ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEVELOPING CORRELATION BETWEEN THE INDEX PROPERTIES AND SWELLING POTENTIAL OF THE EXPANSIVE SOILS FOUND IN WOLISOTOWN

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in School of Civil and Environmental Engineering (Geotechnical Engineering)

By

ASAMNEW GULILAT DEBEBE

Advisor

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February, 2016

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Dedicated to my mother Tejinesh Nigerit

Declaration

I, the undersigned, declare that this thesis is my original work accomplished under the supervision of my research advisor Dr.-Ing. Messele Haile and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

Candidate's name _________________________

Signature ________________________________

Acknowledgement

First and above all I am very thankful to **Almighty God** for his guidance and success in my life.

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Lists of Abbreviation and Symbols

P_{200}%	P200 Percent passing sieve No. 200 (0.075mm opening)
γ_d	Dry density
a_0, a_1	Coefficients of the single linear regression equation
AASHTO	American Association of State Highway and Transportation Officials
Adj. R2	Adjusted R-square (Adjusted Coefficient of Determination)
ASTM	American Society for Testing and Materials
b_0, b_1, b_2, b_n	Coefficients of the multiple linear regression equation
C	Percentage of colloids smaller than 0.002mm
c	Residuals
Ca^{2+}	Calcium ions
CEC	Cation exchange capacity
CH	Inorganic clay of high compressibility
CL	Inorganic clay of low compressibility
CL	Mean confidence level
CM	Inorganic clay of medium compressibility
CSS	Classification of swelling soils
ds/m	Decisiemens per meter
Gs	Specific gravity of solids
K	A constant=$3.6*10^{-5}$
K^+	Potassium ions
LI	Liquidity index
LL	Liquid limit
m	Meter
meq/g	Mill-equivalent per gram
Mg^{2+}	Magnesium Ions
MH	Inorganic silts of high compressibility
ML	Inorganic silts of low compressibility
MM	Inorganic silts of medium compressibility
n	A constant=5, for natural soils

OH	Organic clay of high compressibility
PE	Potential expansiveness
PI	Plastic index
PL	Plastic limit
R^2	R-Square (coefficient of determination)
RF	Rainfall
SP	Swelling potential
SPR	Swelling pressure
Temp	Temperature
USCS	Unified Soil Classification System
w	Natural moisture content
$x_1, x_2,.n_o$	Independent variable
Y	Dependent variable

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Abstract

A considerable surface area of Woliso town is covered by expansive soils which have a tendency to undergo volume change due to change in water content with seasonal moisture variation. Civil engineering structure built on such soils show damage due to uneven movement caused by swelling and shrinking of the soil.

The focus of this study is to develop correlation between index properties and swelling potential of the expansive soils found in Woliso town. Conducting swelling pressure and swelling potential tests is time taking and expensive when compared with a simple index property tests. Therefore, it is helpful and has engineering applications to develop correlation formulas for estimating the swelling potential from simple index properties tests.

The thesis investigated the feasibility of single linear regression analysis and multiple linear regression analysis in correlating swelling potential with soil index properties. A total of 19 disturbed and 19 undisturbed samples were collected from different localities of Woliso town and the necessary laboratory tests were conducted in order to develop the empirical correlations.

In this research regression analysis is used to explore the significance of individual independent (index) soil variables. The empirical correlation is given in the form of an equation of swelling potential as a function of natural moisture content, dry density, grain size analysis, Atterberg Limits .This is done by considering the effect of an individual soil index properties and effect of a combination of soil index properties on the swelling potential results. The empirical correlation using single regression analysis results in a determination coefficient of R-square (R^2) =0.3864 and mean confidence level of (C_L)=96.78%, whereas multiple regression analysis gave comparatively a better correlation with determination coefficient of R-square (R^2) =0.4886 with mean confidence level of (C_L) =95.82%. Results of the validity of the newly developed correlation with control test results shows that, the correlation of swelling potential value with soil index properties is valid only for preliminary design purposes and estimation of swelling potential of the soils.

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Chapter-1
Introduction

1.1General

The significance of developing correlation between index properties and swelling characteristics, like swelling potential and Swelling Pressure, of expansive soil is valuable for Geotechnical engineers since employing index properties for assessing such swelling characters ease the elaborate, time taking, costly sampling and laboratory procedures as compared to having much quicker and easier test and sampling procedure of index properties. Important inferential index properties tests which are in designation for assessing swelling and expansive character of expansive soils are natural Moisture Content ,Dry Density ,Liquid Limit, Plastic Limit plasticity index, liquidity index and grain size distribution. Therefore, in this work we shall use these index properties to estimate the swelling potential which is directly linked with the heave of expansive soils when exposure of moisture.

1.2 Background of the thesis

Wolliso town is located about 114 km to the South West of Addis Ababa which is also a center of South Western Shoa zone. It has educational and health institutes, small factories, hotels and is well known for its natural hot springs and suitability for horticulture. Consequently, there is a great appetite for investment and a place of abode in the town Considerable part of this town is covered with expansive soils especially in locations majorly left for expansion which made it worthy for this study. Expansive soils have got a nature of expansion when they are exposed to moisture and vice versa in the conditions that reduce pore moisture. Alteration of subsoil moisture which is facilitated by seasonal rainy conditions in the region of study leads to alternate expansion and shrinkage of the soil which in turn induces structural distress on structures constructed on them and through time prompt failure of the structure built on it. This effect is more amplified on light weight structures as they lack the counter balancing load as compared to the Swelling Pressure of such soils.

1.3Objective of the study

The primary objectives of this research study are:

- To study and determine index properties of the soils in Woliso town
- To understand and evaluate expansiveness nature of the soil
- To study and determine Swelling Pressure and potential of the soil
- To correlates index properties with swelling potential of the soil

1.4 Design of Experiment and Sampling Distribution

In order to meet the goal of this thesis, basic theories and descriptions of Swelling Pressure and potential test and soil index property is reviewed. Subsequently, previous works by different researchers with regard to prediction of swelling potential value from basic soil index properties are assessed.

To produce satisfactory data for utilizing the correlations, laboratory tests are conducted on samples collected from different localities of Woliso town. After visual identification, expansive soil site investigation was conducted from 10 test pits for a total of 19 laboratory test samples. Out of 19 laboratory test samples 10 samples were collected from an average depth of 1.48m and the remaining 9 samples were collected from same test pits, but from an average depth of 2.32m. Especially samples from places where public institutions exist were given attention. Employing ASTM standards for soil testing, the collected disturbed and undisturbed soil samples were analyzed for Moisture Content, Specific Gravity, Dry Density, Atterberg Limit and Indices, Grain Size Distribution, Swelling Pressure and Swelling Potential. A Free Swell test is conducted in accordance to Gibbs and Holtz, 1969, test procedure based on the above laboratory tests. Based on the analyzed results and soil samples were classified using American Association of State Highway and Transportation Officials (AASHTO) system, Unified Soil Classification System (USCS). Subsequently, for the estimates of the swelling potential from simple index properties tests, statistical regression analyses of test results are carried out and empirical correlations are developed. Finally the validity of the developed correlations is tested. At the end, conclusion and recommendations are made.

1.5 Limitation of the Study

The thesis is conducted on limited samples collected from few locations in Woliso town. In order to conduct the proposed correlation, only nineteen laboratory test results collected from ten test pits are utilized in this research work. In addition the samples are collected can simulate only the moisture conditions of the year 2007 E.C at two different duration of time (late December and early June).With regard to the regression analysis, depending on the trends of the scattering of test results the correlation is analyzed using a linear regression model. The required correlation is carried out by applying a single linear regression equation and multiple linear regression equations with the aid of Microsoft Excel software 2010. Furthermore, the scope of the developed correlation is limited to the test procedures followed in the research work.

1.6 Structure of the Thesis

This thesis consists of seven Chapters; Chapter 1 provides information about the role and significance of correlation, design of experiment and sampling distribution, objectives, limitation of the study and structure of the thesis. Chapter 2 gives an overall view of expansive soils of the world and Ethiopia and their behavior and discusses some previous related conducted works. Chapter 3 provides the information regarding Geography, environmental, metrological conditions of the study area. It also tries to show the geological soil formation of the study area. Chapter 4 discusses sampling and laboratory procedures followed and induced test results as outcome. In Chapter 5, the different types of classification are discussed. Chapter 6 presents the development of empirical correlation and the technique specifically employed in this work. In addition swelling potential prediction models and comparison of the existing and developed empirical equation are discussed. In Chapter 7, conclusion and recommendations are made.

Chapter- 2

Literature Review

2.1 General

Expansive soils are soils that expand when water is added, and shrink when they dry out. This continuous change in soil volume can causes structures built on this soil to move unevenly and exhibit cracks. Each year in the world, expansive soils cause billion dollars in damage to houses, other buildings, roads, pipelines, and other structures[7] .Expansive soils exist all over the world and cause damages to foundations and associated structures (Kariuki, P. C., 2004). Its problem in civil engineering structures was first identified in the later part of 1930's. Since then so many countries reported the problem. Some of these countries are: Argentina, Australia, Burma, Canada, Cuba, Ethiopia, Ghana, India, Israel, Iran, Kenya, Mexico, Morocco, Zimbabwe, South Africa, Spain, Turkey, U.S.A, Venezuela, and a number of other Countries [7].

It has been ascertained that expansive clays cause billions of dollars of damage every year in the USA, more than all other natural hazards combined (Jones and Holtz, 1973, Chen F. H., 1988 and Day, R. W., 1999). Geotechnical engineers did not recognize damages associated with buildings on expansive soils until the late 1930s. The U.S. Bureau of reclamation made the first recorded observation about soil heaving in 1938 (Chen, F. H., 1988). Since then a number of researchers have initiated researches into expansive soils. Problem of expansive soils throughout the five continents results from a wide range of factors. Some of these are:

- Shrinkage and swelling of clay soils resulting from moisture variation
- Type of the clay and size of particles
- Drainage– rise of ground water or poor surface drainage
- Compression of the soil strata resulting from applied load
- Vegetation

Although expansive soils can be found in many countries, the problems related to expansive soils are the most severe and widespread in Ethiopia, but no properly organized and detailed statistics is available. Often, damage from expansive soils can be seen within the first few months or a year after a structure is constructed [7].

Figure 2.1: Distributions of expansive soils in Ethiopia [7]

2.2 Mineralogical structure

2.2.1 General

The behavior of the soil mass mainly depends on micro scale factors such as:-the amount and type of clay minerals in the soil, the chemical structure, the specific area of the clay particles, the soil water chemistry contained within the voids. According to ASTM the term clay is applied to the fraction of grains whose equivalent diameter is less than 0.005mm. The individual grains are fragments of a single mineral i.e. a solid compound with a definite chemical composition and unique crystalline structure. The minerals of clays are formed by the weathering of rocks. The main groups of clay crystalline materials that make up clays are the minerals Kaolinite, Illite and Montmorillonite [9]].

2.2.1.1 Kaolinite

Kaolinite has a structure that consists of one silica sheet and one alumna sheet bonded together in to a layer about 0.72mm thick and stacked repeatedly. The layers are held together by hydrogen bonds. Kaolinite has a few or no exchangeable cation, and the interlayer bonds are relatively strong preventing any hydration between layers and allowing many layers to build up. Kaolinite is relatively stables and water is unable to penetrate between the layers. Consequently Kaolinite shows little swelling on wetting. Kaolinites are found in soils that have undergone considerable weathering in warm, moist climates. They have low Liquid Limit and a low activity [9]].

2.2.1.2 Montmorillonite

Montmorillonites are made up of sheet like unit comprising an alumna octahedral sheet between two silica tetrahedral sheets. As the electrons rotate around the nucleus of an atom there will be times when there are more electrons on one side of the atom than the other, giving rise to a weak instantaneous dipole. Weak Vander Waals forces hold layers together and the bonding of these sheets is rather weak, resulting in a rather unstable mineral, especially when wet. In fact, Montmorillonite display a significant affinity for water, with subsequent swelling and expansion. Its excessive swelling capacity may seriously endanger the stability of overlying structures and road pavements [9]].

2.2.1.3 Illite

The Illites are somewhat similar to Montmorillonites in the structural units, but are different in their chemical composition. In Illite, the layers are separated by potassium ion, where as in Montmorillonite the layers are separated by loosely held water and exchangeable metallic ions. Unlike Montmorillonite particles, which are extremely small and have a great affinity for water, the Illite particles will normally aggregate and there by develop less affinity for water than Montmorillonites. Correspondingly, their expansion properties are less. The Cation Exchange Capacity of Illite is less than that of Montmorillonite [9]].

2.3 Identification of Expansive Soils

The identification of swelling potential of soils assumes significant importance in checking the possible post-construction problems for the structures. Due to steep increase in construction activities in the recent times, there is a need for quick and simple method to facilitate the civil engineers in evaluating and identifying the expansiveness and swelling potential of soils. Identification of potential swelling or shrinking of subsoil problems is an important tool for selection of appropriate foundation (Hamilton, J. J., 1977 and Van Der Merwe D. H., 1964). Despite the lack of standard definition of swell potential (Nelson, J. D. and Miller, D. J., 1992), there exist various geotechnical techniques to identify the swelling potential of soils.

2.3.1 Visual identification

Field estimates of shrink-swell potential can be made by observing desiccation cracks. The development of desiccation cracks in the ground surface is apparent during the dry periods. The degree of potential swell determines the size of the cracks (Day, R. W., 1999).Great potential swell is indicated by large and more frequent polygon arrangements of cracks while low shrink/swell means that potential for shrinkage cracks developing is low. Expansive s oils are often clay like, becoming very sticky when wet and hard and brittle when dry [7].

2.3.2 Laboratory identification

In general, there are three different method of identifying expansive soil in the laboratory. These are [7]:-

- Mineralogical (Chemical Analysis) Identification
- Indirect measurement
- Direct measurement

2.3.2.1 Mineralogical (Chemical Analysis) Identification

The chemical analysis of expansive soils has an important bearing on the swelling potential. There are a lot of factors contributing to the swelling potential of clay like the negative electric charges on the surface of the clay mineral, the strength of the interlayer bonding, and the Cation Exchange Capacity [7].

- PH
- Electrical Conductivity
- Cation Exchange Capacity and
- Exchangeable Base Capacity

2.3.2.1.1 PH

Soil pH is a measure of the amount of acidity or alkalinity (basicity) that is present in soil solution (Soil and its interaction with water). This can directly affect the solubility and uptake of nutrients by plant roots. Many plants are adapTable to a range of soil pH usually from 5.5 to 7.5. Roots are able to alter their micro-environment and extract nutrients that are present in the soil. Some plants such as azaleas, blueberries, and pines grow optimally at a lower ph. A key factor in understanding the pH of soil solution is to be able to measure it properly (Shawn, S. and K. Reed).

2.3.2.1.2 Electrical Conductivity (EC)

Soil electrical conductivity (EC) is a measurement that correlates with soil properties that affect crop productivity, including soil texture, Cation Exchange Capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics. EC of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity. Consequently, EC correlates strongly to soil particle size and texture. EC is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of decisiemens per meter (ds/m) (Robert, B., 2009).

2.3.2.1.3 Cation Exchange Capacity (CEC)

Cations that neutralize the net negative charge on the surface of soil particles in water are readily exchangeable with other cation. The exchange reaction depends mainly on the relative concentrations of cation in the water and also on the electrovalence of the cation. CEC, measured in millequivalents of cations per gram of soil particles, is a measure of the net negative charge on the soil particles, resulting from isomorphous substitution and broken bonds at the boundaries. The values of the Cation Exchange Capacity for the principal clay minerals are indicated in Table: 2.1.Montmorillonite has a relatively large exchange capacity because its particles may consist of single unit sheets. Thus, CEC is the quantity of exchangeable cations required to balance the negative charge on the surface of the clay particle. A high CEC value indicates a high surface activity and a higher swell potential [17]. Different clay minerals have different CEC. See Table 2.1.

Table 2.1: Cation Exchange Capacity of Principal Clay Minerals [9]]

Clay Mineral	CEC (meq/100gm)
Kaolinite	3-15
Illite	10-40
Montmorilonite	70

2.3.2.2 Indirect measurement

There is several indirect measurement methods used to predict swell potential of expansive soils and these methods are summarized below [7].

2.3.2.2.1 Index property

Soils occur naturally 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. Index properties of cohesive soils are used to characterize the physical and mechanical behavior of soils by making use of parameters such as Moisture Content, Dry Density, Specific Gravity, particle size distribution, and Atterberg Limits. Such parameters are useful to provide correlations with engineering soil properties for the estimation of swelling potential of expansive soils.

2.3.2.3 Direct measurement

The most accurate and dependable method of determining the swelling potential and the Swelling Pressure of expansive of soil is by direct measurement. The method quantitatively evaluates the volume change characteristics of expansive soil. It is a convenient and more reliable test because it directly tells the likely in.// situ response of the soil for moisture variations. The test can be done by the use of a conventional one-dimensional consolidation which is available in most soil mechanics laboratories [7].

2.4 Damages as a consequence of expansive Soils

Expansive soils occurring in arid and semi-arid climate regions of the world cause serious problems on civil engineering structures. Such soils swell when given an access to water and shrink when they dry out. The swelling potential of the expansive soil mainly depends upon the properties of soil and environmental factors and stress conditions. Each year, expansive soils cause damage to houses, buildings, roads, pipelines, and other structures. Swelling clays can control the behavior of virtually any type of soil if the percentage of clay is more than about 5 percent by weight [21].

2.5 Swell - Shrink Behavior of expansive soils

The swell - shrink potential of expansive soils is determined by its initial water content, Dry Density, void ratio, internal structure and vertical stresses, as well as the type and amount of clay minerals in the soil. Generally, the larger the amount of these minerals presents in the soil, the greater the expansive potential. Fine-grained clay-rich soils can absorb large quantities of water after rainfall, becoming sticky and heavy. Conversely, they can also become very hard when dry, resulting in shrinking and cracking of the ground [13].

2.6 Factors influencing swelling characteristics of expansive soils

Shrink and Swell in expansive soil can be induced by different factors. Generally, these factors are categorized into three groups namely the soil properties, the environmental factors and the state of stress.

2.6.1 The Soil properties

The soil characteristics influence the basic nature of the internal force field between particles. The following properties are categorized in this group.

- **Clay Mineralogy**

A clay mineral has two fundamental units which forms its structure. These fundamental units are a tetrahedral unit which silicon atom is in the center and four oxygen ions arranged tetrahedral and octahedral unit which has an aluminum atom in the center and six Oxygen or hydroxyl ions arranged octahedral around the aluminum.

