Jimma University
Jimma Institute of Technology
School of Graduate Studies
Faculty of Civil and Environmental Engineering
Geotechnical Engineering Stream

Developing correlation model for UCS from DCP and index properties of soil (A case study of Agaro Town)

A Research Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfilment of the Requirement of Degree of Master of Science in Civil Engineering (Geotechnical Engineering).

By

Biruk Amde

June, 2021
Jimma, Ethiopia

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Main advisor: Dr.Zeinu Ahmed

Co-advisor: Eng. Worku Firomsa

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DECLARATION

I, the undersigned, declare that this thesis entitled: "**Developing correlation model for UCS from DCP and index properties of soil: The case study of Agaro Town.**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

Mr. Biruk Amde ____________________ __________
Student Signature Date

As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by Mr. Biruk Amde entitled:"**Developing correlation model for UCS from DCP and index properties of soil: The case study of Agaro Town.**"

Dr. Zeinu Ahmed _____________ ____/_____/____
Main Advisor Signature Date

Mr. Worku Firomsa (MSc) _____________ ____/_____/____
Co- Advisor Signature Date

Acknowledgment

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Abstract

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 usually leads us to use of unreliable designing methods. To avoid such problems Correlations Dynamic Cone Penetration Index (DCPI) with Unconfined Compressive Strength (UCS) and index properties that make it interesting alternative, due to operating quickly, very light, versatile and user-friendly property of DCP . The dynamic cone penetrometer (DCP) which is a simple test device that is inexpensive, portable, and easy to operate and understand. Unconfined Compressive Strength (UCS) is one of the type of laboratory testing. This laboratory testing is conducted by undisturbed samples. It is difficult to obtain accurate undisturbed samples. Even some designers or companies do not conduct soil investigation for building. Some of these predictions may leads to unexpected failures of structure or uneconomical design. So, prediction of Unconfined Compressive Strength for cohesive soil with the help of Dynamic Cone Penetration Index (DCPI) and index properties of soil provides a good alternative to minimize this problem. To this end, the present research aimed to develop single and multiple correlations of UCS, DCP and index properties of soil and also compare, validate and evaluate the developed model using the controlled test and with related existing model. This research consists of field testing, laboratory testing, and analysis of the results for 30 samples from 15 test pit collected from different location of town. By using the test result regression based statistical analysis was carried out to develop the intended correlation. The parameters considered for this study are Natural moisture contents, Atterberg limits, dry unit weight and specific gravities. The test procedures were based on ASTM laboratory test standards. Regression models were develop using SPSS software and Microsoft Excel for this study to enable the prediction of UCS values. From the study predicting Unconfined compressive strength (UCS) is obtained from multiple linear regression analysis and given by $UCS = 202.211-0.673\ DCPI +6.03\gamma dry -0.406LL -1.511NMC$*, coefficient of determination* $(R^2) = 0.918$ *.The results are expected to have wide application in the construction sector.*

Keyword: *Dynamic Cone Penetration Index, Unconfined Compressive Strength, index properties, Regression models*

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Acronyms

ASTM	American Society for Testing & Material
JIT	Jimma Institute of Technology
JUCAVM	Jimma University College of Agriculture and Veternary Medicine
TSA	Total stress analysis
Su/cu	Undrained shear strength
PI	Plasticity Index
PL	Plastic Limit
LL	Liquid Limit
LI	Liquidity index
UU	Unconsolidated Undrained
UC	Unconfined Compression
R^2	Coefficient of determination
NMC	Natural moisture content
USCS	Unified soil classification system
AASHTO	American Association of State of Highway & Transportation Officials
Gs	Specific Gravity
SPSS	Statistical Package for Social Science Software
SLR	Single Linear Regression
MLR	Multi Linear Regression
Ddry/ρ_{dry}	Dry density
Dbulk/ρ_{bulk}	Bulk density
α/p-value	Significance level
VIF	Variance inflation factors
N	Number of sample

CHAPTER ONE
INTRODUCTION

1.1 Back ground of the study

The dynamic cone penetrometer (DCP) is an in-situ testing device used in fiel exploration and quality control of compacted soils during construction. The DCP is simple to operate, inexpensive, and produces repeatable results. The DCP was originally developed in South Africa for in-situ evaluation of pavement layer strength [1]. The DCP has been correlated to engineering properties such as the California Bearing Ratio (Mohammadi et al, 2008), soil classification (Huntley, 1990), and unconfined compressive strength (McElvaney and Djatnika, 1991; Patel and Patel, 2012; Nemiroff, 2016). Dynamic cone penetrometers come in various different weights and drop heights depending on their intended use. The ASTM-standard device for use in shallow pavement applications consists of a 17.6 lb. (8 kg) or a 10.1 lb. (4.6)) hammer with a drop height of 22.6 inches (575 mm) (ASTM D 6951, 2009).

Determination of the unconfined compressive strength of cohesive soil in the undisturbed, remoulded, or compacted condition, using strain-controlled application of the axial load, test method provides an approximate value of the strength of cohesive soils in terms of total stresses (ASTMD, 2166).

Unconfined Compressive Strength is used to evaluate the suitability of Pavement layers thickness measurement. This test can be done in the laboratory. It is an expensive and time-consuming test. 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 (DCP) and Unconfined Compression Strength (UCS) and index properties of soil in Agaro Town.

1.2 Statement of the problem

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 for UCS from DCP and index properties for soils at various locations of Agaro Town, regional state of Oromia, Ethiopia.

1.3 Research questions

1. What is the unconfined compression strength (UCS), DCP and index properties of soil in Agaro town?
2. How unconfined compression strength (UCS), DCP and index properties of soil in Agaro town could be correlated
3. How much deviation of the value of a result from the developed equation with existing correlation approach related to the study?

1.4 Objectives of the Study

1.4.1 General Objectives

The general objective of the study is to develop correlation model for Unconfined Compression Strength (UCS) from Dynamic Cone Penetration (DCP) and index properties of soil in Agaro town

1.4.2 Specific Objectives

1. To determine unconfined compression strength (UCS), DCP and index properties of soil in Agaro town.
2. To develop correlation between unconfined compression strength (UCS), DCP and index properties of soil in Agaro town
3. To compare, validate and evaluate the developed model using the controlled test and with related existing model

1.5 Scope and Limitation of the Study

This research thesis is limited within the Agaro town. Dynamic Cone Penetration Index (DCPI) is determined at in situ moisture content and density of the soil layers. During laboratory test, UCS strength determination taken into consideration in situ Natural Moisture Content and Bulk Density kept. Result will be correlated by regression analysis and statistical modelling. To analysis the Dynamic Cone Penetration (DCP) test results (field test) and laboratory tests, including single and multiple regression analysis.

1.6 Significance of the Study

The result of this study helps to reduce wastage of time, energy and cost for laboratory engineering property test of unconfine compression strength test by predicting it from DCPI and index properties of the study area. In addition to this study will provide helpful information to various stakeholders as follows;

- Agaro City Administration of will benefit from the study as a source of information and base for the construction industry that can help to minimize the time and cost of laboratory tests.
- The study will provide lessons that will help the concerned body can come up with appropriate measures to address problems resulting from correlation of DCP, index properties and UCS.
- The study will benefit consultants, contractors, researchers and the public at large.
- Other researchers will use the findings as a reference for further research on the correlation among Dynamic Cone Penetration, index properties and Unconfined compressive strength.

1.7 Justification of the study

The reason for operating this study will be providing a reference to reduce the cost and time for laboratory tests by using simple correlation.

For contractors consume time and money for laboratory to find shear strength parameter of a soil is reduce problem by doing this correlation. This assumption causes unpredictable effect on geo-technical structure. To solve this problem simple empirical correlation among Dynamic Cone Penetration, index properties and unconfined compressive strength must be needed.

1.8 Structure of the thesis

This research study comprised of seven chapters and their contents are outlined below: In the first chapter an overview of the background of the research, statement of the problem, research questions, scope, and the final objective of the thesis work and significance of the study was discussed. The second chapter deals with the literature review about unconfined compressive strength of soil, Dynamic Cone Penetration Index and index properties of soil . The third chapter deals with the research methods. The fourth chapter deals with assessments of test results that are gathered from field and laboratory tests and discussion. Chapter five correlation Analysis. Chapter six Discussion on correlation results. The last chapter seven, a conclusion and recommended are derived from results and discussion.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Theoretical review

2.1.1 Dynamic Cone Penetrometer (DCP)

The DCP was developed in South Africa for evaluation of in-situ pavement strength or stiffness in the 1960s. Dr. D. J. van Vuuren designed the original DCP with a 30° cone [2]. The Transvaal Roads Department in South Africa began using the DCP to investigate road pavement in 1973 (Kleyn, 1975). Kleyn reported the relative results obtained using a 30° cone and a 60° cone. In 1982, Kleyn described another DCP design, which used a 60° cone tip, 8 kg (17.6 lb) hammer, and 575 mm (22.6 in) free fall [3]. This design was then gradually adopted by countries around the globe. In 2004, the ASTM D6951-03 Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications described using a DCP with this latest design [4]. The Dynamic Cone Penetrometer (DCP) is one such tool. It is a simple test device that is inexpensive, portable, easy to operate, and easy to understand. It does not take extensive experience to interpret results and several correlations to more widely known strength measurements have been pub1ished. DCP testing consists of using the DCP's free-falling hammer to strike the cone, causing the cone to penetrate the base or subgrade soil, and then measuring the penetration per blow, also called the penetration rate (PR), in mm/blow. This measurement denotes the stiffness of the tested material, with a smaller PR number indicating a stiffer material. In other words, the PR is a measurement of the penetrability of the sub grad soil.

DCP test results consist of number of blow counts versus penetration depth. Since the recorded blow counts are cumulative values, results of DCP test in general are given as incremental values defined as follows [5].

$$DCPI = \Delta DP / \Delta BC$$

Where;

- ✓ DCPI = Dynamic Cone Petro meter Index in units of length divided by blow count;
- ✓ ΔDp = penetration depth;
- ✓ ΔBC = Blow Counts corresponding to penetration depth ΔDp form:

Correlation equation form:

$$UCS = A + B \ln(DCPI)$$

Where ,UCS = Unconfined Compressive Strength,

DCPI = DCP penetration resistance or penetration index in units of mm per blow

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.

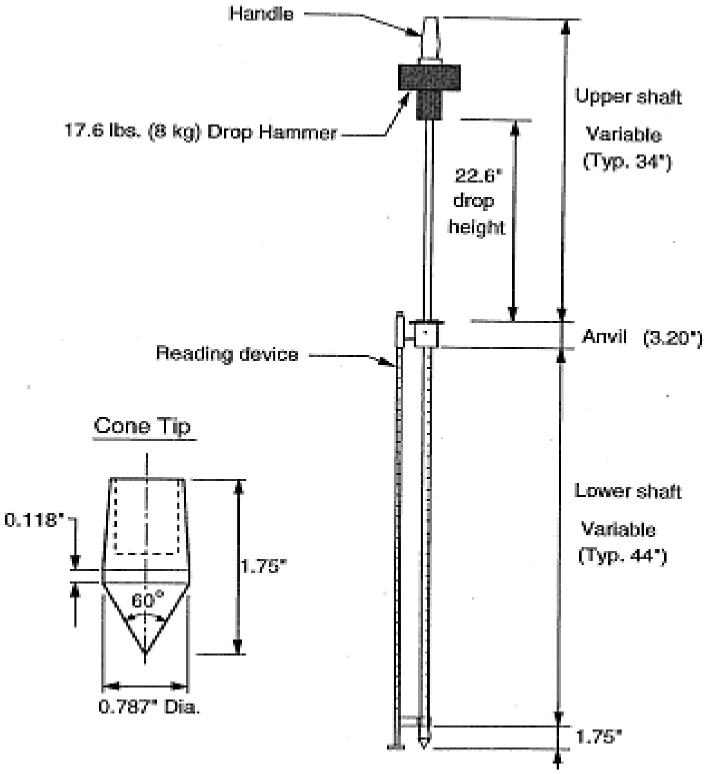


Figure 2- 1: Dynamic Cone Penetrometer [6]

Equipment shows above used for current research, for detail construction notes refer to User Guide to the Dynamic Cone Penetrometer and detail drawings prepared by Minnesota Department of Transportation [6]. The equipment is comprised of the following elements:

a) Handle: The handle is located at the top of the device. It is used to hold the DCP shafts plumb and to limit the upward movement of the hammer

b) Hammer: The 8-kg hammer is manually raised to the bottom of the handle and then allowed to fall freely to transfer energy though the lower shafts to the cone tip. It is guided by the upper shaft.

c) Drop Height (Upper Shaft): The upper shaft is a 16-mm diameter steel, on which the hammer moves. The length of the shaft allows the hammer to drop a distance of 575-mm.

d) Anvil: The anvil serves as the lower stopping mechanism for the hammer. It also serves as a connector between the upper and the lower shaft. This allows for disassembly which reduces the size of the instrument for transport.

e) Steel Rod (Lower Shaft): The lower shaft could be 900-1200-mm long, if possible. marked in 5-mm increment for recording the penetration after each hammer drop.

f) Cone: The cone measures 20 mm in diameter and has a 60^0 cone.

2.1.2 Factors Affecting DCP Results

Hassan [25] 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 [11], [26].

- **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 [11].

- **Moisture Content and Density**

Salgado et al. [7], and Tuncer et al. [8], 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. [7], 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 [9] 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 affected both parameters (CBR and DCPI), but they affect in similar ways.

- **Vertical Confinement and Side Friction**

Livneh et al. [10], 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 [11].

- **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.

2.1.3 Benefits and Limitations of DCP

The DCP offers many benefits compared to other similar hand-held testing devices. Its benefits make the device not only inexpensive, portable and easy to operate and understand but also the most versatile among other similar equipment. Some of these benefits are listed below:

a) **Easy to Use:** It does not take extensive experience to interpret results. An operator can be trained in a matter of minutes. Its light weight makes it preferable for field exploration for lightweight structures.

b) **Fast**: A large amount of data can be taken quickly, and the DCPI values are easily converted into other indices which are used to determine the bearing properties and performance of the underlying soil.

c) **Low Cost:** Currently, the device can be manufactured locally from available material or even could be rented cheaply.

d) **Versatility:** The device has found many applications in the construction field for construction control, supervision and design parameter determination. Some of the items are:

- Compaction control or verification in embankment, drainage and pavement construction.

- Verification or control using penetrometer to check individual foundations during construction where the shear strength characteristics range is generally known.
- Determine the bearing properties and performance of soils.

The dynamic cone penetrometer has its own limitations; some of these are caused by the operator of the equipment. One should not be surprised to find out that the result of two DCP tests done on the same site only a few meters apart is not the same. These errors include tilting of the equipment, falling height of the hammer, etc.

Other than manpower errors there are other limitations:

- Adhesion between the rod and the soil for highly plastic soil and collapsible granular soils.
- It is difficult to penetrate hard and granular materials.
- As in most dynamic tests, the DCP does not give reliable result in saturated fine graded soils. This is because the dynamic load from the equipment is carried by a developed pore water pressure rather than the soil grains in these types of soils.

2.1.4 Unconfined Compressive Strength (UCS)

Unconfined Compressive Strength (UCS) is one of the types of laboratory testing. This laboratory testing is conducted by undisturbed samples. it is difficult to obtain accurate undisturbed samples. A quick test to obtain the shear strength parameters of cohesive (fine grained) soils either in undisturbed or remoulded state. 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. In the unconfined compression test, we assume that no pore water is lost from the sample during set-up or during the shearing process. A saturated sample will thus remain saturated during the test with no change in the sample volume, water content, or void ratio. The unconfined compressive strength (UCS) is the maximum axial compressive stress that a right-cylindrical sample of material can withstand under unconfined conditions—the confining stress is zero. It is also known as the uniaxial compressive strength of a material because the application of compressive stress is only along one axis the longitudinal axis of the sample.

More significantly, the sample is held together by an effective confining stress that results from negative pore water pressures (generated by menisci forming between particles on the sample surface). Pore pressures are not measured in an unconfined compression test;

consequently, the effective stress is unknown. Hence, the undrained shear strength measured in an unconfined test is expressed in terms of the total stress.

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. 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. (Unconfined Compression Test, Advanced Geotechnical Laboratory). UCS used in all geotechnical engineering designs (e.g. design and stability analysis of foundations, retaining walls, slopes and embankments) to obtain a rough estimate of the soil strength and viable construction techniques.

The unconfined compressive strength (q) is the load per unit area at which the cylindrical specimen of a cohesive soil falls in compression.

q = P/A

Where P= axial load at failure, A= corrected area = , where is the initial area of the specimen, = axial strain = change in length/original length.

- Calculate the axial strain,

  $\epsilon_1 = \Delta L/L_0$

where:

ΔL = length change of specimen as read from deformation indicator, mm (in.), and

L_0 = initial length of test specimen, mm (in)

- Calculate the average cross-sectional area, *A*,

$$A = A_0/(1 - \epsilon_1)$$

where:

A_0 = initial average cross-sectional area of the specimen, mm 2(in. 2), and

ϵ_1 = axial strain for the given load, % (ASTM, D 2166)

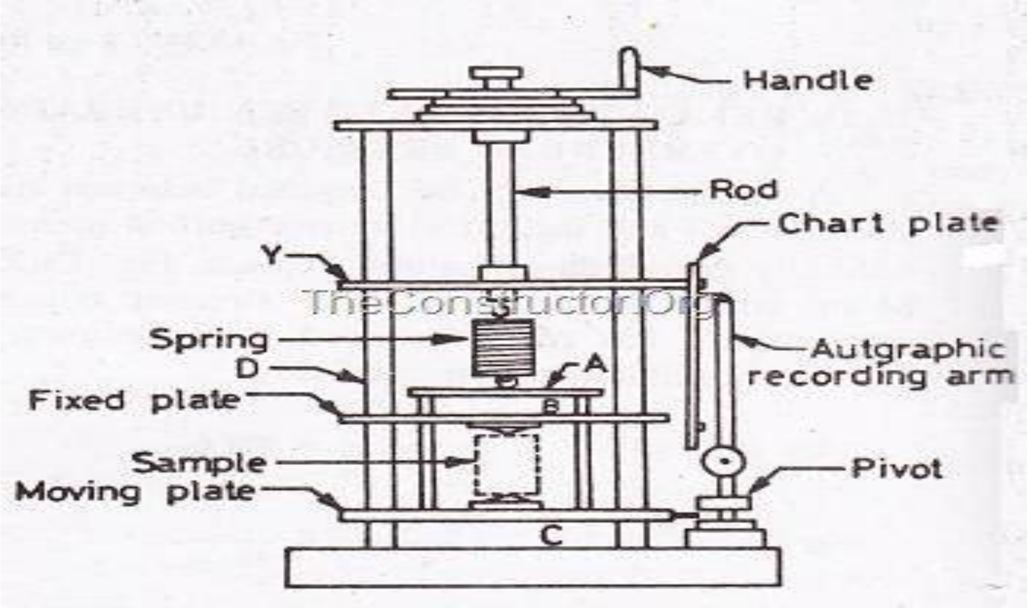
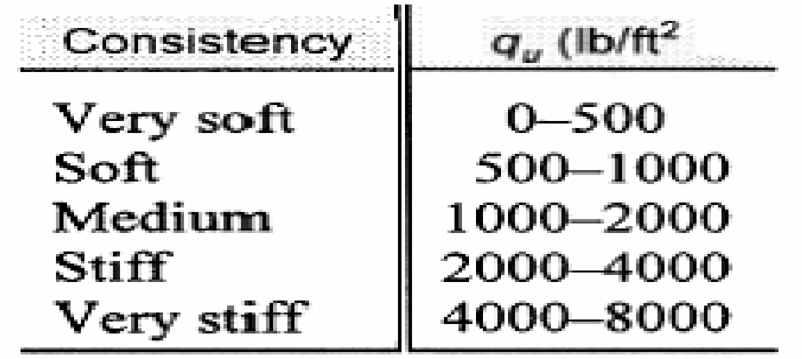


Figure 2- 2: Unconfined compression test equipment (California Test 221, March 2000)

Table 2- 1: Relative consistency as a function of unconfined compressive strength (Das,2002)



Consistency	q_u (lb/ft^2
Very soft	0–500
Soft	500–1000
Medium	1000–2000
Stiff	2000–4000
Very stiff	4000–8000

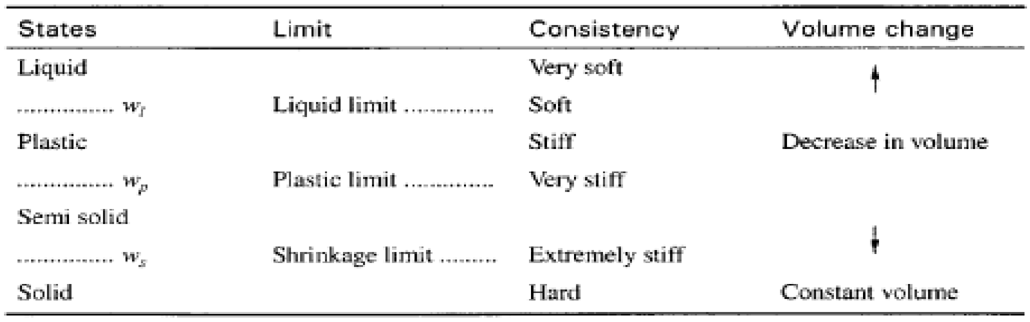
2.1.5 Index Properties of Soil

In nature soil occurs in a large variety. Engineers are continually searching for simplified tests that will increase their knowledge of soils by employing a simple and rapid soil tests. These simplified tests which are indicative of the engineering properties of soils are called index properties [12]. Index properties of cohesive soils are used to characterize the physical and mechanical behaviour of soils by making use of parameters such as moisture content, specific gravity, particle size distribution, Atterberg limits and moisture-density relationships. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties [13].

