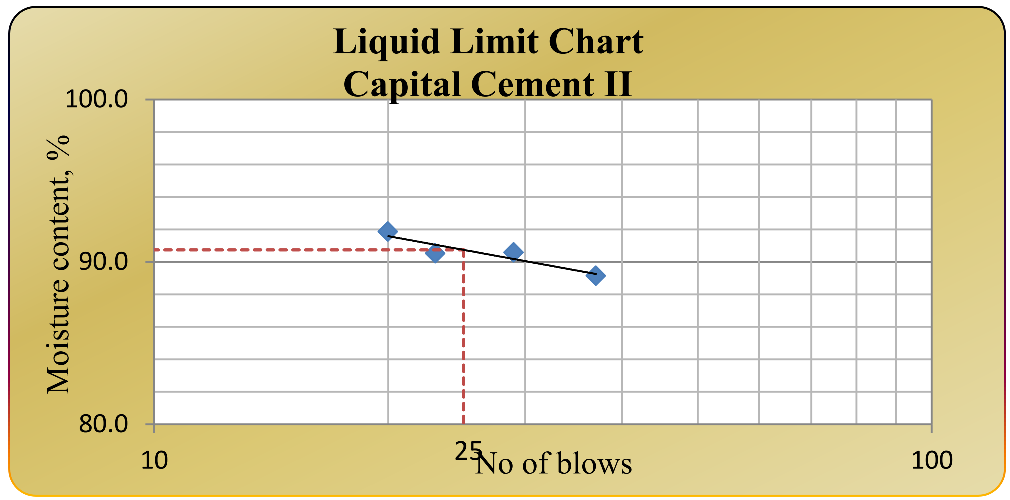
Liquid Limit, % =92 **Plastic Limit, %** =39 **plastic Index, PI** =53



Sample capital cement II
Depth, m: 1.80 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	23	37	20	29	-	-
Can No	02	A3	IT1	L3	L5-Z1	B6
Mass of can, g	15.4	15.5	15.5	15.7	15.6	15.5
Mass of can + Wet soil, g	41.5	32.9	34.3	35.9	20.1	21.8
Mass of can +Oven Dry soil, g	29.1	24.7	25.3	26.3	18.9	20.2
Moisture content, %	90.5	89.1	91.8	90.6	36.4	34.0

Liquid Limit, % =91 **Plastic Limit, %** =35 **plastic Index, PI** =56



Sample	capital cement III
Depth, m:	2.70 m

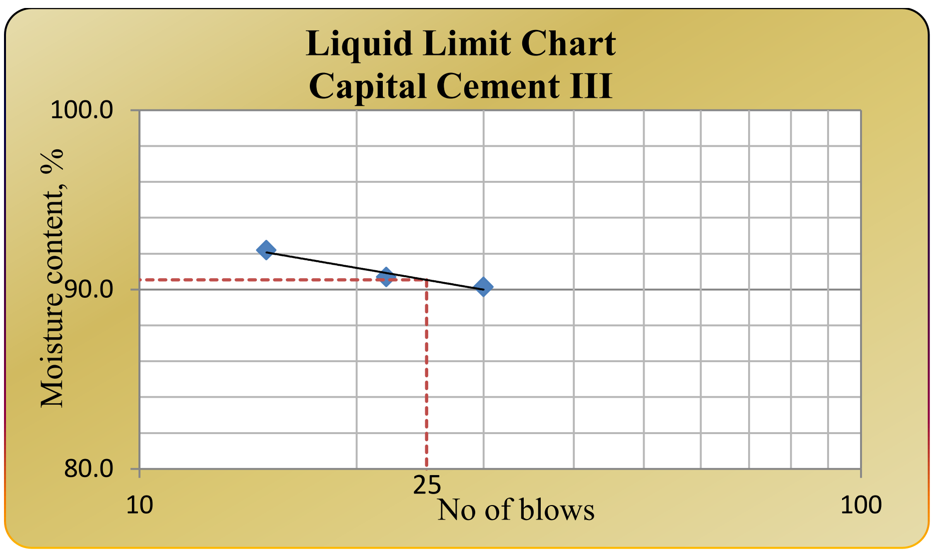
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	15	22	30		-	-
Can No	A19	A3	47		L3	A17
Mass of can, g	15.5	15.4	15.8		15.7	15.9
Mass of can + Wet soil, g	37.6	37.9	31.2		20.5	22.5
Mass of can +Oven Dry soil, g	27	27.2	23.9		19.2	20.7
Moisture content, %	92.2	90.7	90.1		37.1	37.5

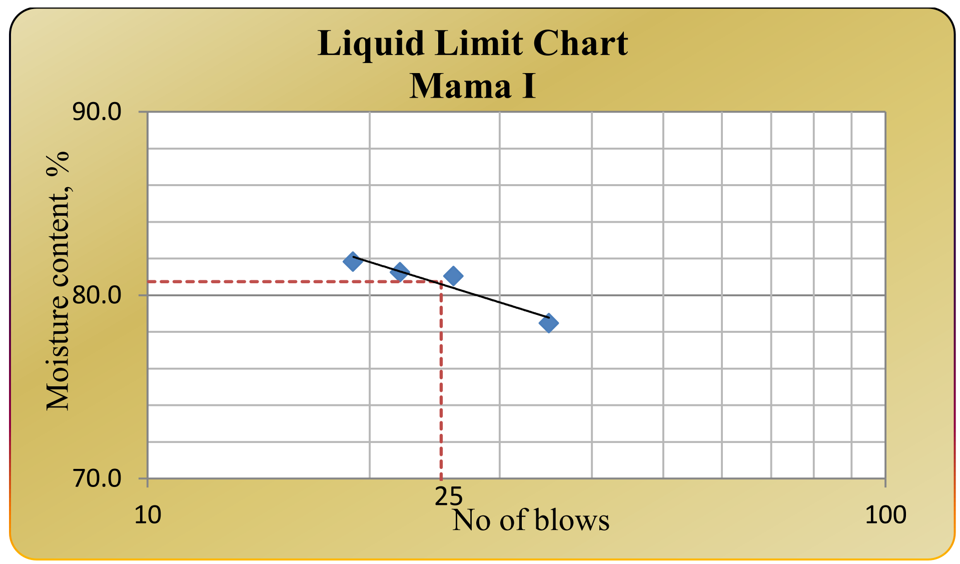
Liquid Limit, % =91 **Plastic Limit, %** =37 **plastic Index, PI** =54

Sample	mama I
Depth, m:	0.72 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	19	22	26	35	-	-
Can No	A4	Z7	G4	MA17	C3	C2
Mass of can, g	15.9	15.6	15.8	15.6	15.6	15.7
Mass of can + Wet soil, g	33.9	38.8	36.8	38.8	21.1	24.8
Mass of can +Oven Dry soil, g	25.8	28.4	27.4	28.6	19.8	22.5
Moisture content, %	81.8	81.3	81.0	78.5	31.0	33.8

Liquid Limit, % =81 **Plastic Limit, %** =32 **plastic Index, PI** =49





Sample	mama II
Date:	18-Jun-2013
Depth, m:	1.40 m

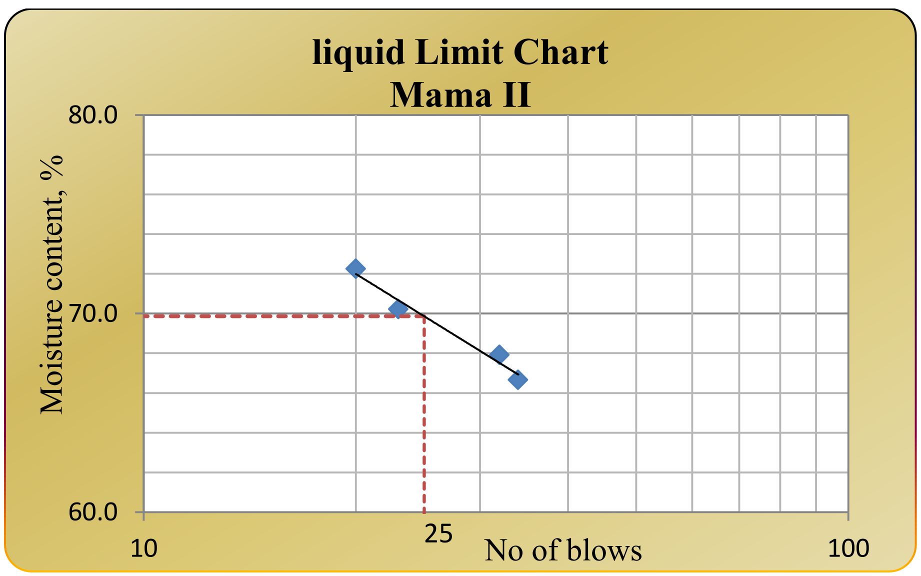
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	34	23	32	20	-	-
Can No	21	G1	A3	MA18	C2	C27
Mass of can, g	15.6	15.6	15.5	15.6	15.8	14.1
Mass of can + Wet soil, g	37.6	37.9	33.3	39.2	24	21.4
Mass of can +Oven Dry soil, g	28.8	28.7	26.1	29.3	22.1	19.7
Moisture content, %	66.7	70.2	67.9	72.3	30.2	30.4

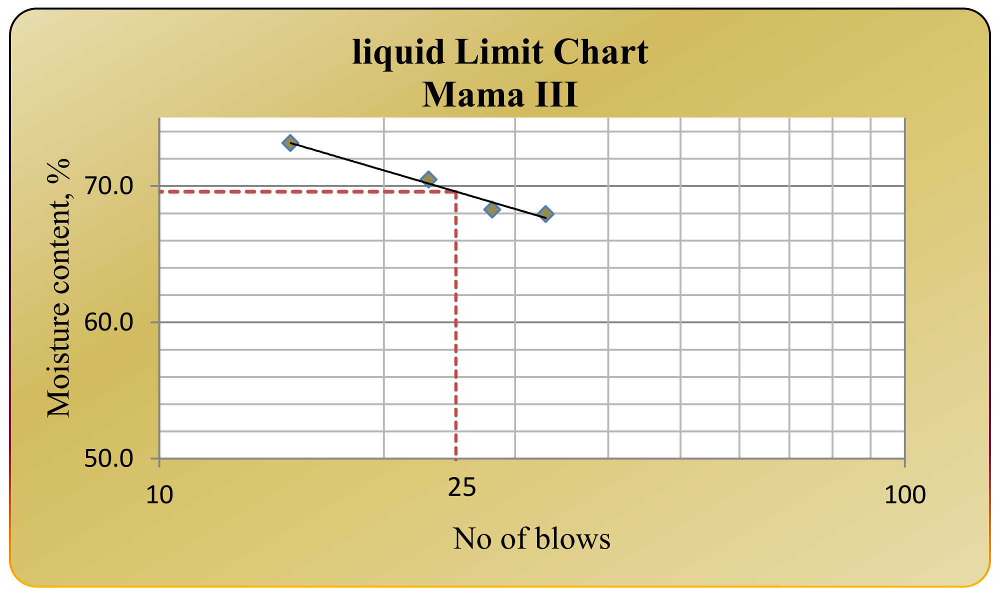
Liquid Limit, LL% **=70** **Plastic Limit, PL%** **=30** **plastic Index, PI** **=40**

Sample	mama III
Date:	
Depth, m:	2.80 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	15	28	33	23	-	-
Can No	47	G4	A4	MA17	L3	Z4
Mass of can, g	15.8	15.4	15.8	15.6	15.5	15.8
Mass of can + Wet soil, g	39.0	36.6	33.6	33.5	21.8	22.3
Mass of can +Oven Dry soil, g	29.2	28.0	26.4	26.1	20.5	20.8
Moisture content, %	73.1	68.3	67.9	70.5	26.0	30.0

Liquid Limit, % = **=70** **Plastic Limit, %** **=28** **plastic Index, PI** **=42**





Sample kentari I

Date:

Depth, m: 0.63 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	16	36	26	21	-	-
Can No	A44	MA17	G4	T3	C3	C2
Mass of can, g	15.4	15.5	15.5	15.5	15.6	15.6
Mass of can + Wet soil, g	34.2	35.8	36.8	35	22.6	25.5
Mass of can +Oven Dry soil, g	26.1	27.5	27.9	26.8	20.9	23.1
Moisture content, %	75.7	69.2	71.8	72.6	32.1	32.0

Liquid Limit, % =72 **Plastic Limit, %** =32 **plastic Index, PI** =40

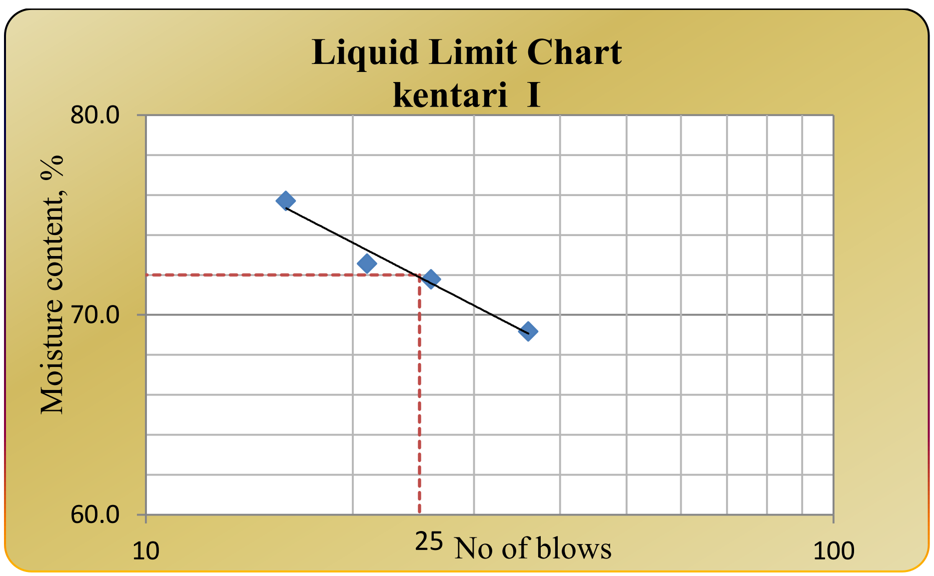
Sample kentari II

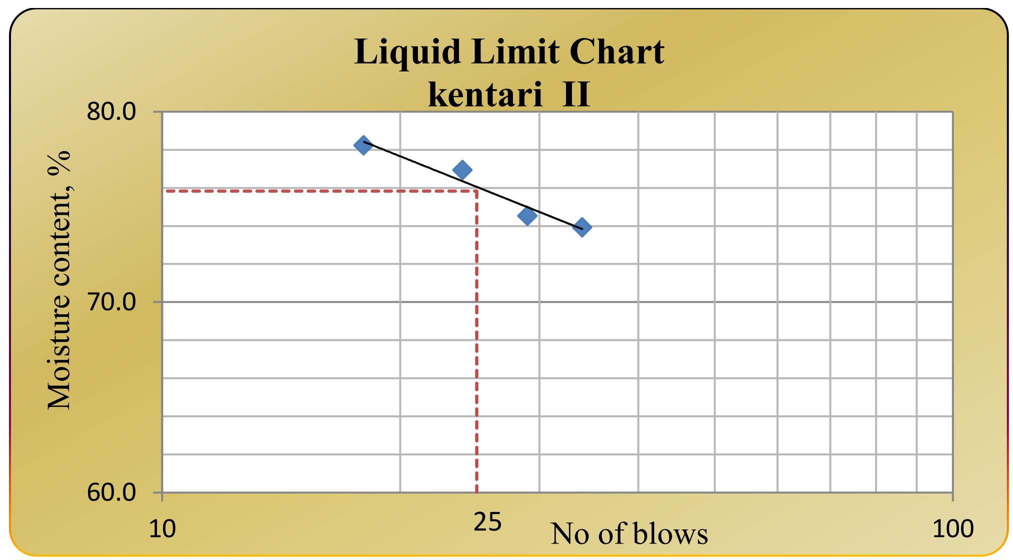
Date:

Depth, m: 1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	24	29	18	34	-	-
Can No	G1	21	A3	MA18	C2	C27
Mass of can, g	15.7	15.6	15.7	15.5	14	15.7
Mass of can + Wet soil, g	34.1	34.1	33.7	35.5	20.5	20.2
Mass of can +Oven Dry soil, g	26.1	26.2	25.8	27	18.9	19.1
Moisture content, %	76.9	74.5	78.2	73.9	32.7	32.4

Liquid Limit, LL% =76 **Plastic Limit, PL%** =33 **plastic Index, PI** =43





Sample kentari III

Date:

Depth, m: 2.85 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	28	34	16	20	-	-
Can No	47	G4	A4	MA17	L3	Z4
Mass of can, g	15.8	15.7	15.1	15.8	14.1	15.9
Mass of can + Wet soil, g	35.0	37.0	36.0	33.5	20.9	22.0
Mass of can +Oven Dry soil, g	26.4	27.6	26.5	25.5	19.1	20.5
Moisture content, %	81.1	79.0	83.3	82.5	36.0	32.6

Liquid Limit, % =81 **Plastic Limit, % =34** **plastic Index, PI =47**

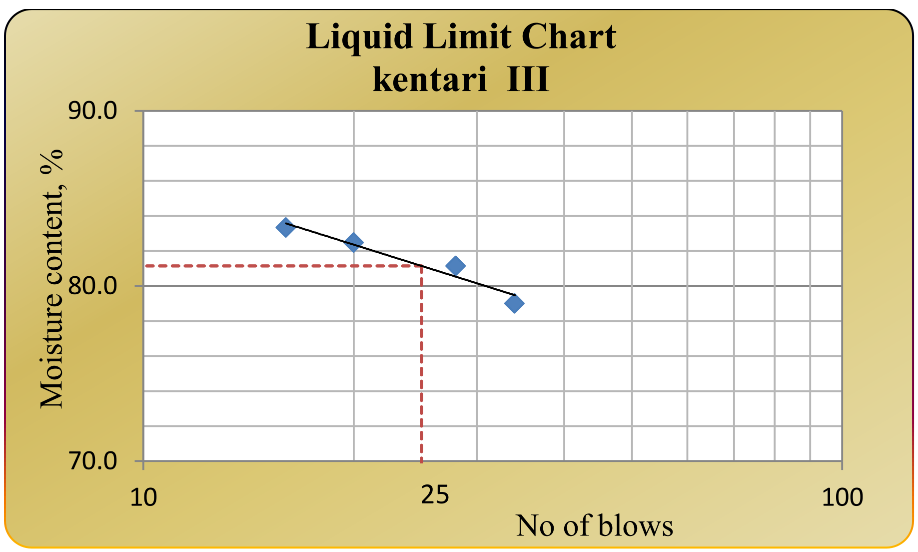
Sample St. Mikael Ch. I

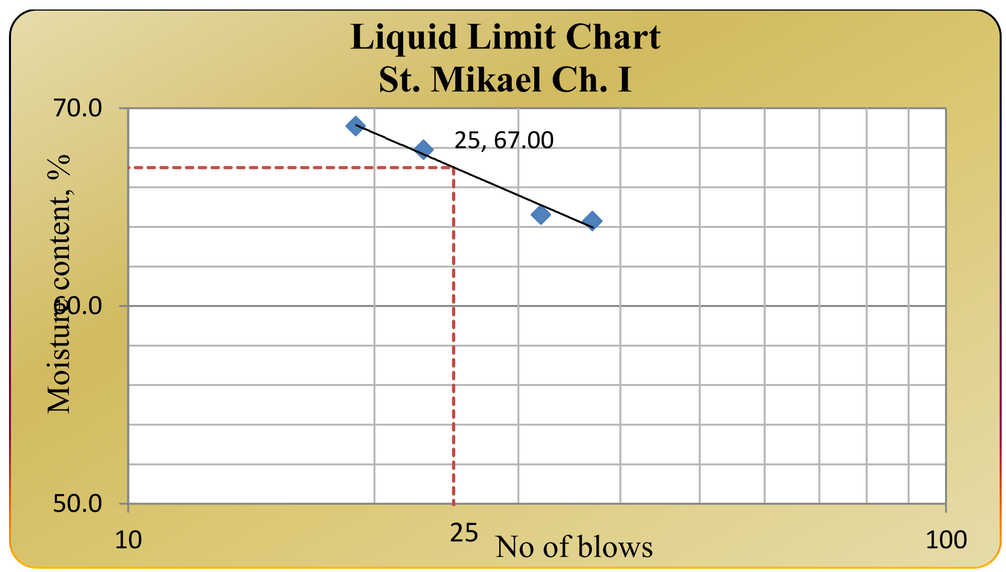
Date:

Depth, m: 1.10 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	37	32	23	19	-	-
Can No	A4	MA17	GG4	T3	C3	C2
Mass of can, g	15.4	14.7	15.1	15.7	15.4	15.8
Mass of can + Wet soil, g	33.8	36.1	33.4	34.3	22.7	22.8
Mass of can +Oven Dry soil, g	26.6	27.7	26	26.7	21	21.1
Moisture content, %	64.3	64.6	67.9	69.1	30.4	32.1

Liquid Limit, % =67 **Plastic Limit, % =31** **plastic Index, PI =36**





Sample St. Mikael Ch. III
Date:
Depth, m: 2.90 m

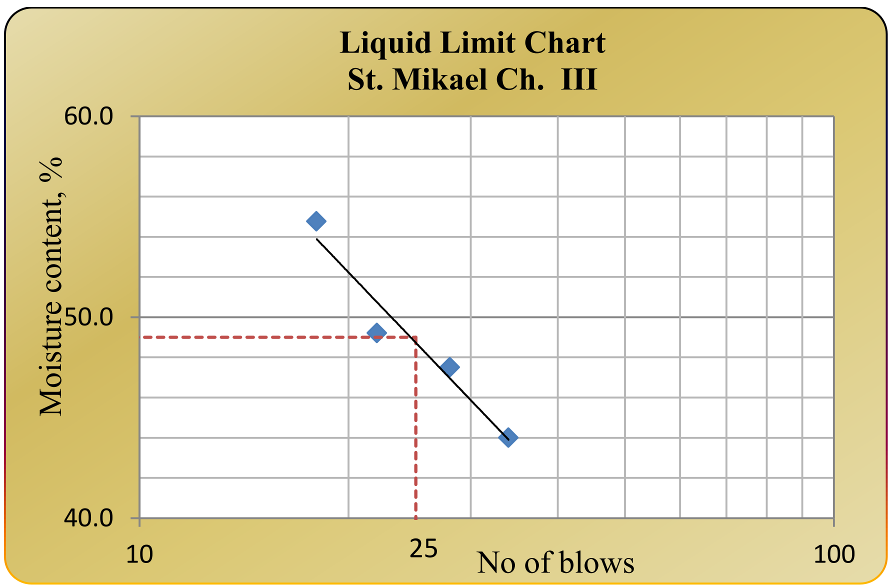
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	18	28	34	22		
Can No	MA13	A5	R2	CC	M2	R1
Mass of can, g	15.1	14.7	15.4	15.1	15.4	15.7
Mass of can + Wet soil, g	34.6	32.4	33.4	33.9	22	22.9
Mass of can +Oven Dry soil, g	27.7	26.7	27.9	27.7	20.7	21.2
Moisture content, %	54.8	47.5	44.0	49.2	24.5	30.9

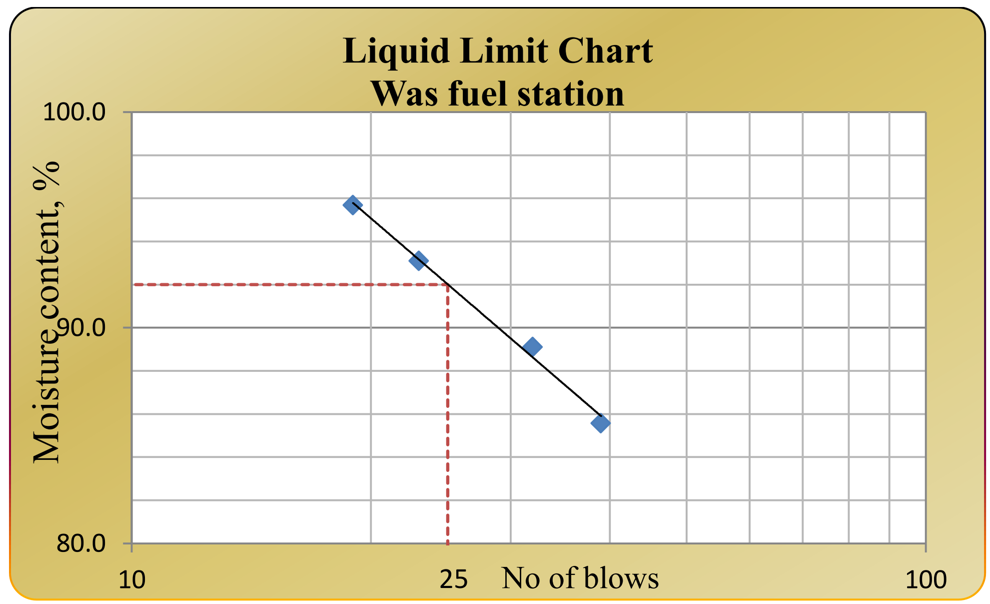
Liquid Limit, LL% =49 **Plastic Limit, PL%** =28 **plastic Index, PI** =21