The combination of these units in different arrangement leads to the formation of different clay minerals. Some of the major minerals include Kaolinite, Montmorilonite and Illite. The existence of Montmorilonite minerals is more responsible for the swelling of the soil. This is because the bond between the fundamental units which forms the structure is weaker than the other mineral and it is easily affected by water [14]

- **Dry Density**

Density in general shows the spacing of particles in a system. As dry density increases there is a closer spacing between particles and swelling potential increases [17].

- **Plasticity**

Soils exhibiting plastic behavior over wide range of moisture content and that have high liquid limits have greater potential for swelling and shrinking. Plasticity is an indicator of swell potential [17].

- **Soil Structure and Fabric**

The term fabric refers to the arrangement of particles, particle groups and pore spaces in a soil. Structure has a broader meaning of the combined effect of fabric, composition and antiparticle force. The unique relationship between water content of a soil and matric suction is influenced by soil fabric which in turn affects the swelling potential of the soil [7].

- **Soil suction**

Soil suction is a measure of a soil’s affinity for water and it is a parameter, which indicates the intensity with which it will attract water. Higher soil suction shows higher affinity for water and vice versa. Since expansion of a soil is predicted on the assumption that the volume change is equal to the volume of water taken up by the soil, higher soil suction could be used as an indication of swelling potential [7].

- **Soil water chemistry**

Soil water has different type of dissolved minerals, which can react with the clay. Clay particles are platelets like in shape and they have negative charges on their surface and positive charges on their edge. The negative charges on the surface of these particles are balanced by the cations from the soil water.

These cations are sodium, calcium, magnesium and potassium, which dissolve in the soil water and are adsorbed on the clay surface as exchangeable cations to balance the negative electrical surface charge.

If the soil water chemistry is changed either by changing the amount of water or the chemical composition, the inter particle force field which is dependent on the negative surface charge and electro chemistry of the soil water will change. This change disturbs the equilibrium and the system tries to adjust itself to the new condition which is manifested as shrinkage or swelling [14].

2.6.2 Environmental Factors

Environmental factors influence the changes that may occur in the internal force system.

These factors are mostly associated with moisture. They are [7]:

- Initial moisture condition
- Climate
- Ground water
- Drainage and manmade water sources
- Vegetation

2.6.3 Stress Condition

Over consolidation, magnitude of surcharge load, thickness and location of potentially expansive layers influence shrink-swell phenomenon occurring in the system. These include the following [7]

- Stress history
- Loading
- Soil profile

2.7 Previous Works

There are some practical experiences for using correlation for estimating engineering properties from different simple index properties tests in Ethiopia. Some related studies for developing correlation between swelling characteristics and index properties of expansive soils found in Ethiopia were conducted in the past for academic purposes. Some of these works are described as follows:-

2.7.1 Study of Nahom Debelo [15]

In this study 20 disturbed and undisturbed samples and were taken out of 10 test pits of Ambo’s expansive soil and tests of Moisture Content, Atterberg Limits, Grain Size Analysis, Dry Density, Specific Gravity, Clay Content, Cation Exchange Capacity and other chemical tests, Swelling

Pressure, Swelling Potential in the intention of developing correlation between swelling potential and index properties and the following conclusions were made.

- After testing the suitability of the existing correlation with control test results, the existing SPO predicting models by former researchers' shows overestimation from the actual test results and are inadvisable (uneconomical) to calculate SPO from the above existing correlations.
- Predicting swelling potential from the developed correlation shows an average deviation of 42.15% from the actual swelling potential. As a result, the above empirical correlation must be used for estimation (primary design) for large and complicated projects. But one can use for design purpose for simple civil engineering structures.
- From the single linear regression analysis developed, the relationship between SPO with Moisture Content is the best among equations developed to calculate SPO from a single index property test.
- From the multiple linear regression analysis developed, the relationship between SPO with Dry Density and plastic index is a relatively improved among the equations developed to calculate SPO from multiple soil index tests.

2.7.2 Study of Dagmawi Nigussie [7]

In this study location of expansive soil of the area is identified and disturbed and undisturbed samples are taken from twenty four different places of Bahir Dar. The laboratory tests conducted to attain the objectives of the study were Moisture Content, Atterberg Limits, Grain Size Analysis, Dry Density, Specific Gravity, Clay Content, Cation Exchange Capacity, Swelling Pressure following conclusions were made after the study.

- The regression analysis showed that there is a relationship between index properties and swelling characteristics of expansive soil of Bahir Dar.
- For the soil of the study area, the single parameter, Moisture Content indicates the swelling property much better than other single parameters.
- Evaluation of the previously developed equations with the present study area showed the necessity of formulation of specific equations for specific areas.
- Cation Exchange Capacity, in combination with other parameters is a powerful tool for prediction of swelling characteristics of Bahir Dar.
- The newly developed equations could be used for estimation of swelling characteristic of the study area.

2.7.3 Study of Daniel Teklu[7]

For his study expansive soils were collected from different parts of Addis Ababa. The laboratory tests conducted to attain the objectives of the study were Moisture Content, Atterberg Limits, Specific Gravity, Dry Density, Clay Content, and Swelling Pressure. Finally following conclusions were made after the study.

- All the previously developed equations do not predict the Swelling Pressure for the soils of study area, except the equation developed by David and Komornik (1969) predict the Swelling Pressure reasonably for soils having smaller density and Swelling Pressure.
- All the developed formulas in this study predict the Swelling Pressure with various degrees of accuracy; a good approximation is obtained by equations which involve Moisture Content, Atterberg Limits and Dry Density. Testing for the validity of the newly developed equations gives very good results.
- The prediction of Swelling Pressure by empirical relationships cannot be expected to yield accurate results. Therefore, for detail investigation Swelling Pressure should be determined from odometer tests on a sample that have an expected initial condition that could yield maximum Swelling Pressure. For small projects and for preliminary design purpose of any size of building the equations developed can be used to predict the Swelling Pressure.
- The equations developed may be further improved by increasing our database from tests performed on a number of undisturbed samples during the driest season of the year and from prepared disturbed samples. Some of the study related to investigation in to some of the index properties and engineering properties of expansive soils over different parts of Ethiopia were:

2.7.4 Study of Kibrom Gebrekirstos [12]

This study is done with the intention of examining the index properties of expansive soils of Mekelle, Swelling Pressure, and strength properties based on samples taken from different places of the study area. A total of 25 disturbed soil samples were collected from14 test pits for index property tests. Another four undisturbed samples are also tested for investigation of Swelling Pressure and unconfined compressive strength tests and finally following conclusions were made after the study.

- Thickness of Mekelle expansive soils ranges from few centimeters to as much as 5 meters.
- Since Mekelle is located in a semiarid climate, where there is a period of rainfall followed by long periods of no rainfall, climate wise expansive soil is a potential problem.
- The general soil classification systems, USCS and AASHTO, show that the expansive soils of Mekelle are poor and unsuitable as construction material and subgrade material.

- Most gray clays of Mekelle are found beneath black clays. As there is no significant distinction between the heaving characteristics of the gray and black soils, problems from expansiveness properties can arise from both clay types.

2.7.5 Swelling potential prediction models

Many relationships have been established from which swelling potential can be estimated based on index test results of soils. The following are correlations developed by different researchers at different time.

1) Anderson et al

$$SP=0.23*PI-3.12 \quad (2.1)$$

2) Seed, Woodward and Lund green

$$SP=60K\,(PI)^{2.44} \quad (2.2)$$

3) Seed et al

$$SP=\frac{3.6*10^{-5}\,(PI^{2.44}\,C^{3.44})}{(C-n)^{2.44}} \quad (2.3)$$

Where: - SP= Swelling potential (%)

PI = Plasticity index (%)

K= a Constant=$3.6*10^{-5}$

C= Percentages of colloids smaller than 0.002mm

n=5, for natural soils

In the above three previously developed equation we see that plastic index is common parameter and in fact one cannot conclude a fair approximation of SP from a single parameter. Whereas, in the previous section SP was correlated with different index soils tests in different combination.

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Chapter-3
Study Area

3.1 General

The formation of the different types of soils is facilitated by the prevailing environmental factors of an area. The climatic conditions, geologic and physiographic set up of an area have impact on the formation of expansive soils since these soils need specific conditions to be fulfilled. Since, a considerable part of Woliso town is covered by expansive soils which requires special consideration for engineering works This chapter is dedicated for the description of , land cover and land use, geologic, climate, and soil characteristics which influence the formation of expansive soils in the town and the nearby area in addition to the back ground and geographic location .

3.2 Location of the study area

The geographical location of Woliso town is approximately between 8^{o} 32'00'' N- 8^{0}53'30'' N latitude and between 37^{0}58'30" E – 37^{0}96'07" E longitude. In relative reference Woliso town is located 114 km in the south west direction of Addis Ababa (Finfine), 60kms South East West of Ambo town. Woliso town is a zonal town with the 2^{nd} grade of administrative status .As the information from the municipality shows, the town previously had four urban kebles (gendas). In addition to these four urban kebeles, now the town is expanded outwards and included certain farmers kebeles associations such as Obii in Northeast and Ejersa in the Southestern direction,

Figure 3.1 Relative location map of Woliso town

Figure3.2 Map of Woliso Town

3.3 Background of the area

Woliso got its name from the middle son of Liben which is one of major clans of Oromo. The city was named Ghion by Emperor Hialesellasie. There is a high school named after Dejazmach Geresu DuKi which was opened in late 1960s. After hydroelectric power station of 40.kwh was built in 1955 the town attained first class township status in 1958.In the year 2000 the multipurpose community Tele- center which was the first in its kind was launched with assistance of British Council. Later in the same year 150 bed hospital (Saint Lukas) was launched with help of Italian aid organization. The second largest flower farm in Ethiopia owned by Indian company Surya Blossoms had its official opening in the year 2009.Ambo university faculty of social sciences, Oromia Institute of water technology and other educational institutes are located in the town .the town is a tourist destinations due to the existence of the hot water springs coupled with close by t lake Wonchi which has got very attractive lake scenery.

3.4 Land Cover and land use

In the study area there are almost no remains of endogenous natural vegetation cover. Woliso and its surrounding areas are dominated by eucalyptus trees, which are owned by the individual's .The eucalyptus trees, are found distributed in all direction of the town and its surroundings. Other trees rarely observed in the town and its surrounding areas are Acacias, Cordial (locally Wanza, Tid, Woira) scientifically Junipers and coniferous forest trees found being distributed in the town and its surrounding specially around river Ejersa.

3.5 Geology

The land features of Woliso town are the results of the past geological history and tectonic movement. The volcanic action in the area is responsible for the existence of hills and hot spring water at the surface.

3.6Climate

According to the data obtained from National Meteorological Agency of Woliso branch Ten years consecutive meteorological data was taken and the following result is observed on the temperature and rainfall.

Temperature: - The mean annual temperature, the mean annual maximum and mean annual minimum temperatures of the town are found to be about, 23.99^{0}C and 9.08^{0}C, respectively, which is the characteristic of a warm temperate climate with cold night specially during winter (Table 3.1)

Rainfall: The mean annual rainfall is about 823.95 mm. The highest rainfall concentration occurs from June to September. Thus Low infiltration of rain Water, storm water occurrence, and inundation of Low gradient areas and incidence of sheet and gully erosion are some of the problems in the town and surrounding areas (Table 3.2)

Table 3.1: Mean Monthly Average Temperature Condition of Woliso town in ^{0}c

Month	January	February	March	April	May	June	July	August	September	October	November	December	Mean Annual
Mean monthly Maximum	24.21	24.53	25.64	25.22	25.89	23.27	21.97	21.3.9	22.05	24.19	23.64	23.25	23.99
Mean monthly Minimum	7.43	8.21	10.11	10.13	11.52	10.57	10.44	10.23	10.03	7.49	6.23	6.57	9.08

Table 3.2: Monthly Average Rainfall Condition of Woliso town

Month	`January	February	March	April	May	June	July	August	September	October	November	December	Mean Annual rain fall
Monthly average rain fall in mm	12.47	42.27	57.53	84.25	60.96	75.64	147.11	189.03	114.36	36.39	3.72	0.22	823.95

3.7 Geography

The town is located on the Shewa plateau. Most of the existing built up areas of the town is almost gentle slope and undulated while some hill slope are also seen in the town. The altitude of the town in average is 2063m above sea level. As regard to the proposed expansion most of the areas are characterized by flat, gentle slopes to undulated plains towards Obii and Michael church. There exists a hill at the center of the town known as Tulu Meja (Meja hill) which provides 360^0 view of the town.

Chapter-4
Sampling and Laboratory Test Result

4.1 Sampling

Since the surface area of Woliso town is covered with expansive and non-expansive soils it was compulsory to go through the town to identify areas with expansive soil. This was done visually with field identification techniques majorly observation of desiccation cracks before proceeding to sampling. In this respect, the central part of the town is found to be covered mainly with red clay soil. Consequently samples are taken on the periphery of the town where the existence of expansive soils is visually identified and priority was given for public institutions like hospitals, university campuses, and other schools and condominiums.

The samples are extracted during two different durations. The first one was in late December and the other was in early June of the year 2014 and 2015 respectively. In the first effort ten samples from five pits (University old, Geresu, Huuyimar, Kidanemehiret and Ejersa) were extracted. On the second round ten samples from five pits (University in, University in front, Michael, Hospital, and Elementary school) were extracted. Except for Geresu all other have dark color until 1.5m and grey below 1.5m. At Geresu the stratum changed black to dark grey at 1.4m from OGL and turned red at 2.2 m.

A total of 19 disturbed and 19 undisturbed representative samples were taken. Undisturbed samples were taken using a ring sampler with diameter of 11cm and height of 20cm. 10 samples were taken from an average depth of 1.48m whereas the other 9 samples were taken from an average depth of 2.32 m. Dry Density, Swelling potential and Swelling Pressure tests were done with the undisturbed samples whereas disturbed soil samples were consumed for Specific Gravity, Atterberg Limit and Indices, Grain Size Analysis, Free Swell. The detail of sampling locations in the town is shown in (Figure 4.1).

Figure 4.1Sampling Distribution for the 10 Test Pits of Expansive Soils Found in Woliso Town

Test pit No	Test pit name
1	University inside
2	University in front
3	University old
4	Kidanemihret
5	Ejersa
6	Geresu
7	Elementary
8	Hospital
9	Huluyimar
10	Michael

4.2 Laboratory Test Results

Laboratory tests are useful in providing reliable data for calculating Swelling Pressure and swelling potential of soils, index properties and other physical characteristics of soils.

4.2.1 Index Properties of Soils

Soils occur naturally 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. Index properties of cohesive soils are used to characterize the physical and mechanical behavior of soils by making use of parameters such as Moisture Content, Dry Density, Specific Gravity, particle size distribution and Atterberg Limits. All the above index properties were tested at Addis Ababa Institutes of Technology Geotechnical Engineering Laboratory for19 samples collected from10 different test pits.

4.2.1.1 Natural Moisture Content

The natural Moisture Content tests were carried out in laboratory as per the procedures of ASTM D2216 Standard Test Method. The laboratory test results show that, Moisture Contents of the study area falls in the range of (30.15-42.06) %.

Table 4.1: Natural Moisture Content Test Results of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth (m)	Natural Moisture Content%
1	Inside the Univerity	1	Black	1.25	31.33
2	Infront of University	1	Black	1.25	40.54
3		2	Black	2.5	39.79
4	Element	1	Black	1.25	35.21
5		2	Black	2.5	42.06
6	Hospital	1	Black	1.25	31.97
7		2	Grey	2.5	35.22
8	Michael	1	Black	1.25	32.72
9		2	Grey	2.5	39.4
10	University old	1	Black	1.5	30.15
11		2	Grey	2.3	39.39
12	Ejersa	1	Black	1.5	34.52
13		2	Grey	2.5	37.25
14	Geresu	1	Black	1.25	33.87
15		2	Grey	1.9	31.84
16	Huluyimar	1	Grey	1.5	34.29
17		2	Grey	2.5	37.77
18	Kidane Mihret	1	Black	1.5	37.74
19		2	Grey	2.5	34.43

4.2.1.2 Dry Density test

ASTM D 2937-00 – Standard Test Method was used for laboratory test procedure to carry out these tests. The laboratory test results show that, Dry Density of the study area falls in the range of (1.23-1.48) g/cm^3.

Table 4.2: Dry Density Test Results of expansive soils found in Woliso.

Test Pit	Sample No	Color	Depth (m)	Bulk Density (KN/ m^3)	Natural moisture content (%)	Dry Density (g/ cm^3)
Inside the University	1	Black	1.25	18.54	31.33	14.13
In front of the University	1	Black	1.25	16.97	40.54	12.07
	2	Black	2.5	16.97	39.79	12.16
Element	1	Black	1.25	18.84	35.21	13.93
	2	Black	2.5	18.15	42.06	13.05
Hospital	1	Black	1.25	17.56	31.97	13.34
	2	Grey	2.5	19.62	35.22	14.52
Michael	1	Black	1.25	17.76	32.72	13.34
	2	Grey	2.5	17.56	39.4	12.65
University old	1	Black	1.5	18.34	30.15	14.13
	2	Grey	2.3	18.74	39.39	13.44
Ejersa	1	Black	1.5	17.85	34.52	13.24
	2	Grey	2.5	17.95	37.25	12.95
Geresu	1	Black	1.25	18.64	33.87	14.22
	2	Grey	1.9	18.93	31.84	14.32
Huluyimar	1	Grey	1.5	18.74	34.29	13.93
	2	Grey	2.5	18.84	37.77	13.64
Kidane Mihret	1	Black	1.5	17.46	37.74	13.34
	2	Grey	2.5	18.54	34.43	1.41

4.2.1.3 Specific Gravity test

These tests were carried out in the laboratory as per the procedures of ASTM D 854-00 – Standard Test Method. The laboratory test results show that, Specific Gravity of the study area falls in the range of (2.6-2.81).

Table 4.3: Specific Gravity Test Results of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth (m)	Specific Gravity
1	Inside the University	1	Black	1.25	2.65
2	In front of the University	1	Black	1.25	2.66
3		2	Black	2.5	2.64
4	Element	1	Black	1.25	2.63
5		2	Black	2.5	2.67
6	Hospital	1	Black	1.25	2.76
7		2	Grey	2.5	2.70
8	Michael	1	Black	1.25	2.73
9		2	Grey	2.5	2.72
10	University old	1	Black	1.5	2.70
11		2	Grey	2.3	2.68
12	Ejersa	1	Black	1.5	2.67
13		2	Grey	2.5	2.60
14	Geresu	1	Black	1.25	2.73
15		2	Grey	1.9	2.70
16	Huluyimar	1	Grey	1.5	2.81
17		2	Grey	2.5	2.74
18	Kidane Mihret	1	Black	1.5	2.71
19		2	Grey	2.5	2.74

4.2.1.4 Atterberg Limit and Indices test

ASTM D 4318 - Standard Test Method was laboratory test procedure to carry out these tests. The detail summary of laboratory test results of the Atterberg Limits and Indices of the study area falls in the ranges of:-Liquid Limit (81-113) %; Plastic Limit (34-48) %; Plastic Index (40-65) % and Liquidity Index(-26.99-5.18) %.