Atterberg Limits

Atterberg, a Swedish scientist, considered the consistency of soils in 1911, and proposed a series of tests for defining the properties of cohesive soils. These tests indicate the range of the plastic state (plasticity is defined as the property of cohesive soils which possess the ability to undergo changes of shape without rupture) and other states. He showed that if the water content of a thick suspension of clay is gradually reduced; the clay water mixture undergoes changes from a liquid state through a plastic state and finally into a solid state. The different states through which the soil sample passes with the decrease in the moisture content are depicted in Fig 2.3. The water contents corresponding to the transition from one state to another are termed as Atterberg Limits and the tests required to determine the limits are the Atterberg Limit Tests. The testing procedures of Atterberg were subsequently improved by A. Casagrande (1932) The transition state from the liquid state to a plastic state is called the liquid limit, wr. At this stage all soils possess a certain small shear strength. This arbitrarily chosen shear strength is probably the smallest value that is feasible to measure in a standardized procedure. The transition from the plastic state to the semisolid state is termed the plastic limit, wp. At this state the soil rolled into threads of about 3 mm diameter just crumbles. Further decrease of the water contents of the same will lead finally to the point where the sample can decrease in volume no further. At this point the sample begins to dry at the surface, saturation is no longer complete, and further decrease in water in the voids occurs without change in the void volume. The color of the soil begins to change from dark to light. This water content is called the shrinkage limit, ws. The limits expressed above are all expressed by their percentages of water contents. The range of water content between the liquid and plastic limits, which is an important measure of plastic behaviour, is called the plasticity index, I},

Table 2- 2: Different states and consistency of soils with Atterberg limit



States	Limit	Consistency	Volume change
Liquid		Very soft	↑
.... w_l	Liquid limit	Soft	
Plastic		Stiff	Decrease in volume
.... w_p	Plastic limit	Very stiff	
Semi solid			
.... w_s	Shrinkage limit	Extremely stiff	↓
Solid		Hard	Constant volume

❖ Liquid Limit

The liquid limit (LL) is the water content, expressed in percent, at which the soil changes from a liquid state to a plastic state and principally it is defined as the water content at which the soil pat cut using standard groove closes for about a distance of 13cm (1/2 in.) at 25 blows of the liquid limit machine (Casagrande Apparatus). The liquid limit of a soil highly depends upon the clay mineral present. The conventional liquid limit test is carried out in accordance of test procedures of AASHTO T 89 or ASTM D 4318. A soil containing high water content is in the liquid state and it offers no shearing resistance.

❖ Plastic Limit

About 15 g of soil, passing through a No. 40 sieve, is mixed thoroughly. The soil is rolled on a glass plate with the hand, until it is about 3 mm in diameter. This procedure of mixing and rolling

is repeated till the soil shows signs of crumbling. The water content of the crumbled portion of the thread is determined. This is called the plastic limit.

❖ Plasticity Index lp

Plasticity index / indicates the degree of plasticity of a soil. The greater the difference between liquid and plastic limits, the greater is the plasticity of the soil. A cohesionless soil has zero plasticity index. Such soils are termed non-plastic. Fat clays are highly plastic and possess a high plasticity index. Soils possessing large values of w, and / are said to be highly plastic or fat. Those with low values are described as slightly plastic or lean. Atterberg classifies the soils according to their plasticity indices as in Table 2.3. A liquid limit greater than 100 is uncommon for inorganic clays of non-volcanic origin. However, for clays containing considerable quantities of organic matter and clays of volcanic origin, the liquid limit may considerably exceed 100. Bentonite, a material consisting of chemically disintegrated volcanic ash, has a liquid limit ranging from 400 to 600. It contains approximately 70 percent of scale-like particles of colloidal size as compared with about 30 per cent for ordinary highly plastic clays. Kaolin and mica powder consist partially or entirely of scale like particles of relatively coarse size in comparison with highly colloidal particles in plastic clays. They therefore possess less plasticity than ordinary clays. Organic clays possess liquid limits greater than 50. The plastic limits of such soils are equally higher.

Therefore soils with organic content have low plasticity indices corresponding to comparatively high liquid limits.

Table 2- 3: Soil classifications according to Plasticity Index

Plasticity index	Plasticity
0	Non-plastic
<7	Low plastic
7-17	Medium plastic
>17	Highly plastic

❖ Specific Gravity

The specific gravity of a given material is defined as the ratio of the weight of a given volume of the material to the weight of an equal volume of distilled water. In soil mechanics, the specific gravity of soil solids (which is often referred to as the specific gravity of soil) is an important parameter for calculation of the weight-volume relationship. determined according to ASTM D 854-98   Thus specific gravity, Gs, is defined as

Gs = unit weight (or density) of soil solids only / unit weight (or density) or water

where W_s = mass of soil solids (g); V_s = volume of soil solids (cm^3); and p_w = density of water (g/cm^3)

❖ Sieve Analysis

The purpose of sieve analysis is to determine the percentage of various grain sizes. The grain size distribution is used to determine the textural classification of soils (i.e., gravel, sand, silty clay, etc.) which in turn is useful in evaluating the engineering characteristics such as permeability, strength, swelling potential, and susceptibility to frost action. The laboratory test is conducted as per AASHTO T 88, or ASTMD 422, D 1140

❖ Moisture Content

Moisture content of soil describes the amount of water present in a quantity of soil in terms of its dry weight. In equation form

$$w = \frac{m_w}{m_s} * 100\text{-}$$

Where:

$m(w)$=mass of water contained in soil.

$m(s)$=mass of dry soil

The purpose of moisture content test is to determine the amount of water present in a quantity of soil. The moisture content test is carried out in the laboratory as per the procedure of AASHTO T 265 or ASTM D 2216 and in the field according to AASHTO T217.

2.2 Review of empirical correlations

The laboratory test results indicated that the DCP provided a reasonable estimate of the unconfined compressive strength of the soil-lime mixtures. The inclusion of data from material with zero lime content has negligible effect on the regression analysis, suggesting that the correlation obtained is primarily a function of strength and is not influenced by the way in which strength is achieved (McElvaney and Djatnika 1991). McElvaney and Djatnika (1991) developed three correlations.

50% probability of underestimation:

$$\log(UCS) = 3.56 - 0.807\log(DN)$$

95% confident that probability of underestimation will not exceed 15 percent:

$$\log(UCS) = 3.29 - 0.809 \log(DN$$

99% confident that probability of underestimation will not exceed 15 percent;

$$\log(UCS) = 3.21 - 0.809\log(DN)$$

Where:

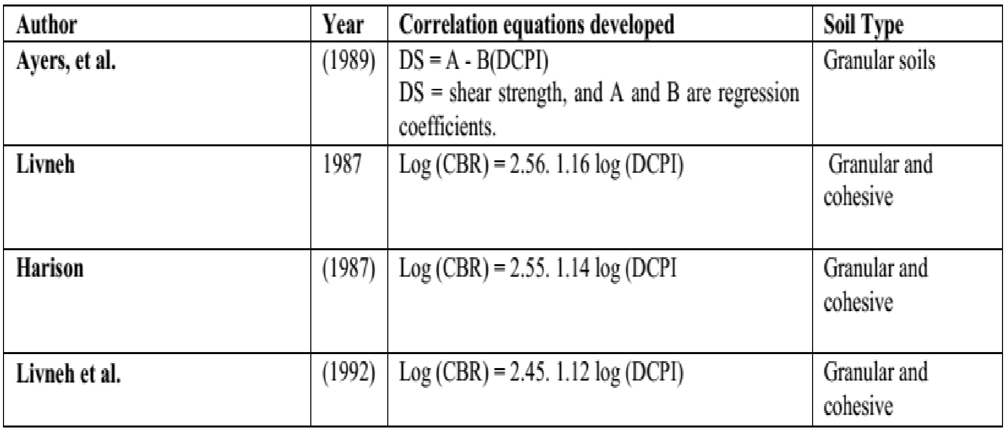
UCS = the unconfined compressive strength (kPa), and

DN = the DCP reading (mm/blow).

dynamic cone penetrometer index for a wide variety of soils that were stabilized using cement, lime, and flyash and unstabilized soil. Patel and Patel (2012) concluded that the correlation between the unconfined compressive strength and the dynamic cone penetrometer index were independent of soil type and the use of cement, lime, or flyash.

The relationship between the soil properties and the penetration index can be improved by normalizing the quantities in a different way [14]. There lies a correlation between the DCPI to index and engineering properties of soils [15]. There is a very good correlation between penetration index with other index and engineering properties obtained for each type of soil tested, the coefficient of determination R2 ranges between 0.96 to 0.99 and the standard error of estimation is relatively low [16]. . Few authors developed correlation equations and are shown in Table I. Development Of Correlation Between Different Soil Properties

Table 2- 4: Correlation Equations among Various Properties [17]



Author	**Year**	**Correlation equations developed**	**Soil Type**
Ayers, et al.	(1989)	DS = A - B(DCPI) DS = shear strength, and A and B are regression coefficients.	Granular soils
Livneh	1987	Log (CBR) = 2.56. 1.16 log (DCPI)	Granular and cohesive
Harison	(1987)	Log (CBR) = 2.55. 1.14 log (DCPI	Granular and cohesive
Livneh et al.	(1992)	Log (CBR) = 2.45. 1.12 log (DCPI)	Granular and cohesive

Table 2- 5: CORRELATION OF SOIL PROPERTIES [18]

Sr.No.	Correlation between properties	Regression analysis	R^2 value
1	SCBR V DCPI	$y = -0.260x + 0.350$	0.845
2	UCBR V DCPI	$y = -1.516x + 1.995$	0.892
3	SCBR V UCS	$y = 1.094x - 0.379$	0.716
4	SCBR V L.L	$y = -0.004x + 1.430$	0.850
5	SCBR V P.I	$y = -0.010x + 1.373$	0.746
6	SCBR V OMC	$y = -0.022x + 1.675$	0.338

- So above table can give the value of R^2 for different correlation of soil properties. So here based on that Regression analysis can get the model equation of different correlation of properties.
- So from this model equation, we can get the value of Soak CBR from other properties of soil. So it’s easy to use & applicable.

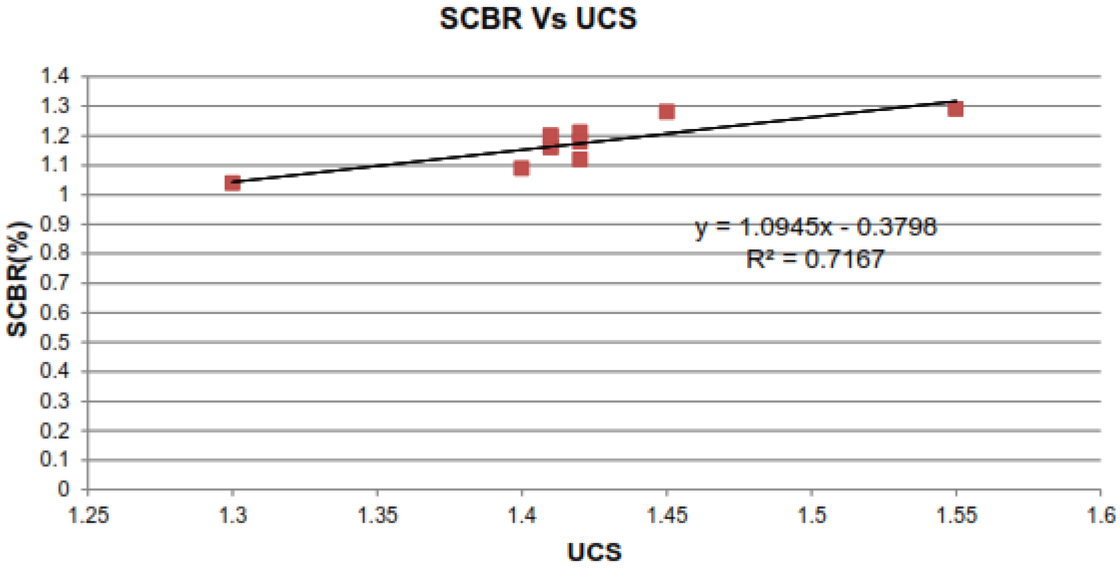


Figure 2- 3: SCBR V UCS[18]

Prediction of UCS from OMC and DCP: A relation between UCS, OMC and DCP is determined from Experimental Investigation is expressed by Equation

UCS = 1.317196471*10-3 OMC -5.688606326*10-1 DCP + 2.929493599

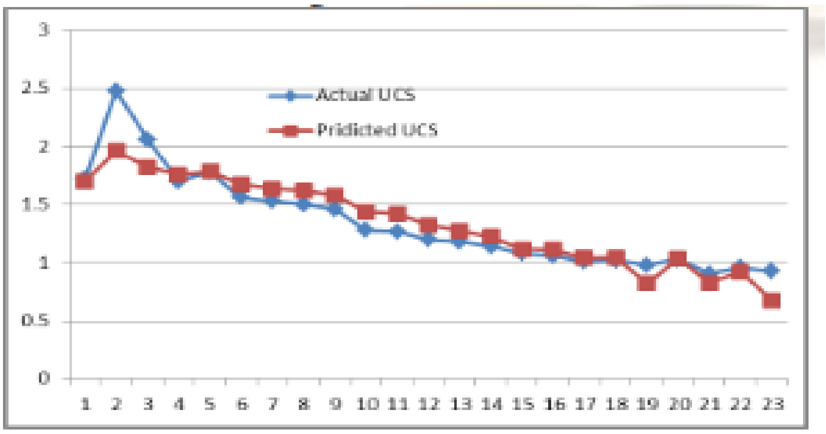


Figure 2- 4: between actual and predicted value UCS Values[19]

CHAPTER THREE

STUDY AREA, MATERIALS AND RESEARCH METHODS

3.1 Study Area

The study conducted in the south- western Ethiopia located in the jimma zone of oromia region in Agaro town. Geographically it is located in 7° 51' 0" latitude north and 36° 39' 0" longitude east. Situated at 1560 meters above sea level. the population of Agaro town was 23246in 1994; 25458 in 2007, and 37400 in 2015 (census,). Location of the research area on the map of Ethiopia is shown in figure 3.1 below.

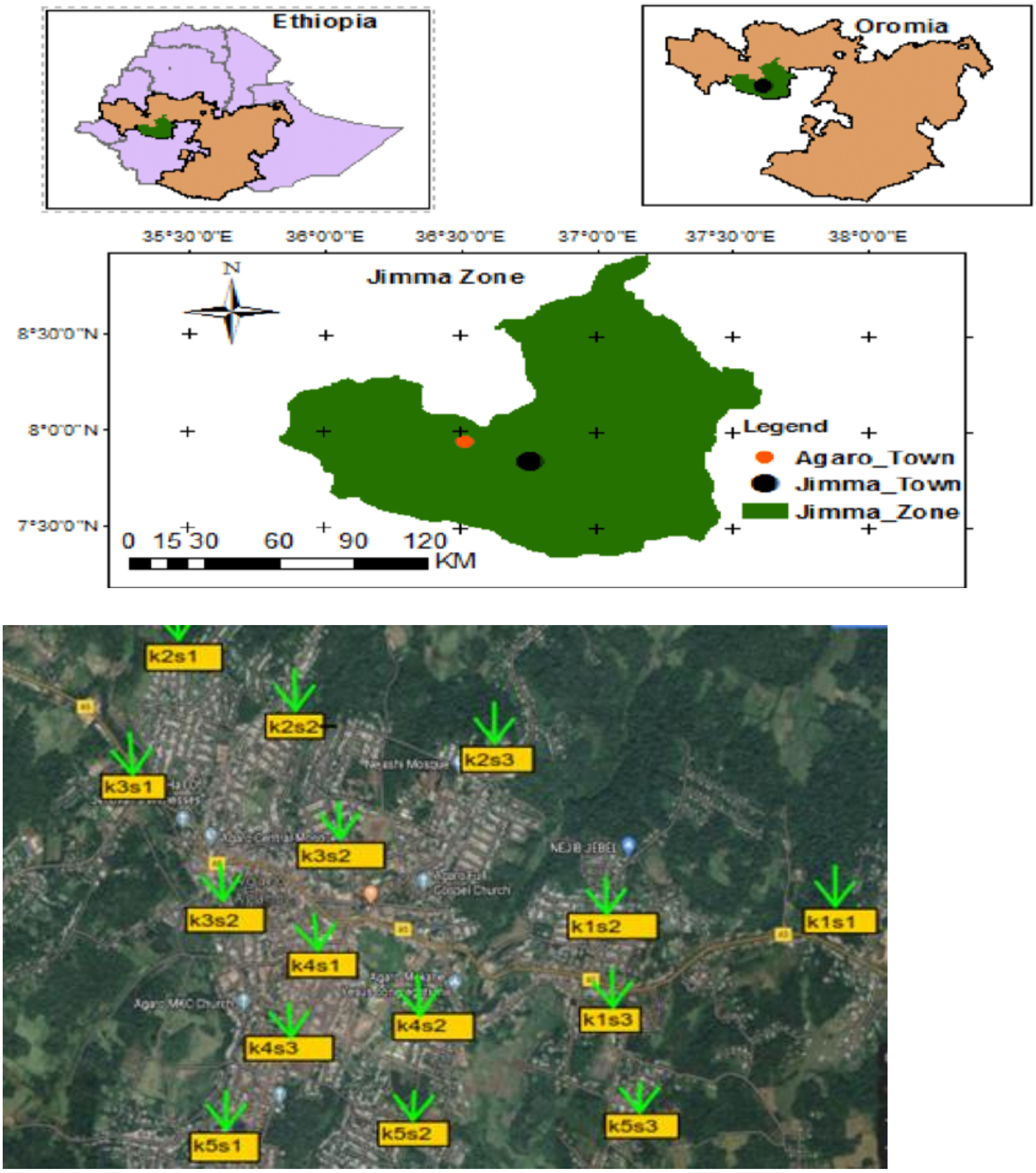


Figure 3- 1; Map of study area (source: google map)

3.2 Research design

The research is designed to attain the specific objective of the study based on a purposive sampling selection process in terms of which a representative sample of materials was taken, and the research was conducted by using both Experimental and Statistical methods. This means that the methodology used in the research is a laboratory analysis of sample data collected from the site, and statistical analysis of simple linear regression and multiple regression will be computed using SPSS software Version 24.0.

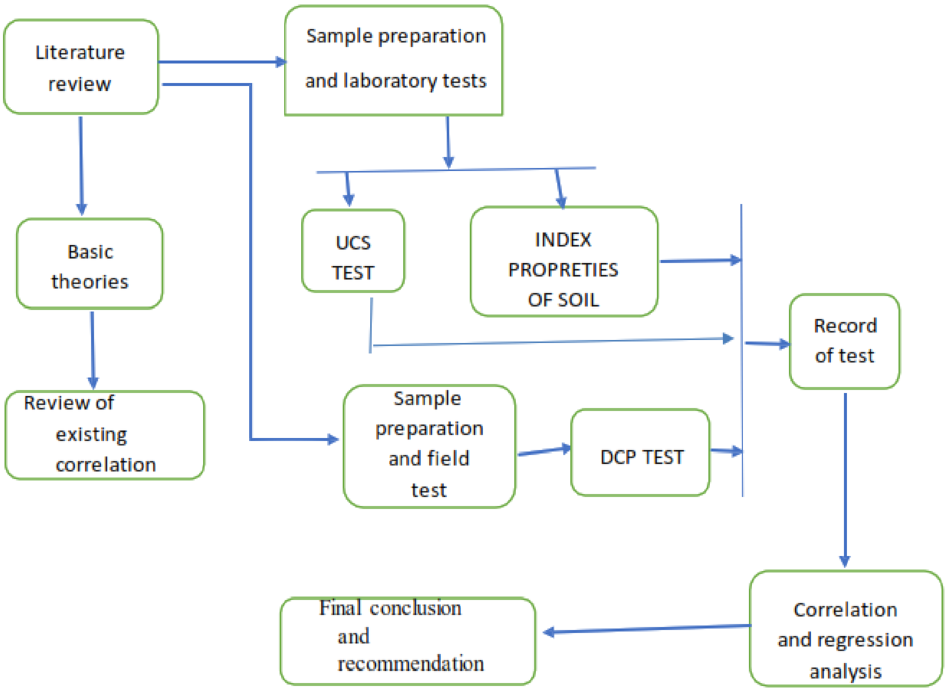


Figure 3- 2: Flow chart of the study

3.3 Data collection process

The data needed for this research were collected from both primary and secondary sources.

Primary sources: - Samples were collected from each test pit, then different laboratory tests were conducted, and the results were recorded.

Secondary sources: - are different journals, previous thesis, books, and websites.

Sampling locations were selected within and outskirts of Agaro town using a purposive sampling technique. Soil samples were collected. The collected soil samples from the field are further analysed in the laboratory to classify and categorize the soil type and also analysed field test and determine the regression and correlation analysis.

Fifteen test pits were excavated using local labor, and samples were collected from each test pits at different depth in different parts of Agaro town. Up to 2 soil samples are taken from one test pit at 1.5m and 3m, in total thirty samples collected for further laboratory investigations and thirty field test is done. Disturbed samples were gathered from test pits to determine index properties, soil classification. Before selecting sampling areas, visual site investigation and information from administrators, residents, and construction organizations were collected to consider soil types and to take samples evenly in the whole town. After observation of the soil type in the whole town, 15 sampling areas were selected from different locations of the town.

3.4 Data processing and analysis

3.4.1 Field Analysis

The DCP test is to be conducted according to new standard test method, ASTM D6951/D6951M-09 [21]. Before using the DCP apparatus, Webster et al. [20], 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 [22]. It should be notable 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, the first few blow excluded (or consider zero) the initial penetration can represent the actual conditions.

3.4.2 Laboratory analysis

The engineering properties soils are classified and identified based on index properties and other tests. Some of this property of soil are; Natural moisture content, Specific gravity, Grain size analysis, Atterberg limit test, and UCS. The entire laboratory tests are performed in Jimma Institute of Technology Geotechnical Laboratory using the following standard testing procedures, (Table 3-1).

Table 3- 1: Standard testing procedures

Test Description	Standard Testing Procedure
Natural Moisture Content	ASTM D 2216
Grain Size Distribution Analysis	ASTM D 422
Atterberg Limits	ASTM D 4318
Specific Gravity	ASTM D 854
Unconfined Compressive Strength	ASTM D2166

3.5 Correlation and regression analysis

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

Fitting a regression model requires several assumptions. The method of least squares is used in order to choose the best fitting line for a set of data. Estimation of the model parameters requires the assumption that, the residuals (actual values less estimated values) corresponding to different observations are uncorrelated random variables with zero mean and constant variance (σ^2). In most practical situation, the variance (σ^2) of the random error (ε) will be unknown and must be estimated from the sample data [23]. The standard error of an estimate gives some idea about the precision of an estimate. During modeling, a variable that shows the least standard error of estimates is the one to be chosen.