Sample was fuel station
Date:
Depth, m: 0.80 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	39	32	23	19	-	-
Can No	PD	PP	D4	TT3	C3	PC2
Mass of can, g	15.1	15.3	15.3	15.1	15.7	15.3
Mass of can + Wet soil, g	33.1	34.4	32.1	37.8	22.5	22.7
Mass of can +Oven Dry soil, g	24.8	25.4	24	26.7	20.6	20.8
Moisture content, %	85.6	89.1	93.1	95.7	38.8	34.5

Liquid Limit, % =92 **Plastic Limit, %** =37 **plastic Index, PI** =55





Sample Youth Center
Date:
Depth, m: 0.75 m

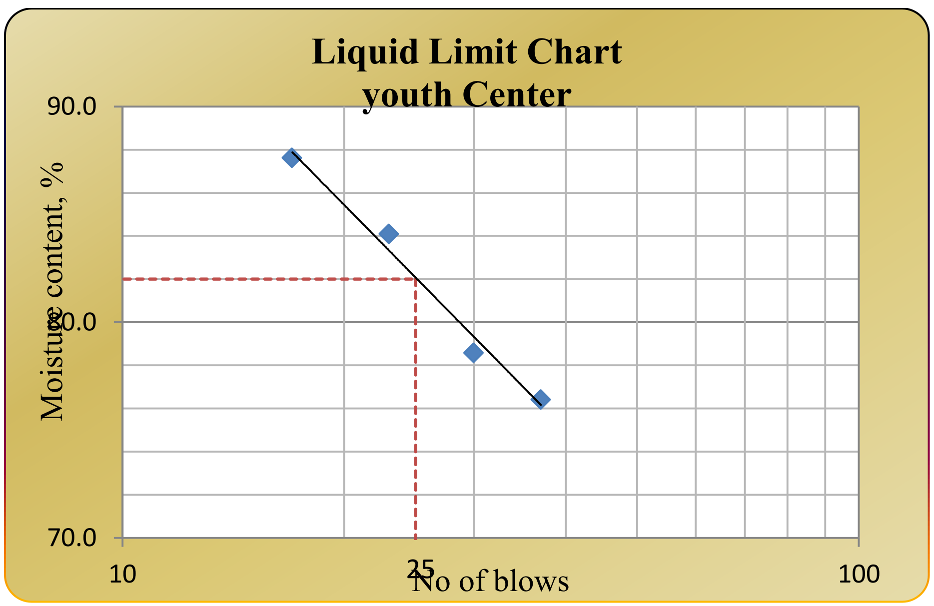
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	37	30	23	17	-	-
Can No	55	T4	PD	PP	P2	TT4
Mass of can, g	15	15.2	15.3	14.9	15.5	15.2
Mass of can + Wet soil, g	33.7	35.2	31.5	34.6	21.9	23.1
Mass of can +Oven Dry soil, g	25.6	26.4	24.1	25.4	20.5	21.2
Moisture content, %	76.4	78.6	84.1	87.6	28.0	31.7

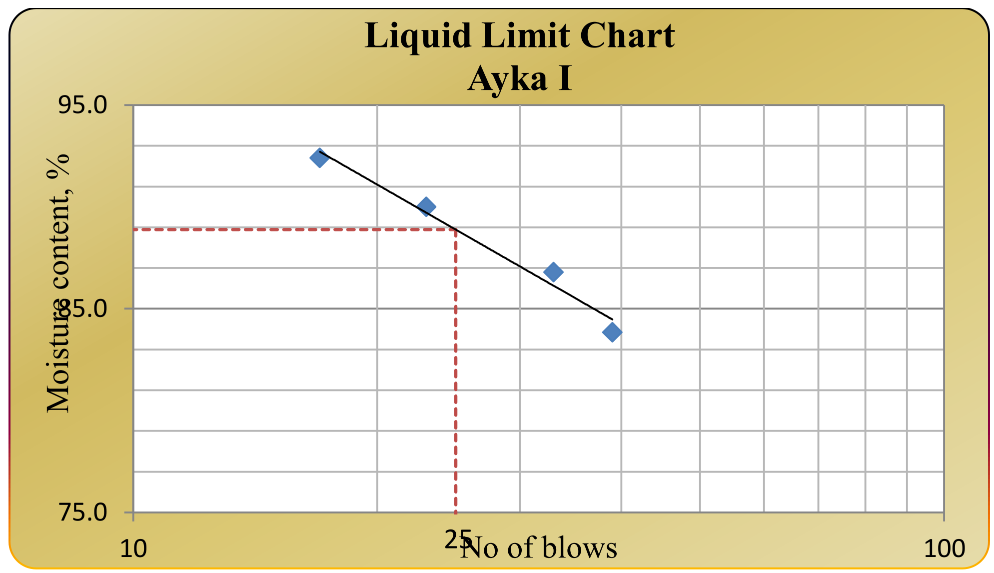
Liquid Limit, % =82 **Plastic Limit, % =30** **plastic Index, PI =52**

Sample Ayka I
Date:
Depth, m: 0.80 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	39	33	23	17	-	-
Can No	R2	CC	M2	R1	T4	LP1
Mass of can, g	15.4	15.1	15.4	15.7	15.3	15.5
Mass of can + Wet soil, g	33.6	34.9	32.5	33.4	22.5	22.1
Mass of can +Oven Dry soil, g	25.3	25.7	24.4	24.9	20.7	20.5
Moisture content, %	83.8	86.8	90.0	92.4	33.3	32.0

Liquid Limit, % =89 **Plastic Limit, % =33** **plastic Index, PI =56**





Sample Ayka II
Date:
Depth, m: 1.60 m

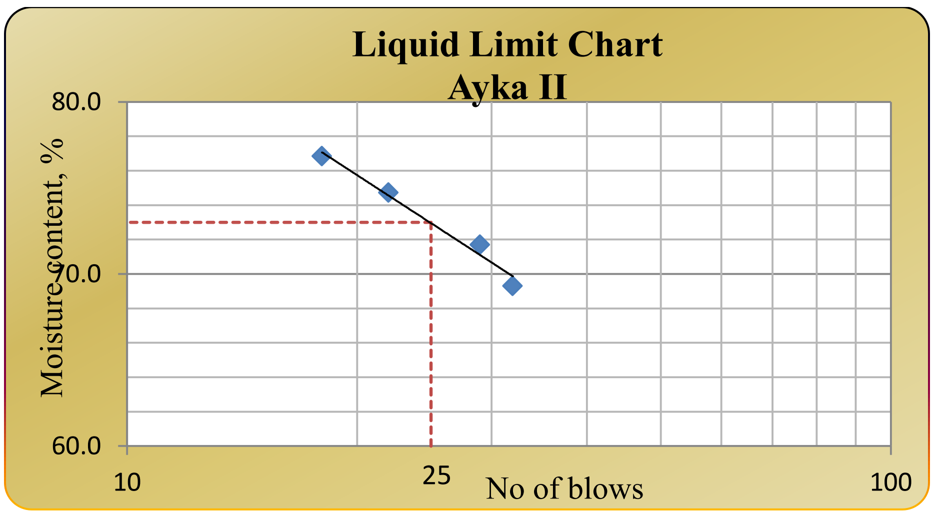
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	32	29	22	18	-	-
Can No	G2	G1	G3	GS	TP1	TP2
Mass of can, g	15.1	15.3	15.3	15.1	15.7	15.1
Mass of can + Wet soil, g	32.2	33.5	31.2	34.2	21.7	22.1
Mass of can +Oven Dry soil, g	25.2	25.9	24.4	25.9	20.1	20.5
Moisture content, %	69.3	71.7	74.7	76.9	36.4	29.6

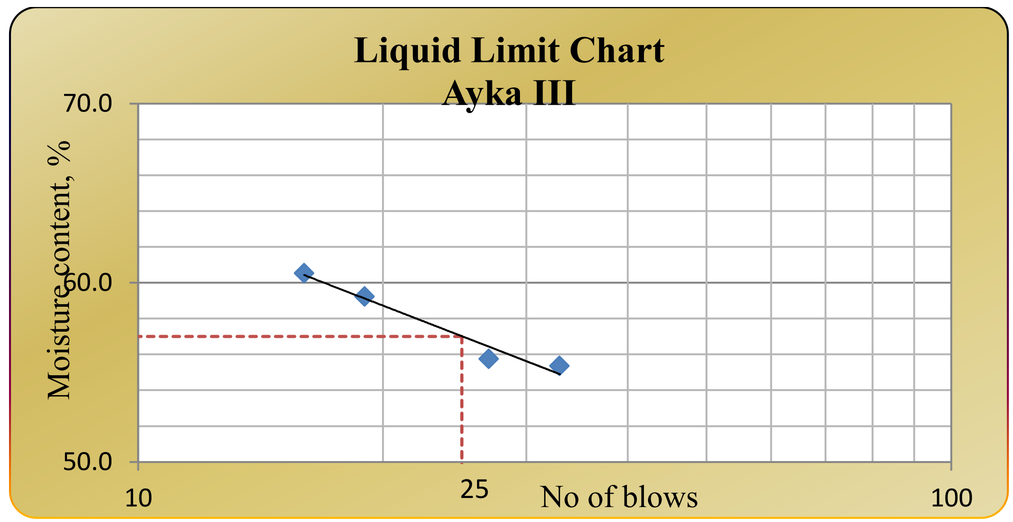
Liquid Limit, % =73 **Plastic Limit, % =33** **plastic Index, PI =40**

Sample Ayka III
Date:
Depth, m: 2.20 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	19	27	16	33	-	-
Can No	A5	R2	CC	M2	T2	K3
Mass of can, g	14.7	15.4	15.1	15.4	15.7	15.1
Mass of can + Wet soil, g	35.4	33	33.4	32.8	21.9	21.6
Mass of can +Oven Dry soil, g	27.7	26.7	26.5	26.6	20.5	20.2
Moisture content, %	59.2	55.8	60.5	55.4	29.2	27.5

Liquid Limit, % =57 **Plastic Limit, % =28** **plastic Index, PI =29**





Sample caba
Date:
Depth, m: 0.75 m

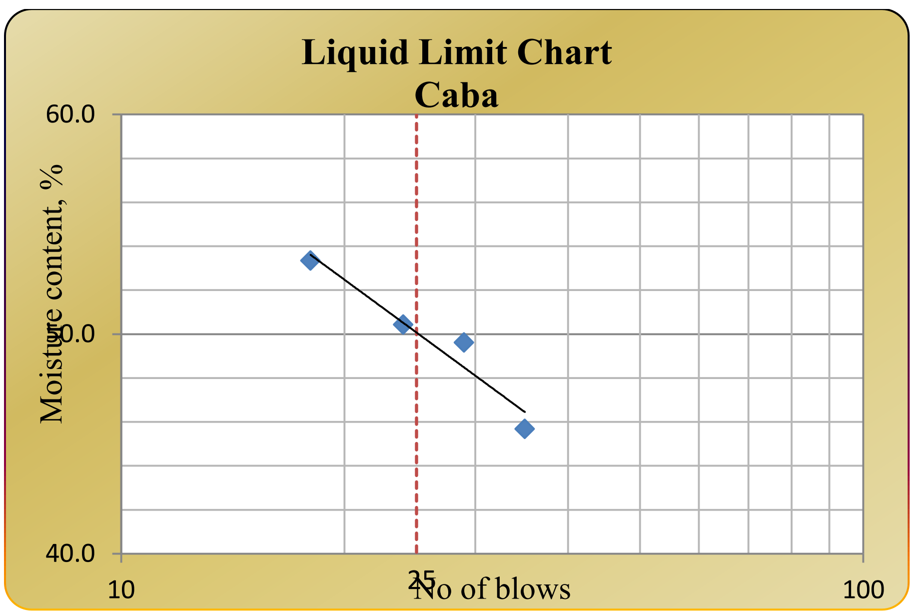
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	24	29	18	35	-	-
Can No	G4	A4	P1	47	TP1	TP3
Mass of can, g	15.7	15.1	15.1	15.8	15.6	15.6
Mass of can + Wet soil, g	33.6	34.1	33.5	34.3	22.8	22.8
Mass of can +Oven Dry soil, g	27.6	27.8	27.1	28.5	20.4	20.5
Moisture content, %	50.4	49.6	53.3	45.7	50.0	46.9

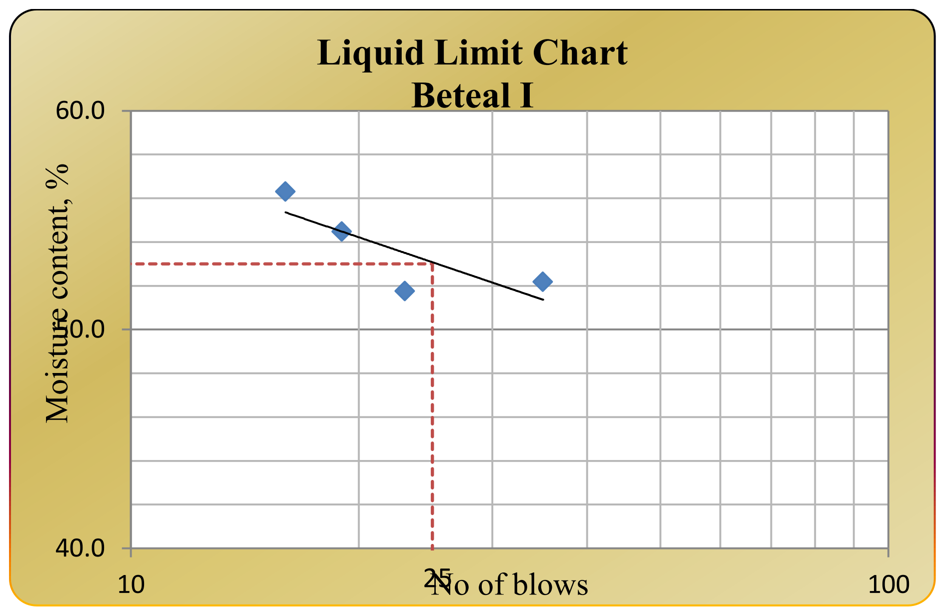
Liquid Limit, % =66 **Plastic Limit, % =48** **plastic Index, PI =18**

Sample Beteal I
Date:
Depth, m: 0.72 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	35	23	19	16	-	-
Can No	C3	E3	M6	D3	P2	Z
Mass of can, g	15.6	15.8	15.6	15.5	15.1	15.7
Mass of can + Wet soil, g	33.1	37.5	34.6	36.6	22.1	23.2
Mass of can +Oven Dry soil, g	27.1	30.1	27.9	29	20.8	21.7
Moisture content, %	52.2	51.7	54.5	56.3	22.8	25.0

Liquid Limit, % =53 **Plastic Limit, % =24** **plastic Index, PI =29**





Sample Beteal II
Date:
Depth, m: 1.40 m

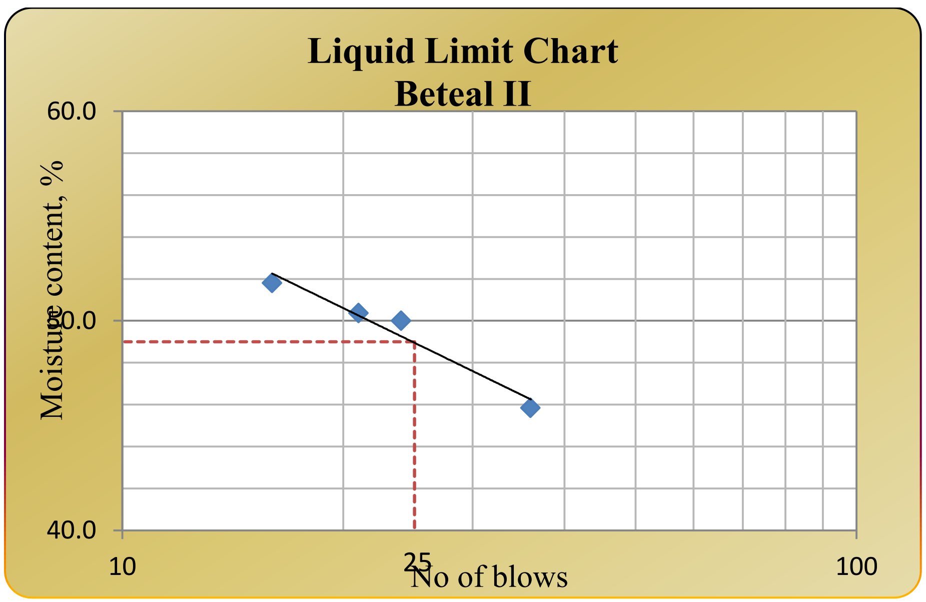
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	36	21	24	16	-	-
Can No	Z1	Z7	ZA1	D3	P2	Z2
Mass of can, g	15.6	15.7	15.6	15.2	15	15.2
Mass of can + Wet soil, g	33.1	36	35.1	36.3	21.6	22.3
Mass of can +Oven Dry soil, g	27.6	29.2	28.6	29.1	20.1	21.1
Moisture content, %	45.8	50.4	50.0	51.8	29.4	20.3

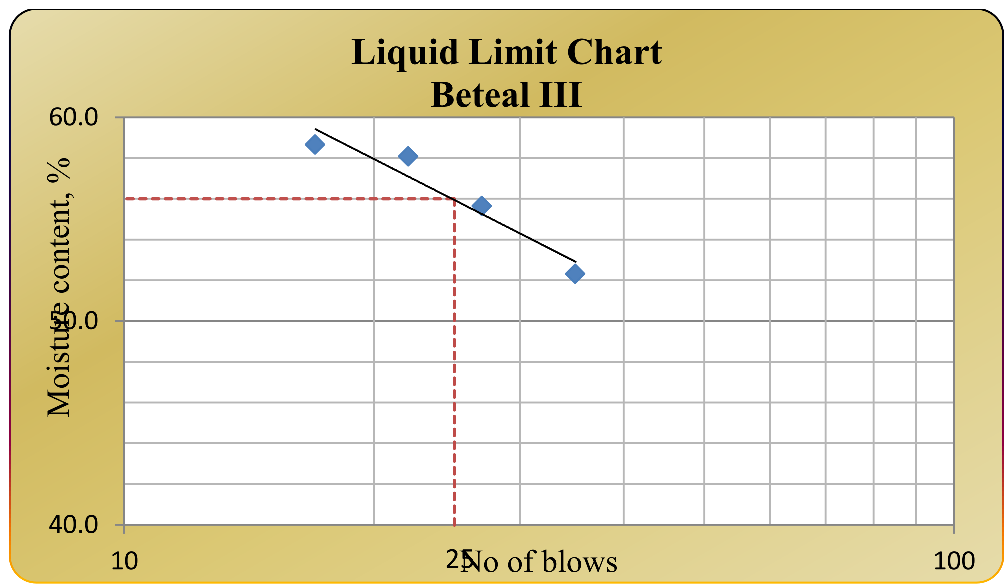
Liquid Limit, % **=49** **Plastic Limit, %** **=25** **plastic Index, PI** **=24**

Sample Beteal III
Date:
Depth, m: 2.40 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	35	27	22	17	-	-
Can No	W1	WT	ZA3	D7	TT	L4
Mass of can, g	15.3	15.4	15.6	15.3	15.4	15.1
Mass of can + Wet soil, g	35.1	36.1	35.2	36.4	22.9	22.7
Mass of can +Oven Dry soil, g	28.3	28.7	28	28.6	21.1	20.8
Moisture content, %	52.3	55.6	58.1	58.6	31.6	33.3

Liquid Limit, % **=56** **Plastic Limit, %** **=32** **plastic Index, PI** **=24**





Sample Oda Flower III
Date:
Depth, m: 2.40 m

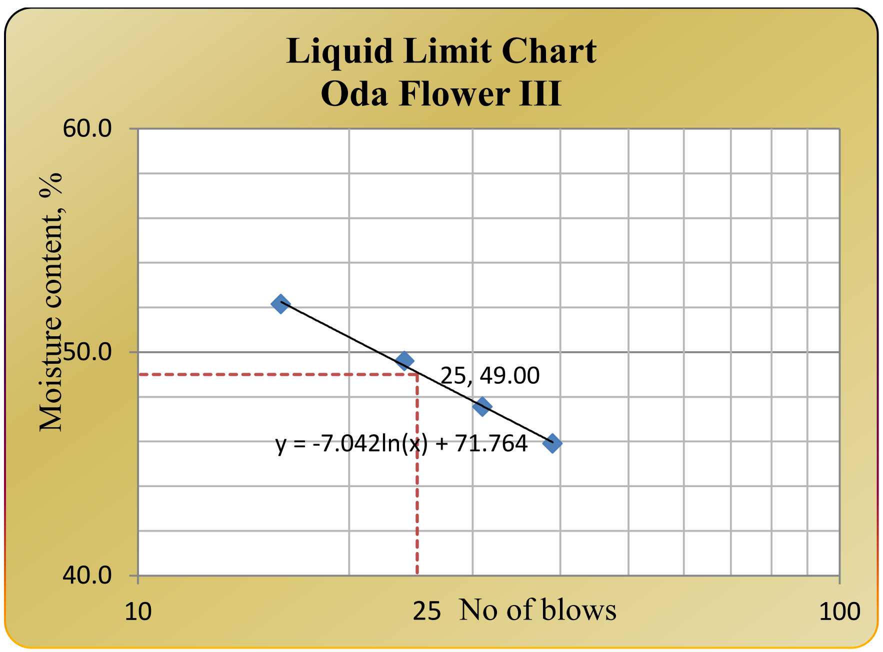
	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	16	24	31	39	-	-
Can No	DC	21	T5	G1	C27	A3
Mass of can, g	15.7	15.4	15.2	15.6	15.4	15.2
Mass of can + Wet soil, g	33.5	33.8	33.2	33.4	21.2	21.6
Mass of can +Oven Dry soil, g	27.4	27.7	27.4	27.8	19.8	20.1
Moisture content, %	52.1	49.6	47.5	45.9	31.8	30.6

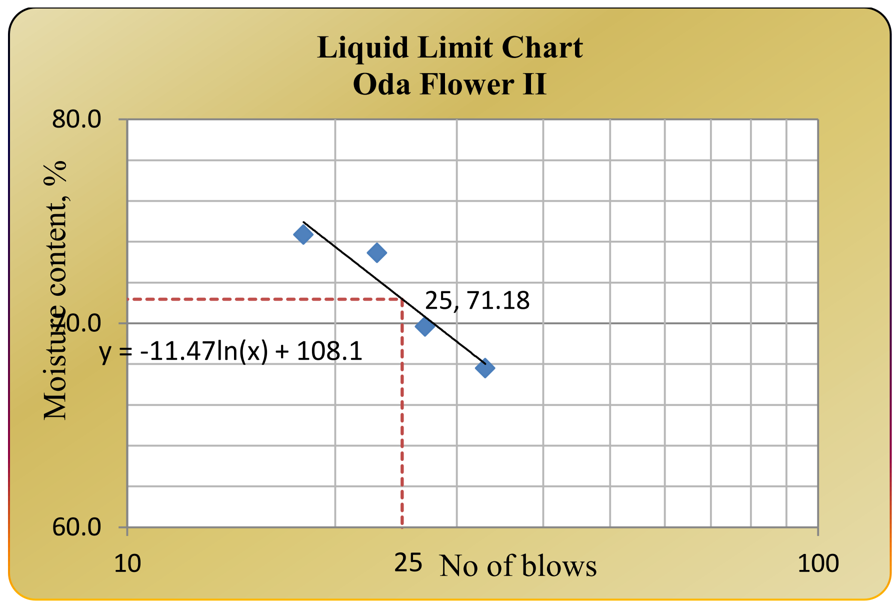
Liquid Limit, % =49 **Plastic Limit, % =31** **plastic Index, PI =18**

Sample Oda Flower II
Date:
Depth, m: 1.40 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	33	27	23	18	-	-
Can No	RS1	H8	RS5	RS11	H44	I54
Mass of can, g	15	15.4	15.2	15.3	15.5	15.1
Mass of can + Wet soil, g	34.8	35.1	34.8	35	21.6	21.6
Mass of can +Oven Dry soil, g	26.8	27	26.5	26.6	19.8	19.7
Moisture content, %	67.8	69.8	73.5	74.3	41.9	41.3

Liquid Limit, % =71 **Plastic Limit, % =42** **plastic Index, PI =29**

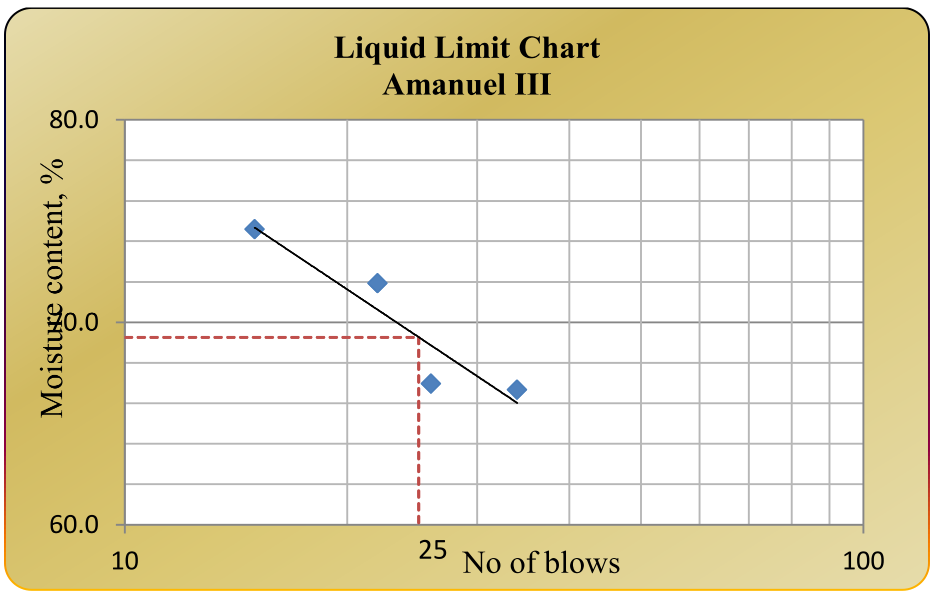




Sample	Amanuel III
Date:	
Depth, m:	2.40 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	34	26	22	15	-	-
Can No	RT	KM	LM	D7	FR	LI
Mass of can, g	15.6	15.7	15.4	15.7	15.4	15.5
Mass of can + Wet soil, g	34.6	33.9	35	37	21.1	21.9
Mass of can +Oven Dry soil, g	27	26.6	26.8	27.9	19.3	19.8
Moisture content, %	66.7	67.0	71.9	74.6	46.2	48.8