Table 4.4: Atterberg Limits and Indices Test Results of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth (m)	Atterberg Limit and Indices test				
					LL (%)	PL (%)	PI (%)	Natural moisture Content	Liquidity Index (%)
1	Inside the University	1	Black	1.25	96	39	57	31.33	-13.46
2	In front of the University	1	Black	1.25	87	38	49	40.54	5.18
3		2	Black	2.5	111	41	68	39.79	-1.73
4	Element	1	Black	1.25	94	45	49	35.21	-19.98
5		2	Black	2.5	94	35	59	42.06	11.97
6	Hospital	1	Black	1.25	87	39	48	31.97	-14.65
7		2	Grey	2.5	89	39	50	35.22	-7.56
8	Michael	1	Black	1.25	88	31	54	32.72	3.02
9		2	Grey	2.5	86	38	48	39.4	2.92
10	University old	1	Black	1.5	103	44	59	30.15	-23.47
11		2	Grey	2.3	98	44	54	39.39	-8.54
12	Ejersa	1	Black	1.5	99	33	60	34.52	2.30
13		2	Grey	2.5	96	46	50	37.25	-17.50
14	Geresu	1	Black	1.25	93	48	45	33.87	-31.40
15		2	Grey	1.9	87	44	44	31.84	-28.28
16	Huluyimar	1	Grey	1.5	113	48	65	34.29	-21.09
17		2	Grey	2.5	95	45	50	37.77	-14.46
18	Kidane Mihret	1	Black	1.5	97	46	51	37.74	-16.22
19		2	Grey	2.5	88	40	48	34.43	-11.60

4.2.2 Grain Size Analysis

Grain Size Analysis tests were carried out in accordance to ASTM D 422 - Standard Test Method. The detail summary of laboratory test results of the Grain Size Analysis of the study area shows: - Percent Gravel (0-8.9) %; Percent Sand (2.3-15.1) %; Percent Silt (15.9-29.2) %; Percent Clay (62-75) % and Percent finer than 0.075mm (80.0-97.7).

Table 4.5: Result of Grain Size Analysis of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth (m)	Grain Size Analysis					Activity = (PI/ clay %)
					Gravel%	Sand %	silt%	Clay%	$P_{200\ (\%)}$	
1	Inside University	1	Black	1.25		13	23	64	87	0.89
2	In front of University	1	Black	1.25		3	26	71	97	0.69
3		2	Black	2.5	0.9	15.1	16	68	84	1
4	Element	1	Black	1.25		5.2	22.8	72	94.8	0.68
5		2	Black	2.5		15.1	15.9	69	84.9	0.85
6	Hospital	1	Black	1.25		4.5	26.5	69	95.5	0.7
7		2	Grey	2.5		5.9	24.4	69.7	94.1	0.72
8	Michael	1	Black	1.25		11.9	22.1	66	88.1	0.82
9		2	Grey	2.5		10.9	24.1	65	89.1	0.74
10	University old	1	Black	1.5		2.3	22.7	75	97.7	0.79
11		2	Grey	2.3	0.3	12.9	20.8	66	86.8	0.82
12	Ejersa	1	Black	1.5		8.7	24.3	67	91.3	0.9
13		2	Grey	2.5	1.3	12.9	22.8	63	85.8	0.79
14	Geresu	1	Black	1.25		8.8	29.2	62	91.2	0.73
15		2	Grey	1.9	8.9	11.1	16	64	80	0.69
16	Hulu yimar	1	Grey	1.5		3.2	20.8	76	96.8	0.86
17		2	Grey	2.5		7.7	22.3	70	92.3	0.71
18	Kidane Mihret	1	Black	1.5	2.3	13.7	22	62	84	0.82
19		2	Grey	2.5	2.7	10.1	17.2	70	87.2	0.69

The grain size distribution of one sample is indicated in fig 4.1.the rest are presented in Appendix B1.

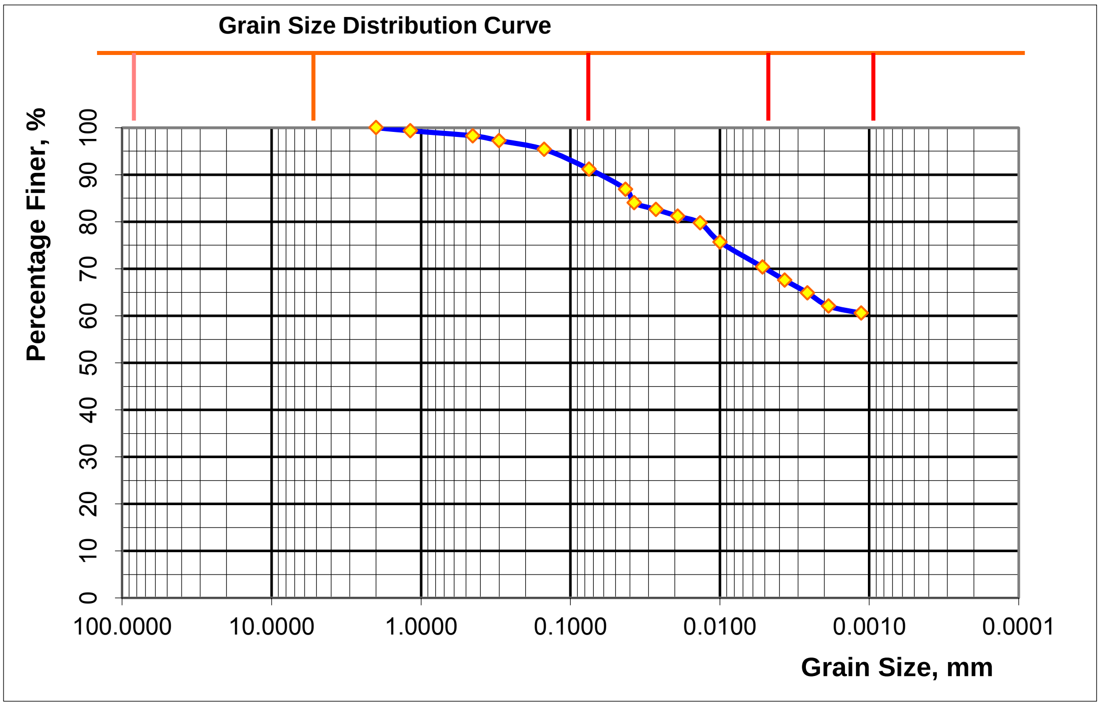

Figure 4.1 Grain distribution curve (Sample Geresu 1)

4.2.3 Swelling Characteristics

All swelling characteristics parameters were tested at Addis Ababa Institutes of Technology Geotechnical Engineering Laboratory on 19 samples collected from10 different test pits.

4.2.3.1 Free Swell Tests

These tests were carried out in accordance to Gibbs and Holtz, 1969, test Procedure. The laboratory test results show that, free swell tests of the study area falls in the range of (90-125) %.

Table 4.6: Free Swell Test Results of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth(m)	Free swell (%)
1	Inside the University	1	Black	1.25	120
2	Infront of the University	1	Black	1.25	115
3		2	Black	2.5	125
4	Element	1	Black	1.25	100
5		2	Black	2.5	120
6	Hospital	1	Black	1.25	90
7		2	Grey	2.5	90
8	Michael	1	Black	1.25	90
9		2	Grey	2.5	95
10	University old	1	Black	1.5	120
11		2	Grey	2.3	105
12	Ejersa	1	Black	1.5	115
13		2	Grey	2.5	100
14	Geresu	1	Black	1.25	95
15		2	Grey	1.9	90
16	Huluyimar	1	Grey	1.5	125
17		2	Grey	2.5	105
18	Kidane Mihret	1	Black	1.5	110
19		2	Grey	2.5	95

The swelling potential of one sample is indicated in fig 4.2.the rest are presented in Appendix B2.

4.2.3.2 Swelling Pressure tests

The Swelling Pressure tests were carried out as per the procedure of ASTM D 4546- Standard Test Method. The laboratory test results show that, Swelling Pressure tests of the study area falls in the range of (43.96-337.04) KPa.

Table 4.7: Swelling Pressure Test result of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth(m)	Swelling pressure (KPa)
1	Inside the University	1	Black	1.25	246.23
2	In front of the University	1	Black	1.25	244.68
3		2	Black	2.5	200.15
4	Element	1	Black	1.25	144.48
5		2	Black	2.5	43.96
6	Hospital	1	Black	1.25	52.74
7		2	Grey	2.5	110.21
8	Michael	1	Black	1.25	69.83
9		2	Grey	2.5	123.62
10	University old	1	Black	1.5	329.94
11		2	Grey	2.3	77.76
12	Ejersa	1	Black	1.5	243.74
13		2	Grey	2.5	124.85
14	Geresu	1	Black	1.25	118.07
15		2	Grey	1.9	65.08
16	Huluyimar	1	Black	1.5	337.04
17		2	Grey	2.5	221.74
18	Kidane Mihret	1	Black	1.5	169.98
19		2	Grey	2.5	75.99

The swelling pressure of one sample is indicated in fig 4.2.the rest are presented in Appendix B2.

4.2.3.3 Swelling potential tests

ASTM D 4546- Standard Test Method procedure was used to test swelling potential. The laboratory test results show that, swelling potential tests of the study area falls in the range of (1.92-12.05) %.

Table 4.8: Swelling Potential Test Results of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth(m)	Swelling Potential (%)
1	University Inside	1	Black	1.25	11.75
2	University In front	1	Black	1.25	4.64
3		2	Black	2.5	7.27
4	Element	1	Black	1.25	3.52
5		2	Black	2.5	3.60
6	Hospital	1	Black	1.25	3.05
7		2	Grey	2.5	3.54
8	Michael	1	Black	1.25	3.13
9		2	Grey	2.5	3.59
10	University old	1	Black	1.5	12.05
11		2	Grey	2.3	3.12
12	Ejersa	1	Black	1.5	7.16
13		2	Grey	2.5	3.84
14	Geresu	1	Black	1.25	3.27
15		2	Grey	1.9	1.92
16	Huluyimar	1	Grey	1.5	11.06
17		2	Grey	2.5	7.52
18	Kidane Mihret	1	Black	1.5	4.71
19		2	Grey	2.5	3.22

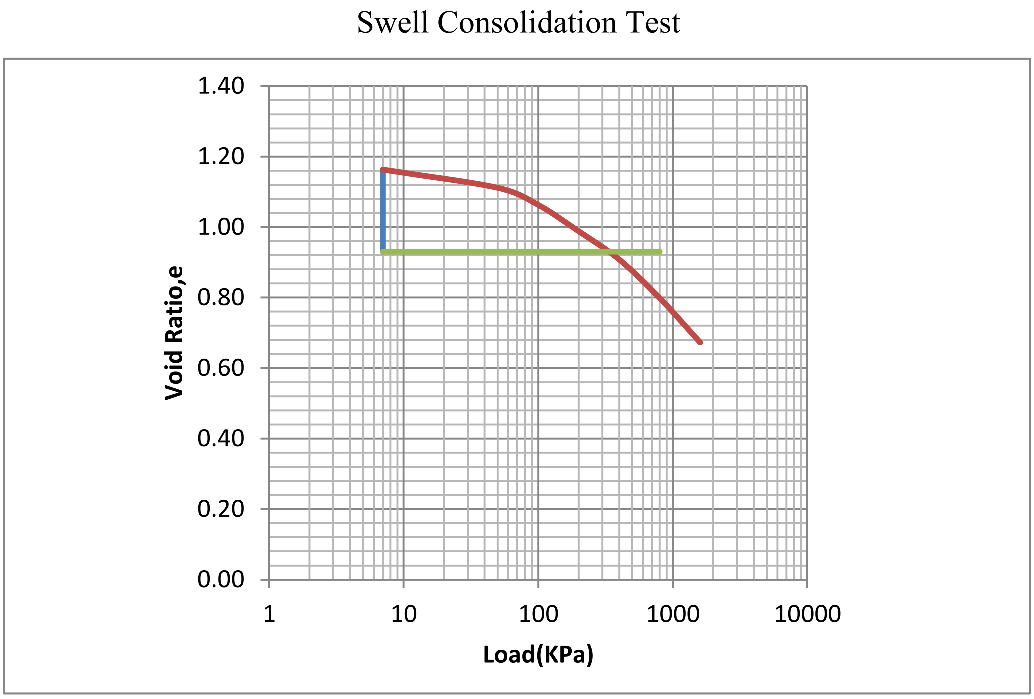

Figure 4.1 Sample of swell consolidation test result (sample university old1)

4.2.3.4 Analysis and Relations of Index Properties and Swelling Characteristics of study area

From Table 4.10 one can see that as two samples University Old at 2.5m depth and pit-Geresu at 1.25 m depth showed great difference results of Swelling Pressure. The first sample gave relatively the highest swelling pressure of 329.94 KPa and 12.05% swelling potential respectively whereas; the second sample gave the lowest Swelling Pressure of 65.08 KPa and 1.92% swelling potential respectively. This can be attributed to the fact that the first sample higher affinity for absorption of water which is clearly seen from higher negative liquidity index and also relatively higher dry density while the second one has relatively lower plasticity index and lower percentage of pass at No 200 sieve.

Again considering the index properties results of the study area, Table 4.9; one can see that as the whole plastic index values of the soils of study area fall above (greater than) 35%. This indicates o high degree of expansiveness potential of the samples considered. [9]

Table 4.9: Summary of All Index Properties and Swelling Characteristics Test Results of expansive soils found in Woliso

Number of Tests	Test Pit	Sample No	Color	Depth (m)	Initial Moisture Content (%)	Dry Density (g/cm^3)	Specific Gravity	Gradation					Atterberg Limits			Liquidity Index (%)	Swelling Characters		
								Gravel (%)	Sand (%)	Silt (%)	Clay (%)	P_{200} (%)	LL (%)	PL (%)	PI (%)		Swelling Pressure (KPa)	Swelling Potential (%)	Free Swell (%)
1	Inside the University	1	Black	1.25	31.33	1.44	2.65	0.7	13	23	64	87	96	39	57	-13.46	246.23	11.75	120
2	In front of University	1	Black	1.25	40.54	1.23	2.66	0.9	3	26	71	97	87	38	49	5.18	244.68	4.64	115
3		2	Black	2.5	39.79	1.24	2.64		15.1	16	68	84	111	41	68	1.73	200	7.27	125
4	Element	1	Black	1.25	35.21	1.42	2.63		5.2	22.8	72	94.8	94	45	41	-19.98	144.48	3.52	100
5		2	Black	2.5	42.06	1.33	2.67		15.1	15.9	69	84.9	94	35	59	11.97	43.96	3.6	120
6	Hospital	1	Black	1.25	31.97	1.36	2.76	2.7	4.5	26.5	69	95.5	87	39	48	-14.65	52.74	3.05	90
7		2	Grey	2.5	35.22	1.48	2.7		5.9	24.4	70	94.1	89	39	50	-7.56	110.21	3.54	90
8	Michael	1	Black	1.25	32.72	1.36	2.73		11.9	22.1	66	88.1	88	31	54	3.02	69.83	3.13	90
9		2	Grey	2.5	39.4	1.29	2.72		10.9	24.1	65	89.1	86	38	40	2.92	123.62	3.59	95
10	University old	1	Black	1.5	30.15	1.44	2.7	0.3	2.3	22.7	75	97.7	103	44	59	-23.47	329.94	12.05	120
11		2	Grey	2.3	39.39	1.37	2.68		12.9	20.8	66	86.8	98	44	54	-8.54	77.76	3.12	105
12	Ejersa	1	Black	1.5	34.52	1.35	2.67	1.3	8.7	24.3	67	91.3	99	33	60	2.30	243.74	7.16	115
13		2	Grey	2.5	37.25	1.32	2.6		12.9	22.8	63	85.8	96	46	50	-17.50	124.85	3.84	100
14	Geresu	1	Black	1.25	33.87	1.45	2.73	8.9	8.8	29.2	62	91.2	93	48	45	-31.40	118.07	3.27	95
15		2	Grey	1.9	31.84	1.46	2.7		11.1	16	64	80	87	44	44	-28.28	65.08	1.92	90
16	Huluyimar	1	Grey	1.5	34.29	1.42	2.81		3.2	20.8	76	96.8	113	48	65	-21.09	337.04	11.06	125
17		2	Grey	2.5	37.77	1.39	2.74	2.3	7.7	22.3	70	92.3	95	45	50	-14.46	221.74	7.52	105
18	Kidane Mihret	1	Black	1.5	37.73	1.36	2.71		10.1	17.2	70	87.2	97	46	51	-16.22	169.98	4.71	110
19		2	Grey	2.5	34.43	1.41	2.74	2.7	13.7	22	62	84	88	40	48	-11.60	75.99	3.22	95

Chapter -5
Classification

5.1 General

In this paper the whole soil samples of the study area are classified based on the two most widely used engineering soil classifications:-

- AASHTO,
- USCS

5.2 American Association of State Highway and Transportation Officials (AASHTO)

The expansive soil samples which were extracted from Woliso Town for this study have fallen under group A-7-5 as per classification AASHTO system since all have PL>30and LL>40.See (figure 5.1).

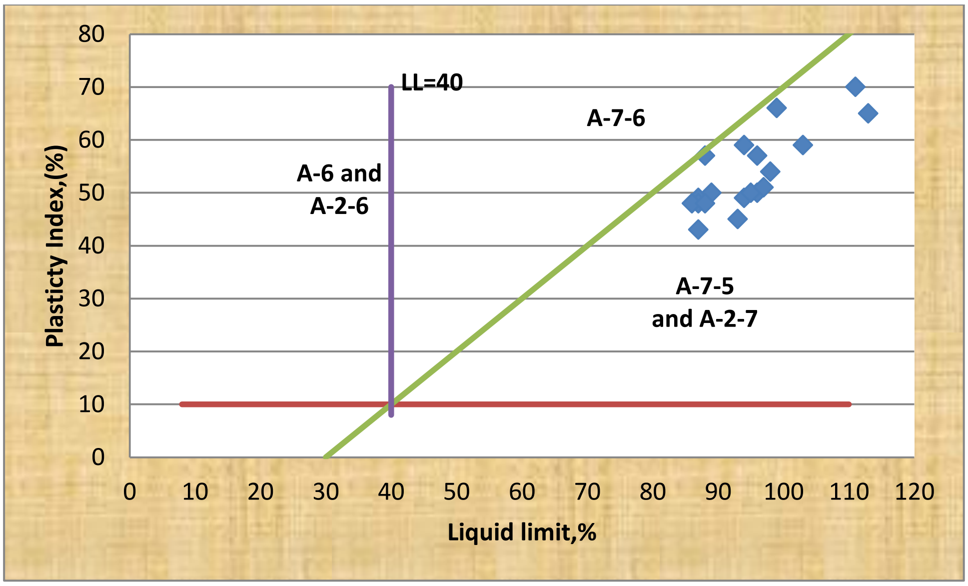

Figure 5.1 Scatter plots of Woliso expansive soils according to AASHTO classification

5.3 Unified Soil Classification System (USCS)

The classification of expansive soils found in Woliso town has fallen under MH and CH group according to USCS. Twelve of the samples are classified under CH group and the rest of them are in the MH group which is inorganic silt with high compressibility. This is discordant with index properties of the soils, since they are highly plastic clay.