A convenient way of measuring how well the regression model performs as a predictor of the dependent variable is to compute the reduction in the sum of squares of deviations that can be attributed to regressor variables and this quantity termed the coefficient of determination, R^2.

The value of R^2 is always between 0 and 1, because R is between -1 and +1, whereby a negative value of R indicates inversely relationship and positive value implies direct relationship. Many problems in engineering require that we decide whether to accept or reject a statement about some correlations. A number of techniques can be used to judge the adequacy of a regression model some of which are standard error (α), R-squared value (R^2), R-adjusted and the t-test [23]. In this study two sets of investigations are conducted. The first set considers UCS as the dependent variable whereas DCPI, γdry, NMC, LI, LL, and PI are independent variables. The second set considers DCPI as the dependent variable and the independent parameters employed for the investigation of UCS are used. To carry out statistical analysis, Microsoft® excel was used for single regression with both linear and non-linear functions whereas SPSS was use for multiple regression. Different models are used and those models with a higher value of coefficient of determination are accepted. Variable numbers of samples are used in correlating the different parameters. So, coefficients of determinations encountered cannot be simply described in narrative terms due to the fact that correlations between different parameters varied from correlation to correlation. The statistical significance of correlation is a function of the number of data being analysed.

CHAPTER FOUR

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 ASTM D6951/D6951M-09, 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.

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 , Natural Moisture Content (NMC), dry density, Unconfined Compression Strength (UCS) and Specific Gravity (Gs) test results are summarized in Table 4-1

Based on the obtained test results of plasticity and grain size distribution the soil classification was made and the result shows that all the sample are classified as fine grained soil. In accordance to the USCS classification system

4.3 Soil classification

The Unified Soil Classification System (USCS) is used to classify soils of the study area.

Table 4- 1: Grain size analysis distribution result of each test pit

Test Pit	**Depth**	**Percent amount of particle Size**			**LL (%)**	**PI (%)**	**Classification according to USCS**
		Gra	**Sand**	**Clay**			
TP1.K01	1.5	0.03	2.29	97.68	30	12	**CL**
	3	25	31.75	43.25	49	8	**OL**
TP2. K01	1.5	1.72	10.29	87.99	70	39	**CH**
	3	1	7	92	66	25	**CH**
TP3.K01	1.5	0	1.66	98.34	49	34	**CL**
	3	0.03	0.61	99.36	70	21	**MH**
TP1.K02	1.5	0.02	3.36	96.62	27.84	4.12	**ML**
	3	0.04	1.05	98.91	35	19	**CL**
TP2. K02	1.5	0.03	2.36	97.61	93	62	**CH**
	3	0.02	1.6	98.38	51	19	**MH**
TP3.K02	1.5	0.03	1.08	98.89	72	40	**CH**
	3	0.78	9.78	89.44	43	10	**ML**
TP1.K03	1.5	22.98	31.93	45.09	35	9	**ML**
	3	0.26	2.99	96.75	73	20	**MH**
TP2.K03	1.5	0	1.02	98.98	73	36	**MH**
	3	25.96	24.08	49.96	44	14	**ML**
TP3.K03	1.5	0.12	2.06	97.82	55	22	**MH**
	3	0.42	4.272	95.308	60.72	17	**MH**
TP1.K04	1.5	0	6.44	93.56	45.79	20.05	**CL**
	3	0	0.98	99.02	80	39	**MH**
TP2.K04	1.5	0.58	3.5	95.52	102.6	50	**MH**
	3	0.09	4.64	95.27	74	27	**MH**
TP3.K04	1.5	2.5	10.62	86.65	52	2	**MH**
	3	0	2.44	97.56	88	57	**CH**
TP1.K05	1.5	0	2.35	97.65	37	6	**CL**
	3	0.4	1.164	98.436	79.51	30	**MH**
TP2.K05	1.5	0.72	3.937	95.343	95.67	30	**MH**
	3	0.7	3.2	96.1	66	33	**CH**
TP3.K05	1.5	0.12	3.46	96.42	62	8	**MH**
	3	0.126	1.944	97.93	67	33	**CH**

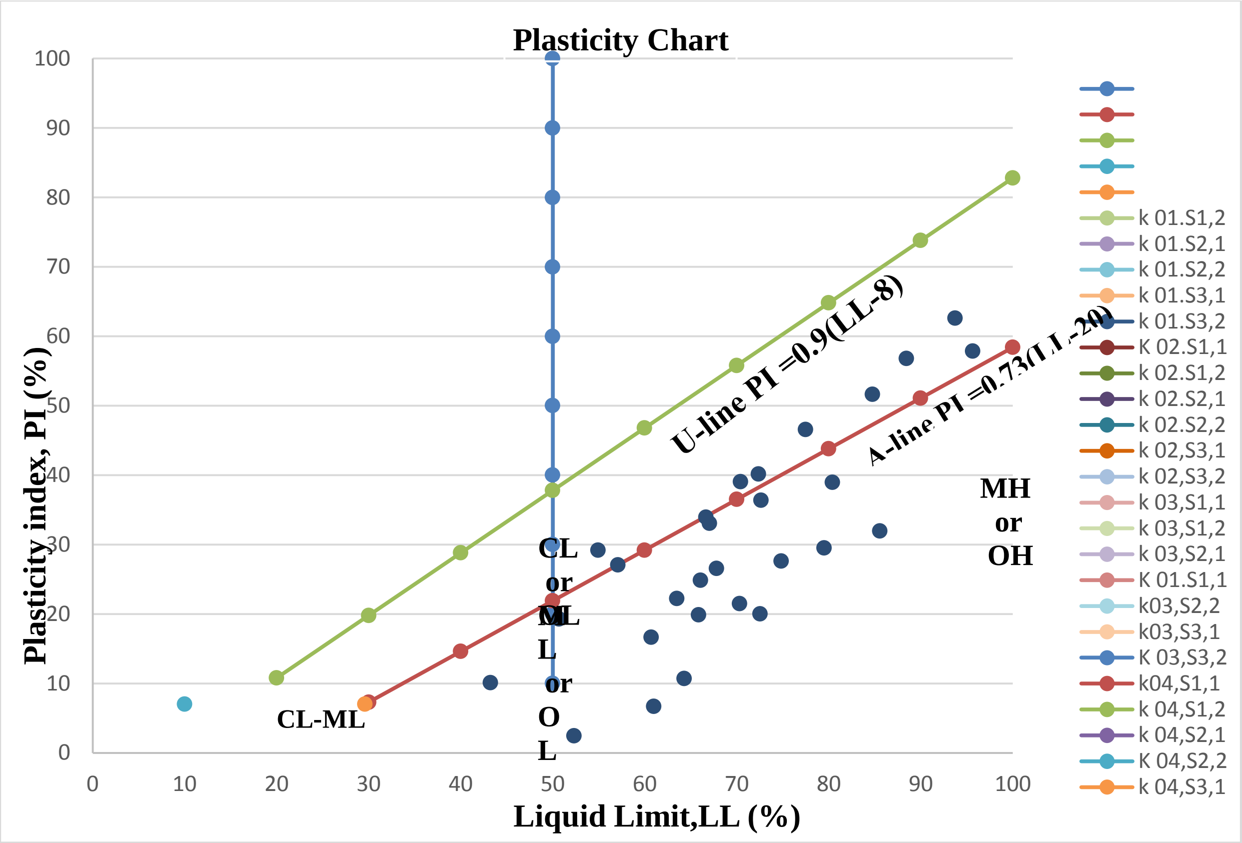


Figure 4- 1: USCS Soil classification chart result

According to USCS from Tabel 4.1 above, half of the soil of the study area falls under MH ,CL,OL,CH ,and ML the rest are categorized CH.

Table 4- 2: Summary of test results

Sample No.	Sample Designation	sample depth	DCPI	NMC	Gs	dry unit weight γdry	UCS	LL	PL	PI
		mm	mm/blow	%		kN/cu.m	kN/m2	%	%	%
1	K 01.S1,1	1500	85.5	38.5	2.72	12.3606	149.85	30.06	17.56	12.5
2	k 01.S1,2	3000	66.92	22.45	2.77	15.1644	189.56	48.96	41.23	7.73
3	k 01.S2,1	1500	72.08	35.9	2.74	13.5378	156.6	70.41	31.34	39.07
4	k 01.S2,2	3000	88.4	36.1	2.77	12.5568	143.81	66.06	41.21	24.85
5	k 01.S3,1	1500	81.08	35.96	2.78	14.5789	156.3	49.37	34.1	15.27
6	k 01.S3,2	3000	71.83	38.8	2.73	13.5808	139.88	70.32	48.83	21.49
7	K 02.S1,1	1500	78.44	34.2	2.75	13.0473	142.71	27.84	23.72	4.12
8	k 02.S1,2	3000	80.15	38.9	2.7	12.1454	114.25	34.83	15.89	18.94
9	k 02.S2,1	1500	90.32	39.31	2.76	13.0473	118.75	93.76	31.16	62.6
10	k 02.S2,2	3000	66.67	18.4	2.81	15.8131	214.26	50.68	31.4	19.28
11	k 02,S3,1	1500	92.83	38.6	2.72	12.4302	125.28	72.38	32.24	40.14
12	k 02,S3,2	3000	68.33	20.4	2.83	16.5245	197.83	43.24	33.12	10.12
13	k 03,S1,1	1500	65.77	26.3	2.78	14.696	168.2	34.64	25.42	9.22
14	k 03,S1,2	3000	69.17	24.3	2.77	15.9903	186.76	54.89	33.13	21.76
15	k 03,S2,1	1500	66.54	26.5	2.76	15.696	176.6	72.65	36.28	36.37
16	k03,S2,2	3000	68.97	28.5	2.76	14.5568	178.21	43.67	30.04	13.63
17	k03,S3,1	1500	73.83	32.3	2.75	12.753	153.14	84.76	33.13	51.63
18	K 03,S3,2	3000	75.01	33.3	2.74	13.1454	140.39	60.72	44.06	16.66
19	k04,S1,1	1500	72.08	25.44	2.79	16.6359	202.63	45.79	25.75	20.04
20	k 04,S1,2	3000	65.34	34.1	2.75	13.4397	165.79	80.43	41.48	38.95
21	k 04,S2,1	1500	85.63	35.5	2.74	13.2435	118.04	102.6	53.03	49.57
22	K 04,S2,2	3000	70.54	29.6	2.72	13.6549	162.23	74.83	47.215	27.615
23	k 04,S3,1	1500	71.67	25.1	2.77	14.3416	174.82	52.32	49.895	2.425
24	k 04,S3,2	3000	81.25	35.7	2.73	11.4397	126.84	88.44	31.65	56.79
25	k 05,S1,1	1500	96.67	43.1	2.71	11.1644	97.02	36.99	30.98	6.01
26	k 05,S1,2	3000	87.55	46.1	2.71	11.5758	114.94	79.51	50	29.51
27	k05,S2,1	1500	95.83	39.1	2.73	12.2435	112.29	95.67	37.8	57.87
28	k05,S2,2	3000	95.04	33.23	2.72	13.5283	137.5	66.67	32.76	33.91
29	k 05,S3,1	1500	72.08	30.6	2.75	14.6473	185.13	60.99	54.32	6.67
30	k 05 S3,2	3000	75.45	27.08	2.77	13.9492	174.67	67.04	34	33.04

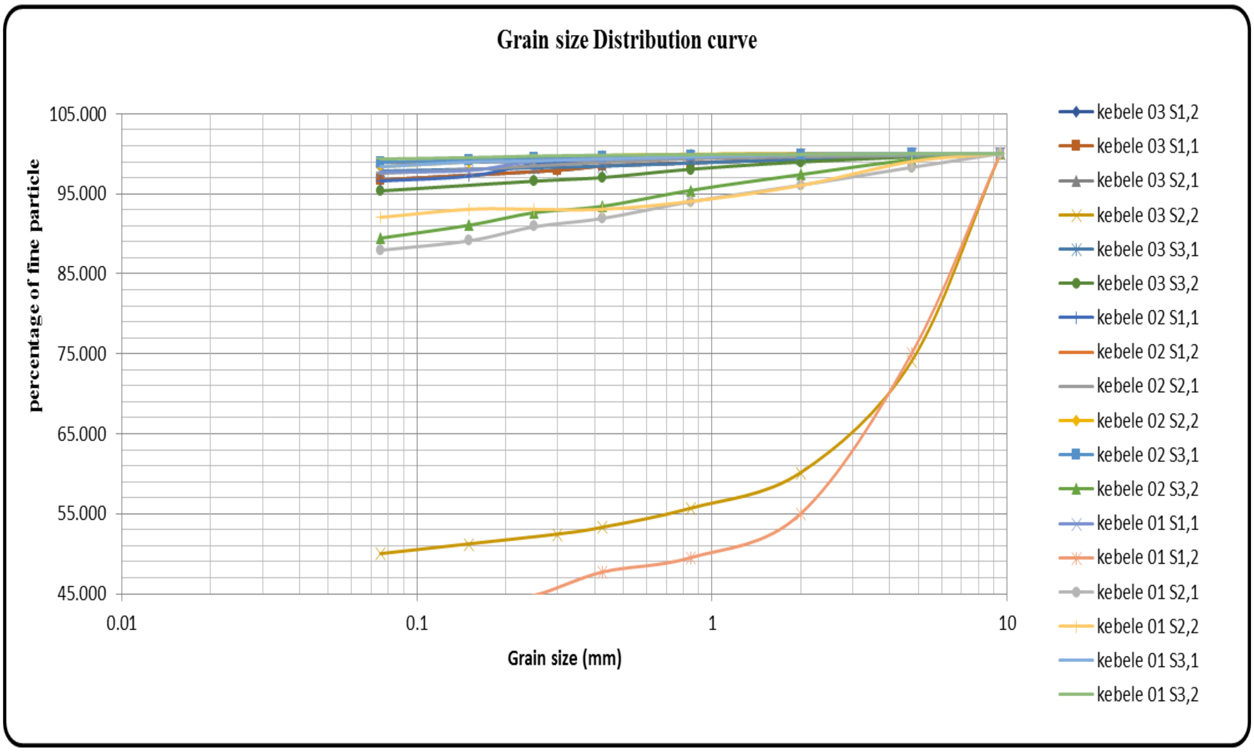


Table 4- 3: Particle Sizes Distribution Curve

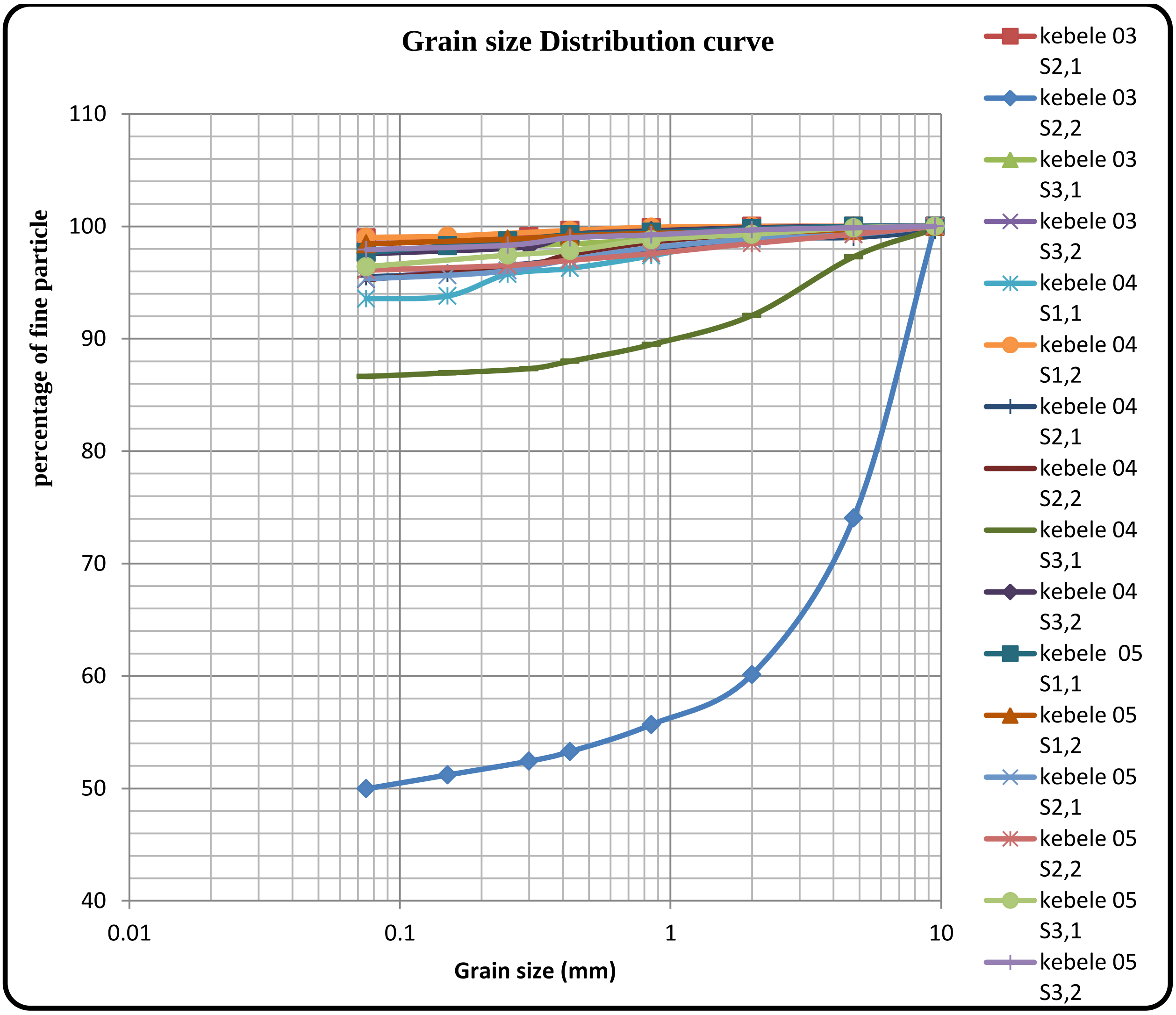


Figure 4- 2: Particle Sizes Distribution Curve

CHAPTER 5

CORRELATION ANALYSIS

5.1 General

Regression analysis is concerned with the procedure how the values of Y depend on the corresponding values of X. Y, whose value is to be predicted, is known as dependent variable and X, which is used in predicting the value of dependent variable, is called independent variable. A regression model that contains more than one independent variable is called multiple regression models. Alternatively, regression model containing one independent variable is termed as simple regression model.

Fitting a regression model requires several assumptions. Estimation of the model parameters requires the assumption that, the residuals (actual values less estimated values) corresponding to different observation are uncorrelated random variables with zero mean and constant variance.

Test of hypothesis and interval estimation requires that the error be normally distributed. In addition, one assumes that the order of model is correct; that is, if one fits a simple linear regression model, one is assuming that the phenomenon actually behaves in a linear or first order manner. During regression analysis, a regression model with higher value coefficient of determination (R^2), which quantifies the proportion of the variance of one variable by the other, is accepted [24].

In this thesis two sets of investigations have been conducted. The first set considers UCS as the dependent variable whereas DCPI, γdry, NMC, PL, LL, PI and Depth are independent variables. The second set considers DCPI as the dependent variable and the independent parameters employed for the investigation of UCS are used. To carry out statistical analysis, Microsoft® excel was used for single regression with both linear and non-linear functions whereas SPSS was use for multiple regression. Different models are used and those models with a higher value of coefficient of determination are accepted. Variable numbers of samples are used in correlating the different parameters. So, coefficients of determinations encountered cannot be simply described in narrative terms due to the fact that correlations between different parameters varied from correlation to correlation. The statistical significance of correlation is a function of the number of datasets being analysed. As a result, when a parameter's correlation is described as "good", "fair" or "poor" in later discussions, the description is given for the relation being discussed.

5.2 Single Linear regression

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), dry density (γdry), Liquid limit (LL), plastic limit (PL), and plastic index (PI).