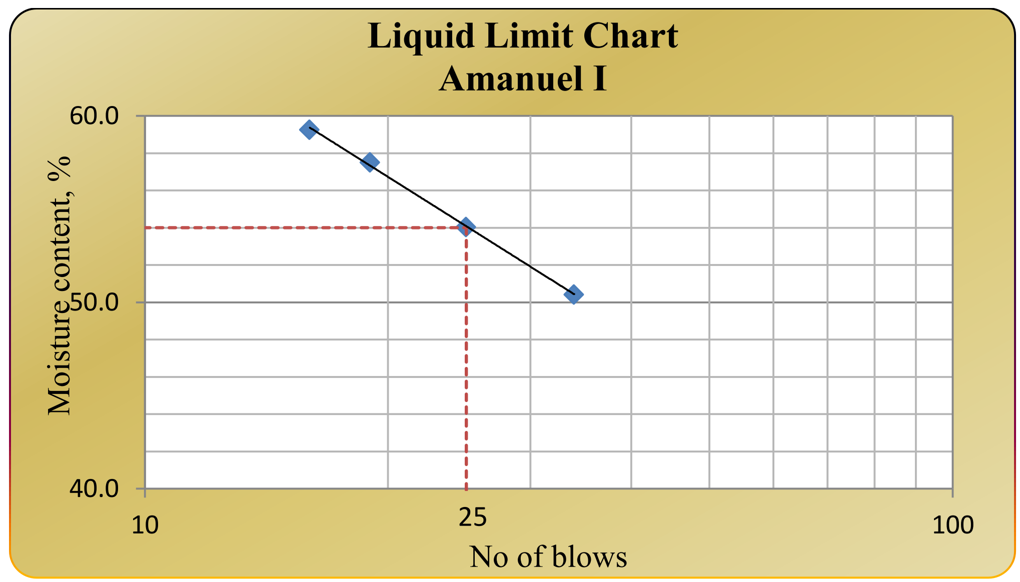
Liquid Limit, % =69 **Plastic Limit, %** =47 **plastic Index, PI** =22



Sample	Amanuel I
Date:	
Depth, m:	0.75 m

	Liquid Limit				Plastic Lim	
Trial No	1	2	3	4	1	
No of blows	34	25	19	16	-	-
Can No	AS	TT3	PP	D4	K7	G6
Mass of can, g	15.4	15.1	15.3	15.3	15.1	15
Mass of can + Wet soil, g	33.3	34.2	34.2	32.5	21.7	21
Mass of can +Oven Dry soil, g	27.3	27.5	27.3	26.1	19.8	20
Moisture content, %	50.4	54.0	57.5	59.3	40.4	36

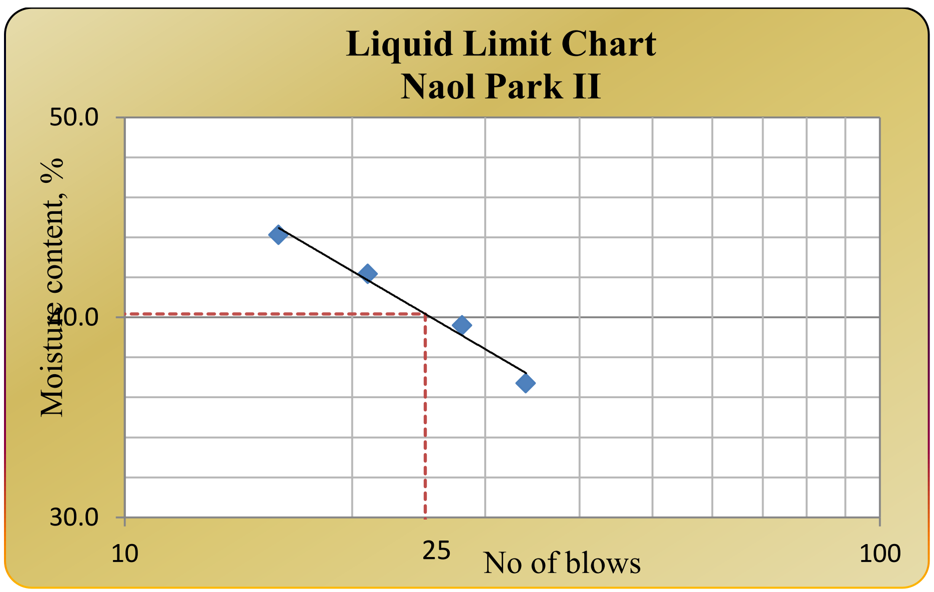
Liquid Limit, % =54 **Plastic Limit, %** =38 **plastic Index, PI** =16



Sample Naol Park II
Date:
Depth, m: 1.20 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	34	28	21	16	-	-
Can No	KB	LP	P4	U4	O6	PL1
Mass of can, g	15.6	15.4	15.2	15.4	15.3	15.6
Mass of can + Wet soil, g	37.2	36.2	36.1	35	22.6	22.2
Mass of can +Oven Dry soil, g	31.4	30.3	29.9	29	21.2	21.1
Moisture content, %	36.7	39.6	42.2	44.1	23.7	20.0

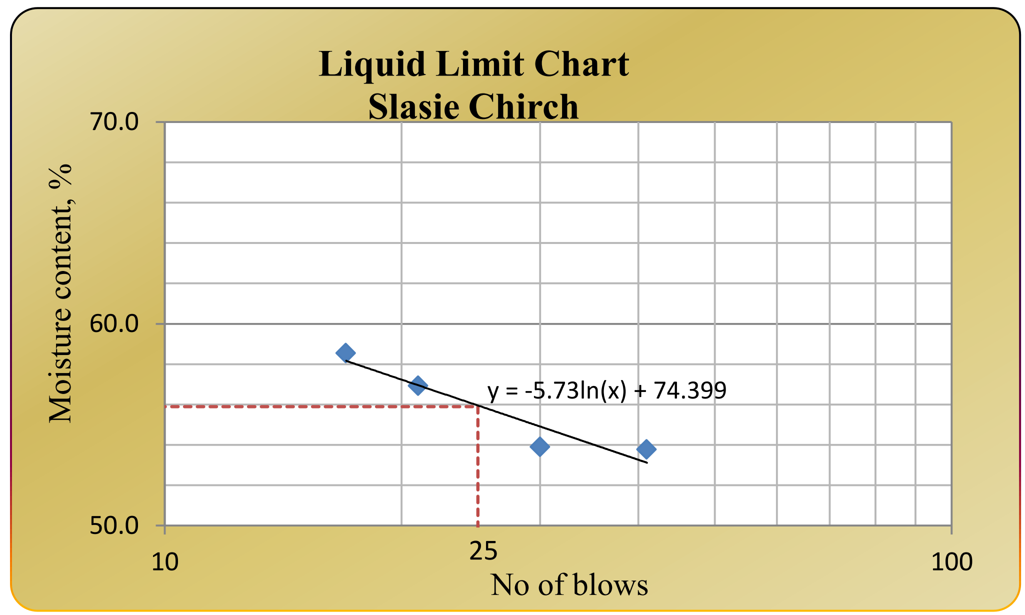
Liquid Limit, % **=40** **Plastic Limit, %** **=22** **plastic Index, PI** **=18**



Sample SILASIE
Date:
Depth, m: 0.70 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
No of blows	41	30	21	17	-	-
Can No	F4	B4	C2/FL5	C7	A4	FL1
Mass of can, g	15.6	13.3	15.6	15.5	15.4	15.5
Mass of can + Wet soil, g	31.9	33	37.1	35	21.4	22.2
Mass of can +Oven Dry soil, g	26.2	26.1	29.3	27.8	19.7	21
Moisture content, %	53.8	53.9	56.9	58.5	39.5	21.8

Liquid Limit, % **=56** **Plastic Limit, %** **=31** **plastic Index, PI** **=25**



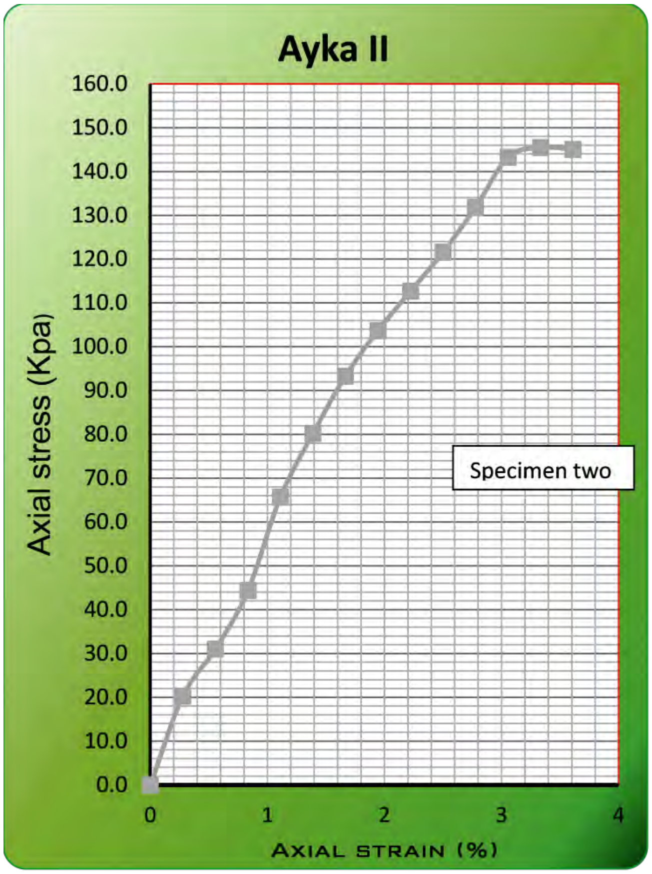
APPENDIX – B4

FREE SWELL INDEX

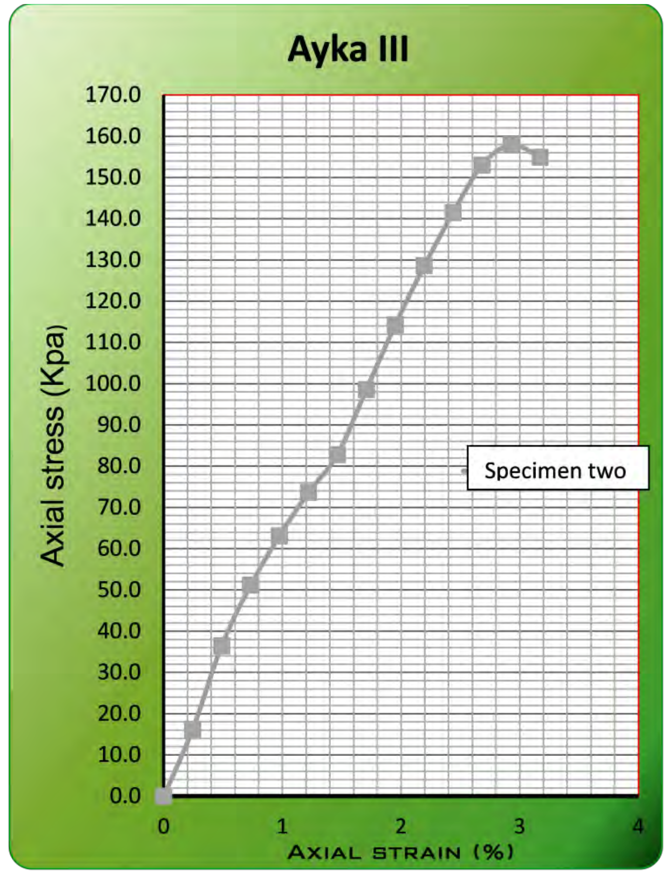
Black expansive soil (Cat -1)				Red soil (Cat -2)			
Sample Name	**Initial Volume**	**Average Final Volume**	**Free Swell Index**	**Sample Name**	**Initial Volume**	**Average Final Volume**	**Free Swell Index**
	(cc)	**(cc)**	**(%)**		**(cc)**	**(cc)**	**(%)**
Ayka I*	10	17	70	Amanuel I	10	13.4	34
Ayka II*	10	15	50	Amanuel II	10	13.2	32
Ayka III*	10	15.1	51	Amanuel III	10	14.2	42
capital cement I*	10	15.7	57	betel I	10	14	40
capital cement II*	10	16.5	65	betel II	10	13.9	39
capital cement III*	10	16.3	63	betel III	10	14.2	42
kentari I*	10	15.3	53	caba	10	13	30
kentari II*	10	15.1	51	Naol Park I	10	14	40
kentari III*	10	16.3	63	Naol Park II	10	13.7	37
mama I*	10	15.8	58	Oda Flower I	10	14.9	49
mama II*	10	15.1	51	Oda Flower II	10	13.9	39
mama III*	10	15.1	51	Oda Flower III	10	14	40
St. Mikael Ch. I*	10	15.1	51	silasie	10	14.1	41
St. Mikael Ch. III	10	13	30	watto	10	13.7	37
Was Fuel*	10	16.4	64				
Youth Center*	10	15.2	52				

APPENDIX – B6

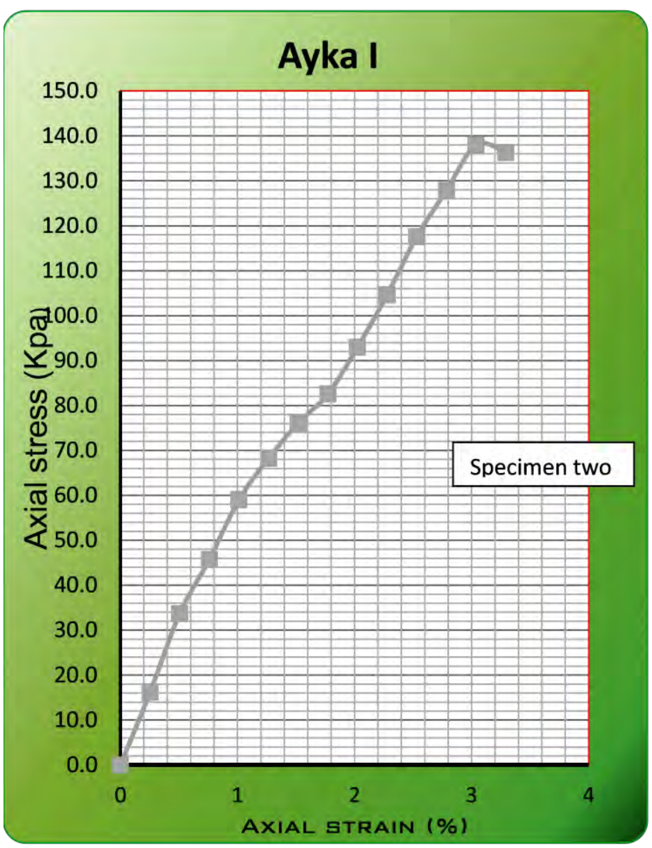
UNCONFINED COMPRESSION TEST RESULTS



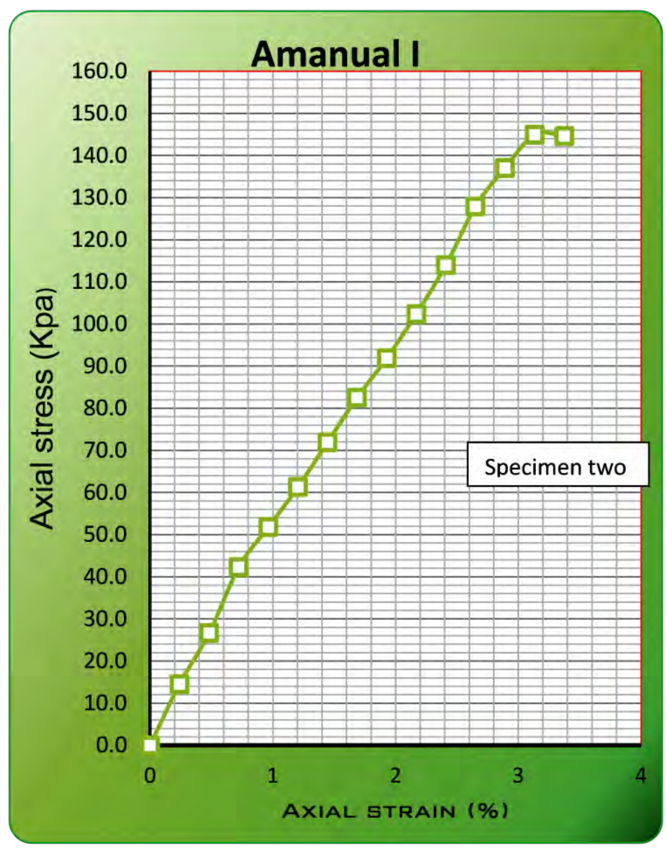
Ayka II
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Axial stress (Kpa)
0
1
2
3
4
Axial strain (%)
Specimen two



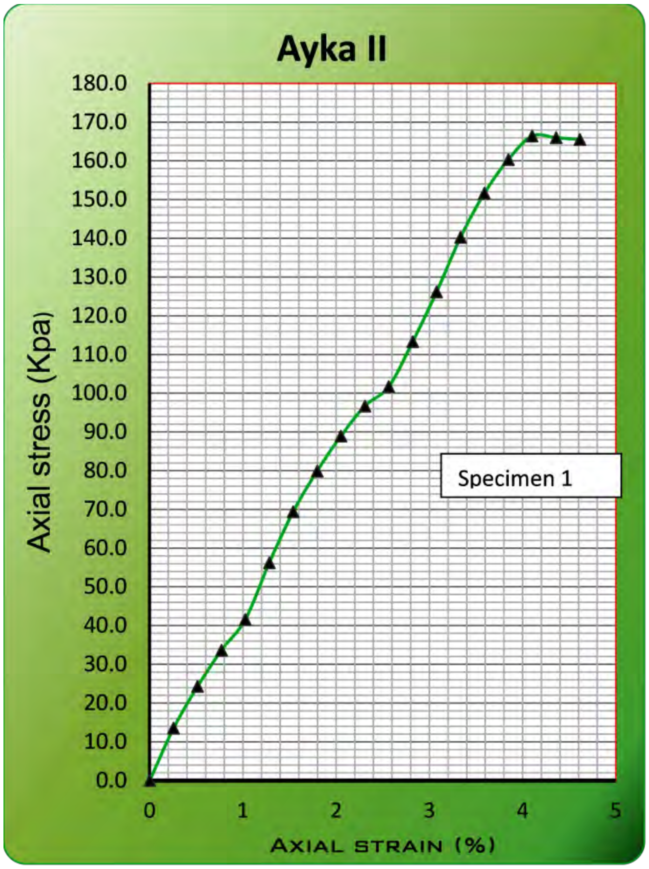
Ayka III
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Axial stress (Kpa)
0
1
2
3
4
Axial strain (%)
Specimen two

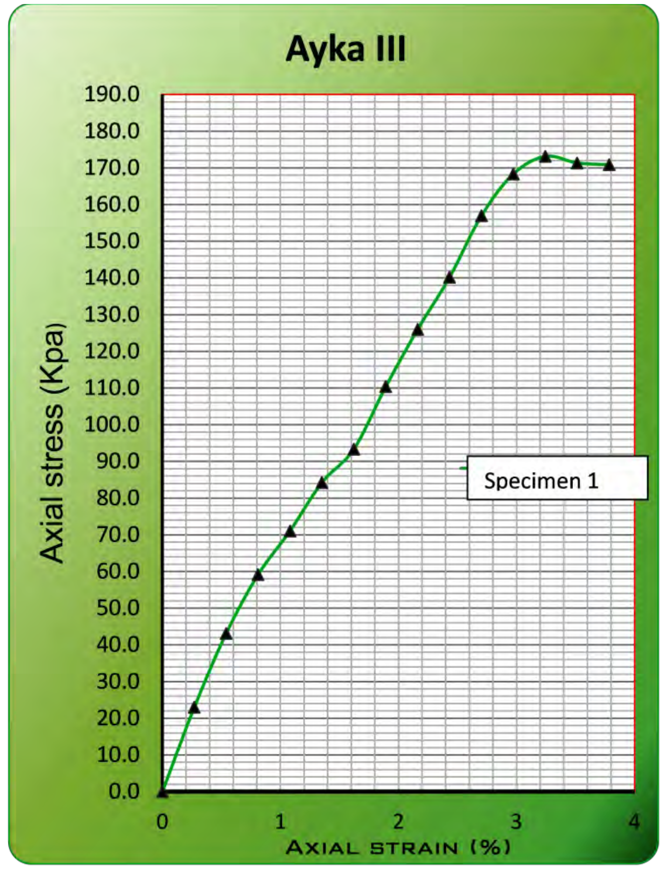


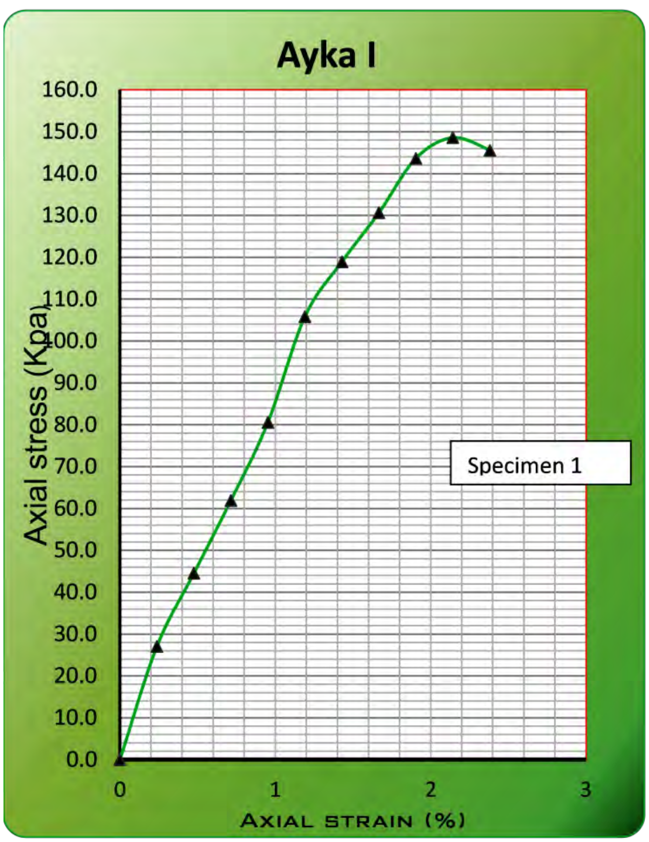
Ayka I
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Axial stress (Kpa)
0
1
2
3
4
Axial strain (%)
Specimen two

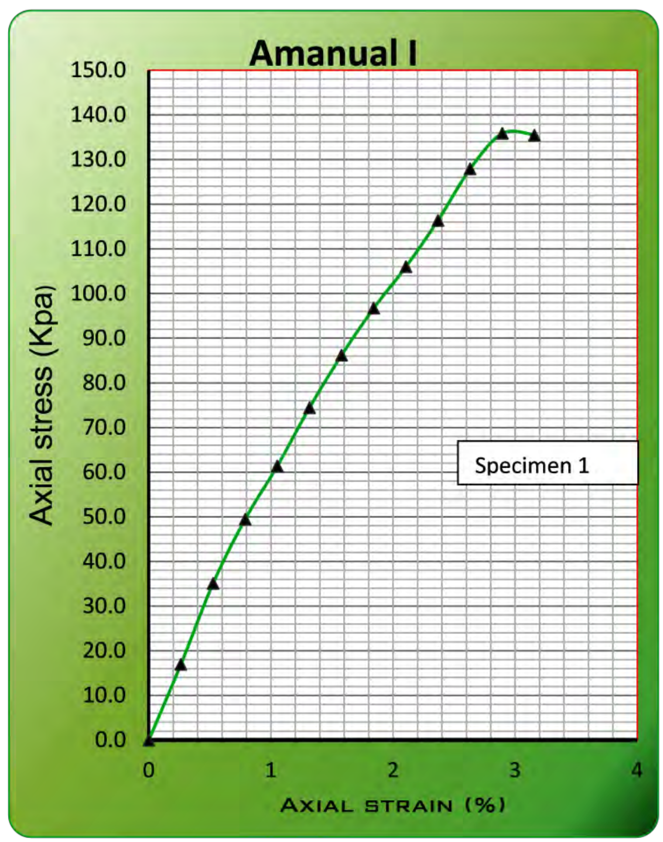


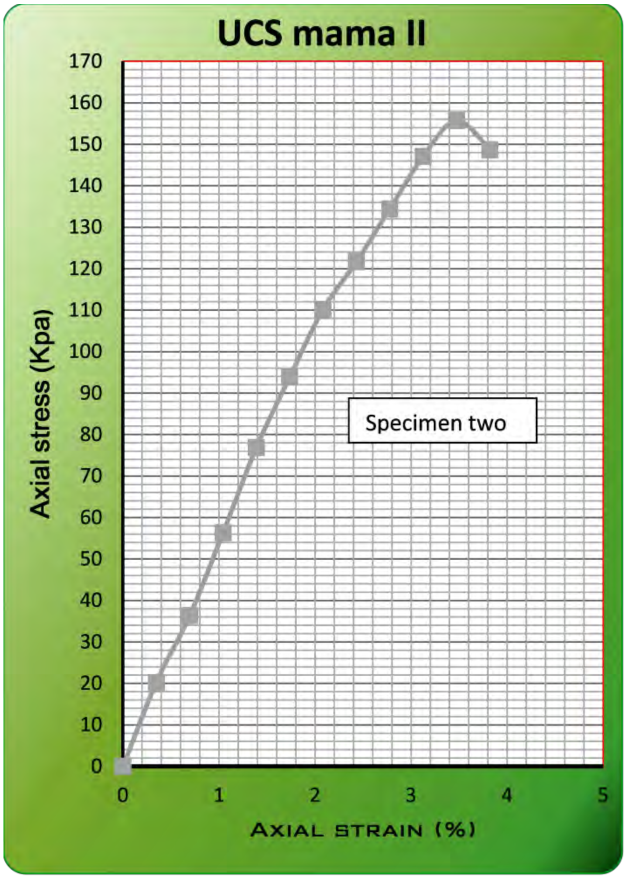
Amanual I
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Axial stress (Kpa)
0
1
2
3
4
Axial strain (%)
Specimen two