Plasticity Chart: - The other way of graphical representation of USCS is a plasticity chart method. Therefore, one can see the same classification with USCS but represented graphically. See (Figure5.2).

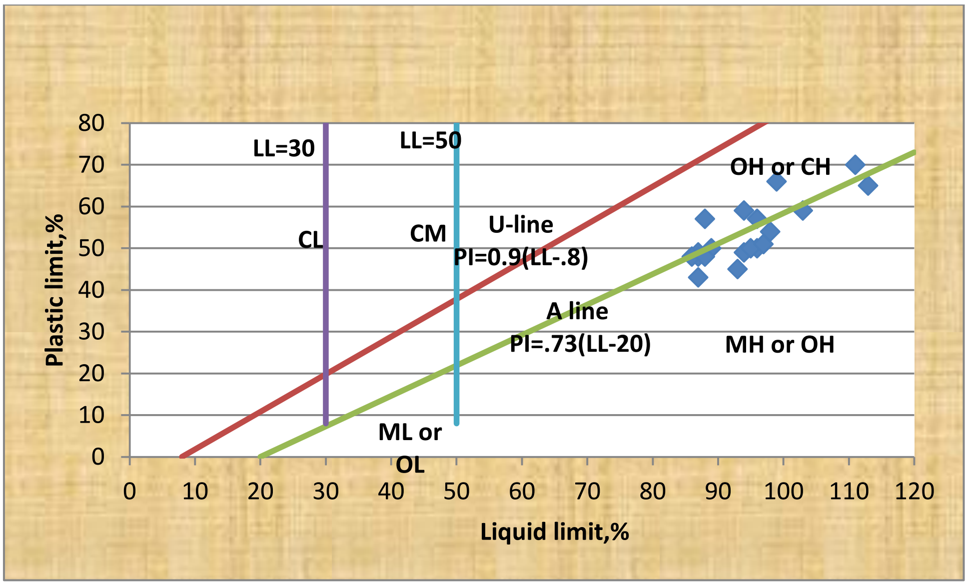

Figure 5.2: Scatter plots of Woliso expansive soils on Plasticity Chart according to (USCS)

Activity Chart: Plastic index versus clay fraction finer than 0.002mm is presented in the form of chart. According to V.D. Merwe method, the whole Woliso town expansive soils are falls in the range of very high potential of expansiveness. See (Fig 5.3).

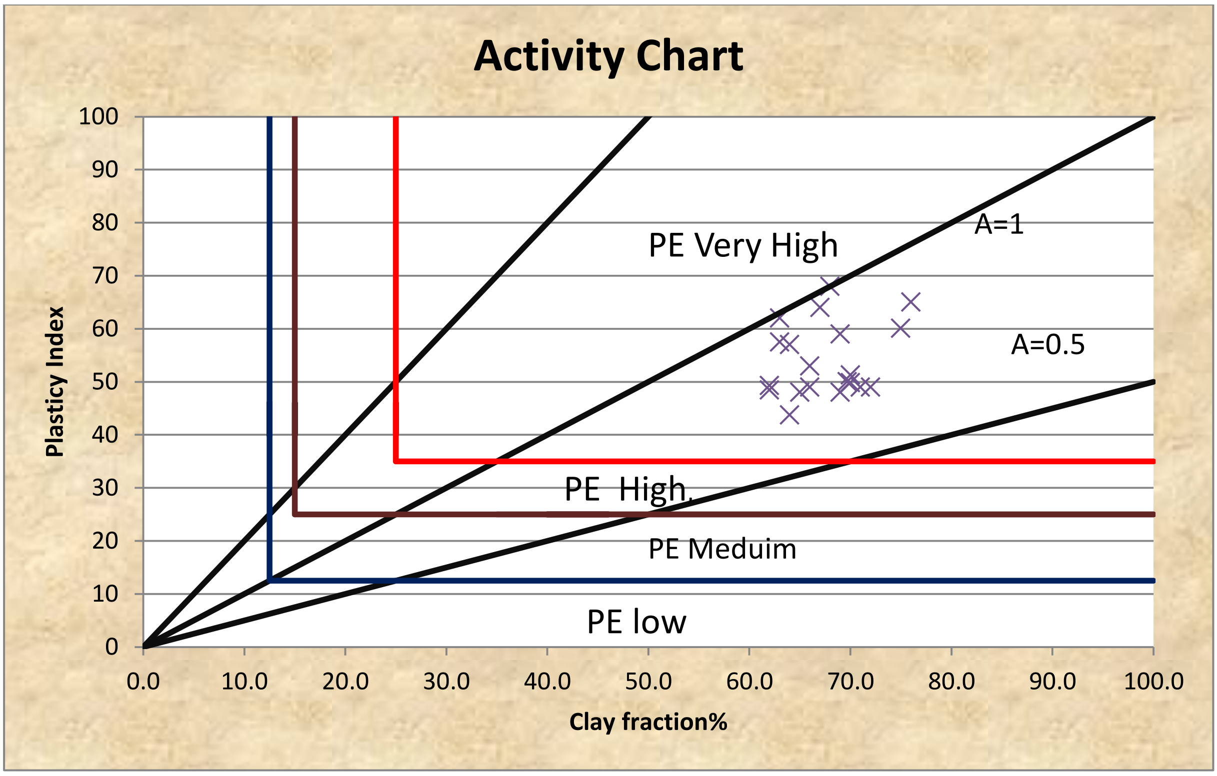

Figure 5.3: Scatter plots of Woliso expansive soils on Activity Chart using method of V.D. Merwe

Table 5.1: Summary of Classification of University expansive soils according to AASHTO and USCS

Number of Tests	Test Pit	Sample No	Color	Depth (m)	Gradation					Atterberg limits			USCS	AASHTO
					Gravel (%)	Sand (%)	Silt (%)	Clay (%)	P_{200} (%)	LL (%)	PL (%)	PI (%)		
1	University Inside	1	Black	1.25	0.7	13	23	64	87	96	39	57	CH	A-7-5
2	University Infront	1	Black	1.25	0.9	3	26	71	97	87	38	49	CH	A-7-5
3		2	Black	2.5		15.1	16	68	84	111	41	68	CH	A-7-5
4	Element	1	Black	1.25		5.2	22.8	72	94.8	94	45	49	MH	A-7-5
5		2	Black	2.5		15.1	15.9	69	84.9	94	35	59	CH	A-7-5
6	Hospital	1	Black	1.25	2.7	4.5	26.5	69	95.5	87	39	48	CH	A-7-5
7		2	Grey	2.5		5.9	24.4	69.7	94.1	89	39	50	CH	A-7-5
8	Michael	1	Black	1.25		11.9	22.1	66	88.1	88	34	54	CH	A-7-5
9		2	Grey	2.5		10.9	24.1	65	89.1	86	41	45	CH	A-7-5
10	University old	1	Black	1.5	0.3	2.3	22.7	75	97.7	103	44	59	MH	A-7-5
11		2	Grey	2.3		12.9	20.8	66	86.8	98	44	54	MH	A-7-5
12	Ejersa	1	Black	1.5	1.3	8.7	24.3	67	91.3	99	33	60	CH	A-7-5
13		2	Grey	2.5		12.9	22.8	63	85.8	96	46	50	CH	A-7-5
14	Geresu	1	Black	1.25	8.9	8.8	29.2	62	91.2	93	48	49	MH	A-7-5
15		2	Grey	1.9		11.1	16	64	80	87	44	43	MH	A-7-5
16	Huluyimar	1	Grey	1.5		3.2	20.8	76	96.8	113	48	65	MH	A-7-5
17		2	Grey	2.5	2.3	7.7	22.3	70	92.3	95	45	50	MH	A-7-5
18	Kidane Mihret	1	Black	1.5		10.1	17.2	70	87.2	97	46	51	CH	A-7-5
19		2	Grey	2.5	2.7	13.7	22	62	84	88	40	48	CH	A-7-5

Chapter-6

Development of Correlation and Discussion

6.1 General

The main purpose of this thesis is to develop relationship between index properties and swelling potential of Woliso expansive soils. This chapter begins with a brief discussion on regression analysis. Finally relationships between swelling potential and index properties test results were developed and discussion are presented.

Swelling potential is a built-in property varying with the effects of Dry Density, Atterberg Limit, the amount of Clay Content, and with the initial Moisture Content. The higher the Dry Density the higher closer particle spacing, therefore causing greater particle interaction and affinity to water resulting in higher swelling potential also the higher the amount of expansive clay, the higher the swelling potential and the higher Moisture Content the lower affinity for water resulting in lower swelling potential.

6.2 Regression Analysis

Regression analysis is an important technique in engineering and science to model and study relationships between two or more variables. 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 simple to practice in solving different engineering problems. Best 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. The confidence level of an estimate gives some idea about the accuracy of an estimate. A variable with a confidence level (C_L) ≥95% is the best to be chosen. A confidence level (C_L) is calculated as the difference of (1-(P-value)) %.

A suitable way of determining 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 regression 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 fact about some correlations. A number of techniques can be used to judge the adequacy of a regression model. Some of which are confidence level (C_L), R-squared value (R^2), and adjusted R-square (Adj.R^2).

In this paper, an attempt is made to apply single linear regression model and multiple linear regression models to obtain the swelling characteristics of soil from soil index properties using a statistical method. The general representation of a probabilistic single and multiple linear regression models have the following form:

$Y = a_0 + a_1x + c$……………………………………………………………………….. (6.1)

$Y = b_0 + b_1x_1 + b_2x_2 \ldots + b_nx_n + c$ ../…………………………………………………….. (6.2)

Where, the slope (a_1) and intercept (a_0) of the single linear regression model are called regression coefficients. Similarly, coefficients b_0, b_1, b_2 and b_n are termed multiple regressions coefficients. The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model) plus the residual term, c [8]. The basic assumption to estimate the regression coefficients of the single and multiple regression models is based on the least square method. For this paper, a regression statistics is employed to investigate the significance of individual regression variables. Therefore, the nineteen laboratory test results of the independent and dependent variables are used in the following regression analysis.

6.2.1 Single Linear Regression Analysis

After correlating swelling potential by one to one with soil index parameters the following equations with their respective regression outputs were summarized in Table 6.1.

Equation 1: Correlation of Swelling Potential (SP) with Moisture Content (w)

The output of regression analysis of correlating SPO with w is given by the following single linear equation. The mean confidence level and determination coefficient is also given below.

$SP = -0.2775 * w + 15.2194$, ($R^2 = 0.0897$, n = 19, C_L=86.22%)

Confidence level 86.22%

For details see the ANOVA analysis of Excel output in Appendix A1.

Equation 2: Correlation of Swelling Potential (SP) with Dry Density (γd)

The output of regression analysis of correlating SP with γ_d is given by the following single linear equation. The mean confidence level and determination coefficient is also given below:

SP =0 .6127*γ_d -2.8971, (R^2 = 0.0181, n = 19, C_L=28.44%)

Confidence level 28.44%

For details see the ANOVA analysis of Excel output in Appendix A1.

Equation 3: Correlation of Swelling Potential (SP) with Plastic Index (PI)

The output of regression analysis of correlating SP with PI is given by the following single linear equation. The mean confidence level and determination coefficient is also given below:

SP = 0.2648*PI-8.8205, (R^2 = 0.3864, n = 19, C_L=96.78%)

Confidence level 96.78%

For details see the ANOVA analysis of Excel output in Appendix A1.

Equation 4: Correlation of Swelling Potential (SP) with Liquidity Index (LI)

The output of regression analysis of correlating SP with LI is given by the following single linear equation. The mean confidence level and determination coefficient is also given below:

SP = 3.8531*LI-+4.9515, (R^2 = 0.0213, n = 19, C_L=72.45%)

Confidence level 74.25%

For details see the ANOVA analysis of Excel output in Appendix A1.

Equation 5: Correlation of Swelling Potential (SP) with Clay Content

The output of regression analysis of correlating SP with Clay Content is given by the following single linear equation. The mean confidence level and determination coefficient is also given below

SP = 0.3747*Clay Content -20.0567, (R^2 = 0.2304, n = 19, C_L=93.45 %)

Confidence level 86.22%

For details see the ANOVA analysis of Excel output in Appendix A1.

6.2.2 Multiple Linear Regression Analysis

In multiple regression analysis the precision of the developed equations are used to be judged not by R square (R^2) rather than adjusted R square (Adj.R^2) in addition to techniques used in a single linear regression analysis. After correlating swelling potential in different combination with two or more index properties parameters, the following equations with their respective regression outputs were summarized in Table 6.1.

Equation A: Correlation of SP with PI and γ_d, n = 19

The output of regression analysis of correlating SP with PI and γ_d is given by the following multiple linear equation. The mean confidence level, determination coefficient and Adj. R-square values are also given below:

SP = 0.3042*PI+1.5197 γ_d -31.4295, (R^2 = = 0.4886, Adj.R^2 = 0.4247)

Confidence level 95.82%

See the ANOVA analysis of Excel output in Appendix A1.

Equation B: Correlation of SP with Clay content and w, n = 19

The output of regression analysis of correlating SP with Clay content and w is given by the following multiple linear equation. The mean confidence level, determination coefficient and Adj. R- square values are also given below:

SP = -0.2822w * + 0.3794* Clay Content -10.2109, (R^2 = 0.3259, Adj.R^2 = 0.2416, C_L=79.47%)

Confidence level 79.47%

See the ANOVA analysis of Excel output in Appendix A1.

Equation C: Correlation of SP with γ_d and w, n =19

The output of regression analysis of correlating SP with γ_d, Clay Content and PI is given by the following multiple linear equation. The mean confidence level, determination coefficient and Adj. R-square values are also given below:

SP = -0.7038 γ_d +0.3756 w +28.2916, (R^2 = 0.1016, Adj.R^2 = -0.0164, C_L=58.60%)

Confidence level 58.60%

See the ANOVA analysis of Excel output in Appendix A1.

Equation D: Correlation of SP with PI and w, n = 19

The output of regression analysis of correlating SP with PI and w is given by the following multiple linear equation. The mean confidence level, determination coefficient and Adj. R-square values are also given below:

SP = 0.2796* PI - 0.3335w+2.3114, (R^2 = 0.5168, Adj.R^2= 0.4562, C_L=73.65%)

Confidence level 73.65%.

For details see the ANOVA analysis of Excel output in Appendix A1..

Where for equations 1-5 and A-D above: -

SP= Swelling potential (%)

w = Natural Moisture Content (%)

Clay fraction=Percentages of clay with equivalent diameters is than 0.002mm (%)

γ_d= Dry Density (kN/m3),

PI = Plasticity index (%)

PL = Plasticity limit (%),

LL = Liquid Limit (%)

Table 6.1 Detail summaries of the developed correlations

No	Types of Regression	Number of samples	Developed Equations	R values	R^2 values	Adjusted R square (Adj. R^2)	Confidence level (C_L)%	Standard error	Order of Equation	Order of accuracy
1	single	19	$SP = -0.2775*w+15.2194$	0.2996	0.0897	0.0362	86.22	3.1210	1	3rd
2	single	19	$SP =0 .6127* \gamma_d -2.8971$	0.1342	0.0180	-0.0398	28.44	3.2417	1	5th
3	single	19	$SP = 0.2648*PI-8.8205$	0.6216	0.3864	0.3503	96.78	2.5624	1	1st
4	single	19	$SP = 3.8531*LI-+4.9515$	0.1460	0.0213	-0.0362	72.45	3.2362	1	4th
5	single	19	$SP = 0.3747*\text{Clay Content} -20.0567$	0.4800	0.2304	0.1852	93.45	2.8697	1	2nd
A	multiple	19	$SP = 0.3042*PI+1.5197 \gamma_d -31.4295$	0.6990	0.4886	0.4247	95.82	2.4113	2	1st
B	multiple	19	$SP = -0.2822w * + 0.3794* \text{Clay Content} -10.2109$	0.5709	0.3259	0.2416	79.74	2.7685	2	2nd
C	multiple	19	$SP = -0.7038 \gamma_d +0.3756 w +28.2916$	0.3188	0.1017	-0.0106	58.56	3.1960	3	4th
D	multiple	19	$SP = 0.2796* PI - 0.3335w+2.3114$	0.7188	0.5167	0.4563	73.65	2.3442	4	3rd

6.3 Discussion on the developed and existing correlation

6.3.1 Relationship of developed with existing correlations

Tables 6.3, below clearly shows the outcome of Anderson et al correlation .It has an average deviation from the actual by 103.29%, over estimating the calculated SP values. Also, the Seed, Woodward and Lund green correlation gives an average deviation from the actual by 664.32% which gives us with highly overestimated the calculated SP value whereas, the Seed et al correlation resulted in an average deviation from the actual by 934.32% which is even much more overestimation than Seed, Woodward and Lund green . Finally, the developed correlation estimates the calculated SP value with average deviation of 38.87% from the actual SP value. Consequently, we can conclude that, prediction (estimates) of the swelling potential of the study area from the above existing correlations (swelling potential predicting mode) gives unrealistic estimates of the swelling potential of the study area.