In single mathematical model analysis, the following general model equations are more preferable or give higher coefficient of determination R^2

I. Linear,

$$UCS = Ax + B$$

II. Power,

$$UCS = A * e^{Bx}$$

III. Logarithmic,

$$UCS = A * \ln[x] + B$$

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

IV. polynomial,

$$UCS = Ax^2 + Bx + C$$

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

5.2.1 Scatter Plot

A scatter plot matrix is shown in Figure 5.1 to 5.7; it indicates the relationship between the independent and dependent variables used for the analysis. Though it is a statistical fact that high correlations between the independent variables improve the regression coefficient R^2 of a model, it is sometimes unrealistic due to the interactions between the independent variables. The statistical strength of the model does not change even though the R^2 increases; this is due to collinearity. Consequently, scatter plots becomes a significant method to estimate the linearities and relationship between the quantitative variables in a data set**.**

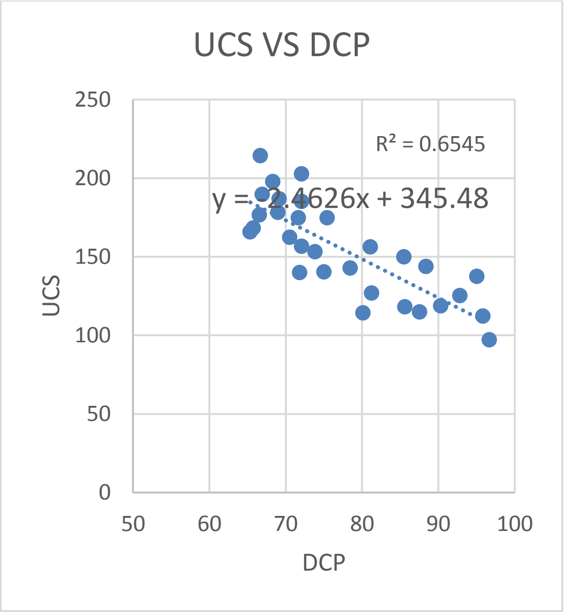


Figure 5- 1: Scatter plot UCS VS DCP

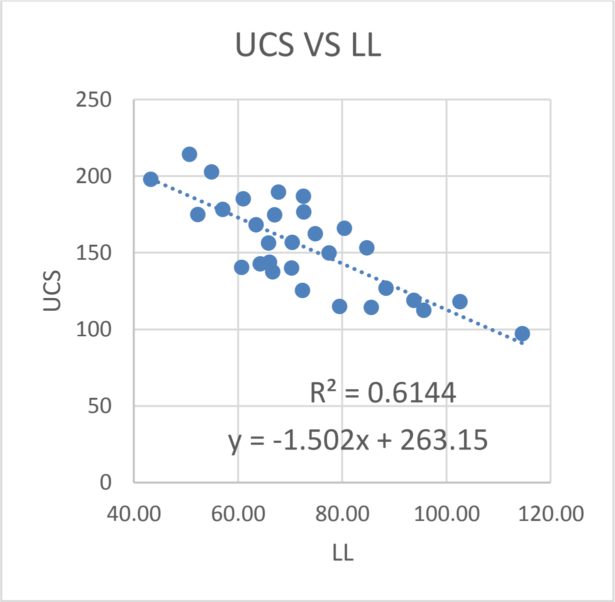


Figure 5- 2: Scatter plot UCS VS LL

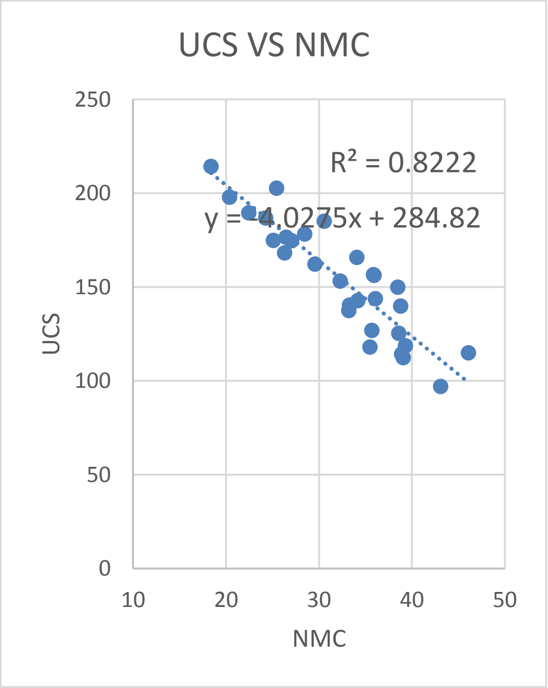


Figure 5- 3 Scatter plot UCS VS NMC

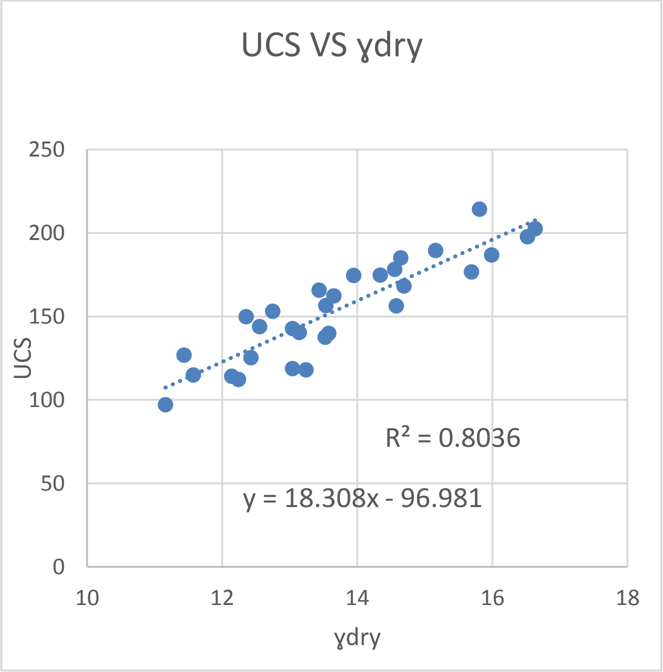


Figure 5- 4: Scatter plot UCS VS ɣdry

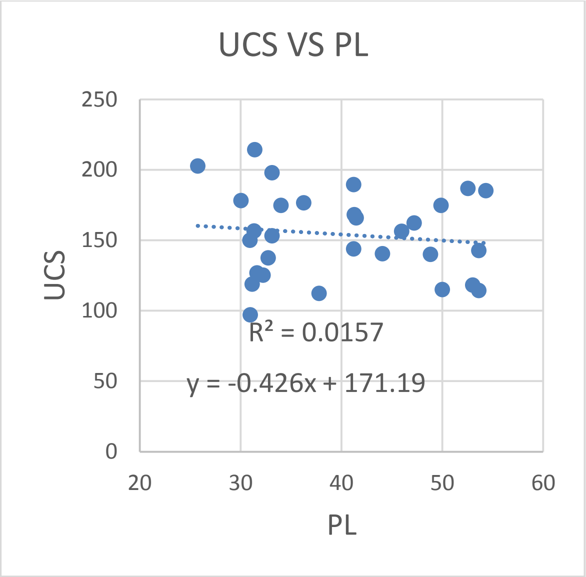


Figure 5- 5: scatter plot UCS VS PL

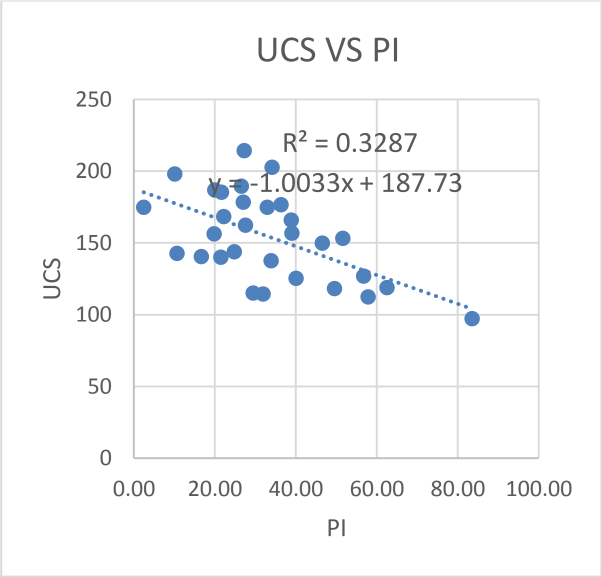


Figure 5- 6: Scatter plot UCS VS PI

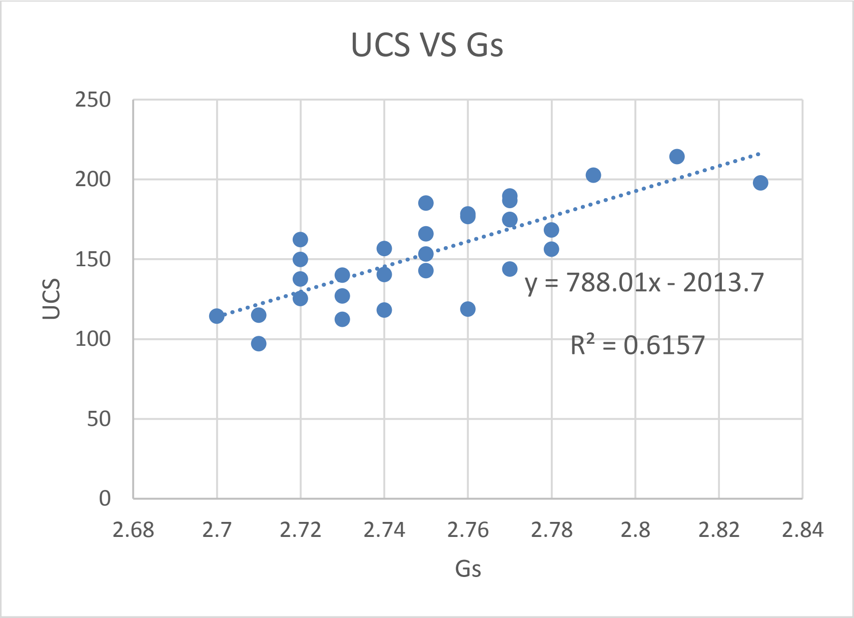


Figure 5- 7: Scatter plot UCS VS Gs

Table 5- 1: Summary of correlation equations and R^2

Dependable Item	Variable Item	Equation	R^2
UCS	DCPI	$y = -2.4626x + 345.48$	0.6545
	LL	$y = -1.502x + 263.15$	0.6144
	NMC	$y = -4.0275x + 284.82$	0.8222
	PI	$y = -1.0033x + 187.73$	0.3287
	ɣdry	$y = 18.308x - 96.981$	0.8036
	Gs	$y = 788.01x - 2013.7$	0.6157

5.3 Multiple Correlations

Multiple regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting an equation to observed data. Every value of the independent variable x is associated with a value of the dependent variable y. To examine the combined effect of some index property on UCS and also DCPI, a multiple regression analysis is conducted. The basic form of the equation is as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon$$

……………………………………………………………………. (5.1)

Model 1: Correlation Between UCS with DCP and NMC

The resulting regression analysis after correlating UCS with DCPI and NMC is expressed by the following multiple linear equations with its corresponding correlation coefficients:

UCS = 323.808 -9.18DCPI- 3.032NMC with R^2 =0.863, Adj. R^2 =0.853 n=30

The details of the statistical out-put of Model A indicates that the relationship developed between UCS with DCPI and NMC is significant ($\alpha<0.05$) as shown in Appendix C

Model 2: Correlation Between UCS with DCP and ɣdry

The resulting regression analysis after correlating UCS with DCP and ɣdry is expressed by the following multiple linear equations with its corresponding correlation coefficients:

UCS = 54.966 – 1.063DCP +13.255 ɣdry with R^2 = 0.864 Adj. R^2 = 0.854

The details of the statistical out-put of Model A indicates that the relationship developed between UCS with NMC and PI is significant ($\alpha<0.05$).

Model 3: Correlation Between UCS with DCPI,PL and PI

The resulting regression analysis after correlating UCS with DCPI, PL and PI is expressed by the following multiple linear equations with its corresponding correlation coefficients:

$UCS = 377.174 - 1.744\ DCPI - 1.501PL - 0.844PI$ with $R^2 = 0.833$ Adj. $R^2 = 0.814$

The details of the statistical out-put of Model A indicates that the relationship developed between UCS with DCPI, PL and PI is significant ($\alpha<0.05$).

Model 4: Correlation Between UCS with Gs, DCPI, ɣdry and NMC

The resulting regression analysis after correlating UCS with LL, DCPI, ɣdry and NMC is expressed by the following multiple linear equations with its corresponding correlation coefficients:

$UCS = 202.211 - 0.673\ DCPI + 6.03\gamma dry - 0.406LL - 1.511NMC$ with $R^2 = 0.918$ Adj. $R^2 = 0.905$

The details of the statistical out-put of Model A indicates that the relationship developed between UCS with LL, DCPI, ɣdry and NMC is significant ($\alpha<0.05$), Besides, the R value of Model 4 is better than all the above stated models. Furthermore, the detail of Model 4 is shown in Appendix C.

CHAPTER-6

DISCUSSION ON CORRELATION RESULTS

6.1 The Developed Correlation

The validation of the developed correlation is conducted by known test results which is from research by Tariku Tafari "Statistical Modeling for the Prediction of Undrained Shear Strength from Index Properties of Cohesive Soils found in Agaro Town". DCPI test results were obtained from field test from different localities of Agaro town. Depending on the relative significance order, Model 4 (UCS = 202.211-0.673 DCPI+6.03γ_{dry} -0.406LL - 1.511NMC) is preferably selected among the different alternative correlations for further verifications. Subsequently, using the control test results and the developed correlation equation, the predicted UCS is determined so as to compare it with the actual UCS value as shown in Table 6.1:

Table 6- 1: Validation of the Developed Correlation

Designation of Test sample	DCP	NMC	GS	ɣdry	LL	PI	UCS actual value from tariku	ucs predicted value	vartion (%)
K 01.S1,1	38.5	85.5	2.72	12.3606	30.06	12.5	105.94	109.439058	3.302868
k 01.S2,1	35.9	72.08	2.74	13.5378	70.41	39.07	121.24	122.182894	0.777709
k 02.S1,2	38.9	80.15	2.7	12.1454	34.83	18.94	117.02	114.019432	2.56415
k02 S3,1	38.6	92.83	2.72	12.4302	72.38	40.14	90.57	81.533896	9.976928
k 03,S3,1	32.3	73.83	2.75	12.753	84.76	51.63	103.76	111.403	7.366037
k 03,S3,2	33.3	75.01	2.74	13.1454	60.72	16.66	119.84	121.073432	1.029232
k04,S2,1	35.5	85.63	2.74	13.2435	102.6	49.57	94.02	87.134275	7.323681
k 04,S3,2	35.7	81.25	2.73	11.4397	88.44	56.79	94.52	88.489901	6.379707
k 05,S1,1	43.1	96.67	2.71	11.1644	36.99	6.01	86.3	79.438722	7.950496
k 05,S1,2	46.1	87.55	2.71	11.5758	79.51	29.51	87.34	76.417664	12.50554

Further to the above, in order to figure out and verify the suitability of the developed correlation using a control test results, a comparison graph is plotted between the actual UCS (UCS actual) and predicted UCS (UCS Predicted) as shown in Figure 6.1:

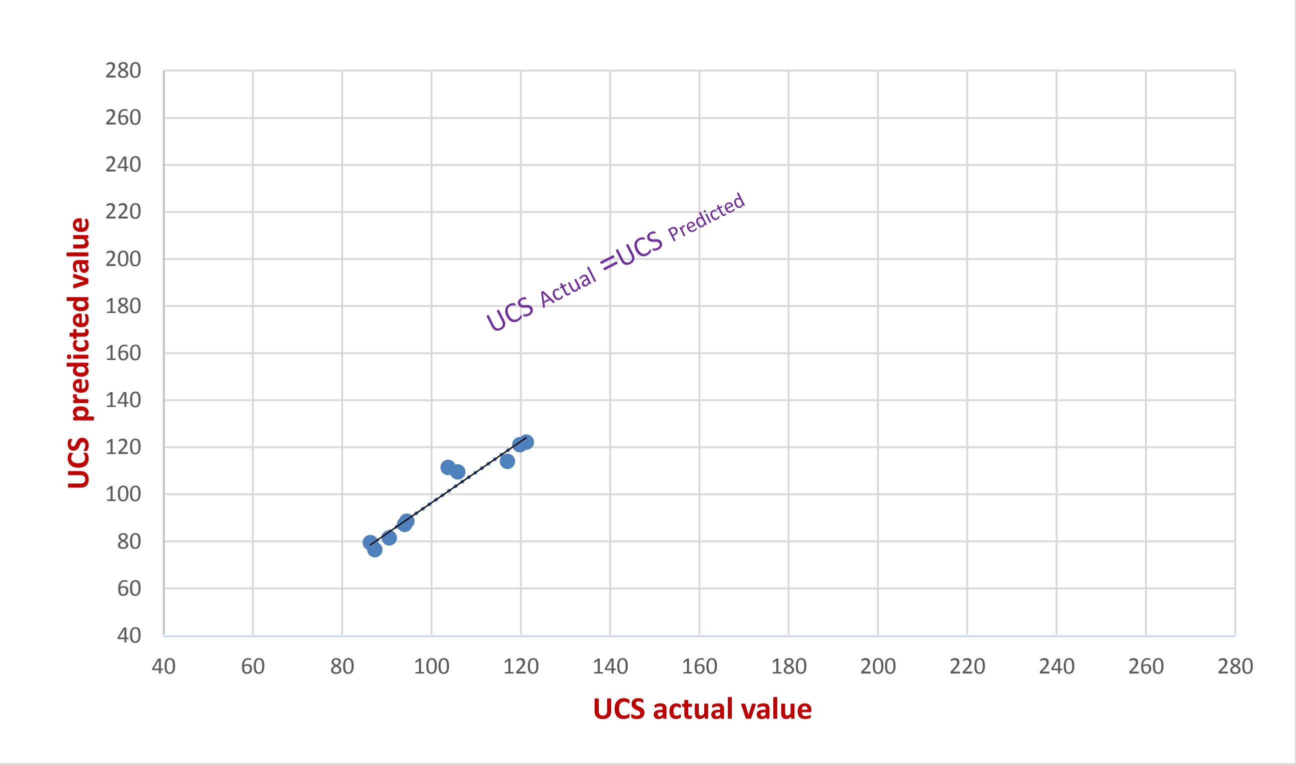


Figure 6- 1: UCS Actual Value vs. UCS Predicted Value

In general, the above scatter plot on Figure 6.1 & Table 6.1 illustrated that the predicted UCS value scatters near the straight line, through which the actual and predicted UCS value is equal, although there is little bit variation between the actual and the measured UCS.

CHAPTER-7

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The major findings and observations are stated in this section. The objective of introducing DCP as a simple test device that is inexpensive, portable, and easy to operate and applying of the equipment for determination of Unconfined Compression Strength of soils is dealt in this thesis. The research was conducted to find a localized correlation between UCS, DCPI and soil index properties within the scope of the study. Accordingly, the required laboratory tests were conducted on samples retrieved from different location of Agaro town. Using the obtained thirty test results a single and multiple linear regression were analysed and a relationship was developed that predict UCS value in terms of DCPI, Gs, LL, PL, PI, ɣdry and NMC.

From the Control test result the predicted value of UCS the result highly approximated to the actual value of UCS sample on the study area. Therefore, 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,V ɣdry, LL and NMC. Therefore, for multiple regression analysis Unconfined Compression Strength (UCS) is better estimated when Dynamic Cone Penetration Index (DCPI), ɣdry ,LL and NMC are introduced as independent variable.

7.2 Recommendation

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. It is recommended to carry out this correlation with a large number of samples including different location of Agaro town which are not covered by this research. It is advisable to conduct frequent researches in different types of soil and increase the sampling depth more than 3m , due to the fact that soil property varies from place to place and seasonally.

Different correlation like correlation between DCP and UCS should be done in the study area since the study area is exposed to rapid civil engineering work. mIt is also recommended to carry out such a study in other parts of Ethiopia

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APPENDIX – A

Field Tests Result

DCPI

A – 1) DCPI Result for Kebele 01 S1,1 at 1.5m depth

No	No. of blows	Cumm. Blows	Depth of penetration (mm)	Penetration rate (mm/blow)
1	0	0	55	55
2	2	2	160	105
3	2	4	230	70
4	3	7	330	100
5	5	12	440	110
6	5	17	540	100
7	5	22	620	80
8	5	27	715	95
9	3	30	760	45
10	5	35	855	95

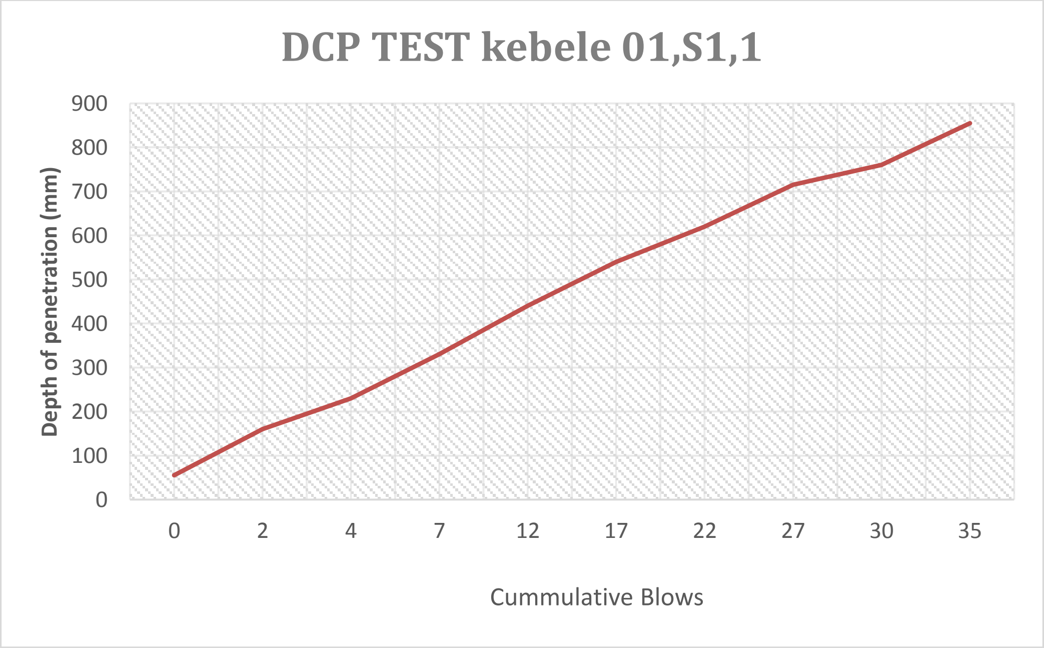


Figure A-1.1 the Dynamic Cone penetration for K01,S1,1

A – 2) DCPI Result for Kebele 01 S1,2 at 3m depth

No	No. of blows	Cumm. Blows	Depth of penetration (mm)	Penetration rate (mm/blow)
1	0	0	60	60
2	1	1	92	32
3	1	2	130	38
4	2	4	205	75
5	2	6	275	70
6	3	9	355	80
7	3	12	444	89
8	2	14	525	81
9	2	16	608	83
10	5	21	671	63
11	2	23	745	74
12	5	28	810	65
13	2	30	870	60