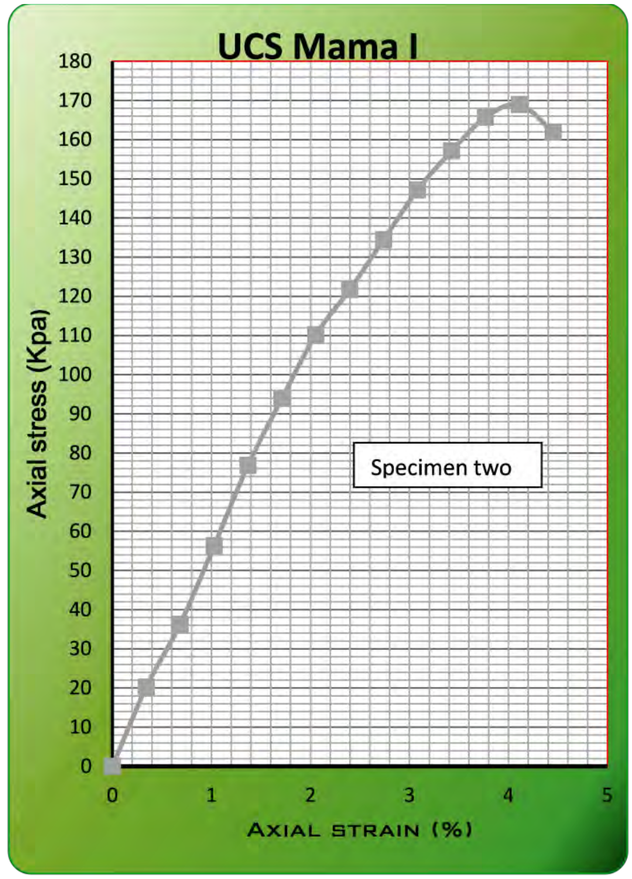

Ayka II
Axial stress (Kpa)
Axial strain (%)
Specimen 1

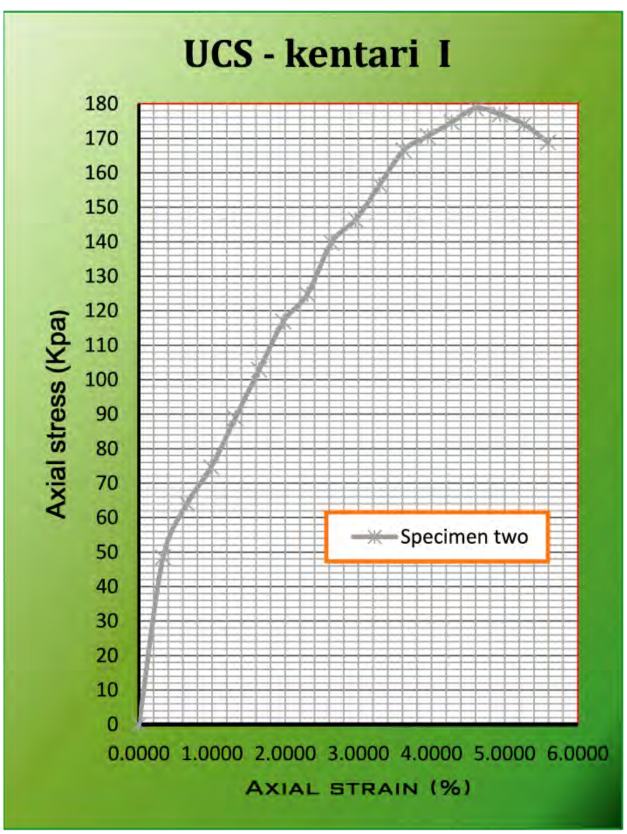

Ayka III
Axial stress (Kpa)
Axial strain (%)
Specimen 1

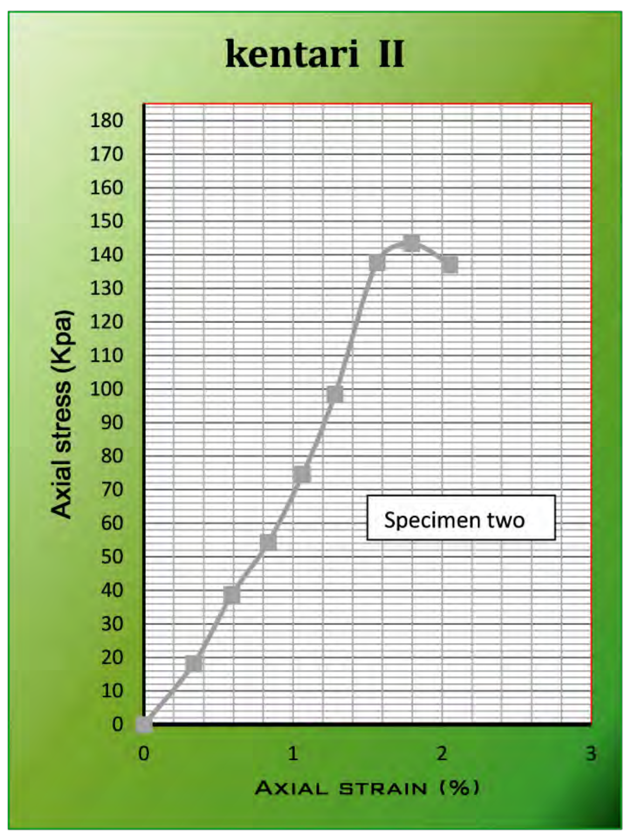

Ayka I
Axial stress (Kpa)
Axial strain (%)
Specimen 1

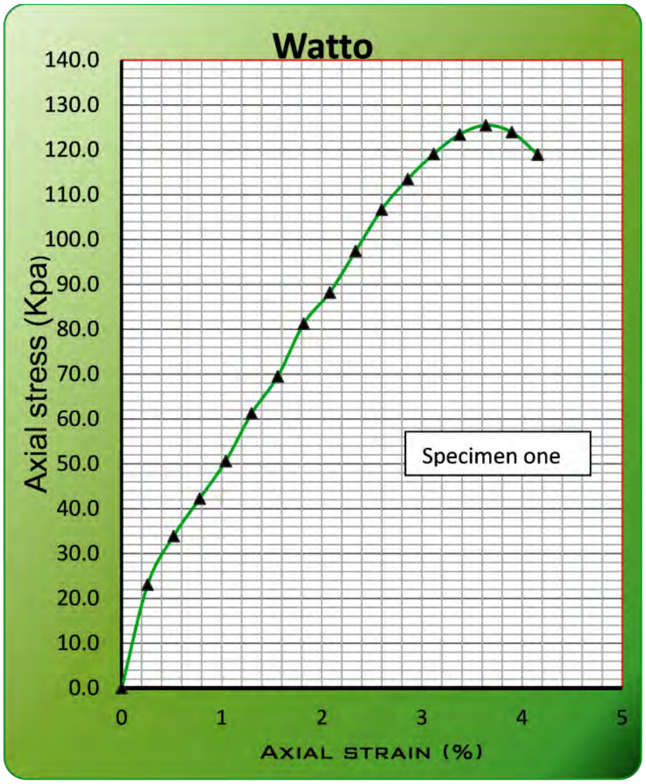

Amanual I
Axial stress (Kpa)
Axial strain (%)
Specimen 1

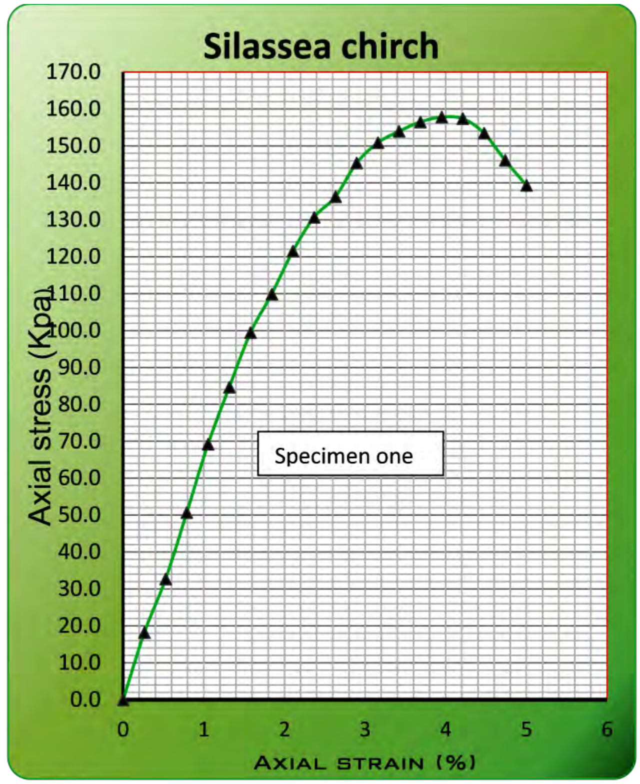

UCS mama II
Axial stress (Kpa)
Specimen two
Axial strain (%)

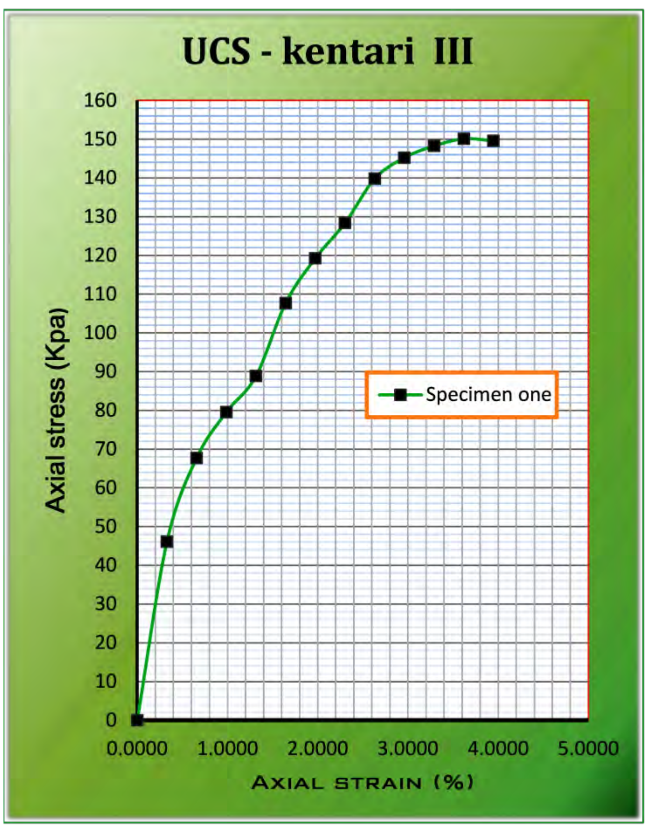

UCS Mama I
Axial stress (Kpa)
Specimen two
Axial strain (%)

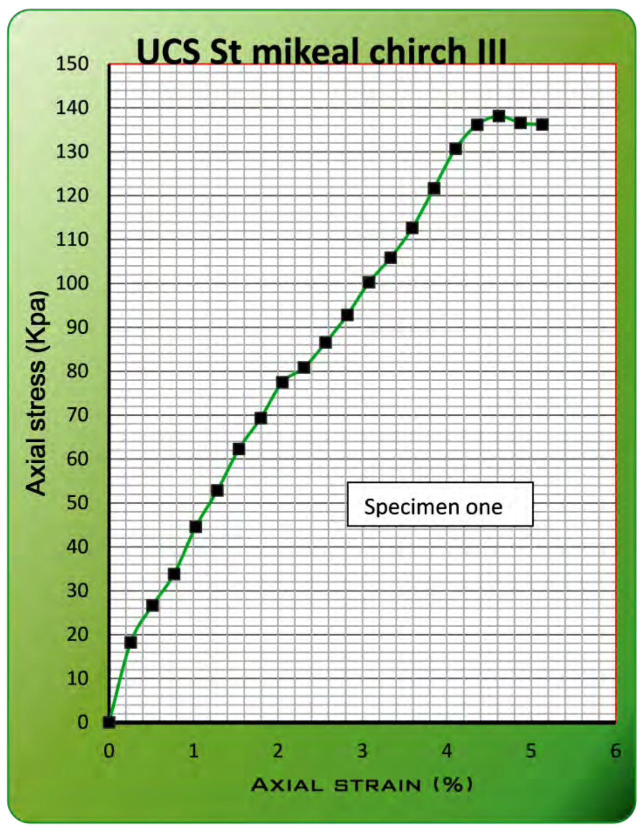

UCS - kentari I
Axial stress (Kpa)
Specimen two
Axial strain (%)

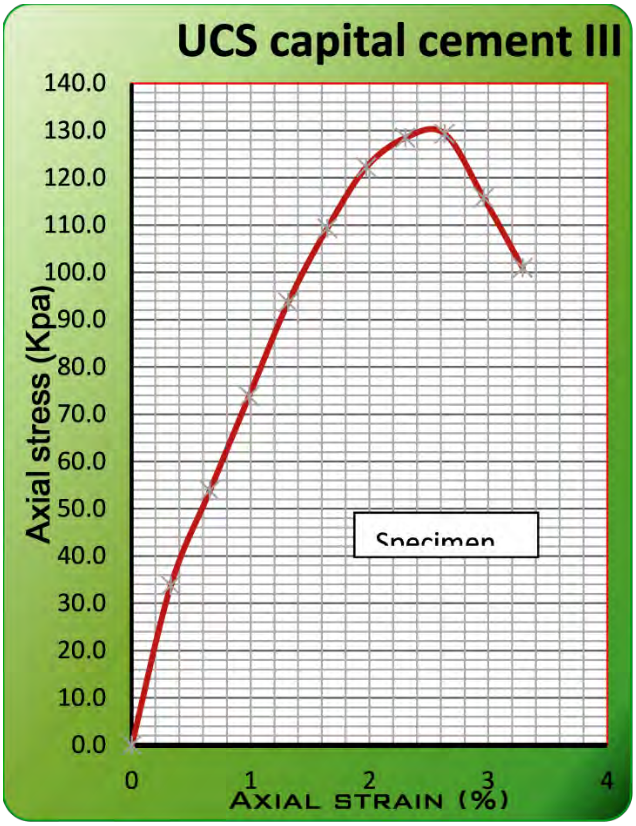

kentari II
Axial stress (Kpa)
Specimen two
Axial strain (%)

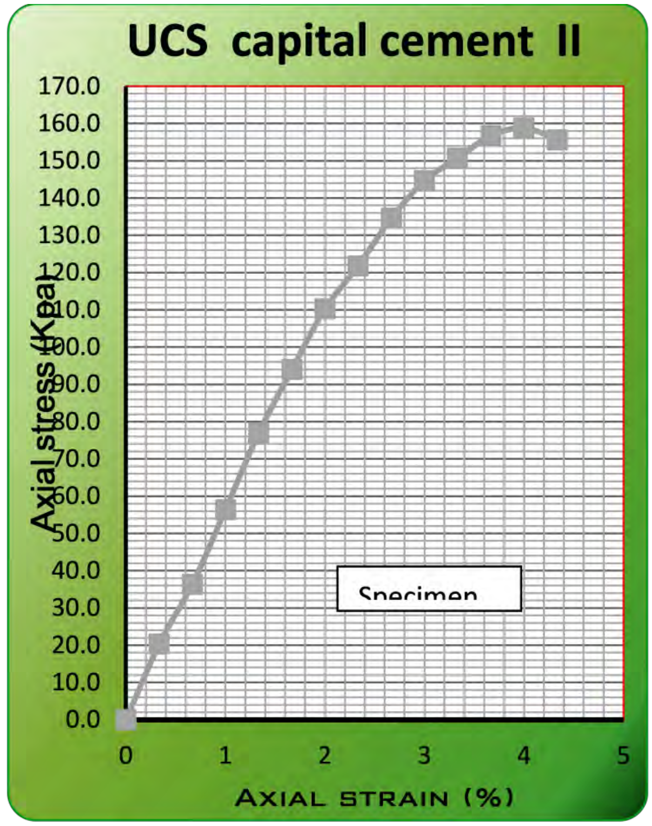

Watto
Axial stress (Kpa)
Axial strain (%)
Specimen one

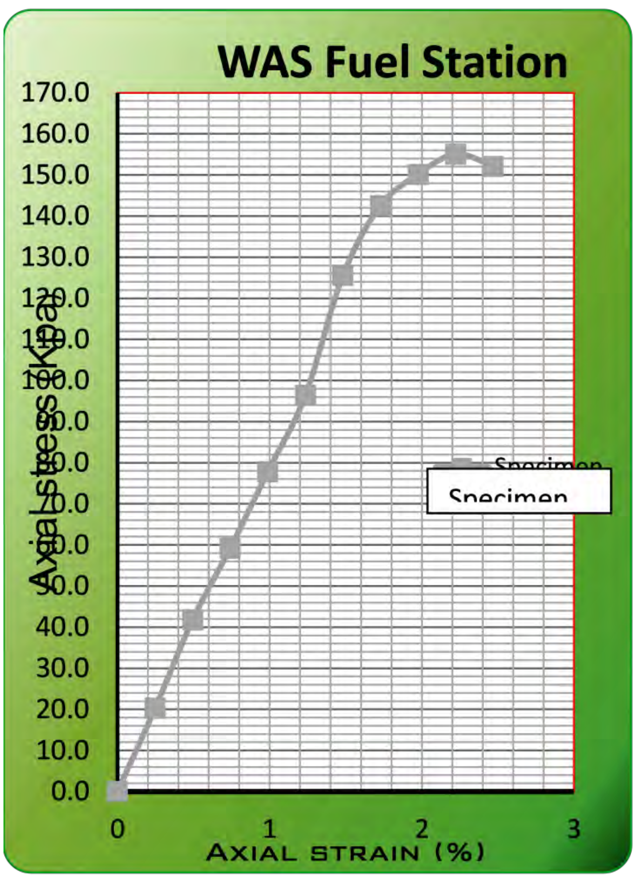

Silassea chirch
Axial stress (Kpa)
Axial strain (%)
Specimen one

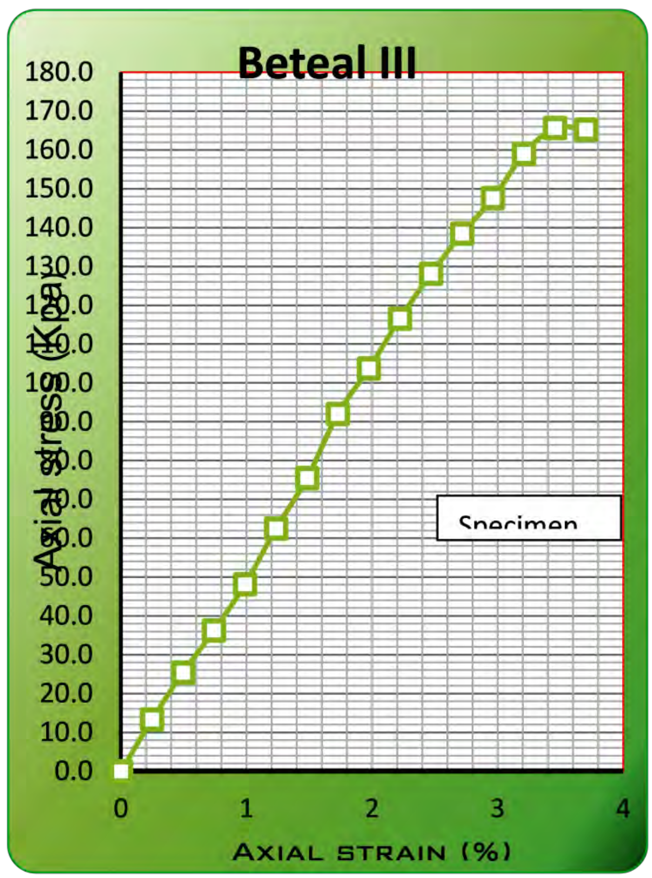

UCS - kentari III
Axial stress (Kpa)
Axial strain (%)
Specimen one

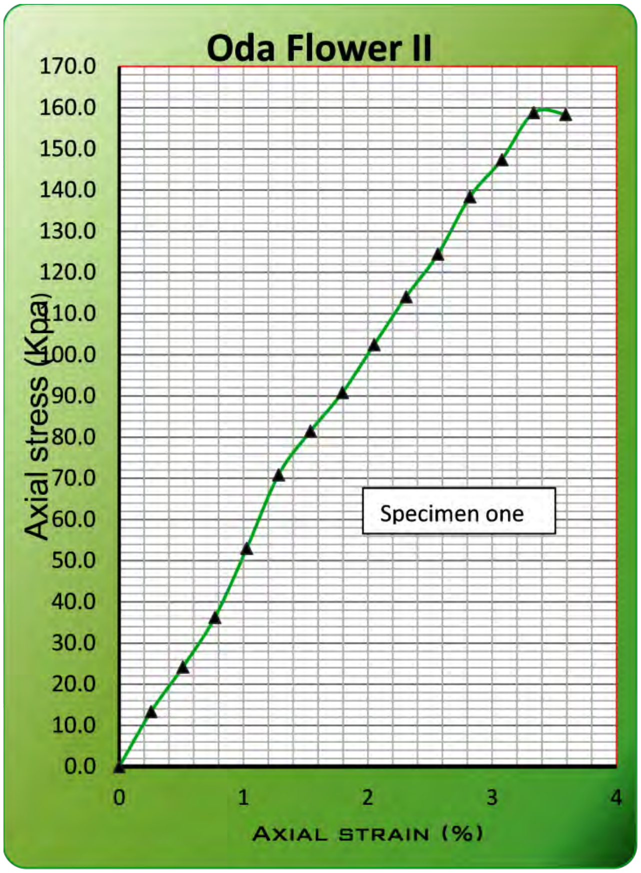

UCS St mikeal chirch III
Axial stress (Kpa)
Axial strain (%)
Specimen one


UCS capital cement III
Axial stress (Kpa)
AXIAL STRAIN (%)

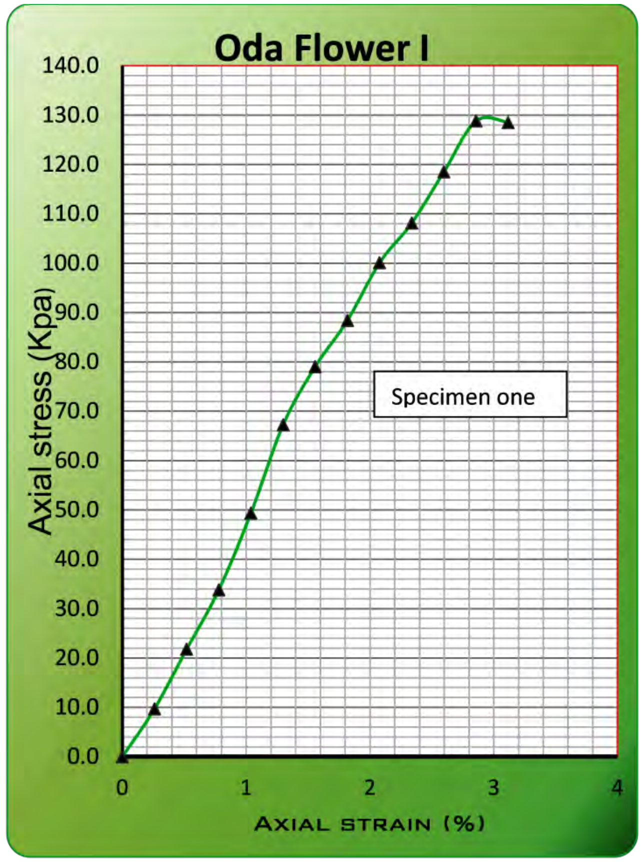

UCS capital cement II
Axial stress (Kpa)
AXIAL STRAIN (%)


WAS Fuel Station
Axial stress (Kpa)
AXIAL STRAIN (%)