Table 6.3 Relationship of developed and Existing Correlations

Sample No	Actual(control values)				Existing Correlations							
					Developed Correlation		Anderson et al		Seed, Woodward and Lund green		Seed et al	
	SP (%)	Dr y density (KN/m^3)	PI (%)	Clay Content (%)	Calculated SP (%)	Difference from the actual (%)	Calculated SP (%)	Difference from the actual (%)	Calculated SP (%)	Difference from the actual (%)	Calculated SP (%)	Difference from the actual (%)
1	11.75	14.13	57	64	7.38	-39.8	9.76	-16.94	39.81	238.8	51.79	340.78
2	4.64	12.07	49	71	1.81	-60.92	8.15	75.65	28.74	519.5	40.65	776
3	7.27	12.16	70	68	8.35	6.5	12.52	72.21	63.94	779.5	87.31	1100.96
4	3.52	13.93	49	72	4.65	31.99	8.15	131.53	28.74	716.6	41.11	1067.99
5	3.6	13.05	59	69	6.35	76.29	10.45	190.28	45.22	1156.1	62.48	1635.56
6	3.05	13.34	48	69	3.45	13.03	7.92	159.67	27.33	796.2	37.77	1138.21
7	3.54	14.52	50	70	5.84	65.11	8.38	136.72	30.2	753	42.06	1088.23
8	3.13	13.34	57	66	6.19	68.45	9.3	197.12	36.43	1064	48.57	1451.76
9	3.59	12.65	48	65	2.40	-33.04	7.92	120.61	27.33	661.4	36	902.7
10	12.05	14.13	59	75	7.99	-33.72	10.45	13.28	45.22	275.3	66.89	455.09
11	3.12	13.44	54	66	5.42	73.77	9.3	198.08	36.43	1067.7	48.57	1456.74
12	7.16	13.24	66	67	8.77	-2.95	10.68	49.16	47.11	558	63.57	787.85
13	3.84	12.95	50	63	3.46	-9.91	8.38	118.23	30.2	686.3	38.79	910.24
14	3.27	14.22	45	62	3.88	18.55	7.23	121.1	23.35	614.1	29.62	805.91
15	1.92	14.32	43	64	3.42	93.82	7	264.58	22.1	1051.3	28.75	1397.64
6	11.06	13.93	65	76	9.51	-13.99	11.83	6.96	57.27	417.9	85.65	674.43
17	7.52	13.64	50	70	4.50	-40.12	8.38	11.44	30.2	301.5	42.21	461.31
18	4.71	13.34	51	70	4.36	-7.43	8.61	82.8	31.69	572.8	44.3	840.55
	3.22	13.83	48	62	4.19	30.21	7.92	145.96	27.33	748.8	34.68	976.88
Average Deviation						38.87		103.29		664.32		934.62

Chapter Seven

Conclusion and Recommendation

7.1 Conclusions

1. After the assessment for rationality of the existing correlation one can easily observe that the existing SP predicting models by different researchers' shows overestimation from the actual test results.
2. Predicting swelling potential from the developed correlation shows an average deviation of 38.87% from the actual swelling potential. Consequently, the above empirical correlation shall be employed only for estimation of SP in the preliminary design for large and complicated projects. But may use for design of for simple civil engineering structures.
3. Results of single linear regression analysis developed above delivers as with the relationship between SP with Liquid Limit to be best among equations developed to calculate SP from a single index property test.
4. The multiple linear regression analysis developed gives as with the relationship between SP with Dry Density and Plastic Index to be best among all other the equations developed to calculate SP from multiple soil index tests.

7.2 Recommendation for future works

The following recommendations are made:

1. The equations developed may be further improved by increasing numbers of samples collected from different locations of Woliso town especially from areas that are not covered in this paper.
2. It is recommended to take samples during different seasons and make the study on the effect of natural Moisture Content on swelling characteristics.

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APPENDIXA: Findings of the ANOVA Excel Analysis Outputs
APPENDIX1: The Outputs of Single Linear Analysis

Equation1:Corelation of Swelling Potential with Moisture Content Summary Output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.324937942
R Square	0.105584666
Adjusted R S	0.052972
Standard Err(	3.042768354
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	1	18.58011162	18.58011162	2.00682978	0.174656534
Residual	17	157.3934673	9.258439255		
Total	18	175.9735789			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	15.93026867	7.45273199	2.137507252	0.04738042	0.206378625	31.65415872	0.20637862	31.65415872
X Variable 1	-0.29391962	0.2074786	-1.416626197	0.17465653	-0.731661201	0.143821962	-0.7316612	0.143821962

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals	Standard Residuals
1	6.721766994	5.028233006	1.700428188
2	4.014767298	0.625232702	0.211438752
3	4.235207013	3.034792987	1.026294433
4	5.58135887	-2.06135887	-0.697102287
5	3.568009476	0.031990524	0.01081843
6	6.533658437	-3.483658437	-1.178089996
7	5.578419674	-2.038419674	-0.689344799
8	6.313218723	-3.183218723	-1.076488468
9	4.349835664	-0.759835664	-0.256958256
10	7.069222806	4.980777194	1.684379767
11	4.352416068	-1.232416068	-0.41677365
12	5.785072145	1.374927855	0.464967729
13	4.981762846	-1.141762846	-0.386116897
14	5.974926722	-2.704926722	-0.914741548
15	6.570856455	-3.650856455	-1.234632368
16	5.85176492	5.20823508	1.761300586
17	4.828924644	2.691075356	0.910057347
18	5.809848969	-2.589848969	-0.875825003
19	4.838962276	-0.128962276	-0.043611959

PROBABILITY OUTPUT

Percentile	Y
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

Equation 2:Corelation of Swelling Potential with Dry Density Summary Output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.13419681
R Square	0.018008784
Adjusted R Sq	-0.03975541
Standard Erro	3.241665376
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.276137113	3.276137113	0.31176381	0.583879765
Residual	17	178.642705	10.50839441		
Total	18	181.9188421			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-2.89710704	14.81817648	-0.195510361	0.84731121	-34.16072661	28.36651254	-34.1607266	28.36651254
X Variable 1	0.612733177	1.097383798	0.558358141	0.58387977	-1.702544255	2.928010609	-1.70254425	2.928010609

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	5.85992504	5.890074961	1.906749617
2	4.43112028	0.208879716	0.067619058
3	4.49915861	2.770841395	0.896983621
4	5.7238484	-2.2038484	-0.713435247
5	5.1115035	-1.5115035	-0.489307647
6	5.31561847	-2.26561847	-0.733431606
7	6.13207833	-2.59207833	-0.839113999
8	5.31561847	-2.18561847	-0.707533809
9	4.83935021	-1.24935021	-0.404442737
10	5.85199118	6.198008821	2.006434726
11	5.36448752	-2.24448752	-0.726591043
12	5.27629827	1.883701734	0.609796578
13	5.07713298	-1.23713298	-0.400487744
14	5.94197929	-2.67197929	-0.864979738
15	6.02849215	-3.10849215	-1.006288758
16	5.71797177	5.342028226	1.729334574
17	5.53679996	1.983200044	0.642006417
18	5.64312596	-2.42312596	-0.784420321
19	5.29349963	-0.58349963	-0.188891942

PROBABILITY OUTPUT

Percentile	Y
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

Equation 3:Corelation of Swelling Potential with Plasticty Index Summary Output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.621617366
R Square	0.38640815
Adjusted R Sq	0.350314512
Standard Erro	2.562442756
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	70.29492321	70.29492321	10.7057135	0.004493964
Residual	17	111.6239189	6.566112876		
Total	18	181.9188421			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-8.82051759	4.375554293	-2.015862904	0.05990162	-18.05213019	0.411095024	-18.0521302	0.411095024
X Variable 1	0.264783727	0.080925144	3.271958663	0.00449396	0.094046597	0.435520857	0.0940466	0.435520857

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	6.401435341	5.348564659	2.227774277
2	4.062974574	0.577025426	0.240341565
3	9.616818895	-2.346818895	-0.977492674
4	4.062974574	-0.542974574	-0.226158767
5	6.986050532	-3.386050532	-1.410351516
6	3.770666978	-0.720666978	-0.300170879
7	4.35528217	-0.81528217	-0.339579824
8	4.062974574	-0.932974574	-0.388600847
9	3.770666978	-0.180666978	-0.075251076
10	7.307253693	4.742746307	1.975439936
11	5.225237407	-2.105237407	-0.876869598
12	8.452970475	-1.292970475	-0.538545675
13	6.539752998	-2.699752998	-1.124496134
14	4.151516614	-0.881516614	-0.367167672
15	2.528994885	0.391005115	0.162860728
16	8.739896108	2.320103892	0.96636539
17	4.304873569	3.215126431	1.339158525
18	4.723536531	-1.503536531	-0.62625026
19	3.896123106	0.813876894	0.338994501

PROBABILITY OUTPUT

Percentile	*Y*
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

Equation 4:Corelation of Swelling Potential with clay Content Summary Output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.347611186
R Square	0.120833537
Adjusted R Sq	0.069117862
Standard Erro	3.923922988
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	1	35.97545091	35.97545091	2.33649736	0.144766269
Residual	17	261.7519175	15.39717162		
Total	18	297.7273684			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	50.51470387	11.37831673	4.439558597	0.00035937	26.50855398	74.52085376	26.508554	74.52085376
X Variable 1	0.182720479	0.119537612	1.528560553	0.14476627	-0.069481838	0.434922796	-0.06948184	0.434922796

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals	Standard Residuals
1	68.05586986	-4.055869858	-1.063592651
2	66.41138555	4.588614453	1.203297142
3	70.79667704	-2.296677044	-0.602270021
4	67.6904289	4.3095711	1.130122097
5	67.6904289	1.3095711	0.3434159
6	66.41138555	2.588614453	0.678826344
7	66.77682651	2.923173495	0.766559568
8	66.59410603	-0.594106026	-0.155795631
9	66.22866507	-1.228665068	-0.322199474
10	69.35297573	5.647024269	1.480849663
11	68.41695542	-2.416955425	-0.63381127
12	68.60739554	-1.607395542	-0.421516012
13	68.14233175	-5.142331753	-1.34850142
14	67.56305575	-5.563055748	-1.458830144
15	66.48501581	-2.48501581	-0.651659113
16	71.162118	4.837881998	1.268663916
17	67.91442614	2.085573861	0.546911294
18	68.23200369	-6.232003691	-1.634251975
19	66.66794876	3.332051238	0.873781786

PROBABILITY OUTPUT

Percentile	Y
2.631578947	62
7.894736842	62
13.15789474	63
18.42105263	64
23.68421053	64
28.94736842	65
34.21052632	66
39.47368421	66
44.73684211	67
50	68.5
55.26315789	69
60.52631579	69
65.78947368	69.7
71.05263158	70
76.31578947	70
81.57894737	71
86.84210526	72
92.10526316	75
97.36842105	76

Equation 5:Corelation of Swelling Potential with Liquidity Index Summary Output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.146037026
R Square	0.021326813
Adjusted R Sq	-0.0362422
Standard Erro	3.236184145
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.879749144	3.879749144	0.37045648	0.550802592
Residual	17	178.039093	10.47288782		
Total	18	181.9188421			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.951514037	1.00779957	4.913193244	0.00013145	2.825242806	7.077785269	2.82524281	7.077785269
X Variable 1	-3.85311627	6.330580226	-0.608651361	0.55080259	-17.20947304	9.503240509	-17.209473	9.503240509

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals	Standard Residuals
1	68.05586986	-4.055869858	-1.063592651
2	66.41138555	4.588614453	1.203297142
3	70.79667704	-2.296677044	-0.602270021
4	67.6904289	4.3095711	1.130122097
5	67.6904289	1.3095711	0.3434159
6	66.41138555	2.588614453	0.678826344
7	66.77682651	2.923173495	0.766559568
8	66.59410603	-0.594106026	-0.155795631
9	66.22866507	-1.228665068	-0.322199474
10	69.35297573	5.647024269	1.480849663
11	68.41695542	-2.416955425	-0.63381127
12	68.60739554	-1.607395542	-0.421516012
13	68.14233175	-5.142331753	-1.34850142
14	67.56305575	-5.563055748	-1.458830144
15	66.48501581	-2.48501581	-0.651659113
16	71.162118	4.837881998	1.268663916
17	67.91442614	2.085573861	0.546911294
18	68.23200369	-6.232003691	-1.634251975
19	66.66794876	3.332051238	0.873781786

PROBABILITY OUTPUT

Percentile	Y
2.631578947	62
7.894736842	62
13.15789474	63
18.42105263	64
23.68421053	64
28.94736842	65
34.21052632	66
39.47368421	66
44.73684211	67
50	68.5
55.26315789	69
60.52631579	69
65.78947368	69.7
71.05263158	70
76.31578947	70
81.57894737	71
86.84210526	72
92.10526316	75
97.36842105	76

APPENDIX 2: The Outputs of Multiple Linear Analyses

Equation A: Correlation of swelling potential (SP) with Plasticy Index and Dry Density

SUMMARY OUTPUT

gression Statistics	
Multiple R	0.6990185
R Square	0.4886269
Adjusted R Squa	0.4247052
Standard Error	2.4112809
Observations	19

ANOVA

	df	SS	MS	F	Significance F
Regression	2	88.89043389	44.44521695	7.644154	0.00467631
Residual	16	93.02840821	5.814275513		
Total	18	181.9188421			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-31.42946	13.29584508	-2.363855877	0.031071	-59.61539399	-3.2435291	-59.615394	-3.243529096
X Variable 1	0.3042202	0.079279838	3.837296374	0.001454	0.136154486	0.47228598	0.13615449	0.472285982
X Variable 2	1.5197777	0.849813848	1.788365368	0.092667	-0.281747224	3.32130254	-0.28174722	3.321302535

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals	Standard Residuals
1	7.419448	4.330552041	1.971006762
2	1.8785239	2.76147611	1.256857794
3	8.2031624	-0.933162432	-0.4247194
4	4.5356301	-1.015630106	-0.462253724
5	6.5321539	-2.932153923	-1.334540067
6	3.3710286	-0.321028625	-0.146112917
7	5.7002316	-2.160231588	-0.983207459
8	3.6965439	-0.566543933	-0.257856715
9	2.3920948	1.197905244	0.545214401
10	8.4118647	3.638135318	1.655860326
11	5.0912928	-1.971292752	-0.897213867
12	8.5044472	-1.344447195	-0.611911481
13	5.9645085	-2.12450855	-0.966948481
14	5.0825828	-1.812582792	-0.824978641
15	3.4535546	-0.533554608	-0.242841959
16	9.7317961	1.328203927	0.604518523
17	4.420546	3.099453991	1.410684993
18	5.1053165	-1.885316498	-0.858082649
19	3.4652736	1.24472637	0.56652456

PROBABILITY OUTPUT

Percentile	Y
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

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Equation B: Correlation of Swelling potential (SP) with Clay content and Natural moisture content

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.5708572
R Square	0.3258779
Adjusted R Squa	0.2416126
Standard Error	2.768523
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	59.28333039	29.64166519	3.867286	0.042648967
Residual	16	122.6355117	7.664719482		
Total	18	181.9188421			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-10.21089	12.70316148	-0.803807146	0.433289	-37.1403913	16.7186074	-37.1403913	16.71860735
X Variable 1	-0.284191	0.188825511	-1.505046862	0.151797	-0.684483443	0.11610096	-0.68448344	0.116100958
X Variable 2	0.3794175	0.160264965	2.367439097	0.030852	0.039670995	0.71916409	0.039671	0.719164091

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	6.1674091	5.582590916	2.416551038
2	2.3120533	2.327946683	1.007704498
3	8.7434436	-1.473443557	-0.637813448
4	5.4973086	-1.977308617	-0.855922862
5	4.8673809	-1.267380867	-0.548614541
6	3.221949	-0.171948956	-0.074432004
7	4.5919691	-1.051969145	-0.455368693
8	3.4870072	-0.357007217	-0.154538667
9	2.4669469	1.123053111	0.486138999
10	8.0408571	4.009142881	1.735448386
11	6.1815441	-3.061544079	-1.325258762
12	6.3670791	0.792920899	0.343233787
13	5.4875634	-1.64756344	-0.713185186
14	5.5369327	-2.266932684	-0.981293205
15	4.0621017	-1.142101721	-0.494384622
16	10.52737	0.532629783	0.230560877
17	5.6298245	1.890175508	0.81820532
18	6.1998884	-2.97988837	-1.289912237
19	3.5713711	1.138628873	0.492881321

PROBABILITY OUTPUT

Percentile	*Y*
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

Equation C: Correlation of swelling potential (SP) with ,Dry Density and Natural misture Content

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.3188279
R Square	0.1016512
Adjusted R Squa	-0.010642
Standard Error	3.1959601
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	18.49226887	9.246134433	0.905227	0.424189516
Residual	16	163.4265732	10.21416083		
Total	18	181.9188421			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	28.291609	29.43468195	0.961165792	0.35077	-34.10712886	90.6903476	-34.1071289	90.69034765
X Variable 1	-0.70385	1.527779057	-0.460701345	0.651213	-3.942596786	2.53489705	-3.94259679	2.534897053
X Variable 2	-0.375623	0.307752051	-1.220536536	0.239945	-1.028027827	0.27678258	-1.02802783	0.276782582

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	6.3495299	5.400470051	2.688354664
2	2.8930155	1.746984455	0.86964908
3	7.8295761	-0.559576104	-0.278557054
4	5.6562323	-2.136232294	-1.063416702
5	6.597294	-2.997293995	-1.492053324
6	3.8840557	-0.834055701	-0.415193032
7	6.2110101	-2.671010051	-1.329629136
8	3.4779863	-0.347986346	-0.173227646
9	2.0318624	1.558137557	0.77564107
10	9.7377087	2.312291323	1.151058909
11	4.6991121	-1.579112092	-0.786082196
12	7.8811995	-0.721199524	-0.359013213
13	4.7196227	-0.879622715	-0.437876297
14	3.8724815	-0.602481479	-0.299915355
15	2.9304344	-0.010434422	-0.005194257
16	11.091896	-0.031895946	-0.015877806
17	5.0644712	2.455528779	1.222362532
18	3.8406351	-0.620635091	-0.308952225
19	4.1918764	0.518123592	0.257921989

PROBABILITY OUTPUT

Percentile	*Y*
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

Equation D: Correlation of swelling potential (SP) with plasticty index and liquid limit

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7188021
R Square	0.5166765
Adjusted R Squa	0.4562611
Standard Error	2.3442169
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	93.99319239	46.9965962	8.552061	0.002977853
Residual	16	87.92564972	5.495353107		
Total	18	181.9188421			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.311496	6.690243727	0.34550251	0.734217	-11.87118713	16.4941791	-11.8711871	16.49417913
X Variable 1	0.2796179	0.07437713	3.759461098	0.001713	0.121945455	0.4372904	0.12194545	0.437290398
X Variable 2	-0.333504	0.160598273	-2.07663664	0.054306	-0.673957388	0.00694887	-0.67395739	0.006948872