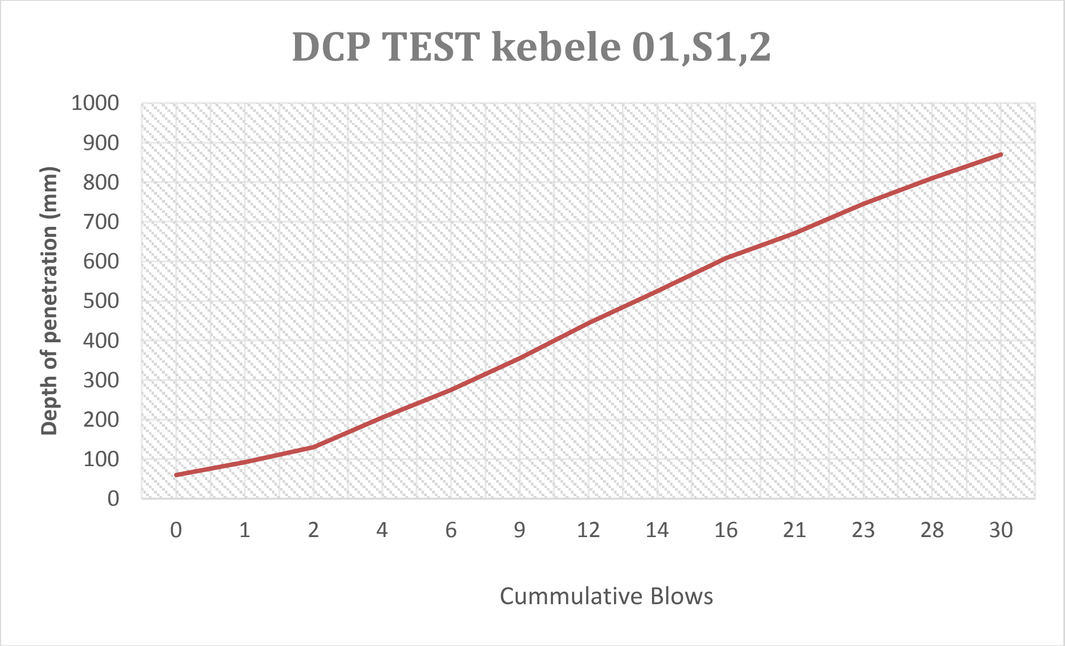
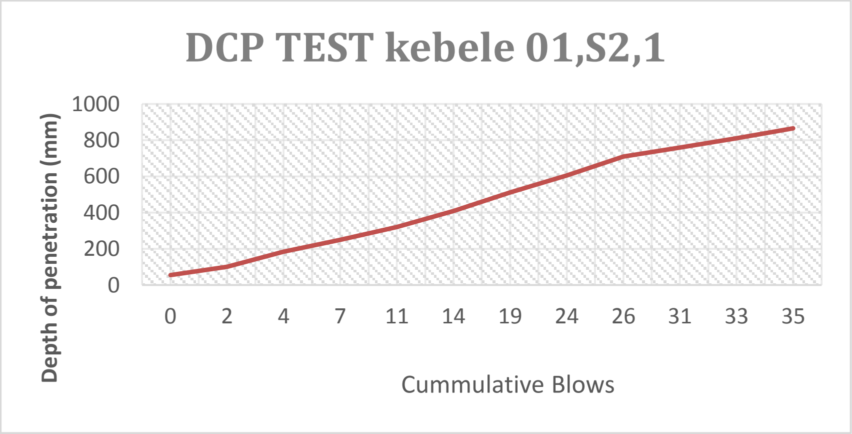


Figure A-1.2 the Dynamic Cone penetration for K01,S1,2

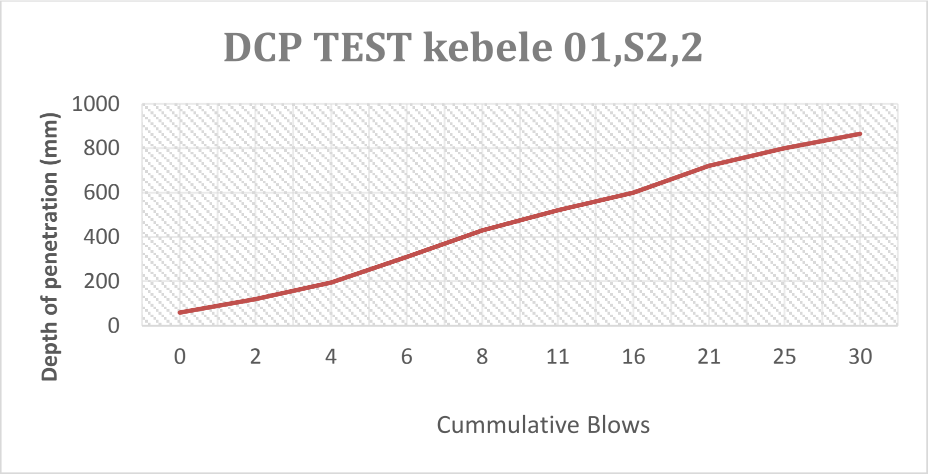
A – 3) DCPI Result for Kebele 01 S2,1 at 1.5m depth

No	No. of blows	Cumm. Blows	Depth of penetration (mm)	Penetration rate (mm/blow)
1	0	0	55	55
2	2	2	102	47
3	2	4	185	83
4	3	7	250	65
5	4	11	320	70
6	3	14	410	90
7	5	19	511	101
8	5	24	605	94
9	2	26	710	105
10	5	31	760	50
11	2	33	810	50
12	2	35	865	55



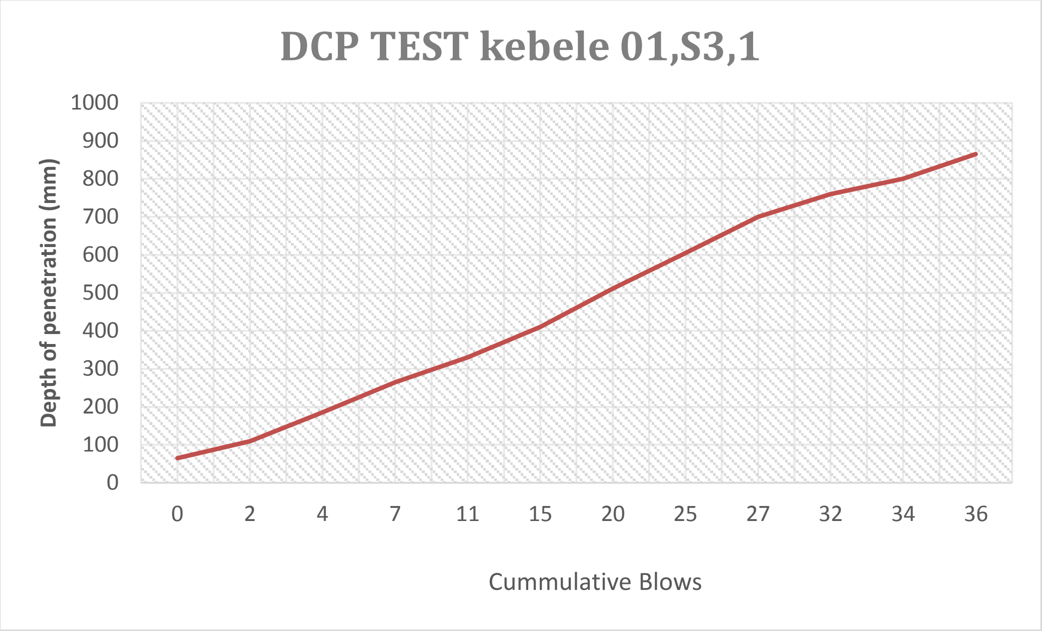
A – 4) DCPI Result for Kebele 01 S2,2 at 3m depth

No	No. of blows	Cumm. Blows	Depth of penetration (mm)	Penetration rate (mm/blow)
1	0	0	60	60
2	2	2	120	60
3	2	4	195	75
4	2	6	310	115
5	2	8	430	120
6	3	11	520	90
7	5	16	600	80
8	5	21	720	120
9	4	25	800	80
10	5	30	864	64



A – 5) DCPI Result for Kebele 01 S3,1 at 1.5m depth

No	No. of blows	Cumm. Blows	Depth of penetration (mm)	Penetration rate (mm/blow)
1	0	0	65	65
2	2	2	110	45
3	2	4	185	75
4	3	7	265	80
5	4	11	330	65
6	4	15	410	80
7	5	20	511	101
8	5	25	605	94
9	2	27	700	95
10	5	32	760	60
11	2	34	800	40
12	2	36	865	65



A – 5) DCPI Result for Kebele 02 S1,1 at 1.5m depth

No	No. of blows	Cumm. Blows	Depth of penetration (mm)	Penetration rate (mm/blow)
1	zero reading	0	45	45
2	2	2	103	58
3	2	4	160	57
4	2	6	211	51
5	5	11	325	114
6	2	13	377	52
7	2	15	435	58
8	3	18	530	95
9	3	21	638	108
10	3	24	730	92
11	3	27	810	80
12	2	29	864	54

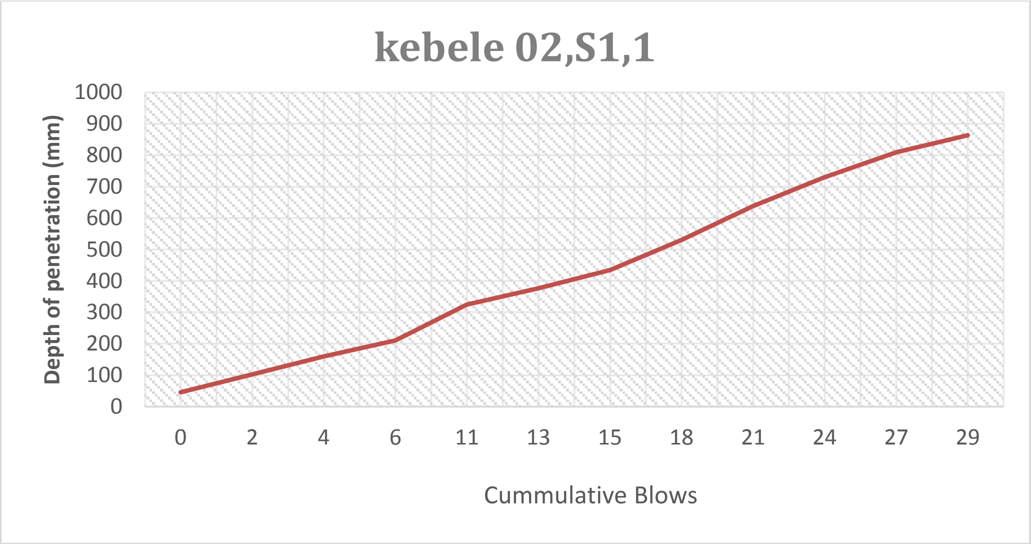


Figure A-1.3 the Dynamic Cone penetration for K02,S1,1

APPENDIX – B

Laboratory Test Results

B-1) Unconfined Compression Strength

B-1.1 UCS Result for Kebele 01 S1,1 at 1.5m , S1.2 at 3m and S2,1 at 1.5m depth

Sample data:			
No of sample	**S1,1**	**S1,2**	**S2,1**
Height, Ho (mm) =	76.90	76.70	75.80
Diameter, D (mm) =	38.00	38.00	38.00
Mass, (gm) =	151.768	149.349	156.084
Area, (cm^2) =	11.34	11.34	11.34
Volume (cm^3) =	87.17	86.94	85.92
Wet density (gm/cm^3) =	1.74	1.72	1.75
Dry density, ρd (gm//cm^3)=	1.26	1.24	1.38
Unconfined compressive strength,qu (kN/m^2)=	**149.85**	**189.56**	**156.60**
Cohesion,Cu (kN/m^2)=	**74.92**	**94.78**	**63.30**

Deformation Height (mm)	**Reading load S1,1 (N)**	**Reading load S1,2 (N)**	**Reading load S2,1 (N)**	**Strain for K01 S1,1 (%)**	**Strain for K01 S1,2 (%)**	**Strain for K01 S2,1 (%)**	**Stress for K01 S1,1 (kPa)**	**Stress for K01 S1,1 (kPa)**	**Stress for K01 S2,1 (kPa)**
0.00	0	0	0	0.0	0.0	0.0	0.00	0.00	0.00
0.05	18.948	13.534	1.083	0.1	0.1	0.1	16.70	11.93	0.95
0.10	30.316	17.865	2.707	0.1	0.1	0.1	26.71	15.74	2.38
0.15	38.437	21.654	3.248	0.2	0.2	0.2	33.84	19.07	2.86
0.20	42.767	24.361	3.248	0.3	0.3	0.3	37.63	21.44	2.86
0.25	47.098	25.985	10.286	0.3	0.3	0.3	41.41	22.85	9.04
0.30	52.512	28.151	13.534	0.4	0.4	0.4	46.14	24.74	11.89
0.35	55.219	30.858	18.406	0.5	0.5	0.5	48.49	27.10	16.16
0.40	58.467	32.482	23.82	0.5	0.5	0.5	51.31	28.51	20.90
0.45	63.339	34.106	27.068	0.6	0.6	0.6	55.55	29.91	23.74
0.50	68.211	37.895	31.94	0.7	0.7	0.7	59.78	33.21	27.99
0.55	72.001	40.061	34.106	0.7	0.7	0.7	63.06	35.09	29.87
0.60	78.497	40.602	40.061	0.8	0.8	0.8	68.71	35.54	35.06
0.65	84.994	44.392	45.474	0.8	0.8	0.9	74.35	38.83	39.77
0.70	87.159	46.016	50.346	0.9	0.9	0.9	76.19	40.22	44.00
0.75	93.114	48.181	56.301	1.0	1.0	1.0	81.34	42.09	49.18
0.80	96.903	50.346	58.467	1.0	1.0	1.1	84.60	43.95	51.03
0.85	101.23	51.429	66.587	1.1	1.1	1.1	88.32	44.87	58.08
0.90	105.02	54.677	70.377	1.2	1.2	1.2	91.56	47.67	61.35
0.95	110.44	57.384	74.708	1.2	1.2	1.3	96.23	50.00	65.08
1.00	112.6	58.467	79.039	1.3	1.3	1.3	98.04	50.91	68.81
1.05	117.48	60.632	82.287	1.4	1.4	1.4	102.22	52.76	71.59
1.10	121.81	62.256	87.159	1.4	1.4	1.5	105.92	54.13	75.78
1.15	126.14	64.963	91.49	1.5	1.5	1.5	109.62	56.45	79.49
1.20	129.93	67.67	96.362	1.6	1.6	1.6	112.83	58.76	83.66
1.25	134.8	68.211	97.986	1.6	1.6	1.6	116.99	59.19	85.02
1.30	138.05	70.377	102.86	1.7	1.7	1.7	119.73	61.03	89.19
1.35	141.84	71.46	107.73	1.8	1.8	1.8	122.93	61.93	93.35
1.40	146.17	74.708	111.52	1.8	1.8	1.8	126.60	64.70	96.56
1.45	147.79	76.332	114.23	1.9	1.9	1.9	127.92	66.07	98.85
1.50	151.58	77.956	119.1	2.0	2.0	2.0	131.11	67.43	102.99

1.55	155.91	81.204	121.26	2.0	2.0	2.0	134.77	70.19	104.79
1.60	157.54	81.204	125.6	2.1	2.1	2.1	136.09	70.14	108.46
1.65	161.33	83.911	128.84	2.1	2.2	2.2	139.27	72.43	111.19
1.70	162.41	85.535	131.01	2.2	2.2	2.2	140.11	73.79	112.98
1.75	164.57	87.159	134.26	2.3	2.3	2.3	141.88	75.14	115.71
1.80	167.82	88.783	135.88	2.3	2.3	2.4	144.58	76.49	117.03
1.85	167.82	90.948	136.96	2.4	2.4	2.4	144.49	78.30	117.88
1.90	169.99	91.49	140.21	2.5	2.5	2.5	146.26	78.71	120.59
1.95	171.07	93.655	141.84	2.5	2.5	2.6	147.09	80.52	121.91
2.00	172.15	94.197	142.38	2.6	2.6	2.6	147.92	80.93	122.29
2.05	172.69	97.986	145.63	2.7	2.7	2.7	148.28	84.13	125.00
2.10	173.24	99.069	144.54	2.7	2.7	2.8	148.66	85.00	123.98
2.15	172.69	100.69	145.08	2.8	2.8	2.8	148.09	86.34	124.36
2.20	174.86	103.4	147.79	2.9	2.9	2.9	149.85	88.60	126.60
2.25	173.78	103.4	146.71	2.9	2.9	3.0	148.82	88.54	125.58
2.30	173.24	105.02	147.79	3.0	3.0	3.0	148.26	89.87	126.42
2.35	174.86	106.65	147.79	3.1	3.1	3.1	149.55	91.20	126.34
2.40	174.86	108.27	147.79	3.1	3.1	3.2	149.45	92.53	126.25
2.45	174.32	109.35	146.71	3.2	3.2	3.2	148.88	93.39	125.24
2.50	173.78	109.9	147.25	3.3	3.3	3.3	148.32	93.79	125.62
2.55	173.24	113.14	145.63	3.3	3.3	3.4	147.76	96.49	124.15
2.60	172.69	114.77	145.08	3.4	3.4	3.4	147.19	97.82	123.60
2.65	173.24	115.85	144.54	3.4	3.5	3.5	147.56	98.67	123.05
2.70	171.61	116.93	144	3.5	3.5	3.6	146.08	99.52	122.51
2.75	172.15	116.93	142.38	3.6	3.6	3.6	146.44	99.46	121.05
2.80	171.61	119.1	142.38	3.6	3.7	3.7	145.88	101.23	120.97
2.85	169.45	121.26	140.21	3.7	3.7	3.8	143.95	103.00	119.04
2.90	167.82	122.35	139.67	3.8	3.8	3.8	142.47	103.86	118.50
2.95	166.74	122.89	138.59	3.8	3.8	3.9	141.45	104.24	117.50
3.00	165.66	123.97	136.42	3.9	3.9	4.0	140.44	105.09	115.59
3.05	163.49	126.14	133.72	4.0	4.0	4.0	138.51	106.85	113.22
3.10	161.87	126.68	132.09	4.0	4.0	4.1	137.04	107.24	111.76
3.15		127.76	130.47		4.1	4.2		108.08	110.32
3.20		128.84	129.39		4.2	4.2		108.92	109.33
3.25		130.47	127.76		4.2	4.3		110.22	107.88
3.30		131.55	125.05		4.3	4.4		111.06	105.52
3.35		132.09			4.4			111.44	
3.40		133.72			4.4			112.74	
3.45		134.26			4.5			113.12	
3.50		136.42			4.6			114.86	
3.55		135.88			4.6			114.32	
3.60		137.51			4.7			115.62	
3.65		138.59			4.8			116.44	
3.70		139.13			4.8			116.82	
3.75		140.75			4.9			118.10	

3.80		142.38			5.0			119.38	
3.85		142.38			5.0			119.30	
3.90		142.92			5.1			119.67	
3.95		144.54			5.1			120.95	
4.00		145.63			5.2			121.77	
4.05		146.17			5.3			122.14	
4.10		146.71			5.3			122.51	
4.15		148.87			5.4			124.23	
4.20		148.33			5.5			123.69	
4.25		148.33			5.5			123.60	
4.30		149.42			5.6			124.43	
4.35		150.5			5.7			125.24	
4.40		151.58			5.7			126.05	
4.45		151.58			5.8			125.96	
4.50		152.66			5.9			126.77	
4.55		152.66			5.9			126.69	
4.60		153.2			6.0			127.05	
4.65		153.75			6.1			127.41	
4.70		155.37			6.1			128.67	
4.75		154.29			6.2			127.68	
4.80		156.45			6.3			129.38	
4.85		156.45			6.3			129.29	
4.90		155.37			6.4			128.31	
4.95		156.99			6.5			129.56	
5.00		155.37			6.5			128.13	
5.05		156.45			6.6			128.93	
5.10		155.91			6.6			128.40	
5.15		154.83			6.7			127.42	
5.20		155.37			6.8			127.77	
5.25		155.37			6.8			127.68	
5.30		155.37			6.9			127.59	
5.35		154.29			7.0			126.62	
5.40		155.37			7.0			127.42	
5.45		154.83			7.1			126.88	
5.50		154.29			7.2			126.35	
5.55		155.37			7.2			127.15	
5.60		154.29			7.3			126.18	
5.65		154.29			7.4			126.09	
5.70		153.75			7.4			125.56	
5.75		153.2			7.5			125.02	
5.80		153.75			7.6			125.38	
5.85		152.12			7.6			123.96	
5.90		152.66			7.7			124.32	
5.95		152.12			7.8			123.79	
6.00		152.12			7.8			123.70	

6.05		151.04			7.9			122.74	
6.10		149.96			8.0			121.77	
6.15		149.96			8.0			121.69	
6.20		149.96			8.1			121.60	
6.25		148.33			8.1			120.19	
6.30		147.79			8.2			119.67	
6.35		147.25			8.3			119.15	
6.40		146.17			8.3			118.19	
6.45		146.17			8.4			118.11	
6.50		144.54			8.5			116.71	
6.55		143.46			8.5			115.75	
6.60		141.29			8.6			113.92	
6.65		140.75			8.7			113.40	
6.70		139.13			8.7			112.02	
6.75		137.51			8.8			110.63	
6.80		136.42			8.9			109.68	
6.85		133.72			8.9			107.43	
6.90		132.63			9.0			106.48	
6.95		131.01			9.1			105.10	