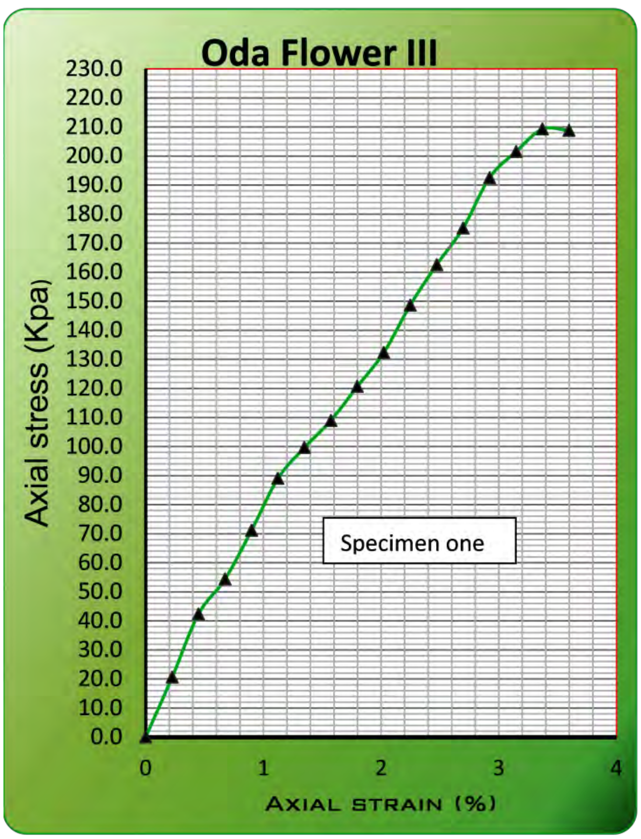

Beteal III
Axial stress (Kpa)
AXIAL STRAIN (%)



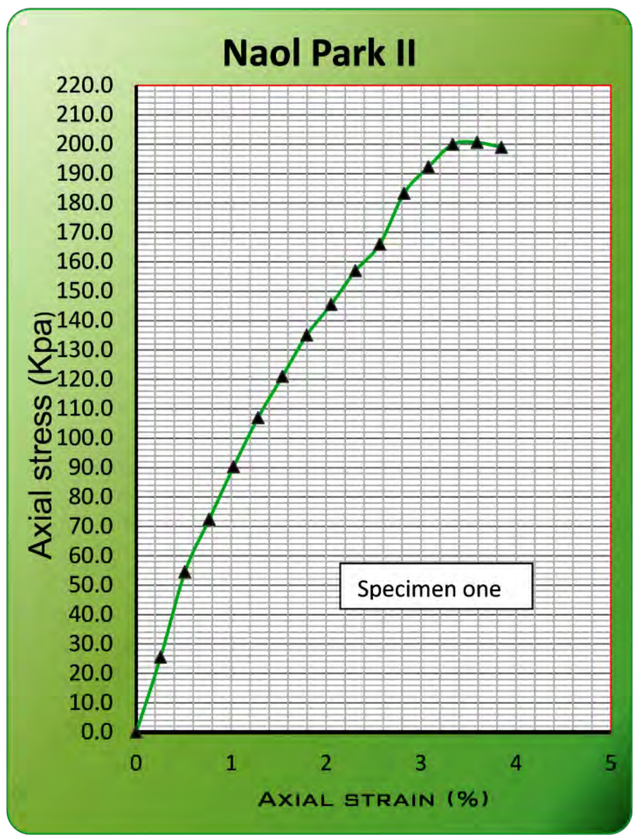
Oda Flower II
Axial stress (Kpa)
Axial strain (%)
Specimen one



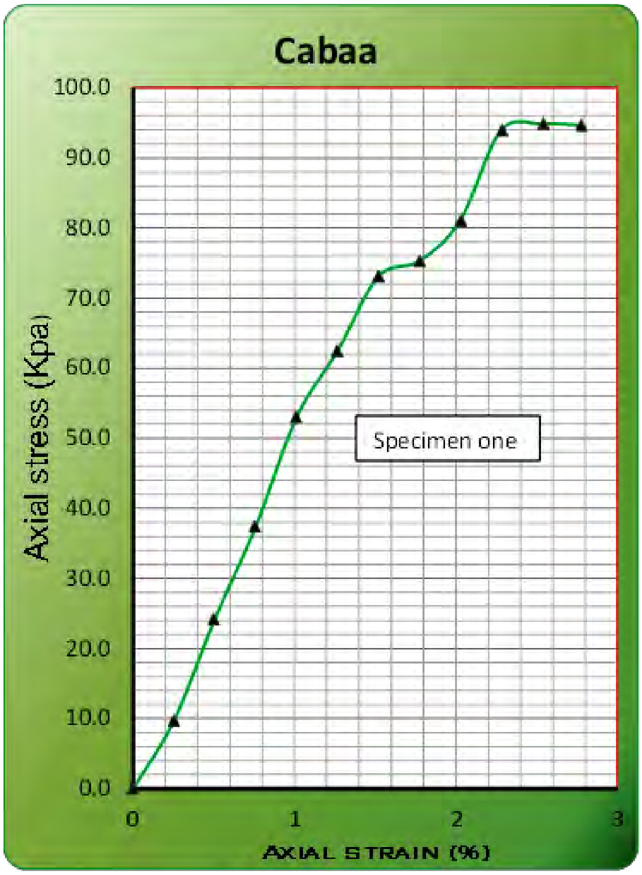
Oda Flower I
Axial stress (Kpa)
Axial strain (%)
Specimen one

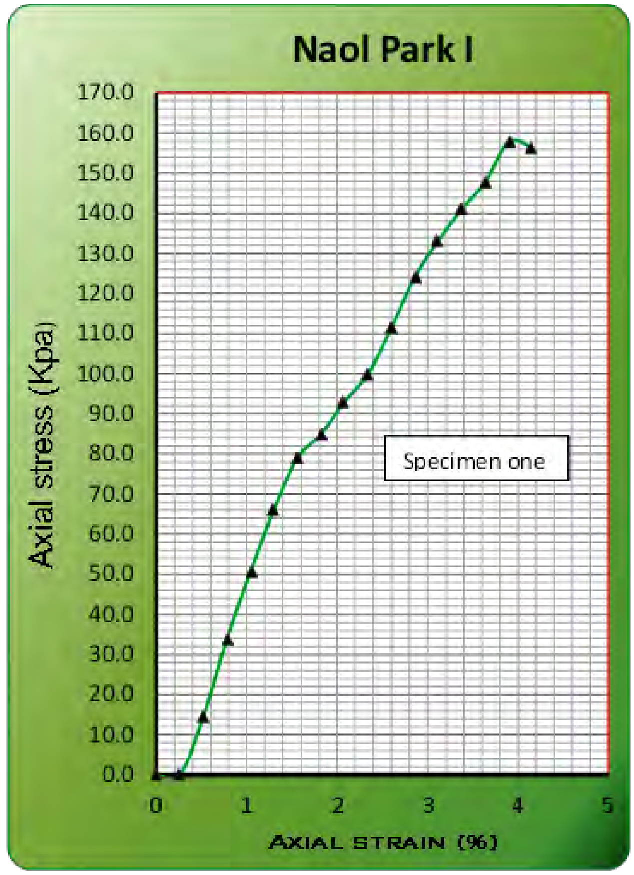


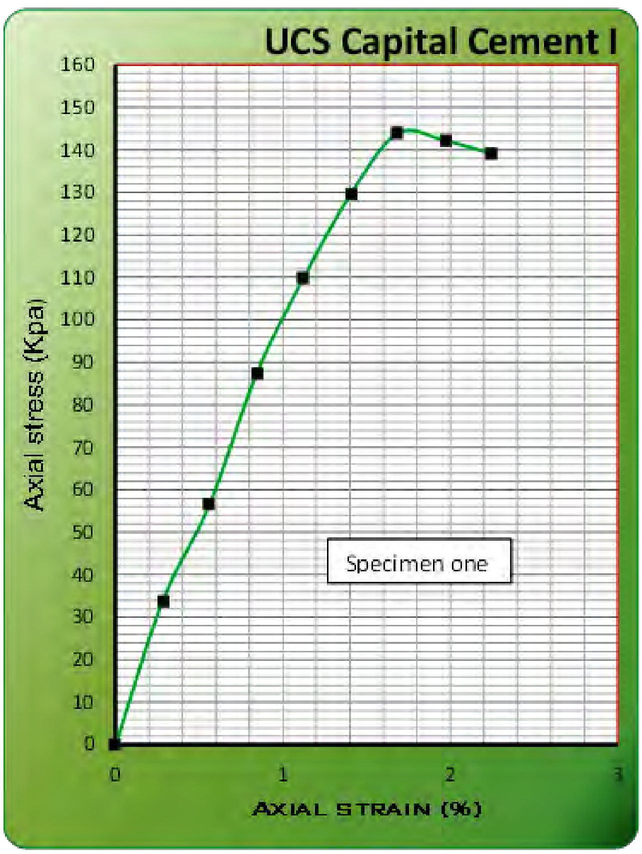
Oda Flower III
Axial stress (Kpa)
Axial strain (%)
Specimen one

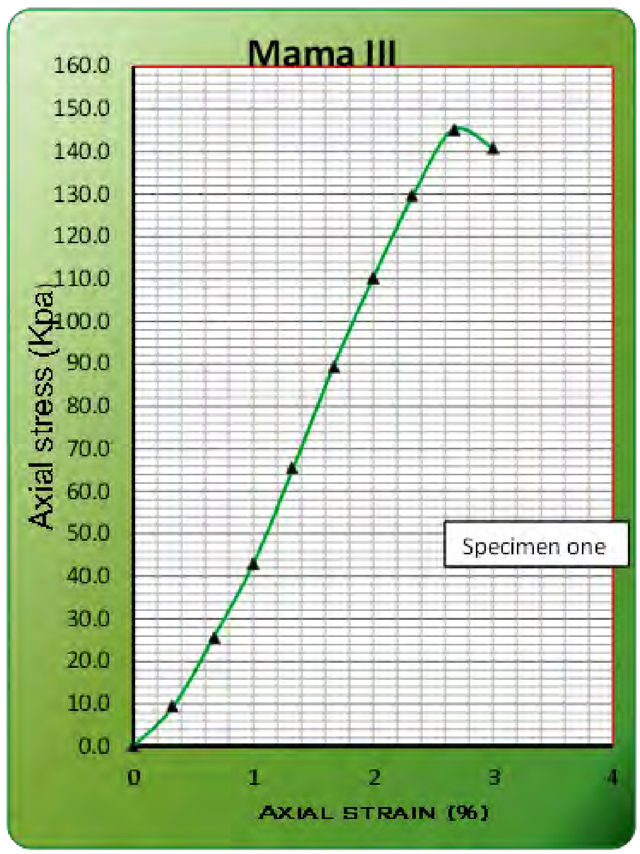


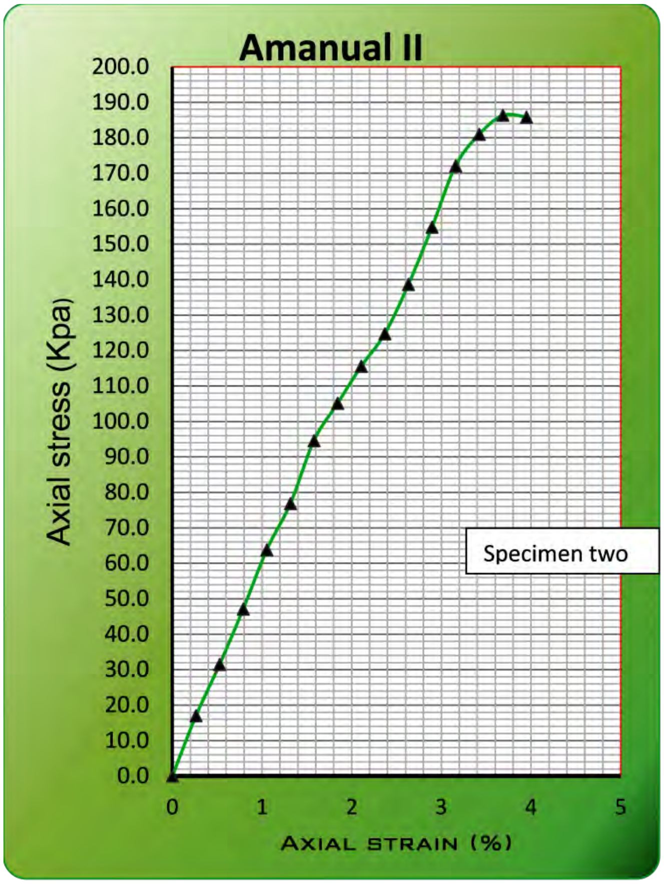
Naol Park II
Axial stress (Kpa)
Axial strain (%)
Specimen one

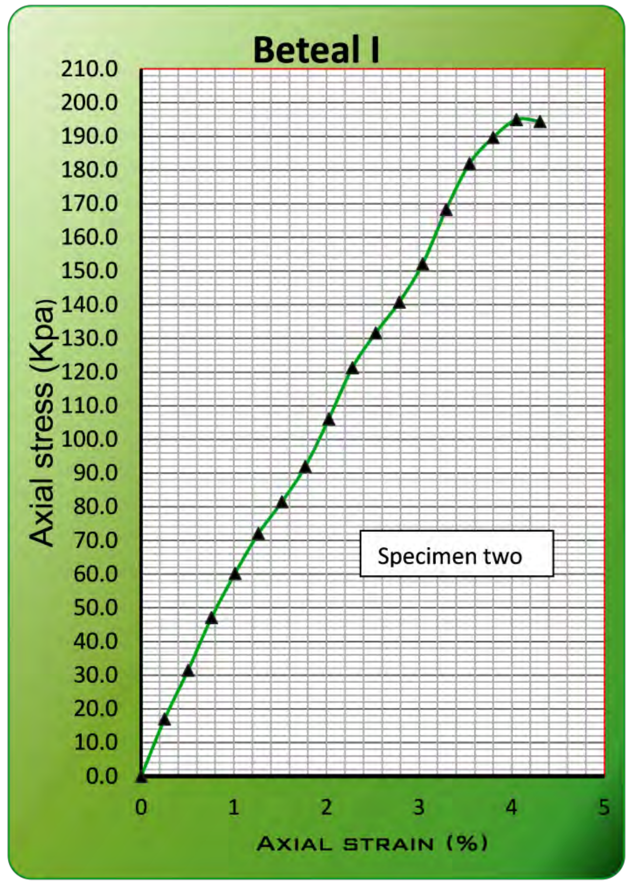

Cabaa
Axial stress (Kpa)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
1
2
3
AXIAL STRAIN (%)
Specimen one

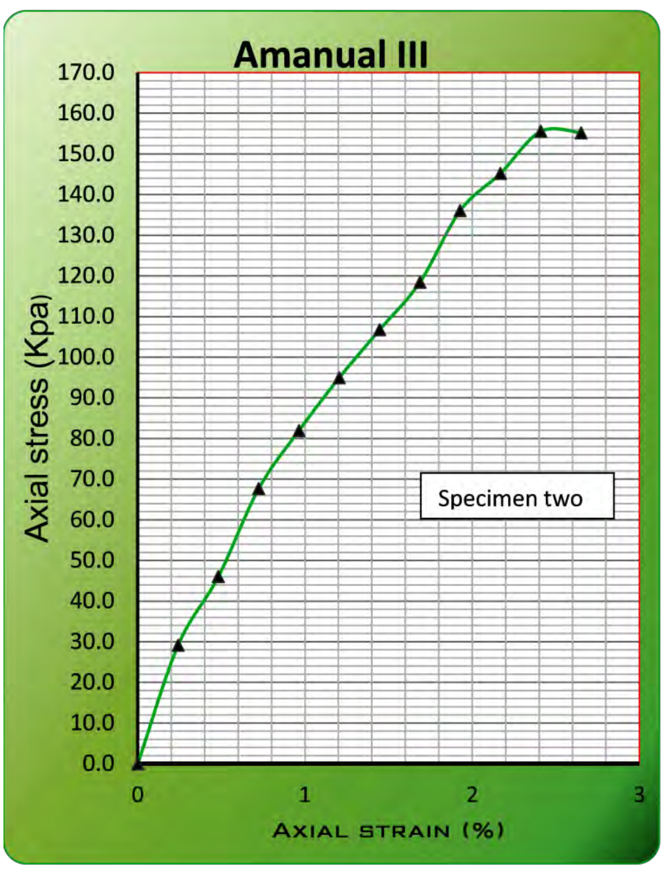

Naol Park I
Axial stress (Kpa)
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
1
2
3
4
5
AXIAL STRAIN (%)
Specimen one

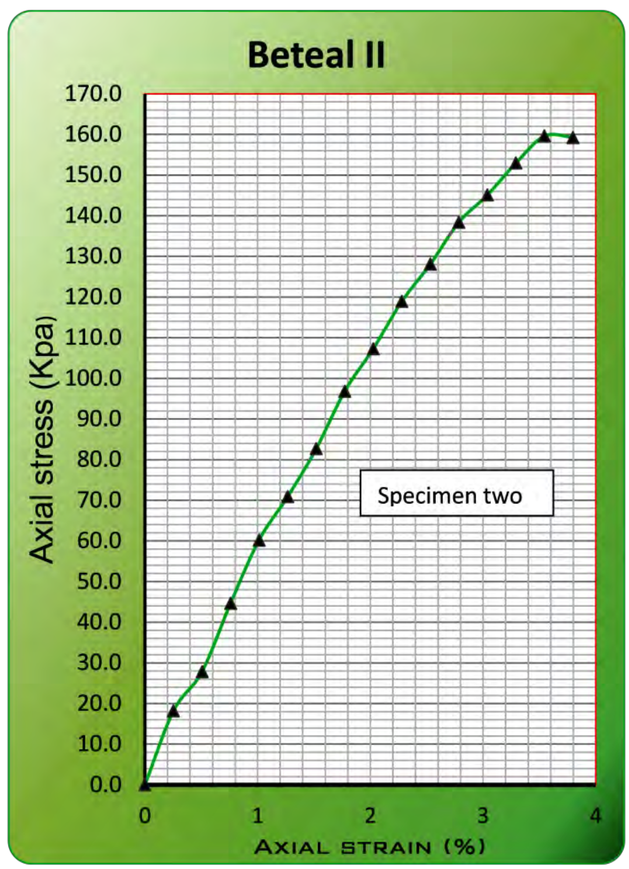

UCS Capital Cement I
Axial stress (Kpa)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
AXIAL STRAIN (%)
Specimen one

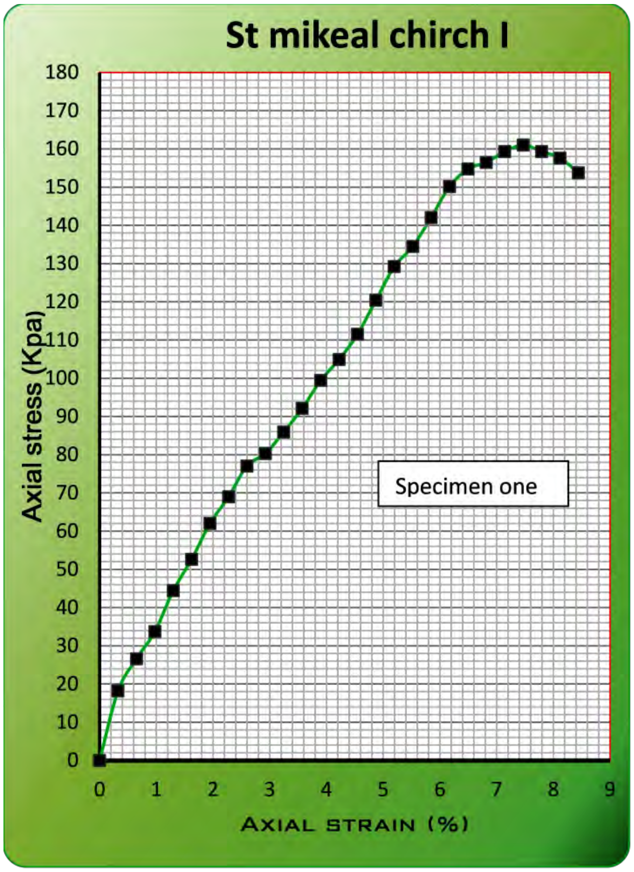

Mama III
Axial stress (Kpa)
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
1
2
3
4
AXIAL STRAIN (%)
Specimen one