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	5.2824363	6.46756372	3.00917516
2	3.2953758	1.344624172	0.625615739
3	8.2000026	-0.930002647	-0.432704027
4	6.4657866	-2.945786575	-1.370591489
5	5.1471093	-1.547109265	-0.719826348
6	3.7931438	-0.743143849	-0.345763893
7	5.2672278	-1.727227843	-0.803630447
8	3.351157	-0.22115702	-0.10289813
9	2.1727647	1.417235298	0.65939965
10	9.3112613	2.738738712	1.274257952
11	5.6426688	-2.522668837	-1.173726728
12	6.0048596	1.155140446	0.537454301
13	4.3327503	-0.492750272	-0.229262817
14	4.3200736	-1.050073639	-0.488569676
15	3.5321048	-0.612104821	-0.284795126
16	11.613295	-0.553294522	-0.257432351
17	6.0974408	1.422559195	0.661876709
18	4.8236005	-1.603600487	-0.746110121
19	4.3069418	0.403058235	0.18753164

PROBABILITY OUTPUT

Percentile	*Y*
2.631578947	2.92
7.894736842	3.05
13.15789474	3.12
18.42105263	3.13
23.68421053	3.22
28.94736842	3.27
34.21052632	3.52
39.47368421	3.54
44.73684211	3.59
50	3.6
55.26315789	3.84
60.52631579	4.64
65.78947368	4.71
71.05263158	7.16
76.31578947	7.27
81.57894737	7.52
86.84210526	11.06
92.10526316	11.75
97.36842105	12.05

APPENDIX B: Test results
APPENDIX B1: Index Properties

Grain Size Analysis

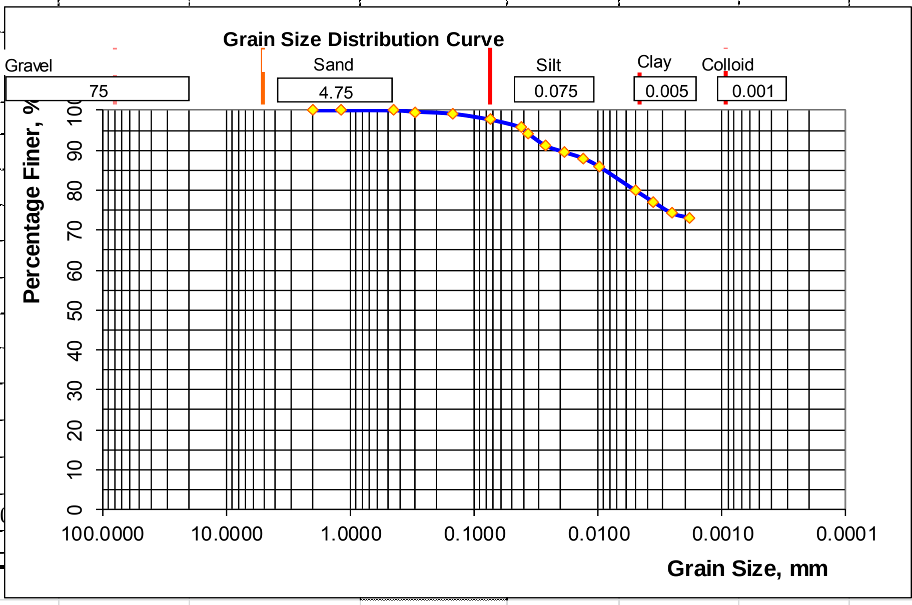
Date	10/2/2015	
Location:		Wolliso
Color ofsample:		Black
Sample No :		University Old 1
Sample Type :		Expansive soil of Wolliso

Sample Depth, m : 1.25m

Sieve Analysis

Total mass of samp 500

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%) (%)
3"								00.0
2"								00.0
1.5"								00.0
1"								00.0
3/4"								00.0
1/2"								00.0
3.8"								00.0
No 4								00.0
No 8								00.0
No 10								00.0
No 16								00.0
No 40								00.0
No 50								99.7
No 100								99.2
No 200	(							97.7
e	---							---



Date 09/02/2015

Hydrometer Analysis

Specific Gravity of soil 2.70

Test Temperature, deg.c

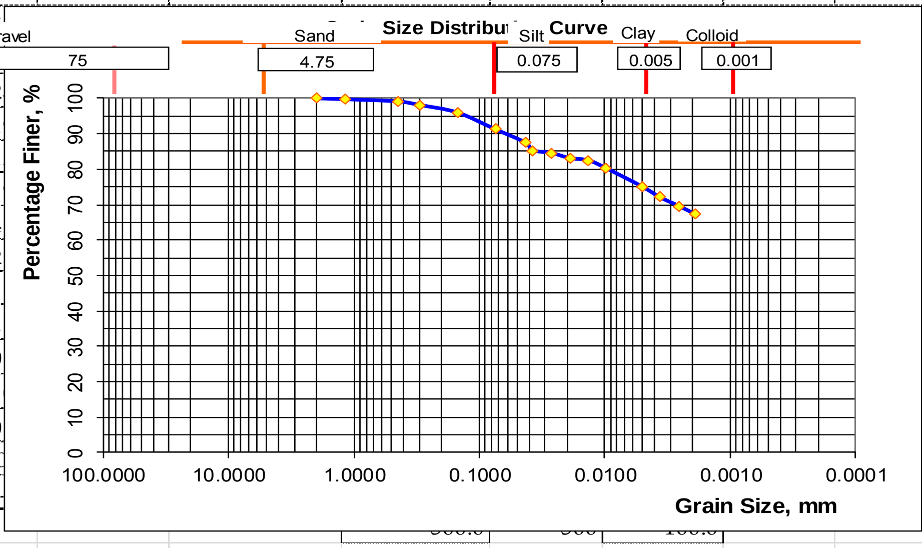
Elapsed time (min)	Actual Hydometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0335	20.3	-0.00264	1.0309	7.45	0.013344	0.0421	98.03	95.77
1	1.0330	20.3	-0.00264	1.0304	7.60	0.013344	0.0368	96.44	94.22
2	1.0320	20.3	-0.00264	1.0294	7.80	0.013344	0.0264	93.26	91.12
4	1.0315	20.3	-0.00264	1.0289	7.95	0.013344	0.0188	91.67	89.56
8	1.0308	21.5	-0.00240	1.0284	8.18	0.013045	0.0132	90.05	87.98
15	1.0300	21.8	-0.00234	1.0277	8.40	0.013000	0.0097	87.86	85.84
30	1.0290	22.3	-0.00224	1.0268	8.60	0.013075	0.0070	85.00	83.05
60	1.0280	22.7	-0.00216	1.0258	8.90	0.013015	0.0050	81.83	79.94
120	1.0270	23.1	-0.00208	1.0248	9.20	0.012955	0.0036	78.90	77.09
240	1.0260	24.0	-0.00027	1.0239	9.40	0.012820	0.0025	75.98	74.23
480	1.0260	22.6	-0.00246	1.0235	9.40	0.013030	0.0018	74.77	73.05
1440	1.0255	20.1	-0.00268	1.0228	9.55	0.013408	0.0011	72.49	70.82

%Gravel	0
%Sand	2.3
%Silt	22.7
%Clay	75.0

Grain Size Analysis

Date			9/2/2015						
Location:			Wolliso						
Color ofsample:			Black						
Sample No :			Ejersa1			Sample Depth, m :		1.25m	
Sample Type :			Expansive soil of Wolliso						
Sieve Analysis						Total mass of sample, g			500

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%) (%)
3''	75.0		19.0	19.0	0.0	0.0	0.0	100.0
2''								.0
1.5''								.0
1''	2							.0
3/4''	1							.0
1/2''	1							.0
3.8''								.0
No 4	4							.0
No 8	2							.0
No 10								.0
No 16	1							.7
No 40	0							.1
No 50								.1
No 100	0							.0
No 200	0.0							.3
e	-----							



Date 09/02/2015

Hydrometer Analysis

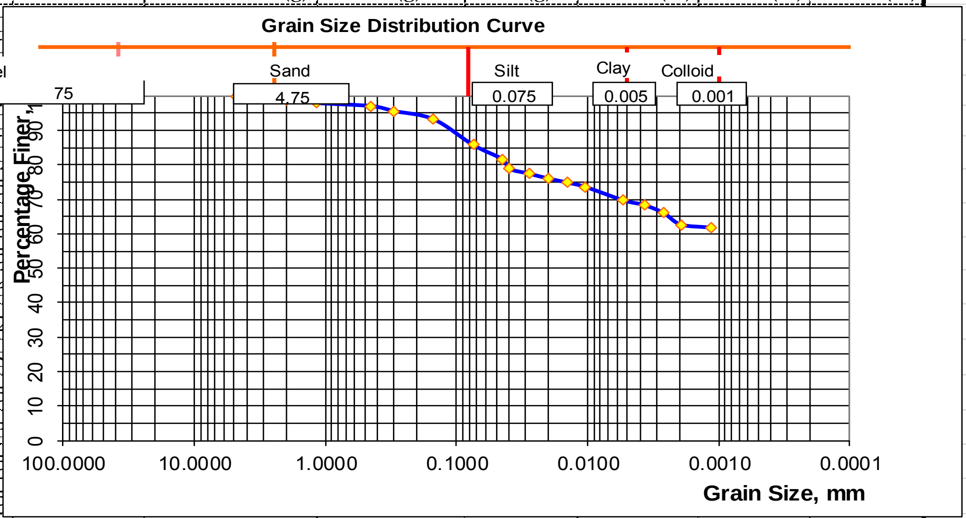
Specific Gravity of soil			2.67		Test Temperature, deg.c				
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0325	20.9	-0.00252	1.0300	7.70	0.0134166	0.0430	95.86	87.52
1	1.0318	20.9	-0.00252	1.0292	7.88	0.0134166	0.0377	93.47	85.33
2	1.0315	20.9	-0.00252	1.0290	7.95	0.0134166	0.0267	92.67	84.60
4	1.0310	20.9	-0.00252	1.0285	8.10	0.0134166	0.0191	91.07	83.14
8	1.0308	21.1	-0.00248	1.0283	8.18	0.013384	0.0135	90.40	82.53
15	1.0300	21.3	-0.00244	1.0276	8.40	0.013352	0.0100	88.13	80.46
30	1.0288	21.5	-0.00224	1.0265	8.68	0.01332	0.0072	84.77	77.39
60	1.0280	22.0	-0.0023	1.0258	8.90	0.01324	0.0051	82.37	75.20
120	1.0270	22.7	-0.00216	1.0247	9.20	0.013135	0.0036	78.98	72.11
240	1.0260	23.9	-0.00192	1.0238	9.40	0.0129496	0.0026	76.23	69.60
480	1.0255	21.2	-0.00246	1.0230	9.55	0.013368	0.0019	73.67	67.26
1440	1.0255	19.4	-0.00282	1.0227	9.55	0.013668	0.0011	72.52	66.21

%Gravel	1.3
%Sand	8.7
%Silt	24.3
%Clay	67.0

Grain Size Analysis

Date	9/2/2015	
Location:	Wolliso	
Color ofsample:	Grey	
Sample No :	Ejersa2	Sample Depth, m : 2.5m
Sample Type :	Expansive soil of Wolliso	
Sieve Analysis		Total mass of sa 500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%)
3"	75.0							
2"								
1.5"	3							
1"	25.0							
3/4"	19.0							
1/2"	12.5							
3.8"	9.5							
No 4	4.75							
No 8	2.36							
No 10	2							
No 16	1.18							
No 40	0.45							
No 50	0.3							
No 100	0.15							
No 200	0.075							
e	-------		1.0	430.0	429.0	85.8	100.0	-------
					500			



Date 09/02/2015

Hydrometer Analysis

Specific Gravity of soil 2.60 Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Finer Combined (%)
0.75	1.0320	19.9	-0.00272	1.0293	7.80	0.013877	0.0448	95.16	81.65
1	1.0310	19.9	-0.00272	1.0283	8.10	0.013877	0.0395	91.91	78.86
2	1.0305	19.9	-0.00272	1.0278	8.25	0.013877	0.0282	90.28	77.46
4	1.0300	19.9	-0.00272	1.0273	8.40	0.013877	0.0201	88.66	76.07
8	1.0295	20.2	-0.00266	1.0268	8.50	0.013826	0.0143	87.23	74.84
15	1.0290	20.5	-0.0026	1.0264	8.60	0.013775	0.0104	85.80	73.62
30	1.0285	21.0	-0.0025	1.0260	8.75	0.01369	0.0074	84.50	72.50
60	1.0275	21.5	-0.0024	1.0250	9.30	0.01361	0.0054	81.25	69.71
120	1.0268	22.3	-0.00224	1.0245	9.13	0.013482	0.0037	79.66	68.35
240	1.0255	24.4	-0.00182	1.0237	9.63	0.01315	0.0026	76.96	66.03
480	1.0250	20.9	-0.00252	1.0225	9.70	0.013707	0.0019	73.06	62.69
1440	1.0250	19.3	-0.00284	1.0222	9.70	0.013979	0.0011	72.02	61.79

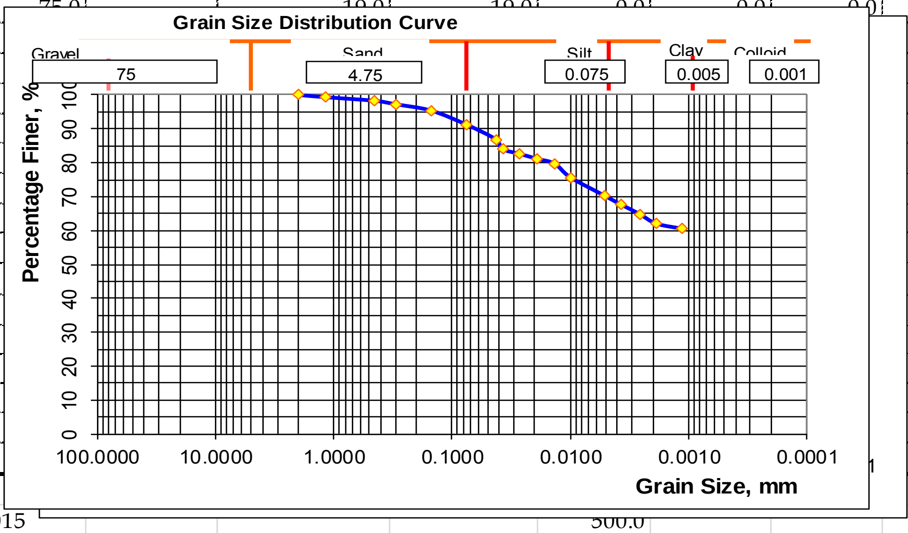
%Gravel	0.0
%Sand	12.9
%Silt	22.8
%Clay	63.0

Grain Size Analysis

Date	12/2/2015
Location:	Wolliso
Color of sample:	Black
Sample No :	Geresu 1
Sample Depth, m :	1.25m
Sample Type :	Expansive soil of Wolliso

Sieve Analysis — Total mass of sample, g: 500

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%) (%)
3''	75.0		19.0	19.0	0.0	0.0	0.0	100.0
2''								100.0
1.5''								100.0
1''								100.0
3/4''								100.0
1/2''								100.0
3.8''								100.0
No 4								100.0
No 8								100.0
No 10								100.0
No 16								99.3
No 40								98.3
No 50								97.3
No 100								95.4
No 200								91.2
e								-------



Date 12/02/2015

Hydrometer Analysis

Specific Gravity of soil: 2.73 — Test Temperature, deg.c

Elapsed time (min)	Actual Hydometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0330	19.5	-0.00280	1.0302	7.60	0.01341	0.0427	95.31	86.93
1	1.0320	19.5	-0.00280	1.0292	7.80	0.01341	0.0375	92.16	84.05
2	1.0315	19.5	-0.00280	1.0287	7.95	0.01341	0.0267	90.58	82.61
4	1.0310	19.5	-0.00280	1.0282	8.10	0.01341	0.0191	89.00	81.17
8	1.0305	19.9	-0.00280	1.0277	8.25	0.01334	0.0135	87.42	79.73
15	1.0290	20.0	-0.00270	1.0263	8.40	0.01333	0.0100	83.00	75.70
30	1.0280	20.5	-0.00256	1.0254	8.60	0.01325	0.0071	80.29	73.22
60	1.0270	20.9	-0.00252	1.0244	9.20	0.01318	0.0052	77.13	70.35
120	1.0260	21.2	-0.00246	1.0235	9.40	0.01314	0.0037	74.10	67.58
240	1.0250	22.9	-0.00224	1.0225	9.70	0.01288	0.0026	71.14	64.88
480	1.0240	21.3	-0.00244	1.0216	9.78	0.01312	0.0019	68.04	62.06
1440	1.0240	18.7	-0.00296	1.0210	10.00	0.01355	0.0011	66.40	60.56

%Gravel	9
%Sand	8.8
%Silt	29.2
%Clay	62.0

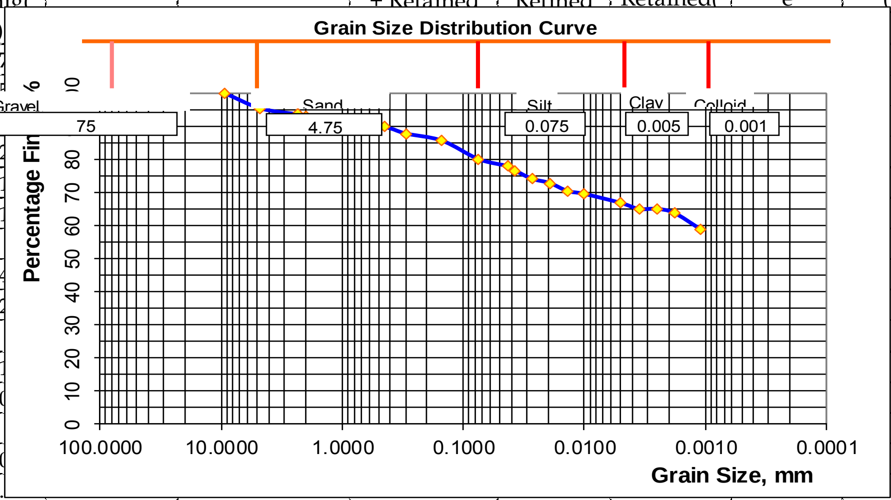
Grain Size Analysis

Date	12/2/2015
Location:	Wolliso
Color of Sample :	Grey
Sample No :	Geresu 2
Sample TYpe :	Expansive soil of Wolliso

Sample Depth, m : 1.9m

Sieve Analysis — Total mass of sample,g 500

Sieve No	Sieve Openinig(mm)			Mass of sieve + Retained	Mass of Retined	e Retained(	Percentag e	Passing (%) (%)
3"	7							100.0
2"								100.0
1.5"								100.0
1"	2							100.0
3/4"	1							100.0
1/2"	1							100.0
3.8"								100.0
No 4	4							95.3
No 8	2							93.5
No 10								92.8
No 16	1							91.6
No 40	(							89.7
No 50								87.7
No 100	(							85.6
No 200	0.							80.0
e	-------			400.0	400.0	80.0	100.0	-------