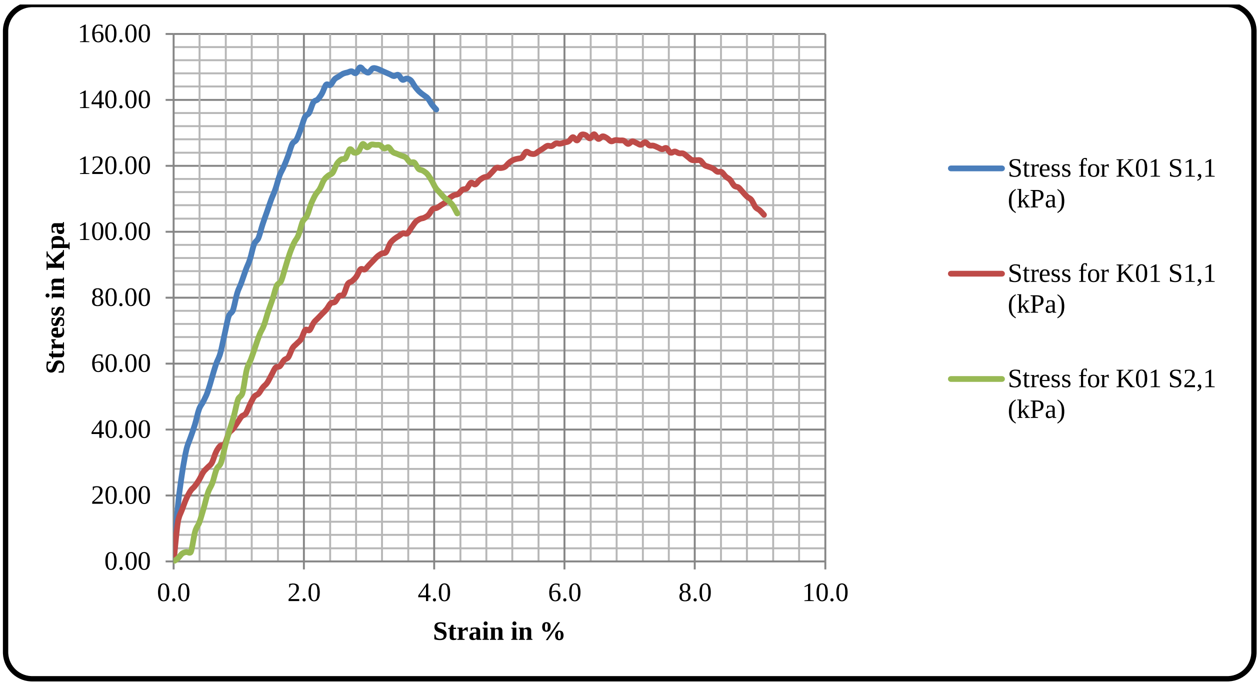


Figure B-1.1 the UCS for K01 S1,1,S1,2 and S2,1

B-1.2 UCS Result for Kebele 02 S1,1 at 1.5m , S1,1 at 3m and S2,1 at 1.5m depth

Sample data:	
No of sample	**S1,1**
Height, Ho (mm) =	77.20
Diameter, D (mm) =	38.00
Mass, (gm) =	156.157
Area, (cm^2) =	11.34
Volume (cm^3) =	87.51
Wet density (gm/cm^3) =	1.78
Dry density, ρd (gm//cm^3)=	1.33
Unconfined compressive strength,qu (kN/m^2)	**142.71**
Cohesion,Cu (kN/m^2)=	**71.36**

Deformation Height (mm)	**Reading load S1,1 (N)**	**Strain for K02S1,1 (%)**	**Stress for K02 S1,1 (kPa)**
0.00	0	0.0	0.00
0.05	1	0.1	0.88

0.10	3	0.1	2.64
0.15	3	0.2	2.64
0.20	3	0.3	2.64
0.25	2	0.3	1.76
0.30	3	0.4	2.64
0.35	3	0.5	2.63
0.40	3	0.5	2.63
0.45	4	0.6	3.51
0.50	3	0.6	2.63
0.55	4	0.7	3.50
0.60	4	0.8	3.50
0.65	6	0.8	5.25
0.70	8	0.9	6.99
0.75	9	1.0	7.86
0.80	11	1.0	9.60
0.85	13	1.1	11.34
0.90	14	1.2	12.21
0.95	16	1.2	13.94
1.00	16	1.3	13.93
1.05	18	1.4	15.66
1.10	18	1.4	15.65
1.15	20	1.5	17.38
1.20	21	1.6	18.24
1.25	23	1.6	19.96
1.30	23	1.7	19.95
1.35	25	1.7	21.67
1.40	25	1.8	21.65
1.45	26	1.9	22.51
1.50	27	1.9	23.36
1.55	28	2.0	24.21
1.60	30	2.1	25.92
1.65	30	2.1	25.90
1.70	32	2.2	27.61
1.75	34	2.3	29.31
1.80	35	2.3	30.16
1.85	36	2.4	31.00
1.90	37	2.5	31.84
1.95	38	2.5	32.68
2.00	38	2.6	32.65
2.05	40	2.7	34.35
2.10	40	2.7	34.33
2.15	42	2.8	36.02
2.20	43	2.8	36.85
2.25	43	2.9	36.83
2.30	45	3.0	38.52

2.35	45	3.0	38.49
2.40	46	3.1	39.32
2.45	47	3.2	40.15
2.50	48	3.2	40.97
2.55	49	3.3	41.80
2.60	50	3.4	42.62
2.65	51	3.4	43.45
2.70	51	3.5	43.42
2.75	53	3.6	45.09
2.80	53	3.6	45.06
2.85	54	3.7	45.88
2.90	55	3.8	46.70
2.95	55	3.8	46.67
3.00	57	3.9	48.33
3.05	57	4.0	48.30
3.10	60	4.0	50.81
3.15	59	4.1	49.93
3.20	60	4.1	50.74
3.25	61	4.2	51.55
3.30	61	4.3	51.51
3.35	62	4.3	52.32
3.40	62	4.4	52.29
3.45	63	4.5	53.09
3.50	63	4.5	53.06
3.55	64	4.6	53.86
3.60	65	4.7	54.67
3.65	64	4.7	53.79
3.70	66	4.8	55.43
3.75	66	4.9	55.40
3.80	67	4.9	56.20
3.85	67	5.0	56.16
3.90	68	5.1	56.96
3.95	69	5.1	57.76
4.00	69	5.2	57.72
4.05	69	5.2	57.68
4.10	69	5.3	57.64
4.15	69	5.4	57.60
4.20	70	5.4	58.39
4.25	70	5.5	58.35
4.30	70	5.6	58.31
4.35	72	5.6	59.94
4.40	71	5.7	59.07
4.45	71	5.8	59.03
4.50	73	5.8	60.65
4.55	73	5.9	60.60

4.60	72	6.0	59.73
4.65	73	6.0	60.52
4.70	73	6.1	60.48
4.75	74	6.2	61.27
4.80	74	6.2	61.22
4.85	73	6.3	60.35
4.90	74	6.3	61.14
4.95	74	6.4	61.10
5.00	74	6.5	61.05
5.05	74	6.5	61.01
5.10	74	6.6	60.97
5.15	74	6.7	60.93
5.20	75	6.7	61.71
5.25	74	6.8	60.84
5.30	74	6.9	60.80
5.35	73	6.9	59.94
5.40	75	7.0	61.54
5.45	75	7.1	61.49
5.50	74	7.1	60.63
5.55	73	7.2	59.77
5.60	73	7.3	59.73
5.65	75	7.3	61.32
5.70	73	7.4	59.65
5.75	73	7.4	59.60
5.80	73	7.5	59.56
5.85	73	7.6	59.52
5.90	73	7.6	59.48
5.95	73	7.7	59.44
6.00	71	7.8	57.77
6.05	72	7.8	58.54
6.10	71	7.9	57.69
6.15	71	8.0	57.65
6.20	70	8.0	56.79
6.25	69	8.1	55.94
6.30	68	8.2	55.09
6.35	68	8.2	55.05
6.40	68	8.3	55.02
6.45	67	8.4	54.17
6.50	66	8.4	53.32
6.55	66	8.5	53.28
6.60	66	8.5	53.25
6.65	65	8.6	52.40
6.70	65	8.7	52.37
6.75	63	8.7	50.72
6.80	62	8.8	49.88

6.85	64	8.9	51.45
6.90	62	8.9	49.81
6.95	61	9.0	48.97
7.00	61	9.1	48.93
7.05	60	9.1	48.10
7.10	60	9.2	48.06
7.15	59	9.3	47.23
7.20	58	9.3	46.40

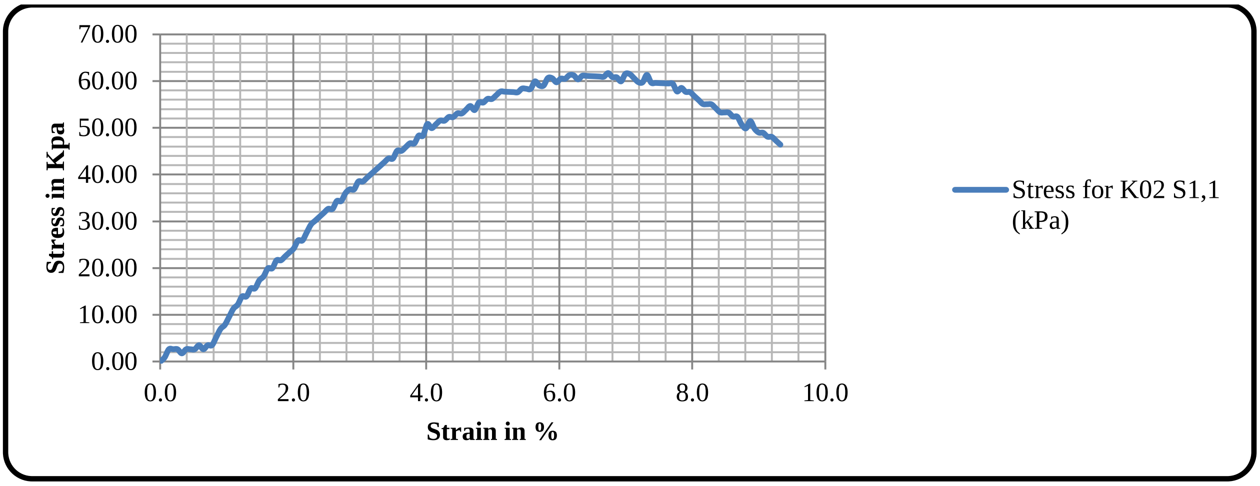


Figure B-1.2 the UCS for K02 S1,1.

B-1.3 UCS Result for Kebele 03 S1,1 at 1.5m , S1,1 at 3m and S2,1 at 1.5m depth

Sample data:			
No of sample	**S1,1**	**S1,2**	**S2,1**
Height, Ho (mm) =	78.50	72.80	77.20
Diameter, D (mm) =	38.00	38.00	38.00
Mass, (gm) =	180	167.714	173.447
Area, (cm^2) =	11.34	11.34	11.34
Volume (cm^3) =	88.98	82.52	85.92
Wet density (gm/cm^3) =	2.02	2.03	2.02
Dry density, ρd (gm//cm^3)=	1.60	1.63	1.60
Unconfined compressive strength,qu (kN/m^2)=	**168.20**	**186.76**	**176.60**
Cohesion,Cu (kN/m^2)=	**84.10**	**93.38**	**88.30**

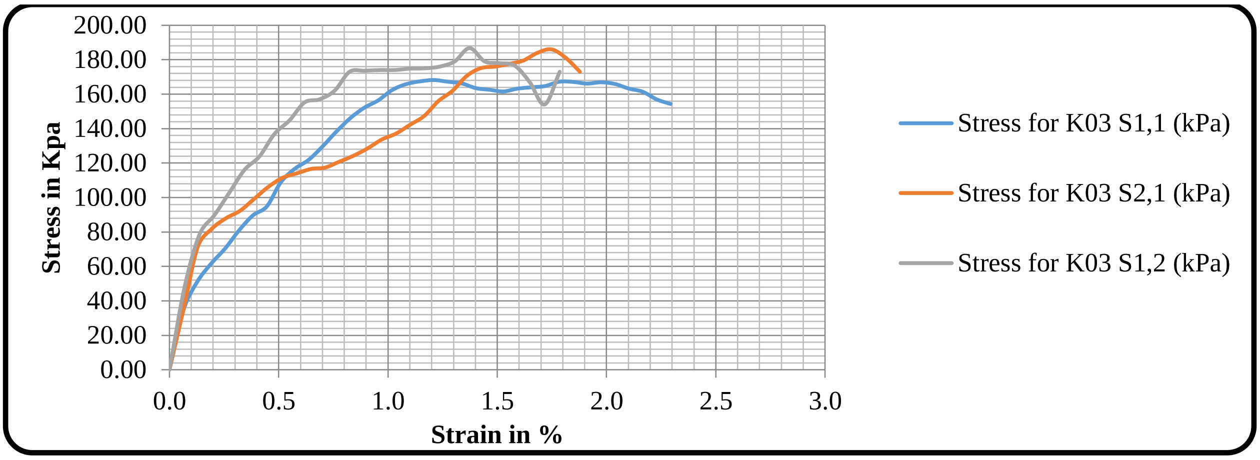


Figure B-1.3 the UCS for K03 S1,1,S1,2

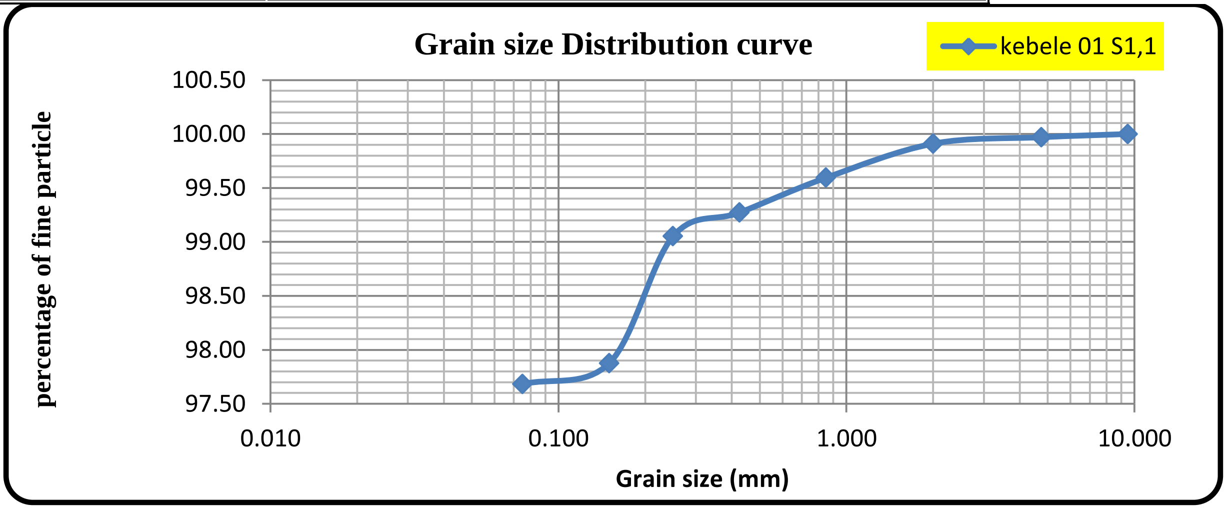
Deformation Height (mm)	**Reading load S1,1 (N)**	**Reading load S1,2 (N)**	**Reading load S2,1 (N)**	**Strain for K03 S1,1 (%)**	**Strain for K03 S1,2 (%)**	**Strain for K03 S2,1 (%)**	**Stress for K03 S1,1 (kPa)**	**Stress for K03 S1,2 (kPa)**	**Stress for K03 S2,1 (kPa)**
0.00	0	0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
0.05	39	54	40.0	0.1	0.1	0.1	34.38	47.61	35.26
0.10	58	89	81.0	0.1	0.1	0.1	51.10	78.41	71.36
0.15	70	102	93.0	0.2	0.2	0.2	61.64	89.80	81.88
0.20	80	117	100.0	0.3	0.3	0.3	70.40	102.93	87.99
0.25	92	132	105.0	0.3	0.3	0.3	80.90	116.05	92.33
0.30	102	141	113.0	0.4	0.4	0.4	89.64	123.88	99.30
0.35	108	156	121.0	0.4	0.5	0.5	94.85	136.96	106.26
0.40	124	165	127.0	0.5	0.5	0.5	108.83	144.76	111.46
0.45	133	177	130.0	0.6	0.6	0.6	116.66	155.18	114.02
0.50	139	188	133.0	0.6	0.7	0.6	121.84	157.00	116.57
0.55	148	202	134.0	0.7	0.8	0.7	129.65	162.00	117.37
0.60	158	215	138.0	0.8	0.8	0.8	138.32	173.00	120.80
0.65	167	221	142.0	0.8	0.9	0.8	146.11	173.60	124.22
0.70	174	234	147.0	0.9	1.0	0.9	152.13	174.00	128.51
0.75	179	245	153.0	1.0	1.0	1.0	156.40	174.00	133.66
0.80	186	251	157.0	1.0	1.1	1.0	162.42	174.80	137.07
0.85	190	261	163.0	1.1	1.2	1.1	165.80	175.00	142.21
0.90	192	268	169.0	1.1	1.2	1.2	167.44	176.00	147.35
0.95	193	276	179.0	1.2	1.3	1.2	168.20	179.00	155.97
1.00	192	278	186.0	1.3	1.4	1.3	167.22	186.76	161.96
1.05	191	279	196.0	1.3	1.4	1.4	166.24	179.00	170.56
1.10	188	284	208.0	1.4	1.5	1.4	163.53	178.00	175.10
1.15	187	284	214.0	1.5	1.6	1.5	162.55	176.60	176.00
1.20	186	284	220.0	1.5	1.6	1.6	161.58	167.00	177.60
1.25	188	284	226.0	1.6	1.7	1.6	163.21	154.00	179.50
1.30	189	280	230.0	1.7	1.8	1.7	163.97	173.00	184.00
1.35	190		233.0	1.7		1.7	164.73		186.00
1.40	193		236.0	1.8		1.8	167.23		181.08
1.45	193		238.0	1.8		1.9	167.12		173.00
1.50	192		239.0	1.9		1.9	166.14		
1.55	193		241.0	2.0		2.0	166.90		
1.60	192		240.0	2.0		2.1	165.93		
1.65	189		241.0	2.1		2.1	163.23		
1.70	187		239.0	2.2		2.2	161.40		
1.75	182		238.0	2.2		2.3	156.98		
1.80	179		238.0	2.3		2.3	154.29		
1.85	176		235.0			2.4	155.27		
1.90			232.0			2.5			
1.95			230.0			2.5			
2.00			222.0			2.6			
2.05			217.0			2.7			
2.10			211.0			2.7			
2.15			202.0			2.8			

B-2 Grain Size Analysis and Atterberg limit result

B2.1 Grain Size Analysis and Atterberg limit results for kebele 01

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	1 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	1.5m Blow NGL
Pit number:	kebele 01 S1,1

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	0.300	0.03	0.03	99.97
2.000	0.600	0.06	0.09	99.91
0.850	3.150	0.32	0.41	99.60
0.425	3.235	0.32	0.73	99.27
0.250	2.194	0.22	0.95	99.05
0.150	11.760	1.18	2.12	97.88
0.075	1.940	0.19	2.32	97.68
pan	976.821	97.68	100.00	0.00
sum	1000.000			

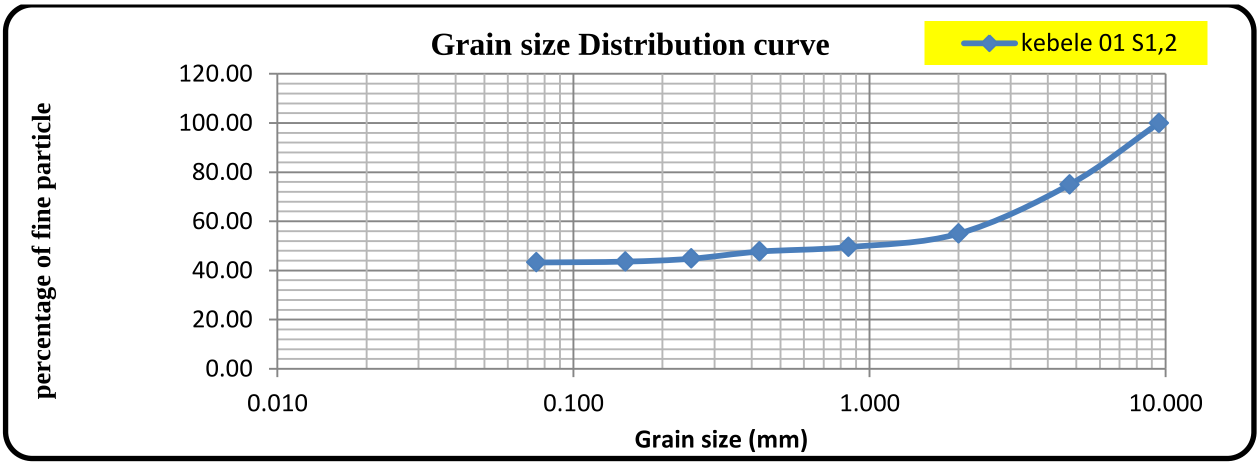


Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 01 S1,1**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	35	24	19		
Trial no.	01	02	03	01	
Wt. of Container, (g)	17.02	17.65	5.57	6.50	
Wt. of container + wet soil, (g)	26.62	29.86	14.22	10.90	
Wt. of container + dry soil, (g)	22.55	24.47	10.38	9.86	
Wt. of water, (g)	4.06	5.39	3.83	1.04	
Wt. of dry soil, (g)	5.54	6.82	4.81	3.36	
Moisture container, (%)	73.39	78.95	79.69	30.95	
Average	77.50			30.95	

Determination of (PI) (LL - PL)	***LL (%)***	***78***	**Sieve Analysis Result**	Percentage of Course Soil	**0.03**	**Soil Classification (USCS)**
	PL	**31**		Percentage of Sandy Soil	**2.29**	
	PI	**47**		Percentage of Fine Soil	**97.68**	**OH (high plasticity organic soil)**

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	1 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	3m Blow NGL
kebele:	kebele 01 S1,2

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	250.000	25.00	25.00	75.00
2.000	200.000	20.00	45.00	55.00
0.850	55.000	5.50	50.50	49.50
0.425	18.102	1.81	52.31	47.69
0.250	29.000	2.90	55.21	44.79
0.150	11.761	1.18	56.39	43.61
0.075	3.671	0.37	56.75	43.25
pan	432.466	43.25	100.00	0.00
sum	1000.000			