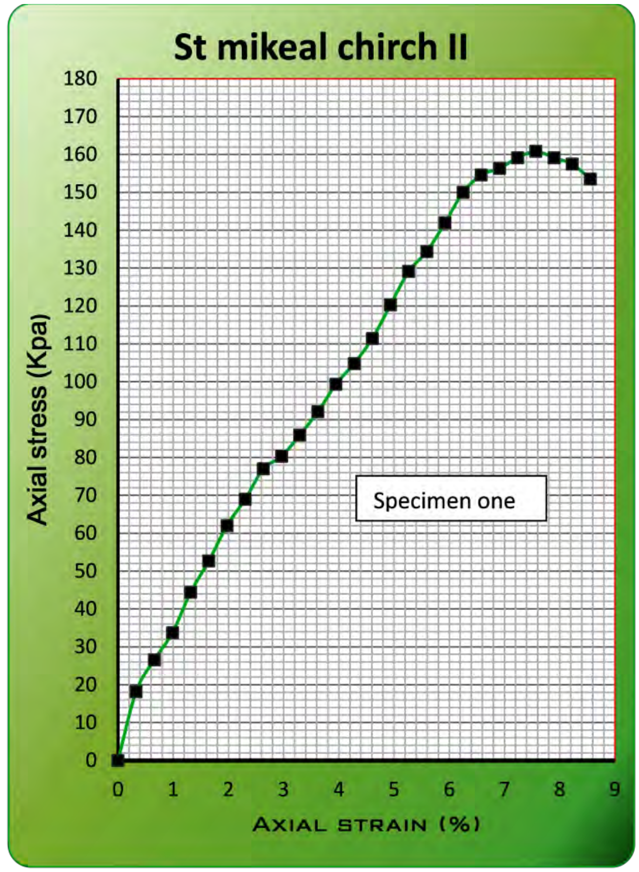

Amanual II
Axial stress (Kpa)
Axial strain (%)
Specimen two

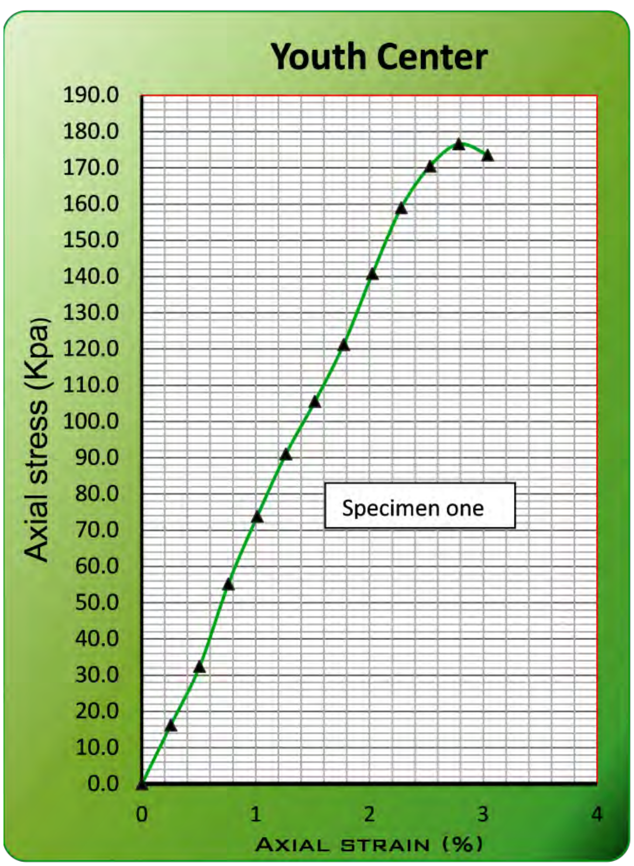

Beteal I
Axial stress (Kpa)
Axial strain (%)
Specimen two

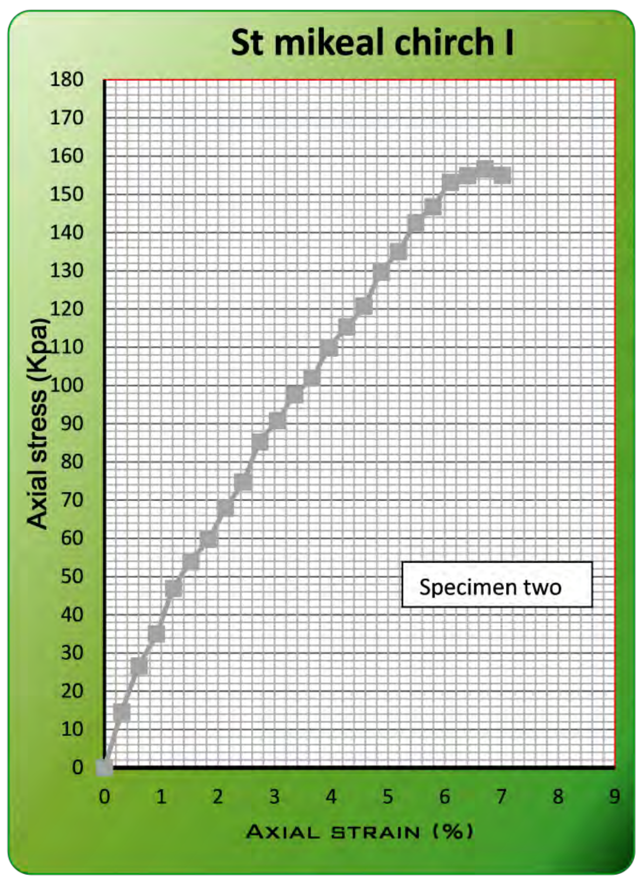

Amanual III
Axial stress (Kpa)
Axial strain (%)
Specimen two

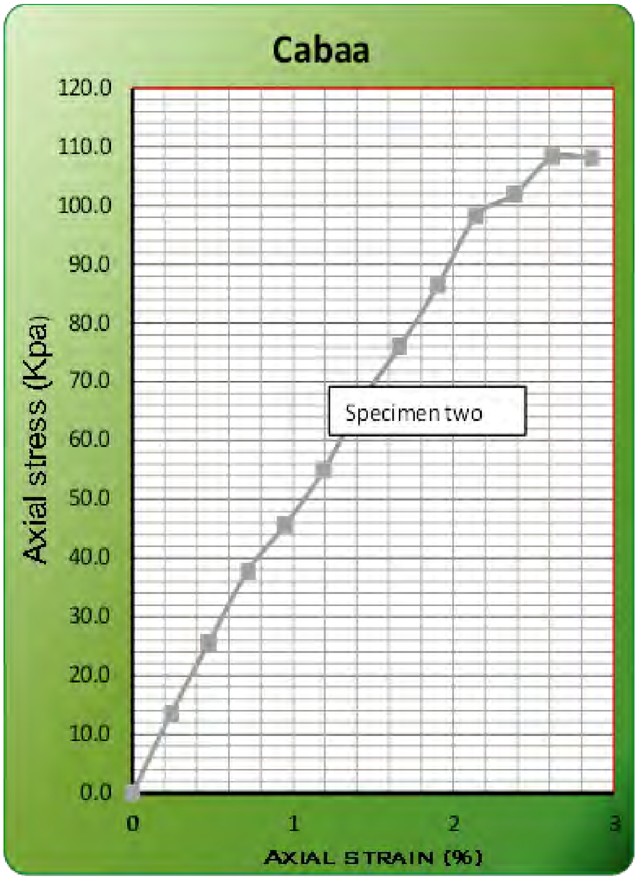

Beteal II
Axial stress (Kpa)
Axial strain (%)
Specimen two

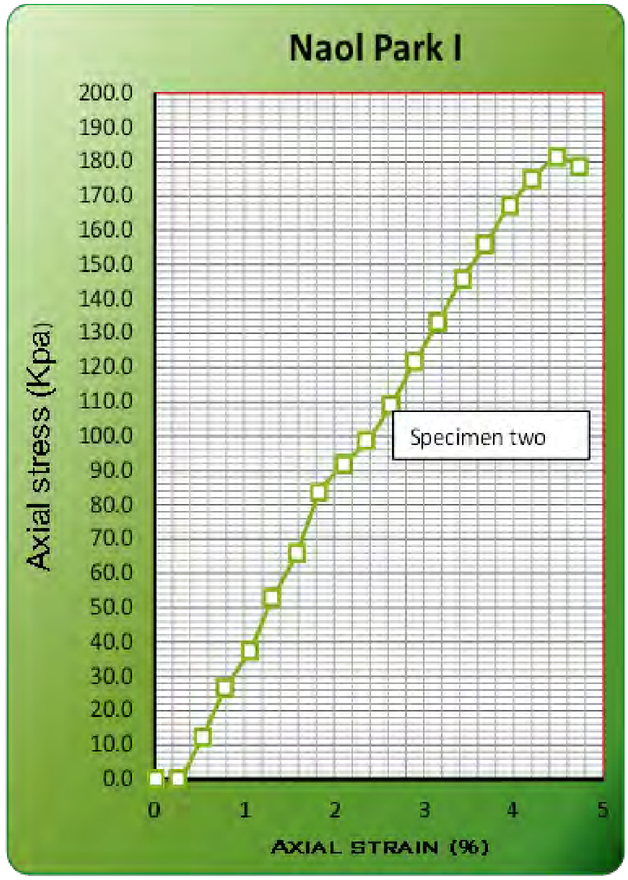

St mikeal chirch I
Axial stress (Kpa)
Axial strain (%)
Specimen one
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9

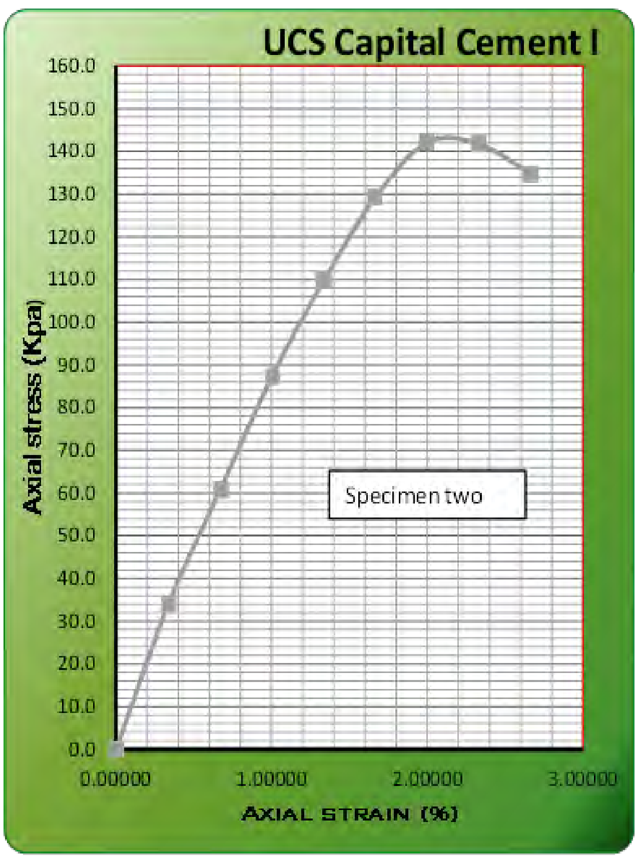

St mikeal chirch II
Axial stress (Kpa)
Axial strain (%)
Specimen one
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9

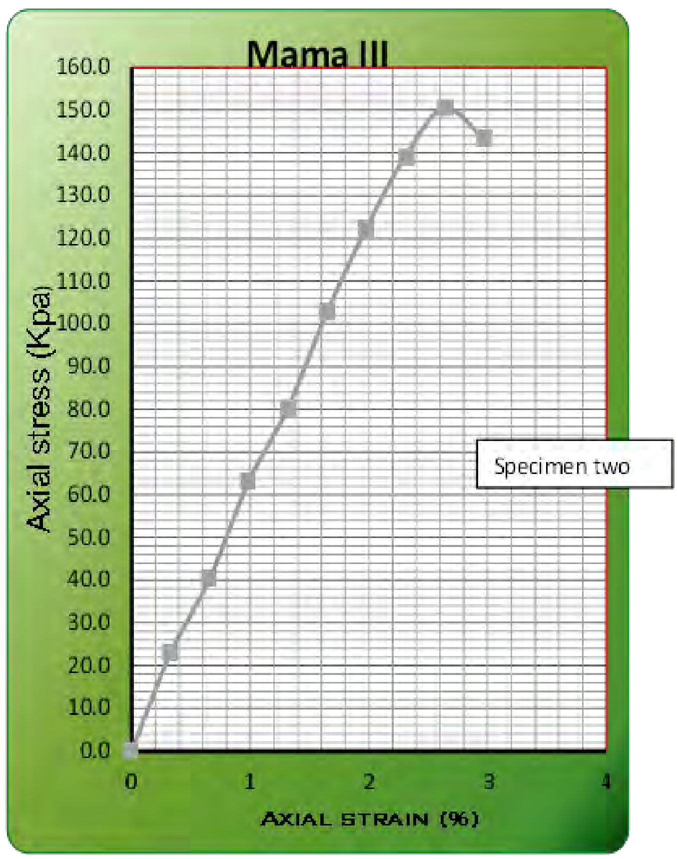

Youth Center
Axial stress (Kpa)
Axial strain (%)
Specimen one
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
1
2
3
4

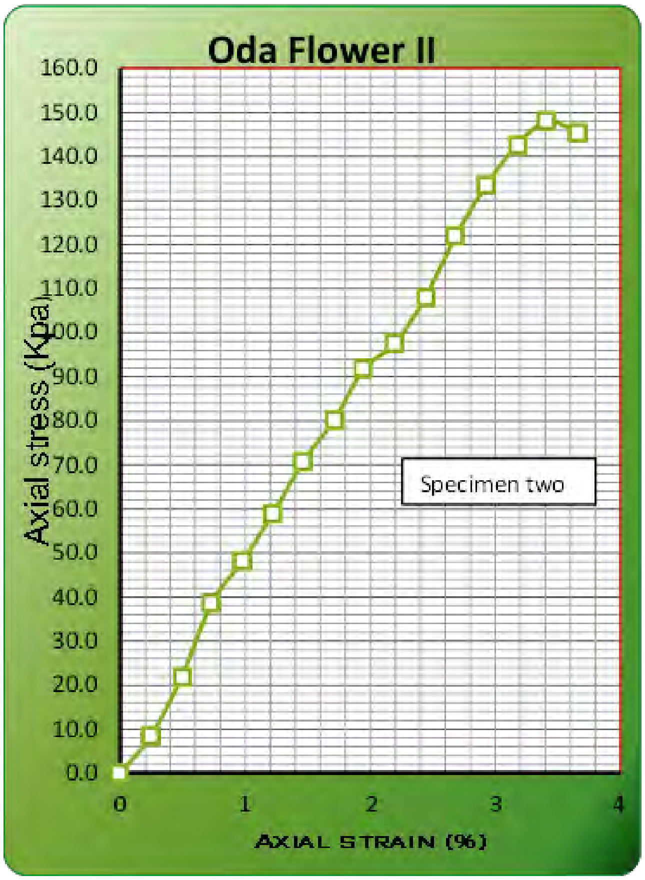

St mikeal chirch I
Axial stress (Kpa)
Axial strain (%)
Specimen two
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9


Cabaa
Axial stress (Kpa)
Specimen two
AXIAL STRAIN (%)

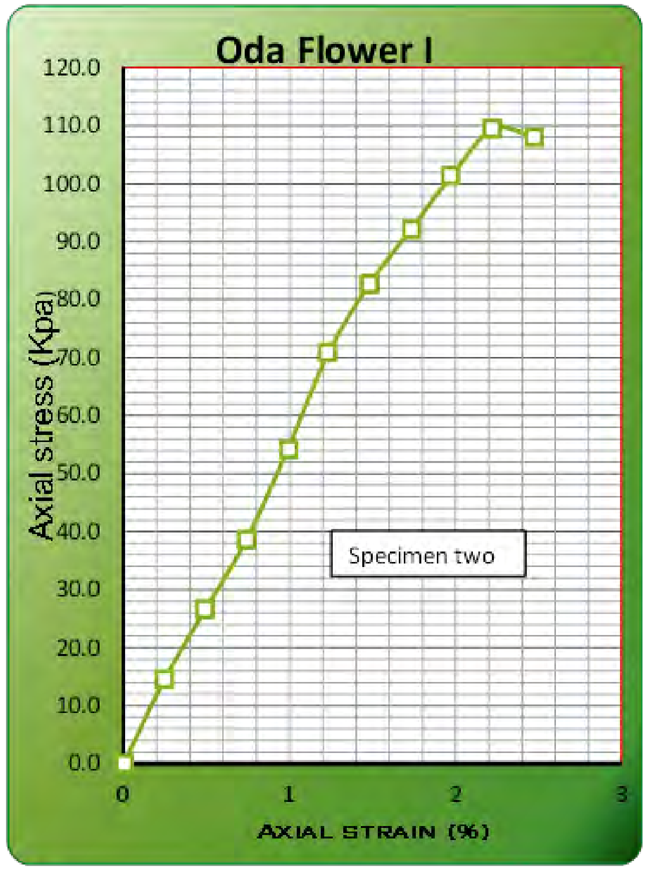

Naol Park I
Axial stress (Kpa)
Specimen two
AXIAL STRAIN (%)


UCS Capital Cement I
Axial stress (Kpa)
Specimen two
AXIAL STRAIN (%)

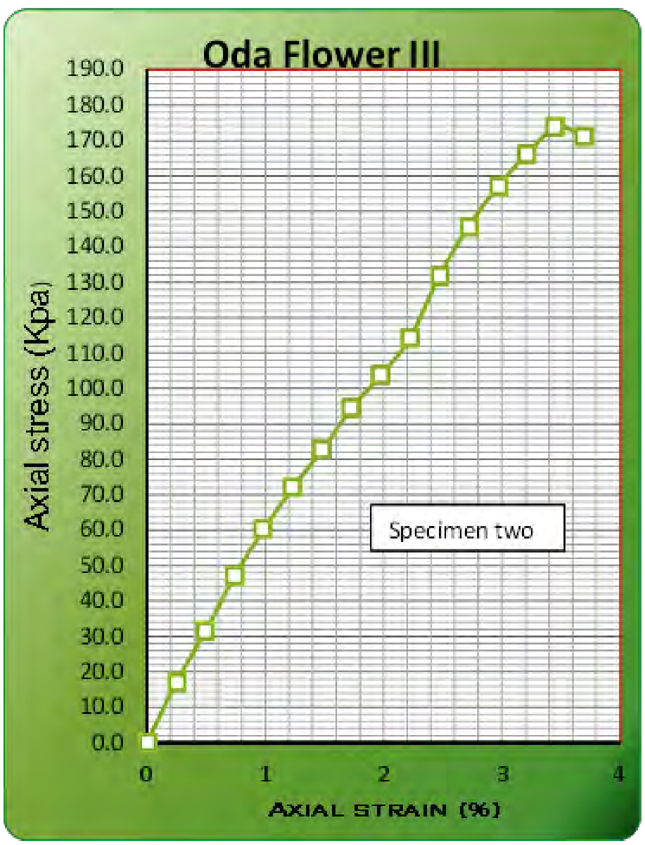

Mama III
Axial stress (Kpa)
Specimen two
AXIAL STRAIN (%)



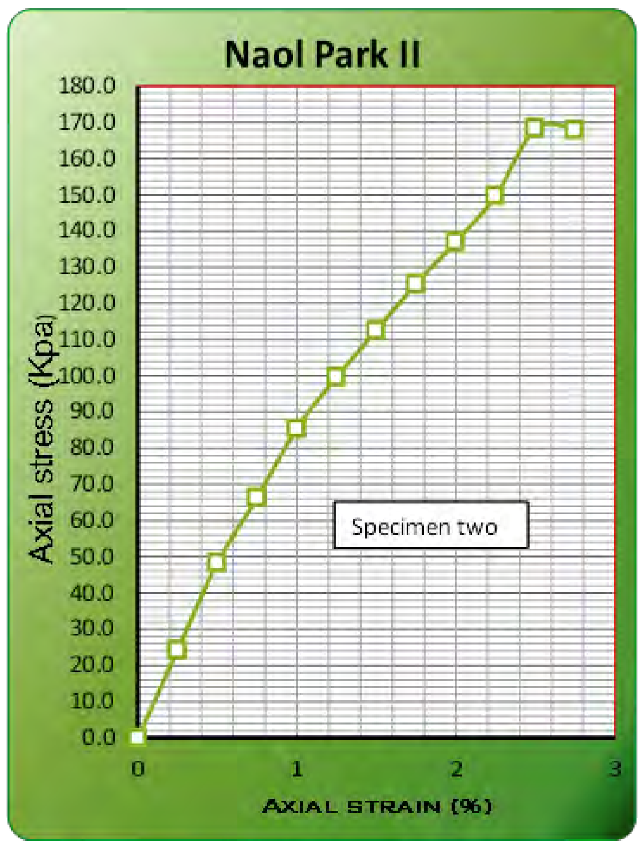
Oda Flower II
Axial stress (Kpa)
Axial strain (%)
Specimen two



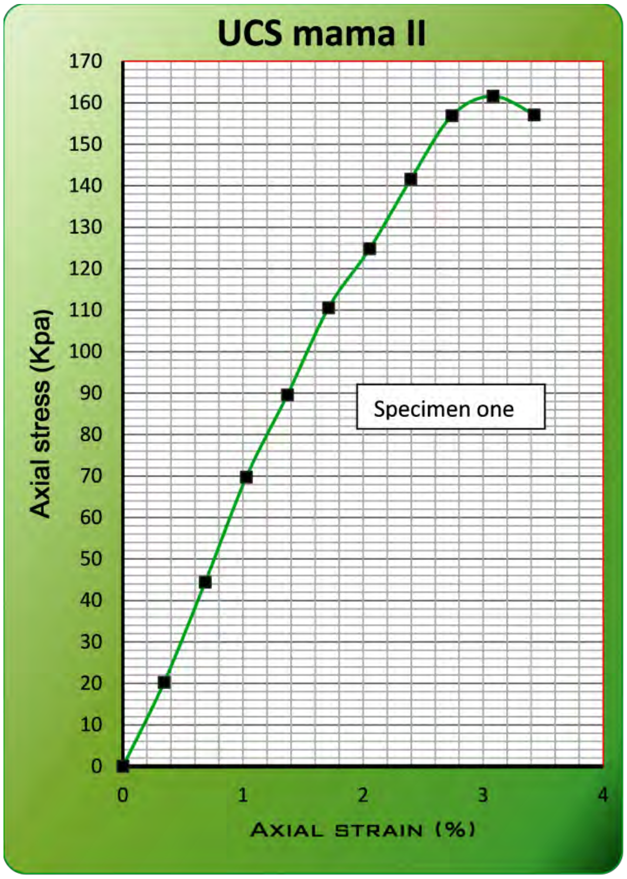
Oda Flower I
Axial stress (Kpa)
Axial strain (%)
Specimen two

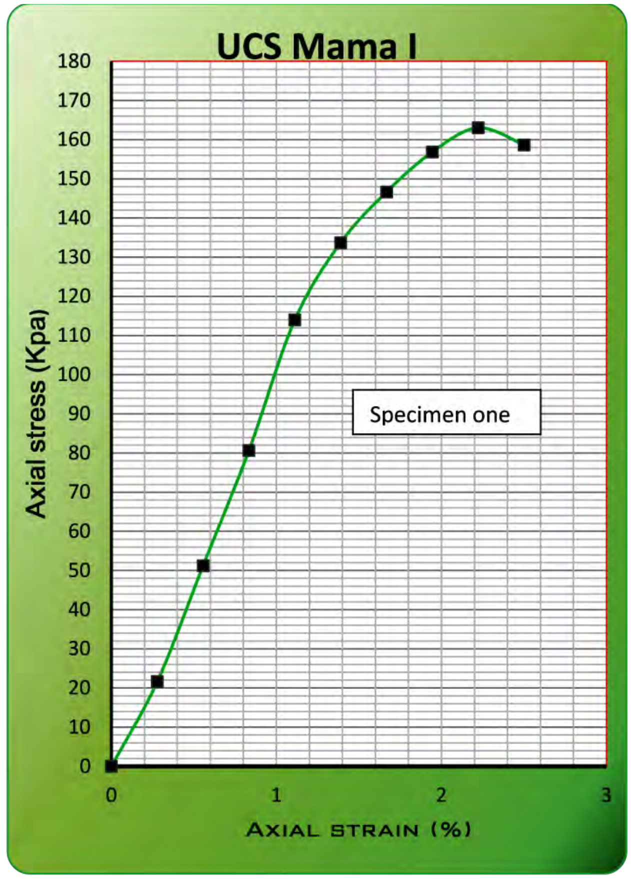


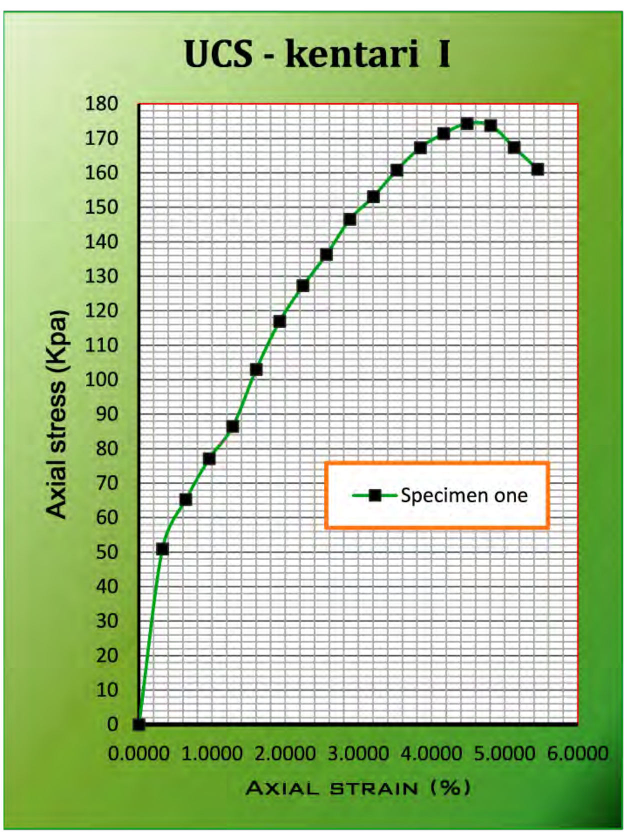
Oda Flower III
Axial stress (Kpa)
Axial strain (%)
Specimen two

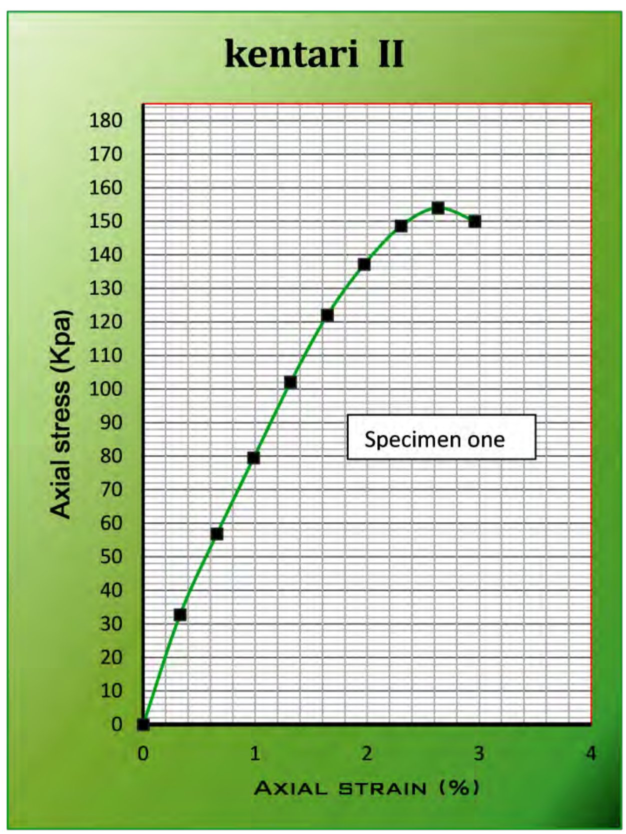


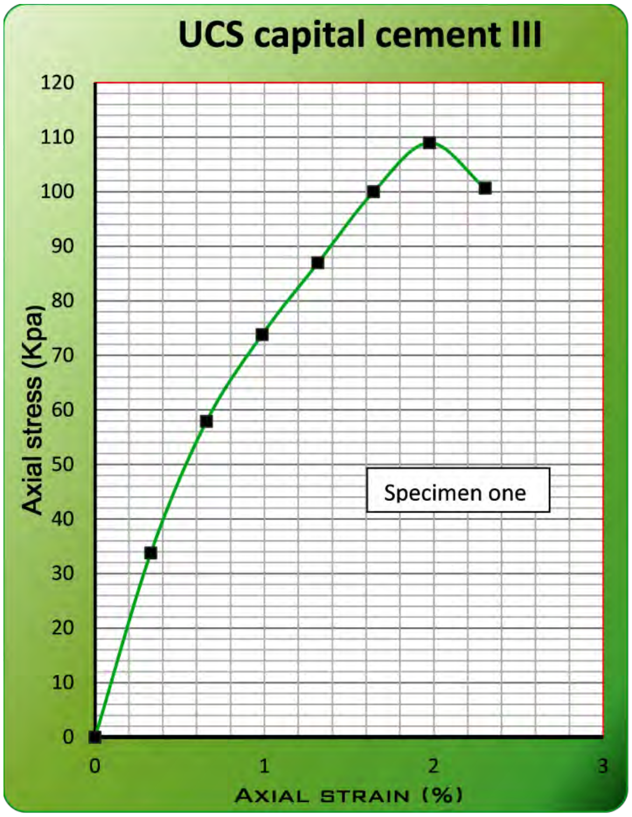
Naol Park II
Axial stress (Kpa)
Axial strain (%)
Specimen two