Date 09/02/2015

Hydrometer Analysis

Specific Gravity of soil 2.70 — Test Temperature, deg.c

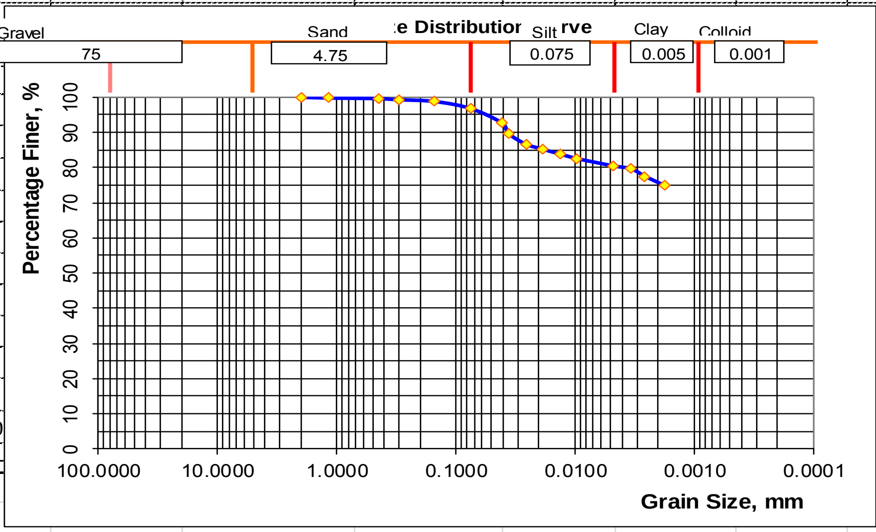
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0335	19.2000	-0.0029	1.0306	7.45	0.01358	0.0428	97.33	77.86
1	1.0330	19.2000	-0.0029	1.0301	7.60	0.01358	0.0374	95.74	76.59
2	1.0320	19.2000	-0.0029	1.0291	7.95	0.01358	0.0271	92.56	74.05
4	1.0315	19.2000	-0.0029	1.0286	8.10	0.01358	0.0193	90.97	72.78
8	1.0305	19.4000	-0.0028	1.0277	8.25	0.01354	0.0138	87.92	70.34
15	1.0300	19.7000	-0.0026	1.0274	8.40	0.01349	0.0101	86.91	69.53
30	1.0293	19.9000	-0.0027	1.0265	8.55	0.01346	0.0072	84.27	67.42
60	1.0290	21.3000	-0.0024	1.0263	8.60	0.01323	0.0050	83.48	66.78
120	1.0280	22.6000	-0.0022	1.0256	8.90	0.01303	0.0035	81.19	64.95
240	1.0278	23.9000	-0.0019	1.0256	8.98	0.01311	0.0025	81.22	64.98
480	1.0275	21.5000	-0.0024	1.0251	9.05	0.01320	0.0018	79.73	63.78
1440	1.0260	18.7000	-0.0028	1.0232	9.40	0.01366	0.0011	73.63	58.90

%Gravel	0
%Sand	11.1
%Silt	16.0
%Clay	64.0

Grain Size Analysis

Date		3/2/2015	
Location:		Wolliso	
Color of sample		Black	
Sample No :		Huluyimar 1	Sample Depth, m : 1.25m
Type of sample:		Expansive soil of Wolliso	
Sieve Analysis			Total mass of sample, g 500

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%)
3"	75.0		50.0	50.0	0.0	0.0	0.0	100.0
2"								100.0
1.5"								100.0
1"								100.0
3/4"								100.0
1/2"								100.0
3.8"								100.0
No 4								100.0
No 8								100.0
No 10								100.0
No 16								99.8
No 40								99.6
No 50								99.3
No 100								98.8
No 200	0							96.8
e	----							-------



Date 03/02/2015

Hydrometer Analysis

Specific Gravity of soil 2.81 Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Finer Combined (%)
0.75	1.0335	20.2	-0.00266	1.0308	7.45	0.013002	0.0410	95.76	92.69
1	1.0325	20.2	-0.00266	1.0298	7.70	0.013002	0.0361	92.65	89.69
2	1.0315	20.2	-0.00266	1.0288	7.95	0.013002	0.0259	89.55	86.68
4	1.0310	20.2	-0.00266	1.0283	8.10	0.013002	0.0185	87.99	85.18
8	1.0305	20.5	-0.00262	1.0279	8.25	0.012954	0.0132	86.57	83.80
15	1.0298	21.1	-0.00228	1.0275	8.45	0.012859	0.0097	85.29	82.56
30	1.0295	22.4	-0.00222	1.0273	8.50	0.012664	0.0067	84.70	81.99
60	1.0290	22.7	-0.00216	1.0268	8.60	0.012619	0.0048	83.15	80.49
120	1.0285	23.5	-0.002	1.0265	8.70	0.0125	0.0034	82.28	79.65
240	1.0285	24.1	0	1.0285	8.70	0.0136184	0.0026	88.49	85.66
480	1.0273	21.7	-0.00232	1.0249	9.20	0.012769	0.0018	77.41	74.93
1440	1.0275	19.1	-0.00288	1.0246	9.05	0.012412	0.0010	76.44	74.00

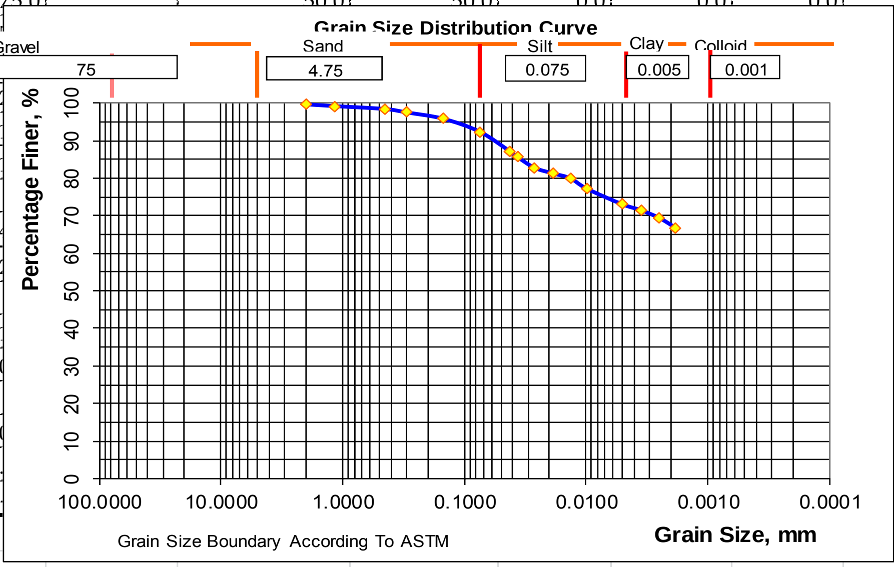
%Gravel	0
%Sand	3.2
%Silt	20.8
%Clay	76.0

Grain Size Analysis

Date	3/2/2015		
Location:	Wolliso		
Color of sample No :	Grey		
Sample No :	Huluyimar 2.	Sample Depth, m :	2.5m
Sample type :	Expansive soil from woliso		

Sieve Analysis — Total mass of sample, g: 500

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%) (%)
3''	75.0		50.0	50.0	0.0	0.0	0.0	100.0
2''								100.0
1.5''								100.0
1''								100.0
3/4''								100.0
1/2''								100.0
3.8''								100.0
No 4								100.0
No 8								100.0
No 10								99.7
No 16								99.2
No 40								98.4
No 50								97.5
No 100								95.8
No 200								92.4
e	----							----



Date 03/02/2015

Hydrometer Analysis

Specific Gravity of soil: 2.74 — Test Temperature, deg.c

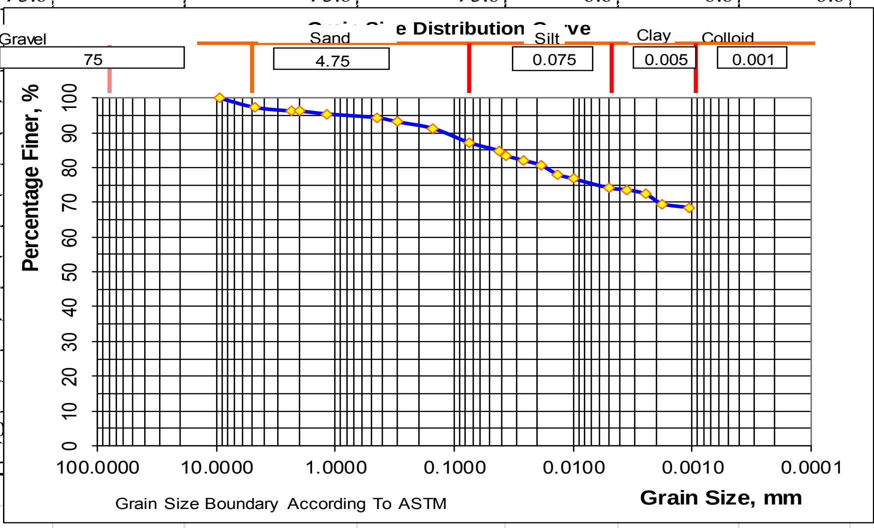
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0325	20.7	-0.00256	1.0299	7.70	0.013176	0.0422	94.29	87.13
1	1.0320	20.7	-0.00256	1.0294	7.80	0.013176	0.0368	92.72	89.75
2	1.0310	20.7	-0.00256	1.0284	8.10	0.013176	0.0265	89.57	86.70
4	1.0305	20.7	-0.00256	1.0279	8.25	0.013176	0.0189	87.99	85.18
8	1.0300	20.9	-0.00252	1.0275	8.40	0.013144	0.0135	86.55	83.78
15	1.0290	21.2	-0.00246	1.0265	8.60	0.013098	0.0099	83.59	80.91
30	1.0283	21.5	-0.0024	1.0259	8.75	0.013052	0.0070	81.41	78.81
60	1.0275	22.1	-0.00228	1.0251	9.05	0.012961	0.0050	79.05	76.52
120	1.0265	23.8	-0.00194	1.0246	9.30	0.012706	0.0035	77.35	74.87
240	1.0255	25.2	-0.00166	1.0238	9.55	0.012498	0.0025	75.08	72.68
480	1.0253	22.0	-0.0023	1.0230	9.63	0.012976	0.0018	72.28	69.97
1440	1.0255	19.6	-0.00342	1.0221	9.55	0.013356	0.0011	69.54	67.31

%Gravel	0
%Sand	7.6
%Silt	22.4
%Clay	70.0

Grain Size Analysis

Date			12/2/2015						
Location:			Wolliso						
Color of the sample			Black						
Sample No :			Kidane mihret1				Sample Depth, m :	1.25m	
Type of sample			Expansive soil of Woliso						
Sieve Analysis						Total mass of sample,		500	

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentag e (%)	Passing (%) (%)
3''	75.0		75.0	75.0	0.0	0.0	0.0	100.0
2''								100.0
1.5''								100.0
1''								100.0
3/4''								100.0
1/2''								100.0
3.8''								100.0
No 4								97.3
No 8								96.3
No 10								96.3
No 16								95.4
No 40								94.3
No 50								93.1
No 100								91.2
No 200	0							87.2
e	---							-------



Date 12/02/2015

Hydrometer Analysis

Specific Gravity of soil 2.71 Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0335	19.5	-0.00280	1.0307	7.30	0.01349	0.0421	97.31	84.83
1	1.0330	19.5	-0.00280	1.0302	7.55	0.01349	0.0371	95.72	83.45
2	1.0325	19.5	-0.00280	1.0297	7.60	0.01349	0.0263	94.14	82.07
4	1.0320	19.5	-0.00280	1.0292	7.70	0.01349	0.0187	92.55	80.69
8	1.0310	19.7	-0.00276	1.0282	8.10	0.01345	0.0135	89.51	78.03
15	1.0305	19.9	-0.00272	1.0278	8.25	0.01342	0.0100	88.05	76.76
30	1.0300	20.1	-0.00268	1.0273	8.40	0.01339	0.0071	86.59	75.49
60	1.0295	21.7	-0.00236	1.0268	8.50	0.01313	0.0049	85.01	74.11
120	1.0290	21.9	-0.00232	1.0266	8.60	0.01310	0.0035	84.44	73.61
240	1.0285	23.9	-0.00192	1.0262	8.70	0.01280	0.0024	82.98	72.34
480	1.0275	21.9	-0.00232	1.0252	8.90	0.01310	0.0018	79.81	69.58
1440	1.0275	19.9	-0.00272	1.0248	8.95	0.01342	0.0011	78.54	68.47

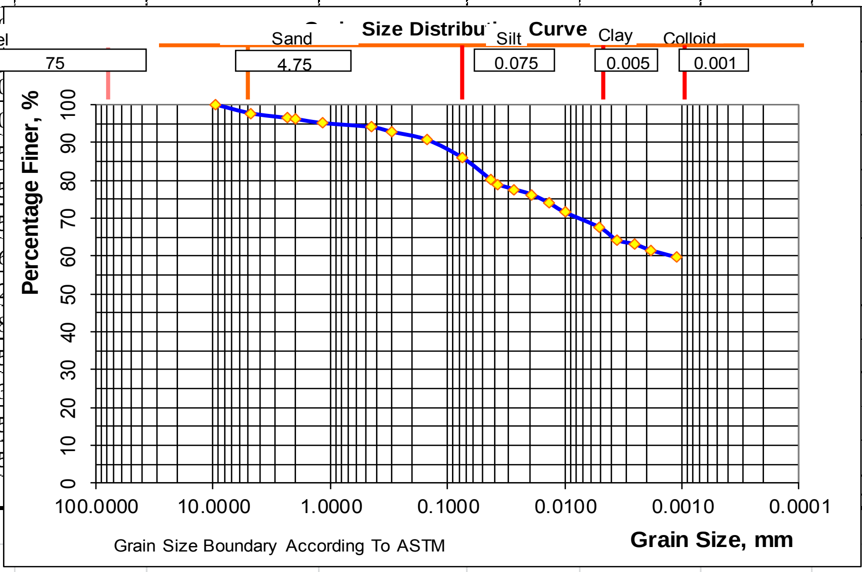
%Gravel	2.3
%Sand	7.7
%Silt	22.3
%Clay	70.0

Grain Size Analysis

Date	12/2/2015	
Location:	Wolliso	
Color of the sample	Black	
Sample No :	Kidane mehret 2	Sample Depth, m : 2.5m
Type of the sample	Expansive soil of Wolliso	

Sieve Analysis — Total mass of sample, 500

Sieve No	Sieve Openinig(mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentage (%)	Passing (%)
3''	75.0		0.0	0.0	0.0	0.0	0.0	100.0
2''	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
1.5''	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
1''	25.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
3/4''	19.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
1/2''	12.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
3.8''	9.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
No 4	4.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	97.7
No 8	2.36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	96.5
No 10	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	96.2
No 16	1.18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	95.2
No 40	0.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	94.1
No 50	0.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92.8
No 100	0.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90.7
No 200	0.075	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	86.0
e	-------	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	----



Date 09/02/2015

Hydrometer Analysis

Specific Gravity of soil 2.74 — Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined
0.75	1.0325	19.3000	-0.00284	1.0297	7.70	0.01353	0.0433	93.41	80.33
1	1.0320	19.3000	-0.00284	1.0292	7.80	0.01353	0.0378	91.84	78.98
2	1.0315	19.3000	-0.00284	1.0287	7.95	0.01353	0.0270	90.26	77.63
4	1.0310	19.3000	-0.00284	1.0282	8.10	0.01353	0.0192	88.69	76.27
8	1.0300	20.1000	-0.00268	1.0273	8.40	0.01327	0.0136	86.04	74.00
15	1.0290	20.6000	-0.00258	1.0264	8.60	0.01319	0.0100	83.21	71.56
30	1.0280	20.7000	-0.00256	1.0254	8.90	0.01318	0.0072	80.12	68.90
60	1.0275	22.1000	-0.00228	1.0249	9.05	0.01296	0.0050	78.55	67.55
120	1.0260	22.6000	-0.00218	1.0237	9.40	0.01289	0.0036	74.70	64.25
240	1.0255	24.2000	-0.00186	1.0233	9.55	0.01281	0.0026	73.44	63.16
480	1.0253	20.9000	-0.00252	1.0227	9.63	0.01314	0.0019	71.59	61.56
1440	1.0250	18.6000	-0.00298	1.0220	9.70	0.01356	0.0011	69.35	59.64

%Gravel	2.7
%Sand	13.7
%Silt	22.0
%Clay	62.0

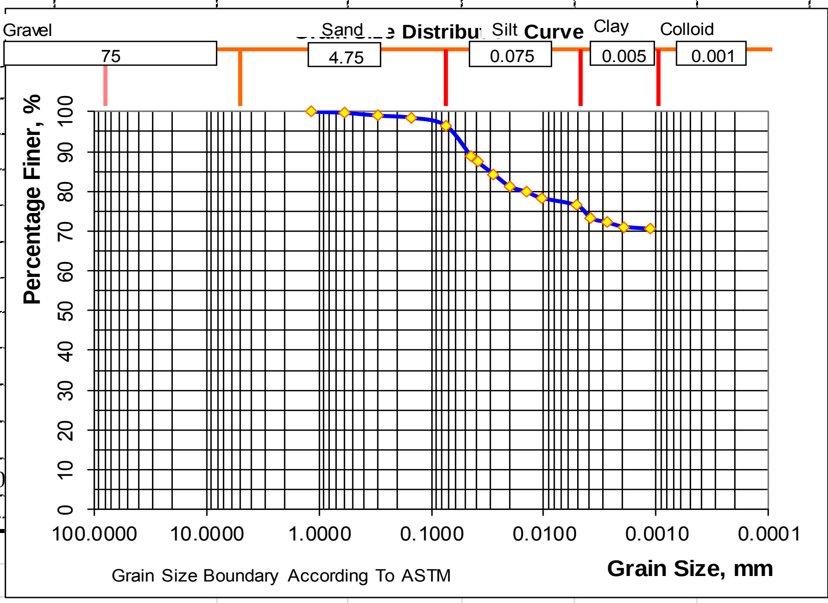
Grain Size Analysis

Date 15/6/2015
Location: Wolliso
Color ofsample: Black

Sample No : University Infront 1 — Sample Depth, m : 1.25m
Sample Type : Expansive soil of Wolliso

Sieve Analysis — Total mass of sample, g 500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentage (%)	Passing (%)
3''	75.0		1057.0	1057.0	0.0	0.0	0.0	100.0
2''								100.0
1.5''								100.0
1''								100.0
3/4''								100.0
1/2''								100.0
3.8''								100.0
No 4								100.0
No 8								100.0
No 10								100.0
No 16								100.0
No40								99.7
No 50								99.0
No 100								98.5
No 200	0							96.6
e	---							-------