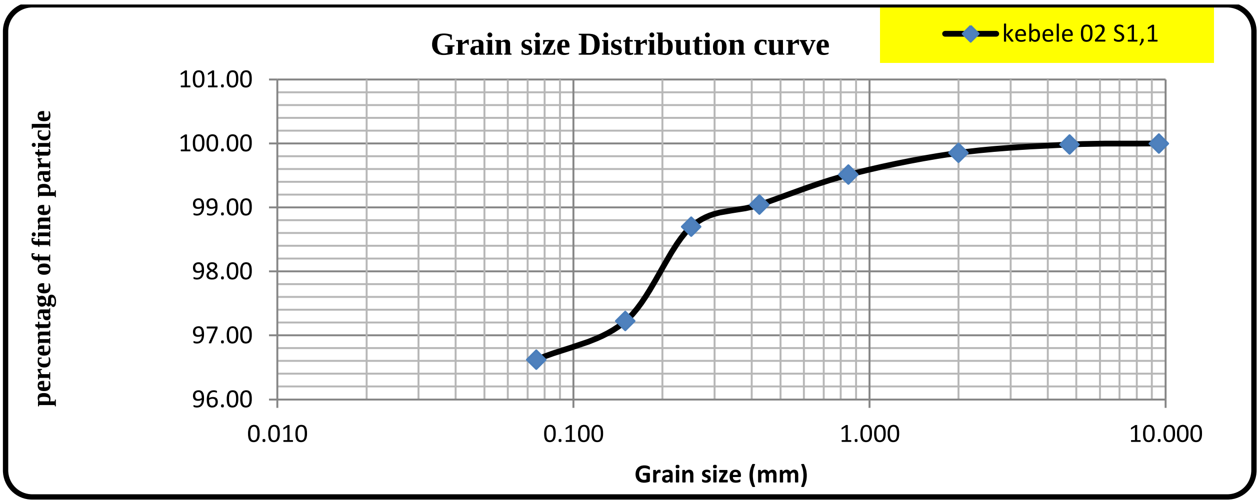
Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 01 S1,2**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	26	26	20		
	01	02	03	01	02
Wt. of Container, (g)	17.50	18.00	18.40	20.20	17.06
Wt. of container + wet soil, (g)	32.00	30.00	30.82	26.38	21.92
Wt. of container + dry soil, (g)	26.24	25.20	25.67	24.56	20.51
Wt. of water, (g)	5.76	4.80	5.15	1.82	1.41
Wt. of dry soil, (g)	8.74	7.20	7.27	4.36	3.46
Moisture container, (%)	65.90	66.67	70.84	41.65	40.80
Average	67.80			41.23	

Determination of (PI) (LL - PL)	***LL (%)***	***68***	**Sieve Analysis Result**	Percentage of Course Soil	**25.00**	**Soil Classification (USCS)**
	PL	**41**		Percentage of Sandy Soil	**31.75**	
	PI	**27**		Percentage of Fine Soil	**43.25**	**SM (silty sand)**

B2.2 Grain Size Analysis and Atterberg limit results for kebele 02

Method of Testing:	Grain Size Analysis (ASTM D-421)			
Method of Testing:	Wet Sieve Analysis			
Wt. of Sample: (g)	1 Kg			
Sample Location:	Agaro city, Oromia			
Depth (m)	1.5m Blow NGL			
Pit number:	kebele 02 S1,1			

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	0.168	0.02	0.02	99.98
2.000	1.300	0.13	0.15	99.85
0.850	3.420	0.34	0.49	99.51
0.425	4.682	0.47	0.96	99.04
0.250	3.449	0.34	1.30	98.70
0.150	14.730	1.47	2.77	97.23
0.075	6.047	0.60	3.38	96.62
pan	966.204	96.62	100.00	0.00
sum	1000.000			



Material location:	**Agaro city, Oromia**
Pit Number	**kebele 02 S1,1**

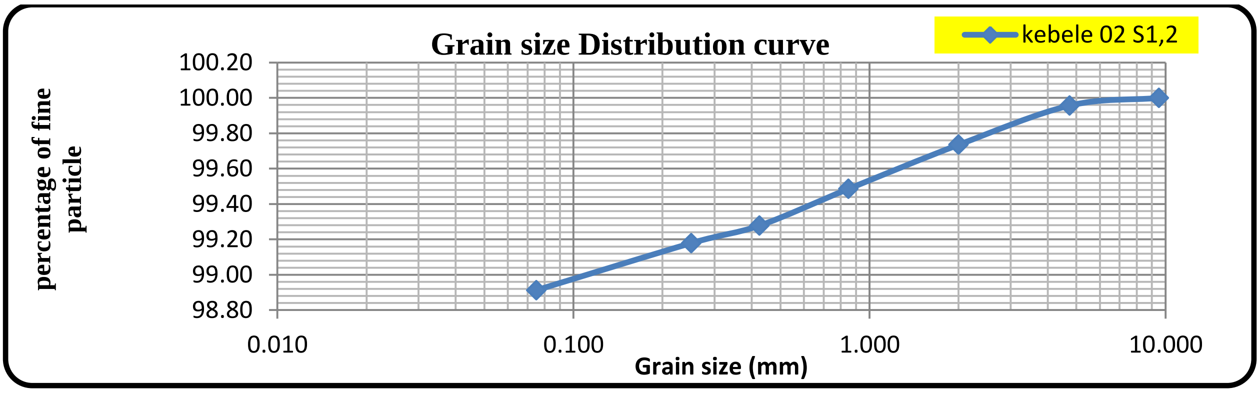
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	27	24	18		
Trial no.	01	02	03	01	
Wt. of Container, (g)	17.68	17.64	18.21	5.48	
Wt. of container + wet soil, (g)	30.43	30.48	33.07	9.39	
Wt. of container + dry soil, (g)	25.44	25.45	27.22	8.03	
Wt. of water, (g)	4.99	5.03	5.85	1.36	
Wt. of dry soil, (g)	7.76	7.81	9.01	2.54	
Moisture container, (%)	64.22	64.45	64.91	53.62	
Average	64.30			53.62	

Determination of (PI) (LL - PL)	***LL (%)***	***64***	**Sieve Analysis Result**	Percentage of Course Soil	**0.02**	**Soil Classification (USCS)**
	PL	**54**		Percentage of Sandy Soil	**3.36**	
	PI	**11**		Percentage of Fine Soil	**96.62**	**OH (high plasticity organic soil)**

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	0.5 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	3m Blow NGL
Pit number:	kebele 02 S1,2

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0	0.00	0.00	100.00
4.750	0.43	0.04	0.04	99.96
2.000	2.22	0.22	0.27	99.74
0.850	2.49	0.25	0.51	99.49

0.425	2.08	0.21	0.72	99.28
0.250	0.99	0.10	0.82	99.18
0.075	2.66	0.27	1.09	98.91
pan	489.13	48.91	50.00	50.00
sum	500.000			



Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 02 S1,2**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	34	24	21		
	1	2	3	01	
Wt. of Container, (g)	18.58	17.85	17.95	5.48	
Wt. of container + wet soil, (g)	46.76	51.04	45.02	9.39	
Wt. of container + dry soil, (g)	35.8	38.05	33.99	8.03	
Wt. of water, (g)	10.96	12.99	11.03	1.36	

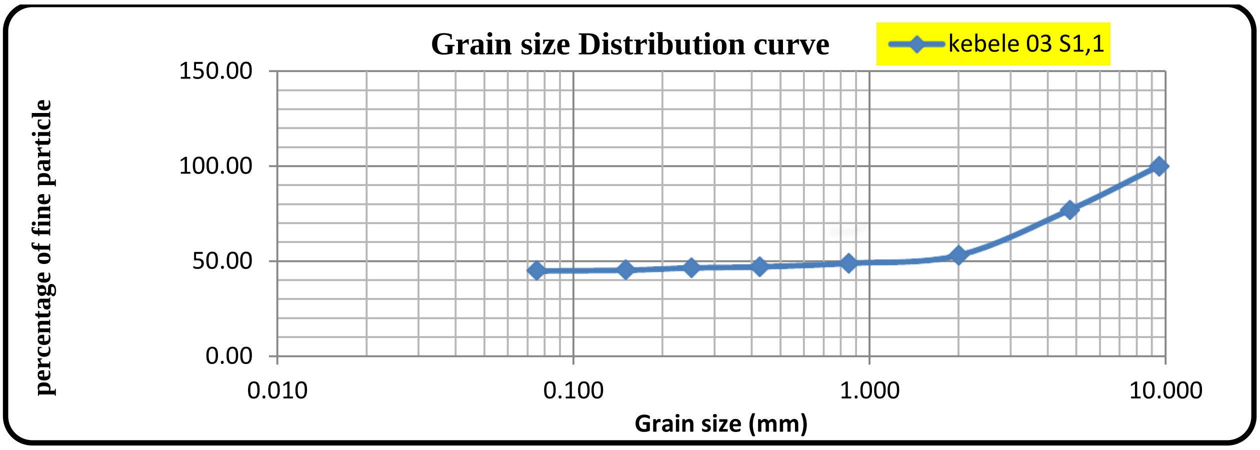
Wt. of dry soil, (g)	17.22	20.2	16.04	2.54	
Moisture container, (%)	63.65	64.31	68.77	53.62	
Average	65.58			53.62	

Determination of (PI) (LL - PL)	***LL (%)***	***66***	**Sieve Analysis Result**	Percentage of Course Soil	**0.04**	**Soil Classification (ASTM D-2487)**
	PL	**54**		Percentage of Sandy Soil	**1.04**	
	PI	**12**		Percentage of Fine Soil	**98.91**	**Organic Clayey soil**

B2.3 Grain Size Analysis and Atterberg limit results for kebele 03

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	1 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	1.5m Blow NGL
kebele:	kebele 03 S1,1

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	229.800	22.98	22.98	77.02
2.000	238.250	23.83	46.81	53.20
0.850	41.710	4.17	50.98	49.02
0.425	18.102	1.81	52.79	47.21
0.250	5.814	0.58	53.37	46.63
0.150	11.761	1.18	54.54	45.46
0.075	3.671	0.37	54.91	45.09
pan	450.892	45.09	100.00	0.00
sum	1000.000			

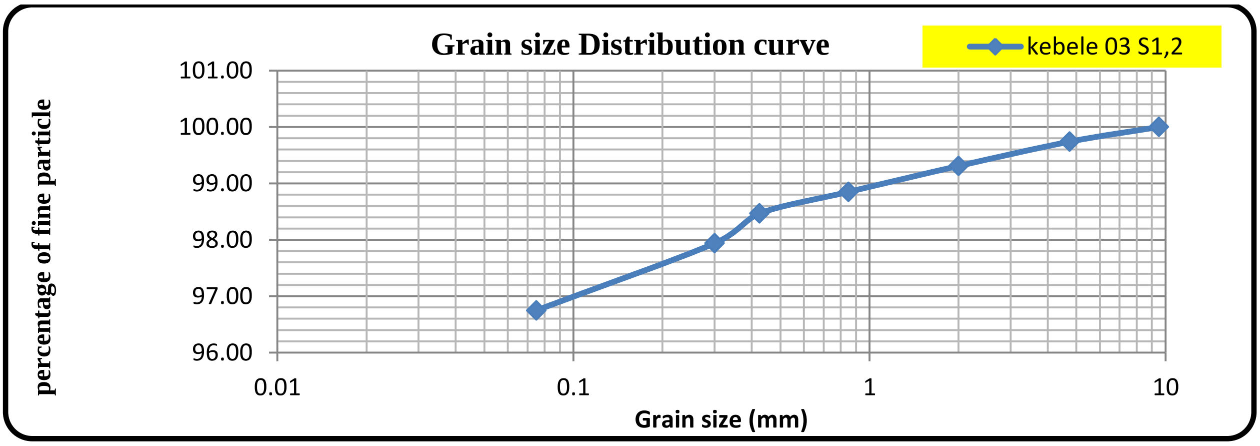


Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 03 S1,1**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	27	26	19		
Trial no.	01	02	03	01	02
Wt. of Container, (g)	18.06	17.76	17.66	20.21	17.06
Wt. of container + wet soil, (g)	31.39	31.51	30.82	26.38	21.92
Wt. of container + dry soil, (g)	26.24	26.17	25.67	24.56	20.51
Wt. of water, (g)	5.15	5.34	5.15	1.82	1.41
Wt. of dry soil, (g)	8.18	8.41	8.01	4.35	3.46
Moisture container, (%)	62.96	63.53	64.29	41.75	40.80
Average	63.50			41.28	

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	1 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	3m Blow NGL
Pit number:	kebele 03 S1,2

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.5	0	0.00	0.00	100.00

4.75	2.6	0.26	0.26	99.74
2	4.31	0.43	0.69	99.31
0.85	4.59	0.46	1.15	98.85
0.425	3.83	0.38	1.53	98.47
0.3	5.28	0.53	2.06	97.94
0.075	11.89	1.19	3.25	96.75
pan	967.5	96.75	100.00	0.00
sum	1000.000			



Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 03 S1,2**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	35	26	15		
	1	2	3	1	2
Wt. of Container, (g)	36.81	41.22	34.62	28.32	37.08
Wt. of container + wet soil, (g)	71.61	68.98	60.03	34.93	43.36
Wt. of container + dry soil, (g)	57.86	57.14	48.9	32.66	41.19
Wt. of water, (g)	13.75	11.84	11.13	2.27	2.17
Wt. of dry soil, (g)	21.05	15.92	14.28	4.34	4.11
Moisture container, (%)	65.32	74.37	77.94	52.3	52.8
Average	72.54			52.55	

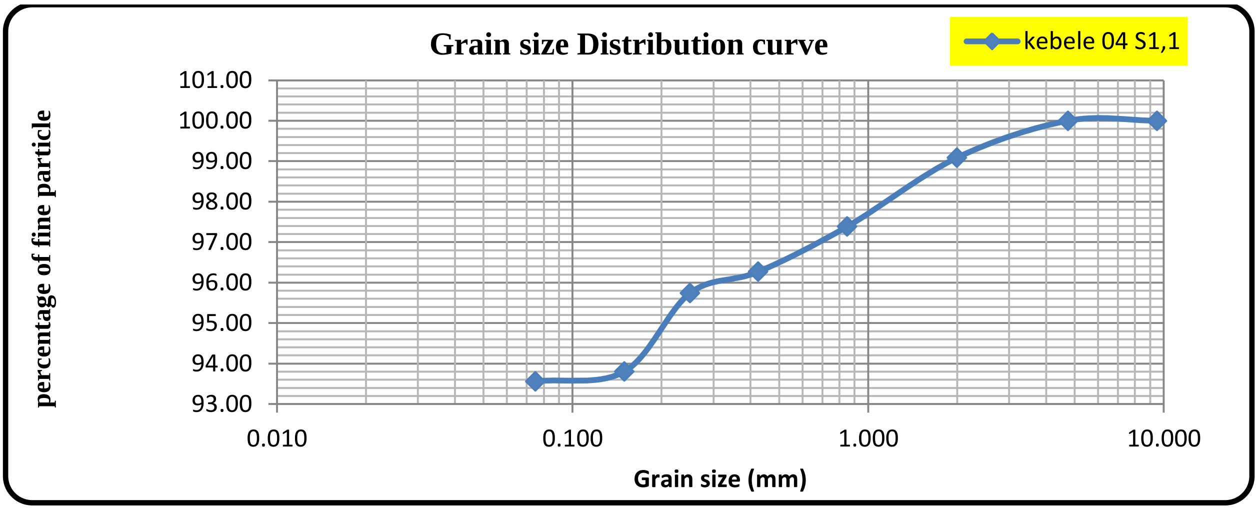
Determination of (PI) (LL - PL)	***LL (%)***	***73***	**Sieve Analysis Result**	Percentage of Course Soil	**0.26**	**Soil Classification (ASTM D-2487)**

	PL	**53**		Percentage of Sandy Soil	**2.99**	
	PI	**20**		Percentage of Fine Soil	**96.75**	**MH**

B2.4 Grain Size Analysis and Atterberg limit results for kebele 04

Method of Testing:	Grain Size Analysis (ASTM D-421)			
Method of Testing:	Wet Sieve Analysis			
Wt. of Sample: (g)	1 Kg			
Sample Location:	Agaro city, Oromia			
Depth (m)	1.5 m Blow NGL			
Pit number:	kebele 04 S1,1			

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	0.000	0.00	0.00	100.00
2.000	9.123	0.91	0.91	99.09
0.850	17.023	1.70	2.61	97.39
0.425	11.169	1.12	3.73	96.27
0.250	5.256	0.53	4.26	95.74
0.150	19.360	1.94	6.19	93.81
0.075	2.464	0.25	6.44	93.56
pan	935.605	93.56	100.00	0.00
sum	1000.000			



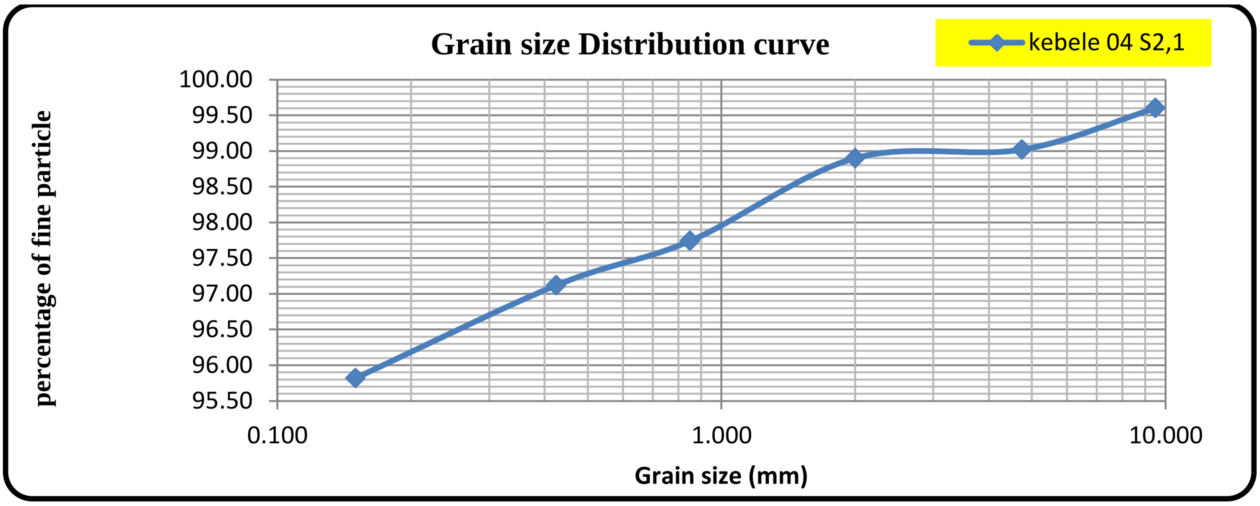
Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 04 S1,1**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	32	21	16		
Trial no.	01	02	03	01	02
Wt. of Container, (g)	18.05	17.58	18.00	19.52	16.31
Wt. of container + wet soil, (g)	32.05	31.26	32.17	23.13	22.90
Wt. of container + dry soil, (g)	27.02	26.07	26.71	22.39	21.56
Wt. of water, (g)	5.03	5.19	5.46	0.74	1.34
Wt. of dry soil, (g)	8.97	8.49	8.71	2.87	5.25
Moisture container, (%)	56.02	61.11	62.67	25.92	25.56
Average	58.80			25.74	

Determination of (PI) (LL - PL)	***LL (%)***	***59***	**Sieve Analysis Result**	Percentage of Course Soil	**0.00**	**Soil Classification (USCS)**

	PL	**26**		Percentage of Sandy Soil	**6.44**	
	PI	**33**		Percentage of Fine Soil	**93.56**	**OH (high plasticity organic soil)**

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	0.5 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	1.5 m Blow NGL
Pit number:	kebele 04 S2,1

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	2	0.40	0.40	99.60
4.750	2.9	0.58	0.98	99.02
2.000	0.6	0.12	1.10	98.90
0.850	5.8	1.16	2.26	97.74
0.425	3.1	0.62	2.88	97.12
0.150	6.5	1.30	4.18	95.82
0.075	1.5	0.30	4.48	95.52
pan	477.6	95.52	100.00	0.00
sum	500.000			



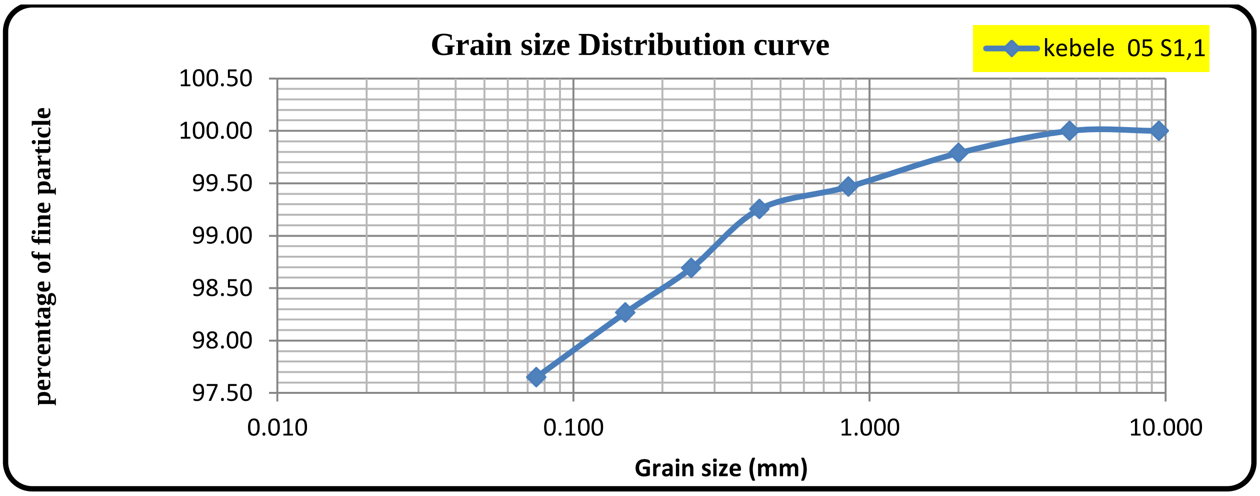
Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 04 S2,1**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	34	24	15		
	1	2	3	1	2
Wt. of Container, (g)	18.6	17.4	17.5	17.9	17.2
Wt. of container + wet soil, (g)	37.1	31.7	33.1	25	23.4
Wt. of container + dry soil, (g)	28.2	24.4	24.9	22.6	21.2
Wt. of water, (g)	8.9	7.3	8.2	2.4	2.2
Wt. of dry soil, (g)	9.6	7	7.4	4.7	4
Moisture container, (%)	92.71	104.29	110.81	51.06	55
Average	102.60			53.03	