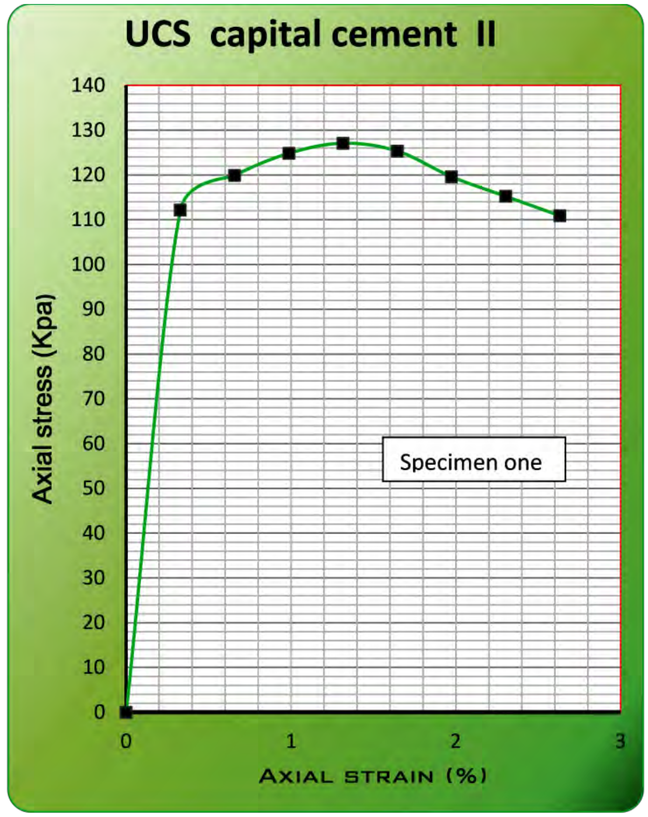

UCS mama II
Axial stress (Kpa)
Specimen one
Axial strain (%)

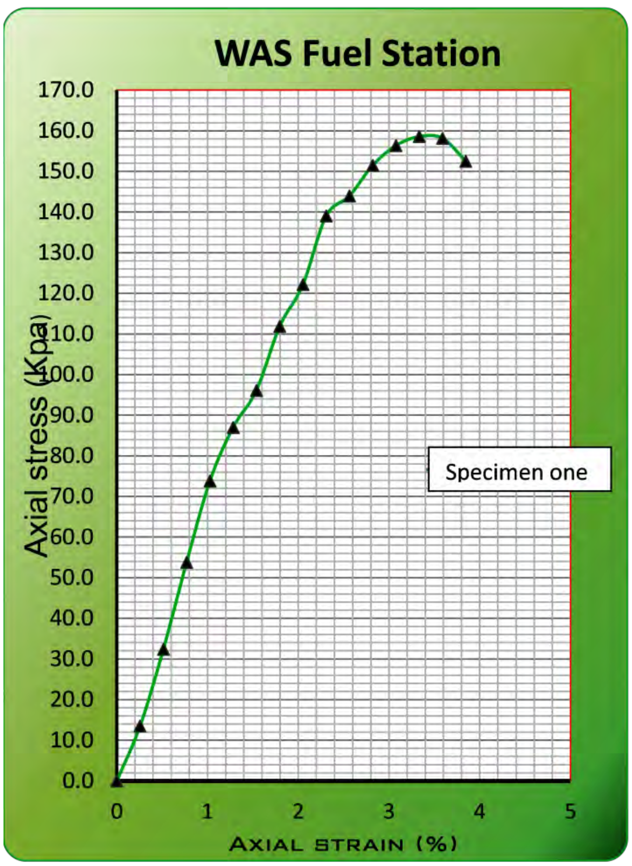

UCS Mama I
Axial stress (Kpa)
Specimen one
Axial strain (%)

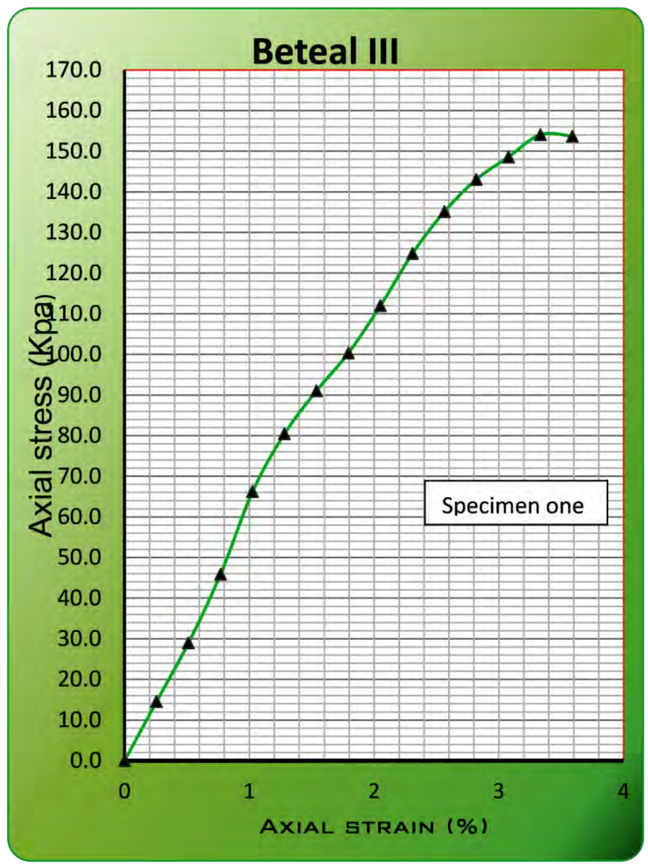

UCS - kentari I
Axial stress (Kpa)
Specimen one
Axial strain (%)

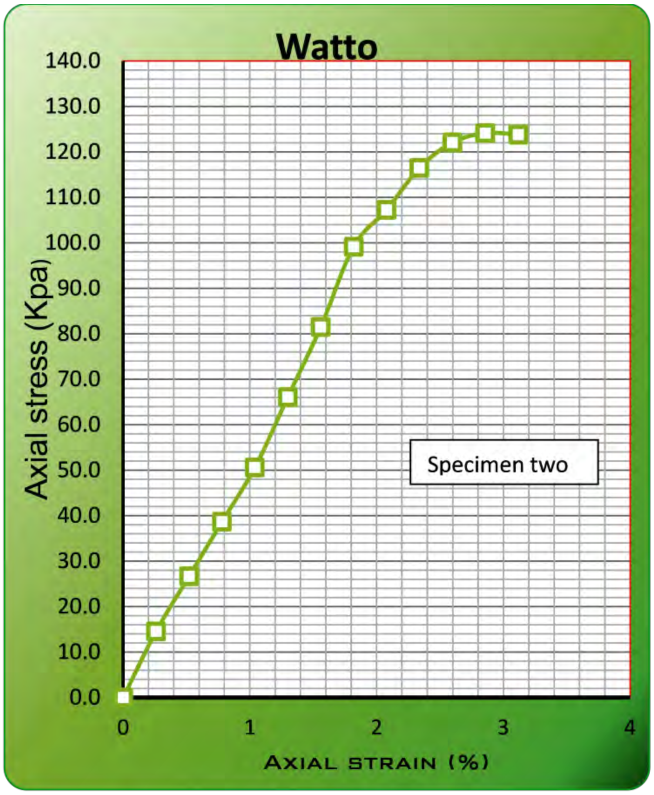

kentari II
Axial stress (Kpa)
Specimen one
Axial strain (%)

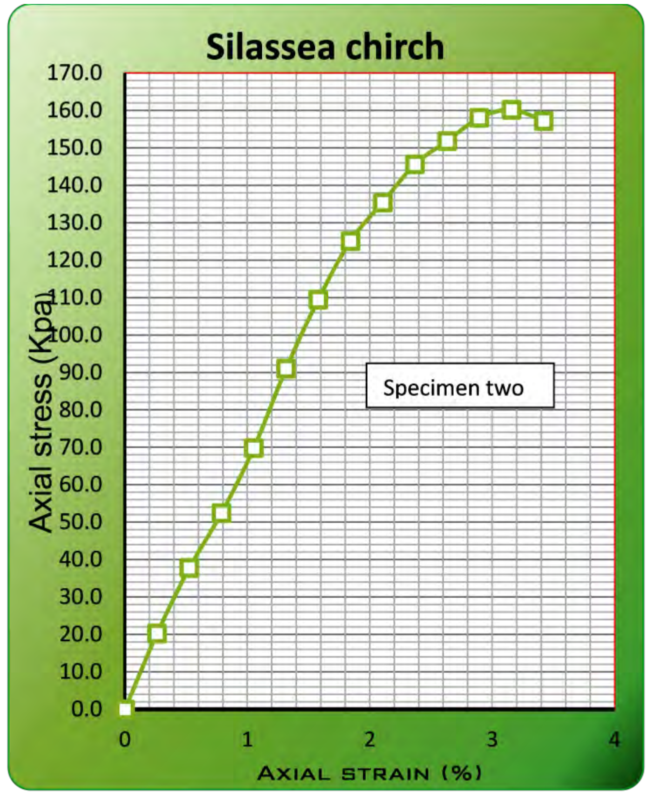

UCS capital cement III
Axial stress (Kpa)
Axial strain (%)
Specimen one

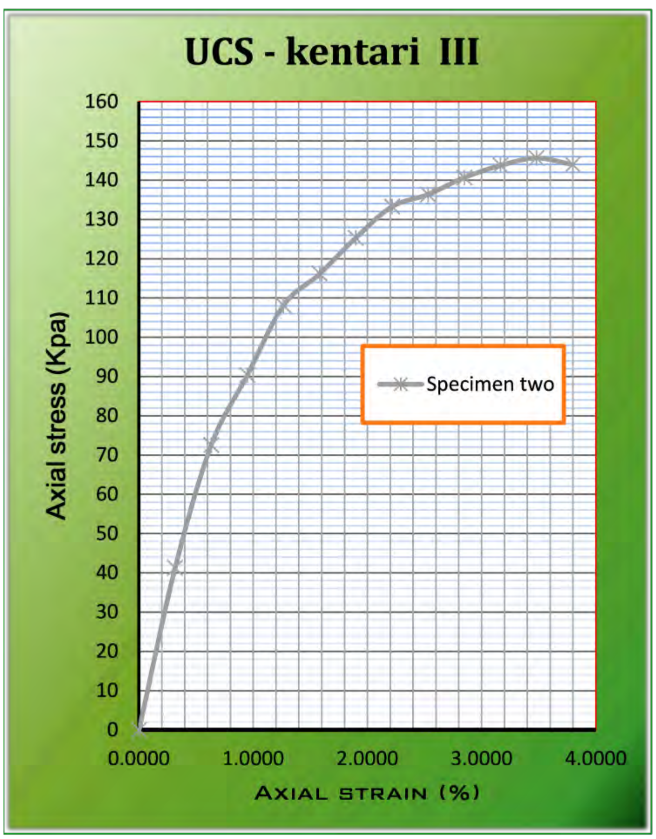

UCS capital cement II
Axial stress (Kpa)
Axial strain (%)
Specimen one

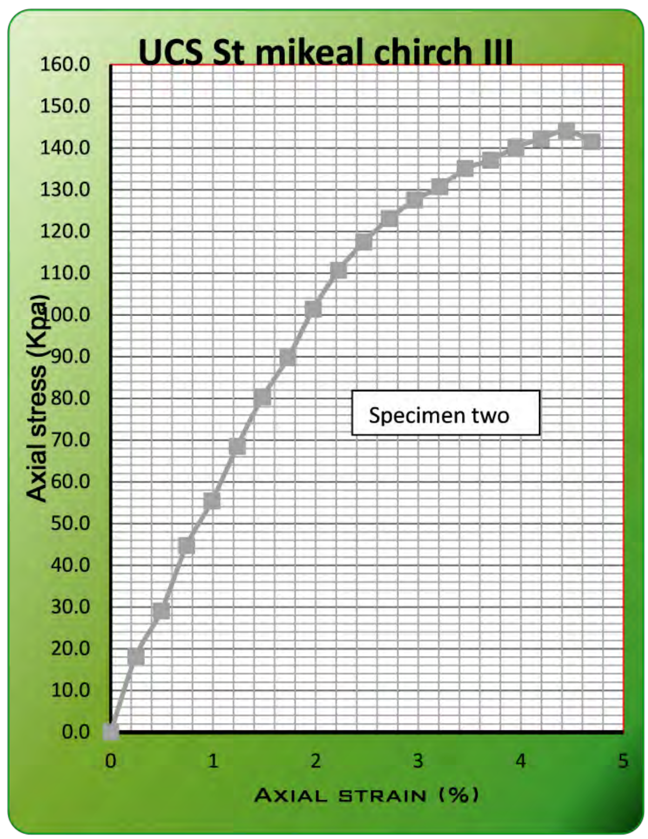

WAS Fuel Station
Axial stress (Kpa)
Axial strain (%)
Specimen one

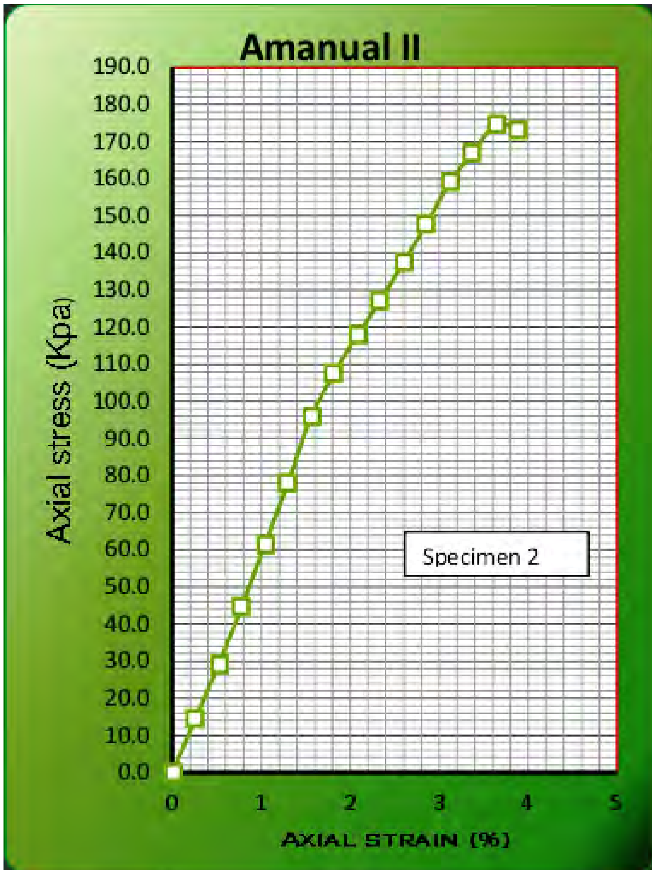

Beteal III
Axial stress (Kpa)
Axial strain (%)
Specimen one

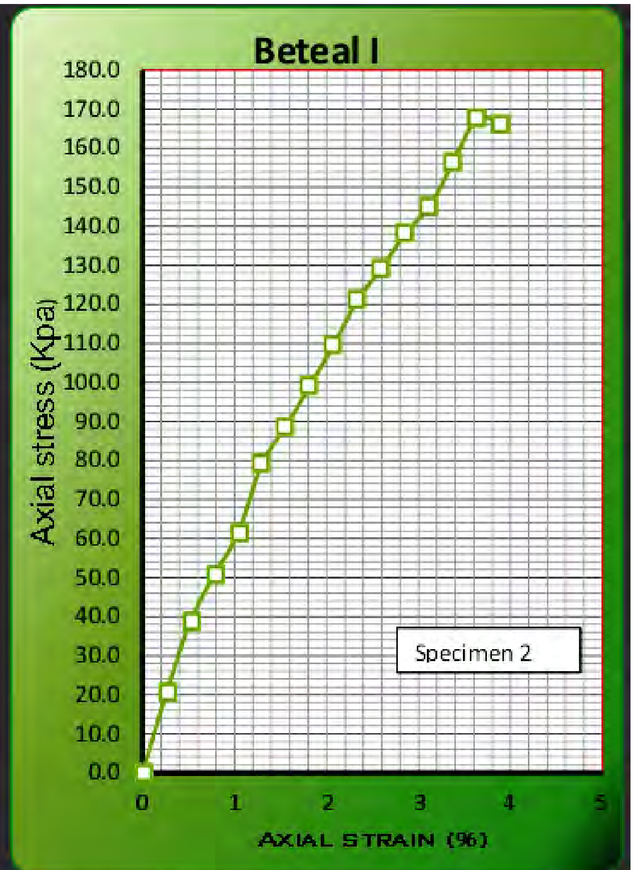

Watto
Axial stress (Kpa)
Axial strain (%)
Specimen two

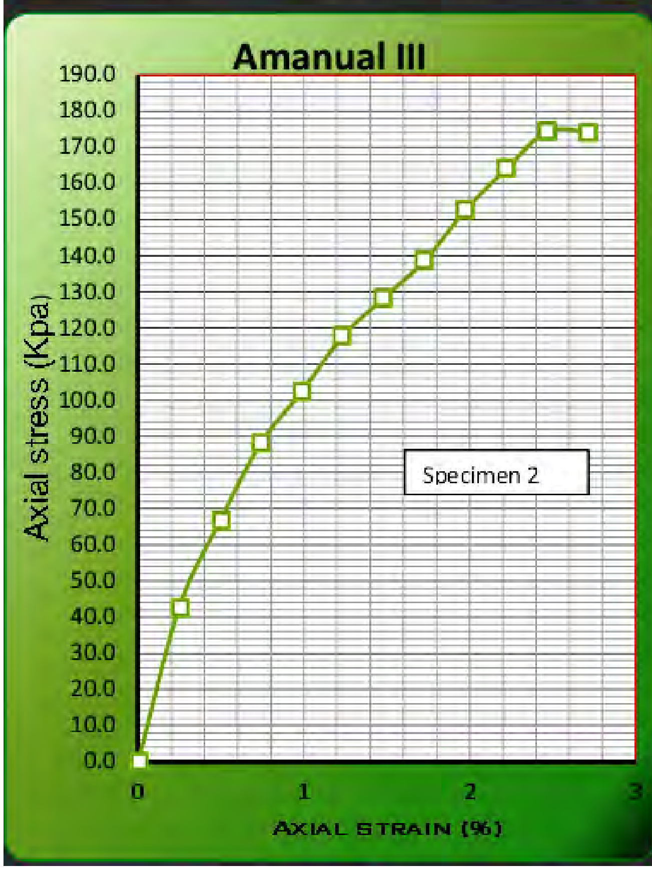

Silassea chirch
Axial stress (Kpa)
Axial strain (%)
Specimen two

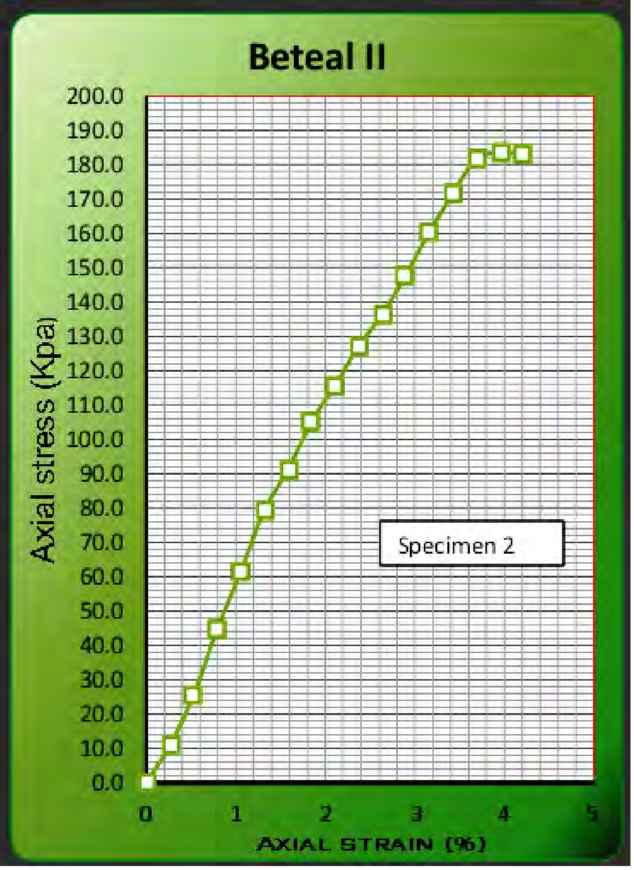

UCS - kentari III
Axial stress (Kpa)
Axial strain (%)
Specimen two


UCS St mikeal chirch III
Axial stress (Kpa)
Axial strain (%)
Specimen two


Amanual II
Axial stress (Kpa)
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 1 2 3 4 5
AXIAL STRAIN (%)
Specimen 2


Beteal I
Axial stress (Kpa)
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 1 2 3 4 5
AXIAL STRAIN (%)
Specimen 2


Amanual III
Axial stress (Kpa)
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 1 2 3
AXIAL STRAIN (%)
Specimen 2


Beteal II
Axial stress (Kpa)
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0 1 2 3 4 5
AXIAL STRAIN (%)
Specimen 2

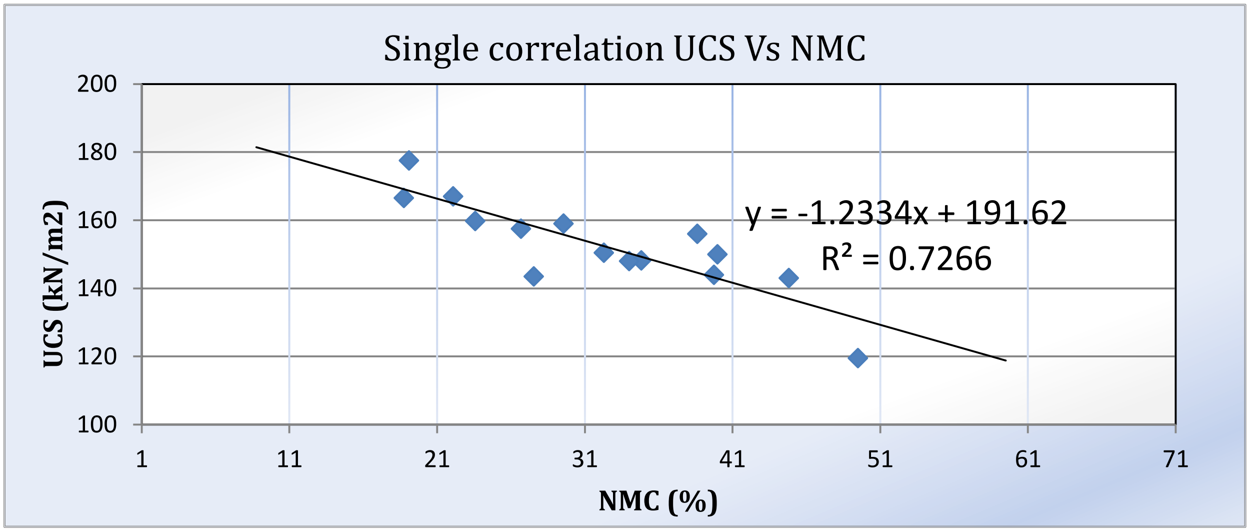
APPENDIX – C

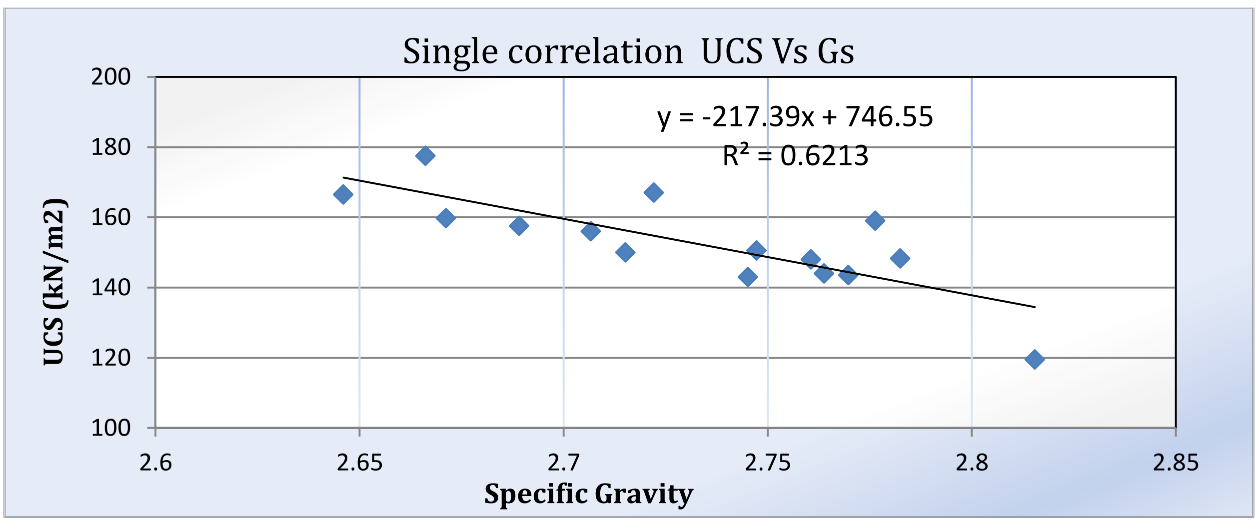
CORRELATIONS ANALYSIS RESULT

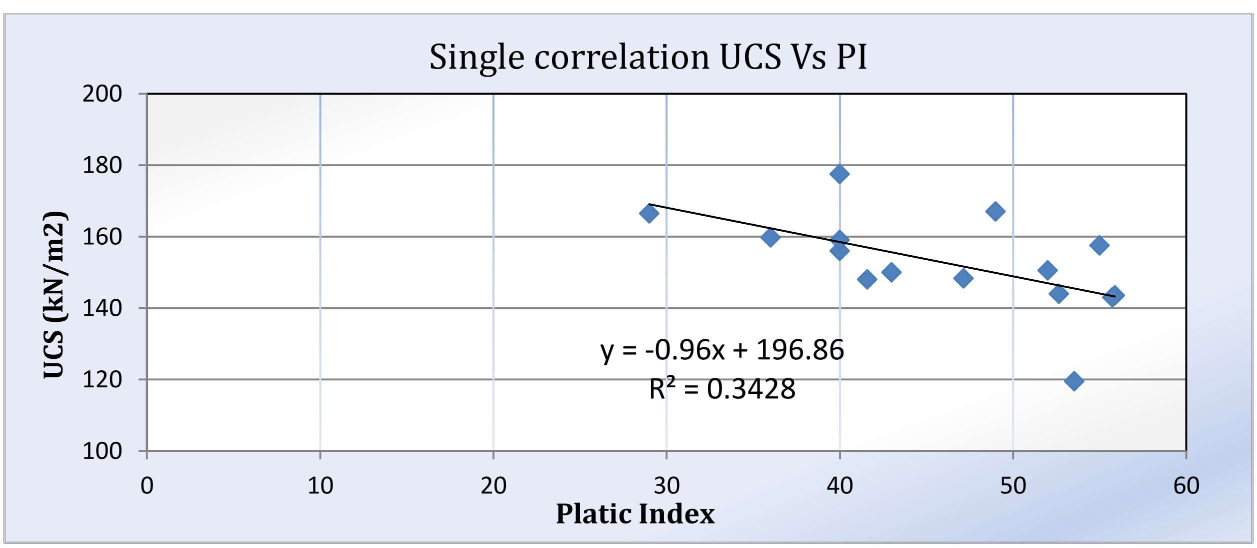
APPENDIX – C1

SINGLE CORRELATIONS ANALYSIS RESULT

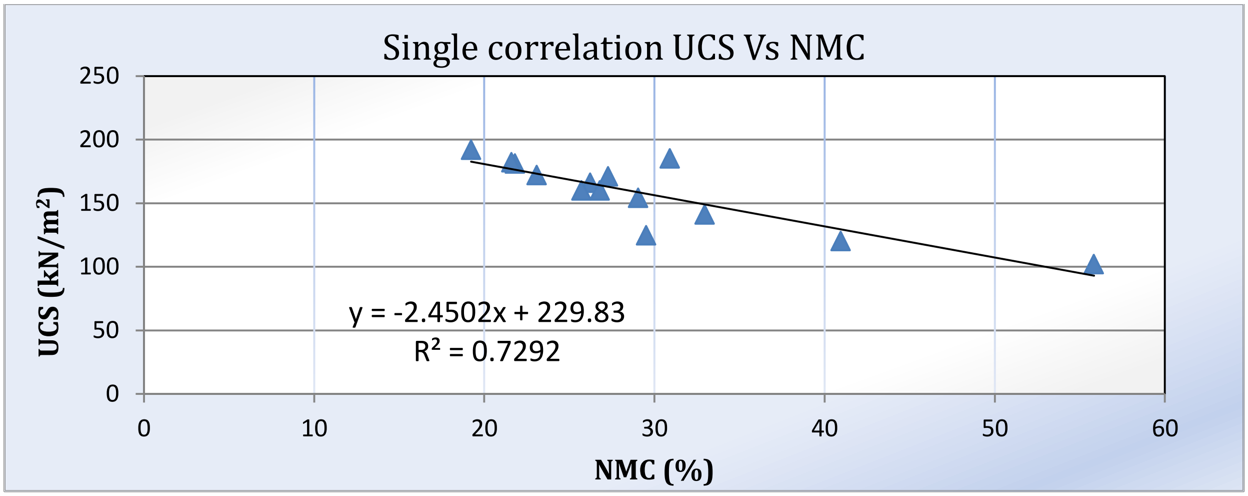
I, CATEGORY -1 (BLACK EXPANSIVE SOIL)