Determination of (PI) (LL - PL)	***LL (%)***	***102.60***	**Sieve Analysis Result**	Percentage of Course Soil	**0.98**	**Soil Classification (ASTM D-2487)**
	PL	**53**		Percentage of Sandy Soil	**3.50**	
	PI	**50**		Percentage of Fine Soil	**95.52**	**MH**

B2.5 Grain Size Analysis and Atterberg limit results for kebele 05

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	1 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	1.5m Blow NGL
Pit number:	kebele 05 S1,1

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	0.000	0.00	0.00	100.00
4.750	0.000	0.00	0.00	100.00
2.000	2.120	0.21	0.21	99.79
0.850	3.210	0.32	0.53	99.47
0.425	2.140	0.21	0.75	99.25
0.250	5.630	0.56	1.31	98.69
0.150	4.235	0.42	1.73	98.27
0.075	6.156	0.62	2.35	97.65
pan	976.509	97.65	100.00	0.00
sum	1000.000			



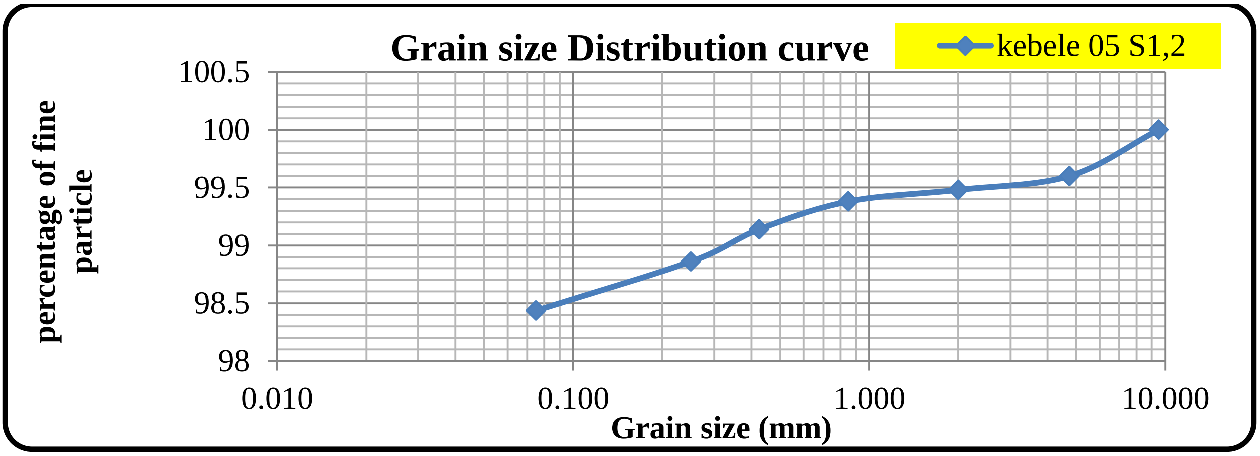
Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 05 S1,1**				
Determination	***Liquid Limit (D-4318)***			***Plastic Limit (D-4318)***	
Number of blows	35	23	21		
Trial no.	01	02	03	01	02
Wt. of Container, (g)	17.68	17.43	17.61	5.97	9.56
Wt. of container + wet soil, (g)	28.68	30.90	28.86	12.80	14.11
Wt. of container + dry soil, (g)	24.12	25.16	23.91	11.17	13.04
Wt. of water, (g)	4.56	5.74	4.95	1.63	1.07
Wt. of dry soil, (g)	6.44	7.73	6.30	5.19	3.49
Moisture container, (%)	70.89	74.26	78.66	31.41	30.56
Average	75.00			30.98	

Determination of (PI) (LL - PL)	***LL (%)***	***75***	**Sieve Analysis Result**	Percentage of Course Soil	**0.00**	**Soil Classification (USCS)**
	PL	**31**		Percentage of Sandy Soil	**2.35**	
	PI	**44**		Percentage of Fine Soil	**97.65**	**OH (high plasticity organic soil)**

Method of Testing:	Grain Size Analysis (ASTM D-421)
Method of Testing:	Wet Sieve Analysis
Wt. of Sample: (g)	0.5 Kg
Sample Location:	Agaro city, Oromia
Depth (m)	3m Blow NGL
pit number	kebele 05 S1,2

Sieve size (mm)	Mass of Retain on Each Sieve (g)	Percentage of Retained Soil	Percentage of cumulative Retained Soil	Percentage of Passing Soil Particle
9.500	2	0.2	0.2	100

4.750	1	0.2	0.4	99.6
2.000	0.6	0.12	0.52	99.48
0.850	0.5	0.1	0.62	99.38
0.425	1.2	0.24	0.86	99.14
0.250	1.4	0.28	1.14	98.86
0.075	2.12	0.424	1.564	98.436
pan	491.18	98.236	99.8	0.2
sum	500			



Material location:	**Agaro city, Oromia**				
Pit Number	**kebele 05 S1,2**				
Determination	**Liquid Limit (D-4318)**			**Plastic Limit (D-4318)**	
Number of blows	24	22	23		
	1	2	5	1	2
Wt. of Container, (g)	34.5	37.8	18.1	6.7	6.4
Wt. of container + wet soil, (g)	50.8	55.2	35.6	13.2	12.8
Wt. of container + dry soil, (g)	44.3	48.1	28.2	11	10.7
Wt. of water, (g)	6.5	7.1	7.4	2.2	2.1
Wt. of dry soil, (g)	9.8	10.3	10.1	4.3	4.3
Moisture container, (%)	66.33	68.93	73.27	51.16	48.84
Average	69.51			50.00	

Determination of (PI) *(LL - PL)*	*LL (%)*	*69.51*	**Sieve Analysis Result**	**Percentage of Course Soil**	**0.4**	**Soil Classification (ASTM D-2487)**
	PL	**50**		**Percentage of Sandy Soil**	**1.16**	
	PI	**20**		**Percentage of Fine Soil**	**98.44**	**MH**

B-3 SPECIFIC GRAVITY TEST RESULT

B-3.1 specific gravity test result for kebele 01

	Kebele 01																		
Sample no.	S1,1			S1,2			S2,1			S2,2			S3,1			S3,2		
Trial No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	
Pycnometer No	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass of calibtrated Pycnometer (clean and dry)(Mp) in gm	28.1	28.6	28.1	28.1	28.3	27.8	28.08	28.59	28.09	28.1	28.29	27.79	16.28	16.12	18.57	28.23	27.51	
Mass of pycnometer +Water (Mpw) in gm at Ti=21c	79.6	79.6	78.6	79.6	79.9	79.5	79.65	79.63	78.64	79.62	79.93	79.42	43.4	42.26	46.53	79.75	78.35	
Mass of Dry soil (Ms) in gm	10.2	10	10	10	10	10	10.28	10.05	10.06	10.02	10.04	10.04	10.65	15.12	13.12	10.20	10.23	
Mass of speciment +pycnometer (Mps) in gm	38.3	38.6	38.1	38.1	38.3	37.8	38.36	38.64	38.15	38.12	38.33	37.83	26.93	31.24	31.69	38.43	37.74	
Mass of Pycnometer + soil + Water (Mpsw) in gm	86.01	85.9	84.92	85.9	86.2	85.79	86.14	86.01	85.01	85.96	86.31	85.82	50.21	51.94	54.89	86.20	84.95	
Temp Of Contents of pycnometer when Mpsw was taken,Tx in C°	23	23	23	24	24	24	23	23	23	24	24	24	24.8	24.8	24.8	22.00	22.00	
Mass of Pcnometer + Water at temperture Tx(Mpw) in gm	79.57	79.57	78.57	79.56	79.86	79.46	79.62	79.6	78.61	79.58	79.89	79.38	43.39	42.25	46.52	79.77	78.37	
K for Tx	0.9986	0.9986	0.9986	0.9991	0.9991	0.9991	0.9986	0.9986	0.9986	0.9991	0.9991	0.9991	0.9999	0.9999	0.9999	0.99960	0.99960	
Specific gravity at Tx	2.71	2.72	2.74	2.73	2.73	2.72	2.73	2.76	2.75	2.75	2.77	2.79	2.78	2.78	2.76	2.70	2.80	
Specific gravity at 20C°	2.71	2.72	2.74	2.73	2.73	2.72	2.73	2.76	2.74	2.75	2.77	2.79	2.78	2.78	2.76	2.70	2.80	
Average specific gravity at 20C°	2.72			2.73			2.74			2.77			2.78			2.73		

B-3.2 specific gravity test result for kebele 02

	Kebele 02																		
Sample no.	S1,1			S1,2			S2,1			S2,2			S3,1			S3,2			
Trial No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2		
Pycnometer No	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	
Mass of calibtrated Pycnometer (clean and dry)(Mp) in gm	28.12	28.32	27.84	28.11	28.31	27.83	16.26	16.08	18.55	28.421	31.575	31.347	31.575	16.1	18.58	27.83	28.32		
Mass of pycnometer +Water (Mpw) in gm at Ti=21c	79.64	79.95	79.42	79.64	79.95	79.42	43.39	42.25	46.52	120.62	138.126	127.722	124.622	42.24	46.5	79.54	79.61		
Mass of Dry soil (Ms) in gm	10.01	10.02	10	10.02	10.03	10.01	10.67	15.16	13.14	20	19.99	19.733	20.848	13.15	14.1	10.02	10.01		
Mass of speciment +pcnometer (Mps) in gm	38.13	38.34	37.84	38.13	38.34	37.84	26.93	31.24	31.69	47.21	51.565	51.08	50.717	29.25	32.68	37.85	38.33		
Mass of Pycnometer + soil + Water (Mpsw) in gm	85.98	86.2	85.76	85.99	85.2	86.3	50.19	51.93	54.88	134	138.3	140.1	138	50.2	55.46	86.2	86.3		
Temp Of Contents of pycnometer when Mpsw was taken,Tx in C°	24	24	24	24	24	24	24.8	24.8	24.8	23	23	23	24	24.8	24.8	24	24		
Mass of Pcnometer + Water at temperture Tx(Mpw) in gm	79.6	79.91	79.38	79.6	79.91	79.38	43.38	42.24	46.51	120.62	125.574	127.722	124.622	42.23	46.29	79.54	79.91		
K for Tx	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9999	0.9999	0.9999	0.9986	0.9986	0.9986	0.9999	0.9999	0.9999	0.9991	0.9991		
Specific gravity at Tx	2.76	2.69	2.76	2.76	2.12	3.24	2.76	2.77	2.75	3.02	2.75	2.68	2.79	2.54	2.86	2.98	2.77		
Specific gravity at 20C°	2.76	2.68	2.76	2.76	2.11	3.24	2.76	2.77	2.75	3.02	2.75	2.68	2.79	2.54	2.86	2.98	2.76		
Average specific gravity at 20C°	2.73			2.70			2.76			2.81			2.72			2.83			

B-3.3 specific gravity test result for kebele 03

	Kebele 03																		
Sample No.	S1,1			S1,2			S2,1			S2,2			S3,1			S3,2			
Trial No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2		
Pycnometer No	A1	B1	C1	A	B	C	A1	B1	C1	A1	B1	C1	A	B	C	A	B	C	
Mass of calibtrated Pycnometer (clean and dry)(Mp) in gm	28.1	28.6	28.1	28.1	28.3	27.8	28.08	28.59	28.09	28.09	28.58	28.1	16.25	16.07	18.54	26.67	27.78		
Mass of pycnometer +Water (Mpw) in gm at Ti=21c	79.6	79.6	78.6	79.6	79.9	79.5	79.65	79.63	78.64	79.64	79.61	78.63	43.38	42.28	46.55	79.6	79.8		
Mass of Dry soil (Ms) in gm	10.2	10	10	10	10	10	10.28	10.05	10.06	10.26	10.07	10.07	10.68	15.17	13.15	10.02	10.01		
Mass of speciment +pycnometer (Mps) in gm	38.3	38.6	38.1	38.1	38.3	37.8	38.36	38.64	38.15	38.35	38.65	38.17	26.93	31.24	31.69	36.69	37.79		
Mass of Pycnometer + soil + Water (Mpsw) in gm	86.01	85.9	84.92	85.9	86.3	85.5	86.14	86.13	85.01	86.13	85.98	85.02	50.18	51.93	54.89	85.7	86.4		
Temp Of Contents of pycnometer when Mpsw was taken,Tx in C°	23	23	23	24	24	24	23	23	23	23	23	23	24.8	24.8	24.8	24	24		
Mass of Pcnometer + Water at temperture Tx(Mpw) in gm	79.47	79.43	78.57	79.46	79.76	79.32	79.62	79.66	78.61	79.56	79.58	78.6	43.37	42.27	46.54	79.32	79.98		
K for Tx	0.9986	0.9986	0.9986	0.9991	0.9991	0.9991	0.9986	0.9986	0.9986	0.9986	0.9986	0.9986	0.9999	0.9999	0.9999	0.9991	0.9991		
Specific gravity at Tx	2.79	2.83	2.74	2.81	2.89	2.62	2.73	2.81	2.75	2.78	2.74	2.76	2.76	2.75	2.74	2.75	2.79		
Specific gravity at 20C°	2.78	2.83	2.74	2.81	2.89	2.62	2.73	2.80	2.74	2.78	2.74	2.76	2.76	2.75	2.74	2.75	2.79		
Average specific gravity at 20C°	2.78			2.77			2.76			2.76			2.75			2.74			

B-3.4 specific gravity test result for kebele 04

		Kebele 04																	
Sample No.	S1,1			S1,2			S2,1			S2,2			S3,1			S3,2			
Trial.no	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	
Pycnometer No	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass of calibtrated Pycnometer (clean and	28.08	28.59	28.09	16.26	16.08	18.56	16.29	16.11	18.59	28.11	28.28	27.78	16.25	16.07	18.54	26.67	27.78	
Mass of pycnometer +Water (Mpw) in gr	80	79.63	78.64	43.37	42.27	46.54	43.35	42.26	46.53	79.63	79.99	79.44	43.38	42.28	46.55	79.6	79.8	
Mass of Dry soil (Ms) in gm	10.28	10.05	10.06	10.67	15.16	13.13	10.64	15.13	13.1	10.02	10.06	10.06	10.68	15.17	13.15	10.02	10.01	
Mass of speciment +pcnometer (Mps) in g	38.36	38.64	38.15	26.93	31.24	31.69	26.93	31.24	31.69	38.13	38.34	37.84	26.93	31.24	31.69	36.69	37.79	
Mass of Pycnometer + soil + Water (Mps	86.14	86.45	85.01	50.16	51.91	54.86	50.12	51.87	54.82	85.94	86.32	85.81	50.25	51.93	54.89	85.7	86.4	
Temp Of Contents of pycnometer when M	23	23	23	24.8	24.8	24.8	24.8	24.8	24.8	24	24	24	24.8	24.8	24.8	24	24	
Mass of Pcnometer + Water at temperture	80	79.6	78.61	43.36	42.26	46.53	43.34	42.25	46.52	79.59	79.99	79.4	43.37	42.27	46.54	79.32	79.98	
K for Tx	0.9986	0.9986	0.9986	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9991	0.9991	0.9991	0.9999	0.9999	0.9999	0.9991	0.9991	
Specific gravity at Tx	2.48	3.14	2.75	2.76	2.75	2.74	2.76	2.75	2.73	2.73	2.70	2.76	2.81	2.75	2.74	2.75	2.79	
Specific gravity at 20C°	2.48	3.14	2.74	2.76	2.75	2.74	2.76	2.75	2.73	2.73	2.69	2.75	2.81	2.75	2.74	2.75	2.79	
Average specific gravity at 20C°	2.79			2.75			2.74			2.72			2.77			2.73		

B-3.5 specific gravity test result for kebele 05

	Kebele 05																	
Sample No.	S1,1			S1,2			S2,1			S2,2			S3,1			S3,2		
Trial No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Pycnometer No	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass of calibtrated Pycnometer (	28.1	28.3	27.82	28.08	28.27	27.79	28.09	28.31	27.82	28.1	28.61	28.12	28.11	28.6	28.11	26.67	27.78	29.07
Mass of pycnometer +Water (Mp	79.63	79.94	79.41	79.62	79.94	79.45	79.61	79.92	79.42	79.64	79.62	78.62	79.63	79.61	78.61	79.6	79.8	79.73
Mass of Dry soil (Ms) in gm	10.4	10	10.5	10.5	10.07	10	10.04	10.2	10.02	11	10.1	10.03	10.25	10.04	10.04	10.02	10.01	10
Mass of speciment +pcnometer (	38.5	38.3	38.32	38.58	38.34	37.79	38.13	38.51	37.84	39.1	38.71	38.15	38.36	38.64	38.15	36.69	37.79	38.43
Mass of Pycnometer + soil + Wat	86.25	86.31	85.78	85.99	86.33	85.83	85.96	86.29	85.78	86.37	86.05	85.03	86	86.03	85.02	85.8	86.4	85.79
Temp Of Contents of pycnometer	24	24	24	24	24	24	24	24	24	23	23	23	23	23	23	24	24	24
Mass of Pcnometer + Water at te	79.59	79.9	79.37	79.58	79.9	79.41	79.57	79.88	79.38	79.61	79.59	78.59	79.6	79.58	78.58	79.32	79.98	79.43
K for Tx	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9986	0.9986	0.9986	0.9986	0.9986	0.9986	0.9991	0.9991	0.9991
Specific gravity at Tx	2.78	2.79	2.57	2.57	2.77	2.79	2.75	2.69	2.77	2.59	2.77	2.79	2.66	2.80	2.79	2.83	2.79	2.75
Specific gravity at 20C°	2.78	2.78	2.56	2.56	2.76	2.79	2.75	2.69	2.77	2.59	2.77	2.79	2.66	2.79	2.78	2.83	2.79	2.74
Average specific gravity at 20C°	2.71			2.71			2.73			2.72			2.75			2.77		

APPENDIX-C

Details of the SPSS Regression Analysis Outputs

Appendix C-1: Single Linear Regression Analysis

Model 1: Correlation Between UCS and DCPI

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.234[a]	.055	.021	58.71404

a. Predictors: (Constant), DCPI

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5585.047	1	5585.047	1.620	.214[b]
	Residual	96525.477	28	3447.338		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), DCPI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	294.383	107.434		2.740	.011
	DCPI	-1.863	1.463	-.234	-1.273	.214

a. Dependent Variable: UCS

Model 2: Correlation Between UCS and NMC

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.650[a]	.423	.402	45.88445

a. Predictors: (Constant), NMC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	43159.805	1	43159.805	20.500	.000[b]
	Residual	58950.719	28	2105.383		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), NMC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	333.754	39.642		8.419	.000
	NMC	-5.561	1.228	-.650	-4.528	.000

a. Dependent Variable: UCS

Model 3: Correlation Between UCS and LL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.124[a]	.015	-.020	59.92047

a. Predictors: (Constant), LL

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1577.564	1	1577.564	.439	.513[b]
	Residual	100532.960	28	3590.463		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), LL

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	202.864	68.085		2.980	.006
	LL	-.641	.967	-.124	-.663	.513

a. Dependent Variable: UCS

Model 4: Correlation Between UCS and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.250[a]	.062	.029	58.47306

a. Predictors: (Constant), Gs

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6375.769	1	6375.769	1.865	.183[b]
	Residual	95734.755	28	3419.098		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), Gs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1363.396	1114.405		-1.223	.231
	Gs	554.494	406.056	.250	1.366	.183

a. Dependent Variable: UCS

Appendix C-2: Multiple Linear Regression Analysis

Model A: Correlation Between UCS with DCPI and PI

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.242[a]	.059	-.011	59.66473

a. Predictors: (Constant), PI, DCPI

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5993.759	2	2996.879	.842	.442[b]
	Residual	96116.766	27	3559.880		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), PI, DCPI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	294.894	109.184		2.701	.012
	DCPI	-1.985	1.530	-.249	-1.297	.206
	PI	.286	.843	.065	.339	.737

a. Dependent Variable: UCS

Model B: Correlation Between UCS with LL, NMC and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.673[a]	.453	.384	48.00403

a. Predictors: (Constant), LL, NMC, Gs

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	45740.713	3	15246.904	6.616	.002[b]
	Residual	55305.295	24	2304.387		
	Total	101046.007	27			

a. Dependent Variable: UCS

b. Predictors: (Constant), LL, NMC, Gs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	687.202	561.136		1.225	.233
	NMC	-5.485	1.396	-.627	-3.930	.001
	Gs	-116.433	213.153	-.088	-.546	.590
	LL	-.579	.785	-.112	-.737	.468

a. Dependent Variable: UCS

Model D: Correlation Between UCS with DCPI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.353[a]	.125	.060	57.53103

a. Predictors: (Constant), Gs, DCPI

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12745.386	2	6372.693	1.925	.165[b]
	Residual	89365.138	27	3309.820		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), Gs, DCPI

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	1216.573	635.758		1.914	.066
	DCPI	-1.901	1.434	-.239	-1.325	.196
	Gs	-338.973	230.463	-.265	-1.471	.153

a. Dependent Variable: UCS

Model E: Correlation Between UCS with PI and NMC

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.651[a]	.424	.381	46.68909

a. Predictors: (Constant), PI, NMC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	43253.998	2	21626.999	9.921	.001[b]
	Residual	58856.526	27	2179.871		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), PI, NMC

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	338.147	45.538		7.426	.000
	NMC	-5.576	1.252	-.652	-4.454	.000
	PI	-.133	.642	-.030	-.208	.837

a. Dependent Variable: UCS

Model E: Correlation Between UCS with DCPI and NMC

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.651[a]	.423	.380	46.70721

a. Predictors: (Constant), DCPI, NMC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	43208.304	2	21604.152	9.903	.001[b]
	Residual	58902.220	27	2181.564		
	Total	102110.524	29			

a. Dependent Variable: UCS

b. Predictors: (Constant), DCPI, NMC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	322.476	85.731		3.761	.001
	NMC	-5.640	1.358	-.659	-4.153	.000
	DCPI	.189	1.265	.024	.149	.883

a. Dependent Variable: UCS

Appendix D. Selected sample picture

OK