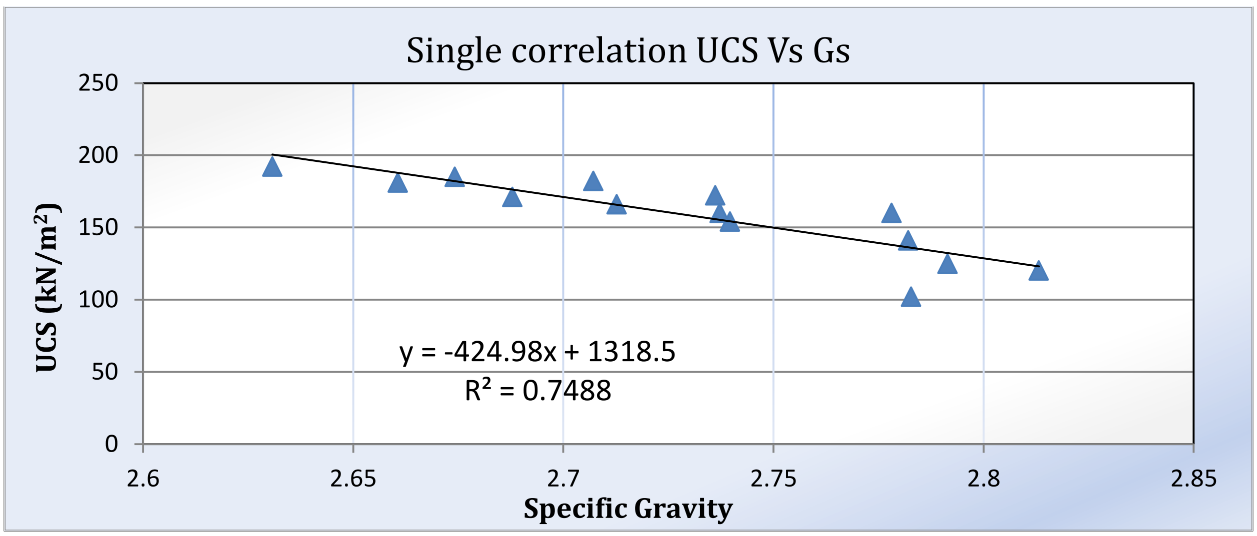


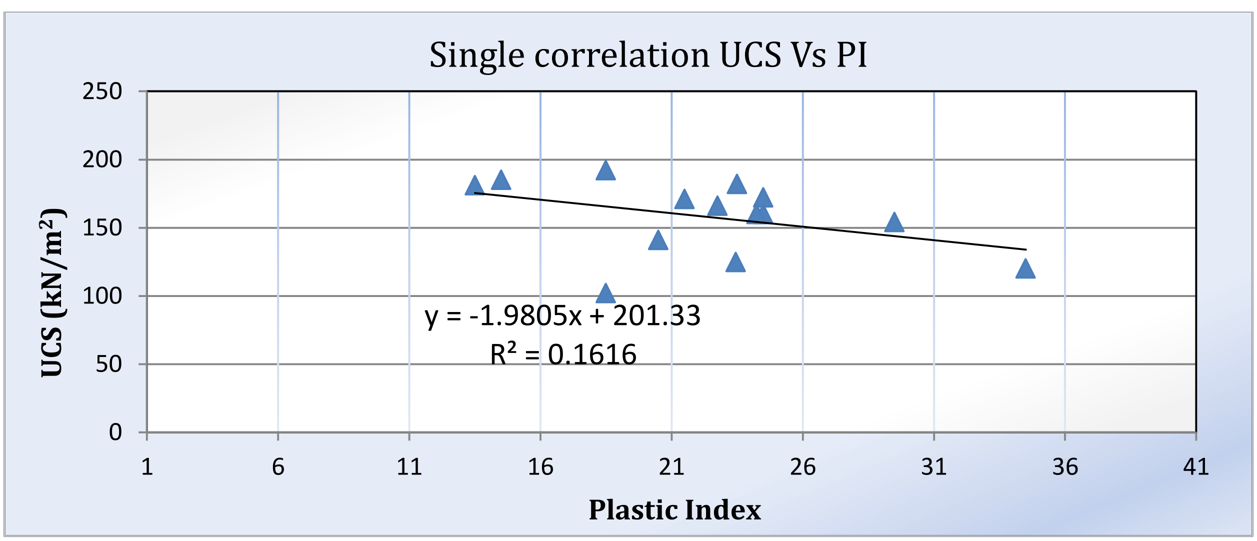




II, CATEGORY -2 (RED SOIL)







APPENDIX – C2

SPSS ANALYSIS RESULT

APPENDIX – C2.1

I, MULTIPLE REGRESSION OF CATEGORY -1 (BLACK SOIL)

A. Final significant parameters on developing Equation

Regression

Notes

Output Created		14-APR-2017 13:29:00
Comments		
Input	Data	E:\thesis\Analysis\cat 2_2\CAT -2.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	14
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT UCS /METHOD=ENTER DCPI LI /SCATTERPLOT=(UCS ,UCS) (UCS ,*ZRESID).
Resources	Processor Time	00:00:00.59
	Elapsed Time	00:00:00.56
	Memory Required	2604 bytes
	Additional Memory Required for Residual Plots	488 bytes

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LI, DCPI[b]	.	Enter

a. Dependent Variable: UCS

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.876[a]	.768	.725	14.102

a. Predictors: (Constant), LI, DCPI

b. Dependent Variable: UCS

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7230.049	2	3615.024	18.179	.000[b]
	Residual	2187.402	11	198.855		
	Total	9417.451	13			

a. Dependent Variable: UCS

b. Predictors: (Constant), LI, DCPI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	205.464	10.266		20.015	.000
	DCPI	-3.353	.644	-.879	-5.206	.000
	LI	.204	6.045	.006	.034	.974

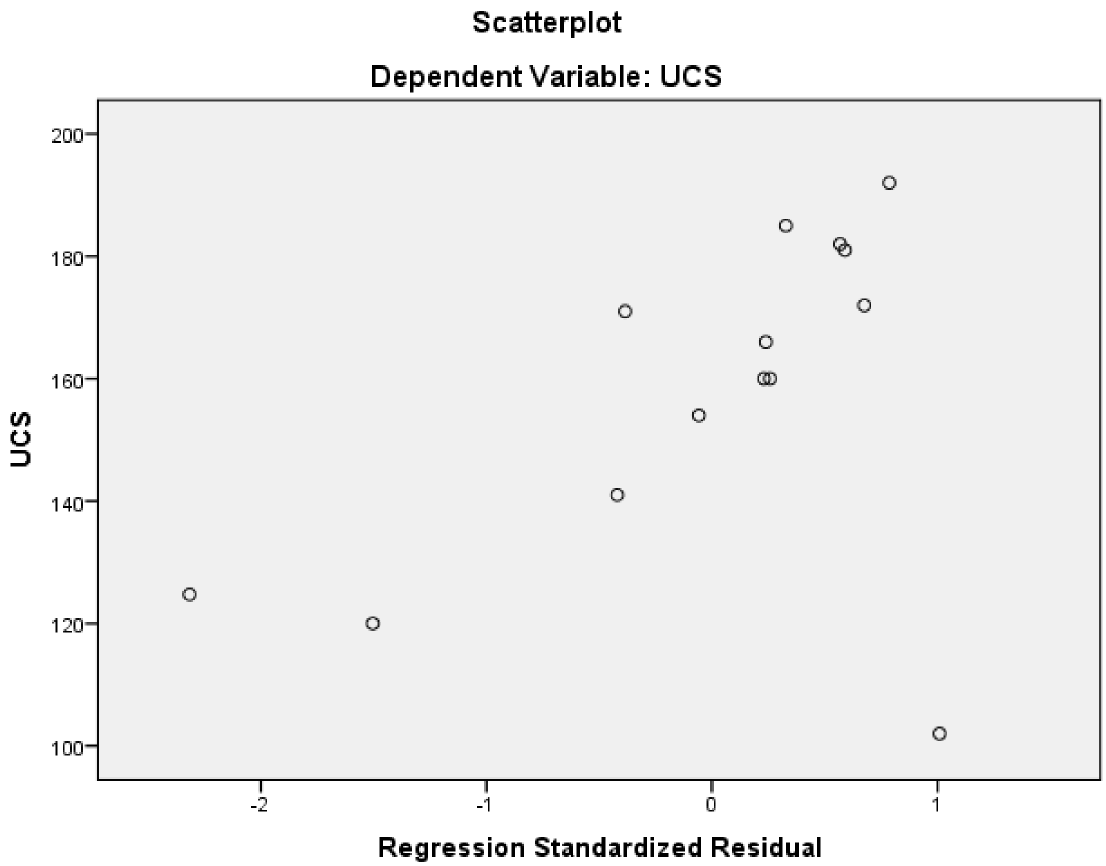
a. Dependent Variable: UCS

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	87.77	180.91	157.91	23.583	14
Residual	-32.658	14.231	.000	12.972	14
Std. Predicted Value	-2.974	.975	.000	1.000	14
Std. Residual	-2.316	1.009	.000	.920	14

a. Dependent Variable: UCS

Charts



APPENDIX – C2.2

MULTIPLE REGRESSION OF CATEGORY -2 (RED SOIL)

A. First Assumption (All parameters assumed have factor on UCS Determination)

Regression

Notes

Output Created		14-APR-2017 13:05:54
Comments		
Input	Data	E:\thesis\Analysis\cat 1_2\Cat 1.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	15
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		REGRESSION /MISSING LISTWISE /STATISTICS COEFF OUTS CI(95) R ANOVA /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT UCS /METHOD=ENTER DCPI LI /SCATTERPLOT=(*ADJPRED ,*ADJPRED) (UCS ,*ADJPRED).
Resources	Processor Time	00:00:00.41
	Elapsed Time	00:00:00.42
	Memory Required	2404 bytes
	Additional Memory Required for Residual Plots	488 bytes

[DataSet1] E:\thesis\Analysis\cat 1_2\Cat 1.sav

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	LI, DCPI[b]	.	Enter

a. Dependent Variable: UCS

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.904[a]	.817	.786	6.229

a. Predictors: (Constant), LI, DCPI

b. Dependent Variable: UCS

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2078.315	2	1039.158	26.780	.000[b]
	Residual	465.643	12	38.804		
	Total	2543.958	14			

a. Dependent Variable: UCS

b. Predictors: (Constant), LI, DCPI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	171.893	4.419		38.900	.000
	DCPI	-.986	.201	-.784	-4.903	.000
	LI	-12.058	11.142	-.173	-1.082	.300

Coefficients[a]

Model		95.0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	162.265	181.521
	DCPI	-1.424	-.548
	LI	-36.334	12.217

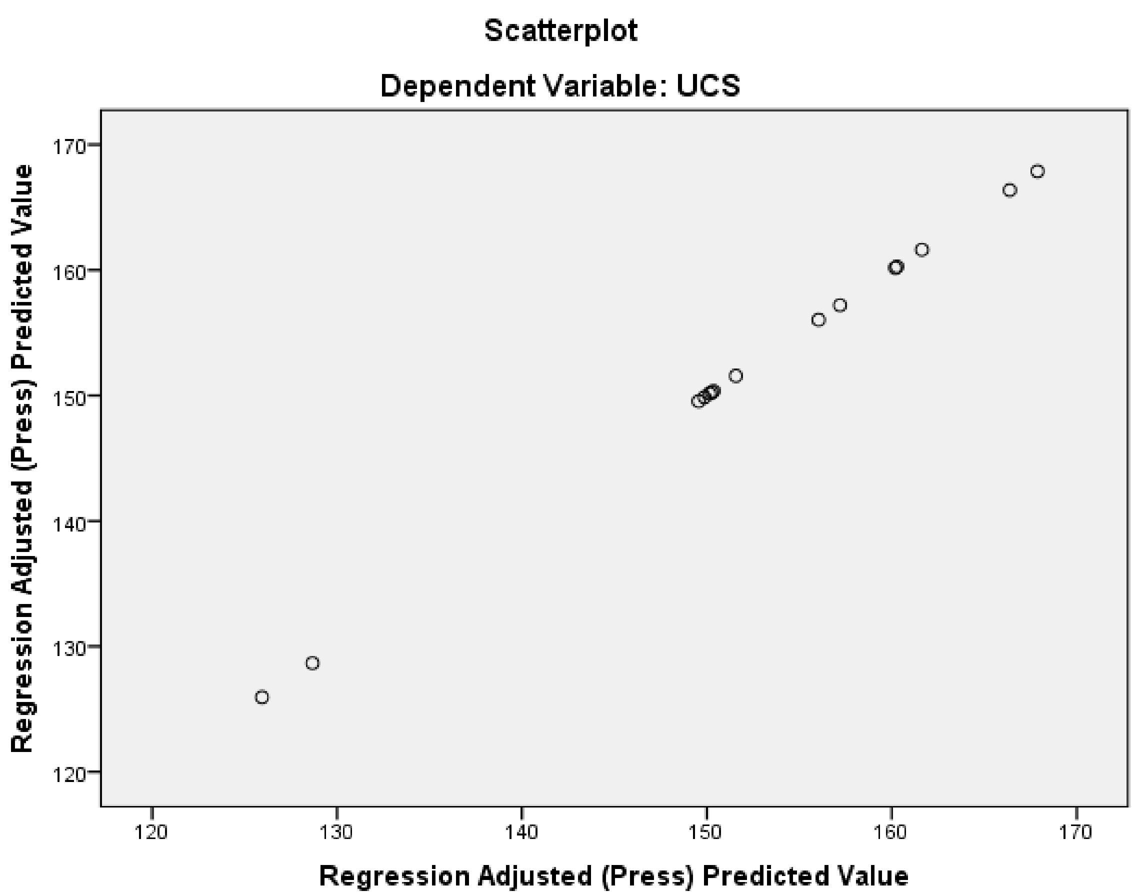
a. Dependent Variable: UCS

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	122.07	167.58	152.67	12.184	15
Std. Predicted Value	-2.511	1.224	.000	1.000	15
Standard Error of Predicted Value	1.649	4.830	2.627	.959	15
Adjusted Predicted Value	125.94	167.88	152.40	11.866	15
Residual	-7.152	13.512	.000	5.767	15
Std. Residual	-1.148	2.169	.000	.926	15
Stud. Residual	-1.219	2.456	.021	1.045	15
Deleted Residual	-8.068	17.315	.270	7.440	15
Stud. Deleted Residual	-1.247	3.333	.099	1.244	15
Mahal. Distance	.047	7.485	1.867	2.217	15
Cook's Distance	.000	.566	.105	.180	15
Centered Leverage Value	.003	.535	.133	.158	15

a. Dependent Variable: UCS

Charts



APPENDIX – D

TYPICAL DATA RECORDING AND ANALYSIS SHEET

I, Typical DCP Data Record Sheet

Site Name:	**Amanuel**	Test Date	18-Jun-14	Group name		
Start Test Depth(m):	0.0 m	profile	3 layer	Group symbol		
			Soil Data:			
presence of boulder	yes	Dilatance	non	color	wet	Dark red
plasticity	moderate	toughness	high		dry	light red
dry strength	high	NMC	moderate	odder	non	

Penetration data record and analysis sheet

No	Number of Blows	Reading of penetration	Cumulative Penetration (mm)	penetration between readings	Penetration Depth (mm)	Penetration rate (mm/blow)
zero reading	0	148			0	
1	0	164	16	16	16	0.0
2	2	204	56	40	56	20.0
4	2	234	86	30	86	15.0
5	2	259	111	25	111	12.5
7	2	289	141	30	141	15.0
8	2	324	176	35	176	17.5
9	2	352	204	28	204	14.0
10	2	389	241	37	241	18.5
11	2	417	269	28	269	14.0
12	1	440	292	23	292	23.0
13	2	474	326	34	326	17.0
14	2	494	346	20	346	10.0
15	2	518	370	24	370	12.0
16	2	540	392	22	392	11.0
17	5	585	437	45	437	9.0
18	5	625	477	40	477	8.0
19	5	670	522	45	522	9.0
20	2	694	546	24	546	12.0
21	2	715	567	21	567	10.5
22	2	735	587	20	587	10.0
23	2	767	619	32	619	16.0
24	2	801	653	34	653	17.0
25	2	834	686	33	686	16.5
26	2	868	720	34	720	17.0
27	2	906	758	38	758	19.0
28	2	943	795	37	795	18.5

II, UCS Typical Laboratory Data Analysis

Location	Mama II			*Specimen one*			
Depth	1.40 m			mass of sample (g) =		143.10 g	
diameter (m)=	0.036			Ring Calibration Factor, kN/div		0.00138	
height (m)=	0.073			date of sample		31-May	
A_o (m^2)	0.001018			date of lab		1-Jun	
L/D	2.03			Moisture content, %			
				Wet unit weight, kN/m3			
deformation dial reading	**load dial reading**	**ΔL =[1]/100**	**strain = [3]/length**	**% strain =[4]*100**	**corrected area**	**load**	**stress**
	Div	**mm**			**m^2**	**(KN)**	**(kpa)**
0	0	0	0.0000	0	0.001018	0.00000	0.00000
25	15	0.25	0.0034	0.342466	0.001021	0.02070	20.26682
50	33	0.5	0.0068	0.684932	0.001025	0.04554	44.43
75	52	0.75	0.0103	1.027397	0.001028	0.07176	69.78
100	67	1	0.0137	1.369863	0.001032	0.09246	89.59
125	83	1.25	0.0171	1.712329	0.001036	0.11454	110.60
150	94	1.5	0.0205	2.054795	0.001039	0.12972	124.82
175	107	1.75	0.0240	2.39726	0.001043	0.14766	141.59
200	119	2	0.0274	2.739726	0.001047	0.16422	156.92
225	123	2.25	0.0308	3.082192	0.00105	0.16974	161.62
250	120	2.5	0.0342	3.424658	0.001054	0.16560	157.12

III, Bulk Unit Weight Data Analysis Format

Unit Weight	*Specimen one*	*Specimen two*
Diameter of sample, (cm)	3.6	3.6
Area of sample, (cm^2)	10.18	10.18
Length of sample, (cm)	9.0	7.3
Volume of sample ,(cm^3)	91.6088418	74.3049494
Weight of sample, (g)	163.30	148.10
Unit Weight , (KN/M^3)	***1782.58***	***1993.14***
Avg. Unit Weight of sample, (KN/M^3)	***1887.86***	

IV, Wet Sieve Data Analysis Format

Specimen Location	Mama II	
NMC of the soil		
Specimen depth from the ground surface	1.40 m	
Specimen trial	1	2
Moisture can	IT1	G1
Mc =Mass of empty & clean can (grams)	16	16
M_1 =Mass of can and moist soil (grams)	36	37
M_2 =Mass of can and dry soil (grams)	31.7	32.3
Ms =Mass of dry soil (grams)	15.7	16.3
M_w =Mass of pore water (grams)	4.3	4.7
Natural moisture content, (%)	27.4%	28.8%
ɯ = average natural moisture content, (%)	28.1%	
Determination percentage of pass 0.075 mm	**unit**	**quantity**
mass of natural soil (before wash)	gm	700
mass dry soil (before wash)	gm	503.2
mass of dry soil + bowl (after wash)	gm	172.6
mass of bowl (after wash)	gm	40.6
mass of dry soil (after wash)	gm	132
mass pass 0.075 mm	gm	371.2
percentage of pass 0.075 mm	%	73.77

V, Dry Sieve Data Analysis Format

Specimen Location Mama II

Date

Depth 1.40 m

total sample mass 503.22

%age of pass 75 μm 74.00

Sieve opening (mm)	Mass of sieve (g)	Mass of sieve with retained soil (g)	Mass of retained soil (g)	%age retained, %	Cum. %age retained, %	Cum. %age passing, %
4.75	430.6	432	1.4	0.28	0.278	100.000
2.36	328.4	331.5	3.1	0.62	0.894	99.000
2	378.8	383.9	5.1	1.01	1.908	98.000
1.18	372.1	374.6	2.5	0.50	2.405	98.000
0.85	344.8	346.1	1.3	0.26	2.663	97.000
0.6	324.4	325.9	1.5	0.30	2.961	97.000
0.425	305.4	317.2	11.8	2.34	5.306	95.000
0.3	302.4	311.8	9.4	1.87	7.174	93.000
0.15	277.6	351.8	74.2	14.75	21.919	78.000
0.075	272.6	293.4	20.8	4.13	26.052	74.000
Pan	256.1	257.0	0.9	73.95	100.000	0.000
wash			371.2			
Total	3593.2	3725.2	503.21988	100		

VI, Hydrometer Data Analysis Format

Specimen Location		Mama II	
	Date		
	Depth	1400 mm	

specific gravity	2.78
total sample mass	503.22
%age of pass 75 µm	74.00

Elapsed Time, T (min)	Actual Hydrometer Reading, R_A	test temperature(^oC)	Composite Correction	Corrected Hydrometer Reading, R_c	Effective Depth, L (cm)	Coefficient, K	Percent finer	Grain size (mm)	Percent finer for combined analysis
1	1.0310	17.0	-0.0033	1.0277	8.1	0.01364	87%	0.03882	64.1%
2	1.0300	17.0	-0.0033	1.0267	8.4	0.01364	83%	0.02795	61.8%
5	1.0280	18.0	-0.0031	1.0249	8.9	0.01347	78%	0.01797	57.6%
15	1.0240	18.0	-0.0031	1.0209	10.0	0.01347	65%	0.01100	48.3%
30	1.0225	18.0	-0.0031	1.0194	10.3	0.01347	61%	0.00789	44.9%
60	1.0210	19.00	-0.0029	1.0181	10.7	0.01331	57%	0.00562	41.9%
127	1.0200	19.00	-0.0029	1.0171	11.0	0.01331	53%	0.00392	39.6%
246	1.0185	20.00	-0.0027	1.0158	11.4	0.01314	49%	0.00283	36.5%
360	1.0175	20.00	-0.0027	1.0148	11.7	0.01314	46%	0.00237	34.2%
1440	1.0135	20.00	-0.0027	1.0108	12.7	0.01314	34%	0.00123	25.0%