Date 19/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.66 — Test Temperature, deg.c

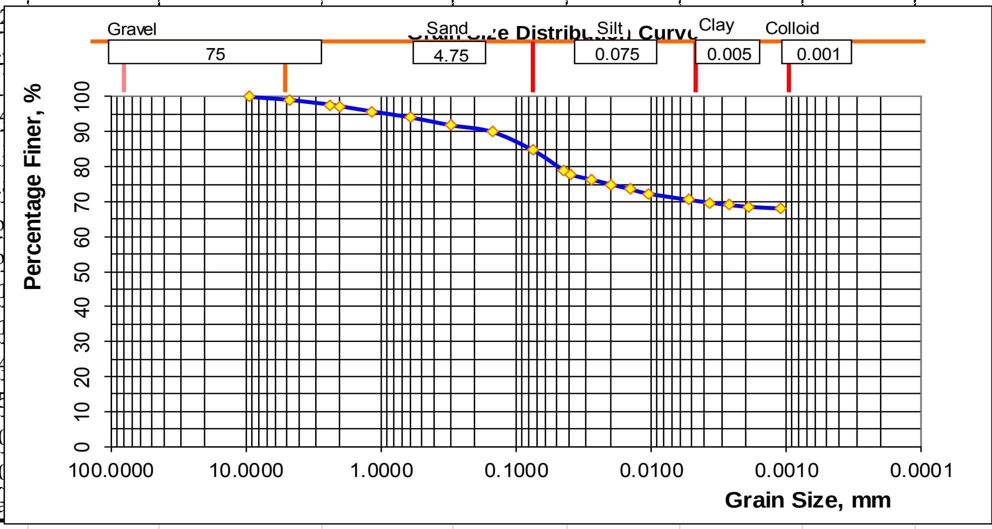
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0315	19.7000	-0.00276	1.0287	7.97	0.013676	0.0446	92.11	88.96
1	1.0310	19.7000	-0.00276	1.0282	8.10	0.013676	0.0389	90.50	87.41
2	1.0300	19.7000	-0.00276	1.0272	8.36	0.013676	0.0280	87.30	84.32
4	1.0290	19.7000	-0.00276	1.0262	8.63	0.013676	0.0201	84.09	81.22
8	1.0285	20.0000	0	1.0285	8.76	0.013608	0.0142	91.34	88.22
15	1.0280	20.0000	0	1.0280	8.89	0.013608	0.0105	89.73	86.67
30	1.0280	19.5000	-0.0028	1.0252	8.89	0.013693	0.0075	80.76	78.00
60	1.0275	19.6000	-0.00278	1.0247	9.03	0	0.0000	79.16	76.46
120	1.0265	19.4000	-0.00282	1.0237	9.30	0.01371	0.0038	75.89	73.30
240	1.0260	20.1000	0	1.0260	9.42	0.0136184	0.0027	83.33	80.48
480	1.0255	20.8000	-0.00254	1.0230	9.55	0.0136912	0.0019	73.58	71.07
1440	1.0260	17.4000	-0.0032	1.0228	9.40	0.014056	0.0011	73.07	70.57

%Gravel	0.9
%Sand	3.0
%Silt	26.0
%Clay	71.0

Grain Size Analysis

Date			14/6/2015						
Location:			Wolliso						
Color ofsample:		Grey							
Sample No :			University Infront 2			Sample Depth, m :		2.5m	
Sample Type :			Expansive soil of Wolliso						
Sieve Analysis					Total mass of sample, g			500	

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentage (%)	Passing (%)
3''	75.0		1057.0	1057.0	0.0	0.0	0.0	100.0
2								0.0
1.								0.0
								0.0
3/4								0.0
1/								0.0
3.								0.0
No								9.1
No								7.8
No 1								7.3
No 1								5.9
No 4								4.1
No 5								1.8
No 10								0.0
No 20								4.8
pa								-
					499.9			
Date 12/06/2015					499.9			



Hydrometer Analysis

Specific Gravity of soil 2.64 Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0315	20.8000	-0.00254	1.0290	7.97	0.013726	0.0447	93.24	79.07
1	1.0310	20.8000	-0.00254	1.0285	8.10	0.013726	0.0391	91.63	77.70
2	1.0305	20.8000	-0.00254	1.0280	8.23	0.013726	0.0278	90.02	76.33
4	1.0300	20.8000	-0.00254	1.0275	8.36	0.013726	0.0198	88.41	74.97
8	1.0295	20.7000	-0.00256	1.0269	8.50	0.013743	0.0142	86.73	73.55
15	1.0290	20.9000	-0.00252	1.0265	8.75	0.013709	0.0105	85.25	72.29
30	1.0285	20.4000	-0.00262	1.0259	8.75	0.013794	0.0074	83.32	70.66
60	1.0285	20.6000	-0.00266	1.0258	8.83	0.013828	0.0053	83.19	70.55
120	1.0283	20.0000	0	1.0283	8.83	0.01369	0.0037	90.95	77.13
240	1.0280	20.3000	0	1.0280	8.89	0.013811	0.0027	90.15	76.44
480	1.0280	19.0000	-0.0029	1.0251	8.89	0.013838	0.0019	80.81	68.53
1440	1.0283	17.5000	-0.0032	1.0251	8.83	0.014124	0.0011	80.65	68.06

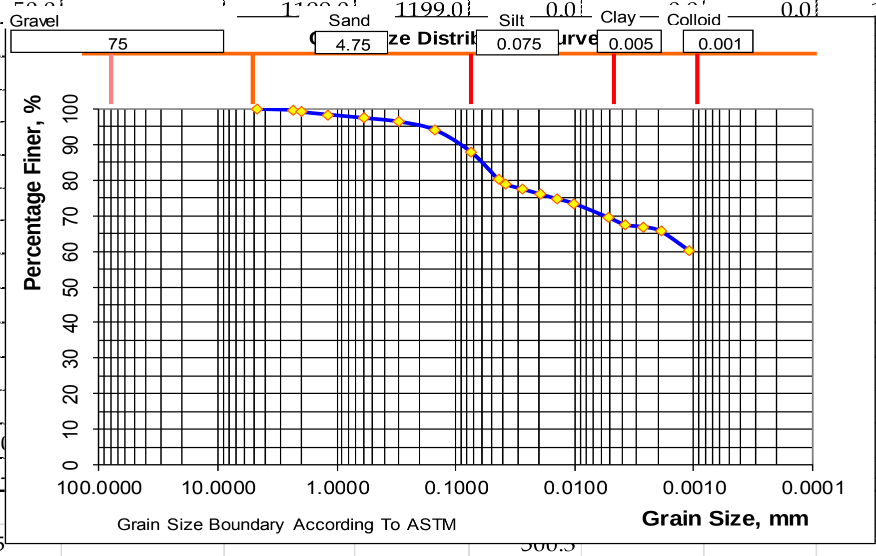
%Gravel	0.9
%Sand	14.3
%Silt	16.3
%Clay	68.5

Grain Size Analysis

Date	15/6/2015				
Location:	Wolliso				
Color ofsample:	Black				
Sample No :	Michael 1		Sample Depth, m :	1.25m	
Sample Type :	Expansive soil of Wolliso				

Sieve Analysis — Total mass of san 500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	Mass of sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percenta ge (%)	Passing (%) (%)
3"	75.0		1057.0	1057.0	0.0	0.0	0.0	100.0
2"	[illegible]		[illegible]	1199.0	0.0		0.0	100.0
1.5"								100.0
1"								100.0
3/4"								100.0
1/2"								100.0
3.8"								100.0
No 4								100.0
No 8								99.7
No 10								99.2
No 16								98.4
No 30								97.5
No 50								96.4
No 100								94.1
No 200								88.0
pan	---							---



Date 12/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.73 — Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrome ter	Effective Depth (cm)	Coefficien t K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0320	17.9000	-0.00312	1.0289	7.80	0.0136834	0.0441	91.15	80.26
1	1.0315	17.9000	-0.00312	1.0284	7.95	0.0136834	0.0386	89.57	78.87
2	1.0310	17.9000	-0.00312	1.0279	8.10	0.0136834	0.0275	87.99	77.49
4	1.0305	17.9000	-0.00312	1.0274	8.25	0.0136834	0.0197	86.41	76.10
8	1.0300	17.9000	-0.00312	1.0269	8.40	0.0136834	0.0140	84.84	74.71
15	1.0295	18.2000	-0.00306	1.0264	8.50	0.013632	0.0103	83.45	73.48
30	1.0285	18.2000	-0.00306	1.0254	8.75	0.013632	0.0074	80.29	70.70
60	1.0280	18.6000	-0.00298	1.0250	8.90	0.013564	0.0052	78.96	69.54
120	1.0273	18.6000	-0.00298	1.0243	9.20	0.013564	0.0038	76.60	67.45
240	1.0270	18.8000	-0.00294	1.0241	9.20	0.01353	0.0026	75.94	66.87
480	1.0265	19.0000	-0.0029	1.0236	9.30	0.013496	0.0019	74.48	65.59
1440	1.0248	17.9000	-0.00312	1.0216	9.75	0	0.0000	68.27	60.11

%Gravel	0.0
%Sand	11.9
%Silt	22.1
%Clay	66.0

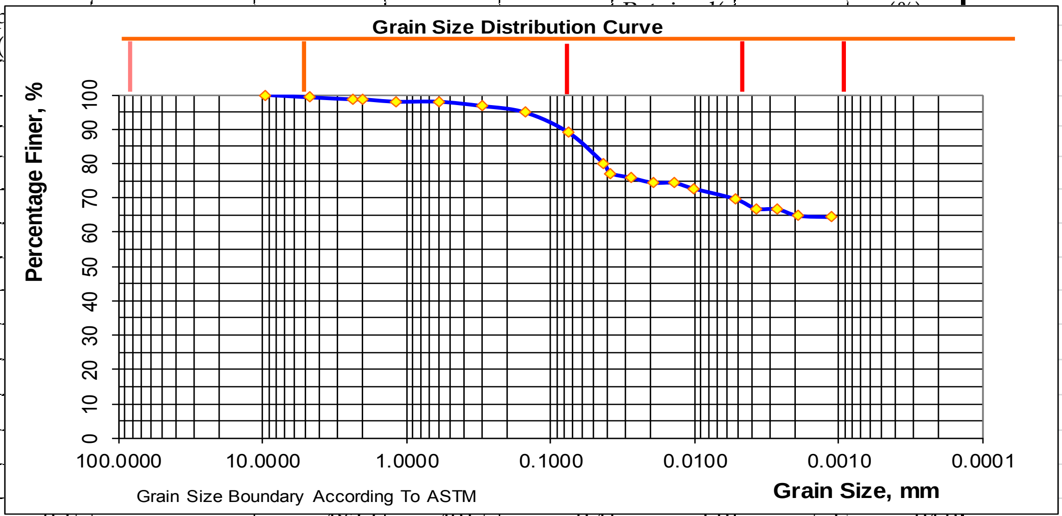
Grain Size Analysis

Date: 15/6/2015
Location: Wolliso

Color ofsample: Grey
Sample No : Michael 2 — Sample Depth, m : 2.5m
Sample Type : Expansive soil of Wolliso

Sieve Analysis — Total mass of san 500

Sieve No	Sieve Op (			Mass of sieve +	Mass of	Percentag e	Cum. Percenta	Perc. Passing
3''								
2''								
1.5''								
1''								
3/4''								
1/2''								
3.8''								
No 4								
No 8								
No 10								
No 16								
No 40								
No 50								
No 100	0.15		482.1	491.5	9.4	1.9	5.1	94.9
No 200	0.075		459.3	488.5	29.2	5.8	10.9	89.1
pan	-------		424.0	869.3	445.3	89.1	100.0	-------
				0.0	500			



Date 19/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.72 — Test Temperature, deg.c

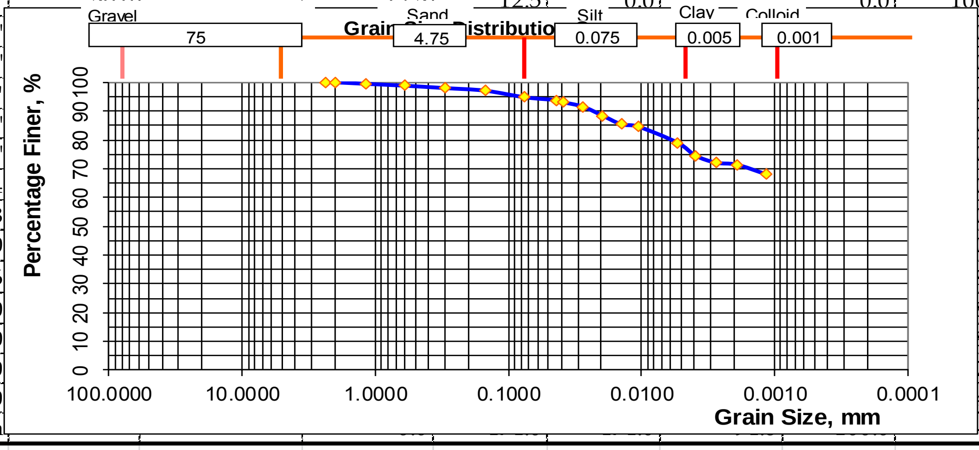
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0310	20.6000	-0.00258	1.0284	7.80	0.013268	0.0428	89.89	80.04
1	1.0300	20.6000	-0.00258	1.0274	8.40	0.013268	0.0385	86.72	77.23
2	1.0295	20.6000	-0.00258	1.0269	8.50	0.013268	0.0273	85.14	75.82
4	1.0290	20.6000	-0.00258	1.0264	8.60	0.013268	0.0195	83.56	74.41
8	1.0290	20.5000	-0.00260	1.0264	8.60	0.013284	0.0138	83.50	74.36
15	1.0285	20.1000	-0.00268	1.0258	8.75	0.013348	0.0102	81.66	72.72
30	1.0280	20.3000	-0.00264	1.0254	8.90	0.013316	0.0073	80.21	71.43
60	1.0275	19.7000	-0.00276	1.0247	9.05	0.013415	0.0052	78.25	69.68
120	1.0265	19.7000	-0.00276	1.0237	9.30	0.013415	0.0037	75.08	66.86
240	1.0265	19.4000	-0.00282	1.0237	9.30	0.013466	0.0027	74.89	66.69
480	1.0260	18.5000	-0.0030	1.0230	9.40	0.013619	0.0019	72.74	64.78
1440	1.0260	17.8000	-0.00314	1.0229	9.40	0.013739	0.0011	72.30	64.39

%Gravel	0.0
%Sand	10.9
%Silt	24.1
%Clay	68.5

Grain Size Analysis

Date	17/6/2015		
Location:	Wolliso		
Color ofsample:	Black		
Sample No :	Elementary 1	Sample Depth, m :	1.25m
Sample Type :	Expansive soil of Wolliso		
Sieve Analysis		Total mass of san	500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percenta ge (%)	Passing (%) (%)
3''	75.0		19.0	19.0	0.0	0.0	0.0	100.0
2''	50.0		12.5	12.5	0.0	0.0	0.0	100.0
1.5''								0.0
1''								0.0
3/4''								0.0
1/2''								0.0
3.8''								0.0
No 4								0.0
No 8								0.0
No 10								0.0
No 16								9.5
No 40								8.8
No 50								8.0
No 100								7.1
No 200								4.8
pan								



Date 19/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.63 Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0338	18.1000	-0.00308	1.0307	7.30	0.0140606	0.0439	98.97	93.83
1	1.0335	18.1000	-0.00308	1.0304	7.45	0.0140606	0.0384	98.17	93.06
2	1.0330	18.1000	-0.00308	1.0299	7.60	0.0140606	0.0274	96.55	91.53
4	1.0320	18.1000	-0.00308	1.0289	7.80	0.0140606	0.0196	93.32	88.47
8	1.0310	18.1000	-0.00308	1.0279	8.10	0.0140606	0.0141	90.10	85.41
15	1.0308	17.9000	-0.0031	1.0277	8.33	0.014096	0.0105	89.23	84.59
30	1.0295	18.2000	-0.00306	1.0264	8.50	0.0140432	0.0075	85.32	80.88
60	1.0290	17.7000	-0.00316	1.0258	8.60	0.014132	0.0054	83.39	79.05
120	1.0275	17.8000	-0.00314	1.0244	9.20	0.014114	0.0039	78.61	74.52
240	1.0265	18.8000	-0.00294	1.0236	9.30	0.0139388	0.0027	76.03	72.07
480	1.0260	20.2000	-0.00266	1.0233	9.40	0.0137	0.0019	75.32	71.40
1440	1.0255	17.3000	-0.00324	1.0223	9.55	0.014204	0.0012	71.83	68.10

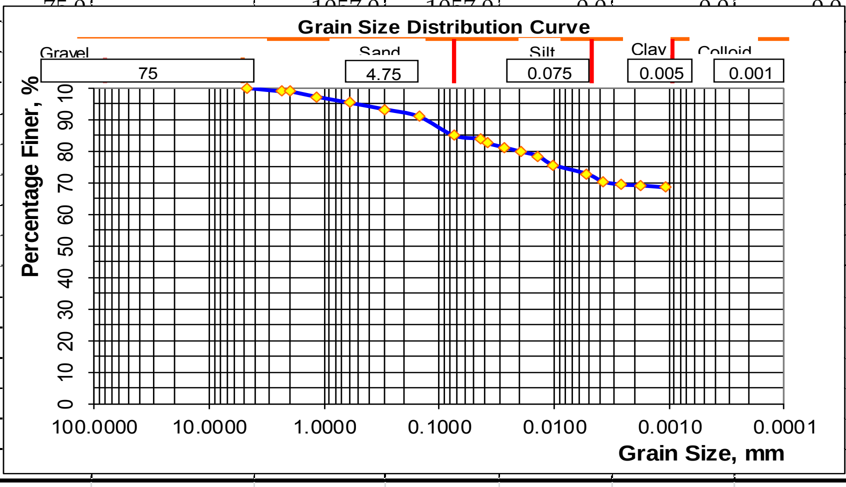
%Gravel	0.0
%Sand	5.2
%Silt	22.8
%Clay	72.0

Grain Size Analysis

Date	19/6/2015		
Location:	Wolliso		
Color ofsample:	Grey		
Sample No :	Elementary2	Sample Depth, m :	2.5m
Sample Type :	Expansive soil of Wolliso		

Sieve Analysis — Total mass of sample, 500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percenta ge (%)	Passing (%) (%)
3''	75.0		1057.0	1057.0	0.0	0.0	0.0	100.0
2''								100.0
1.5''								100.0
1''								100.0
3/4''								100.0
1/2''								100.0
3.8''								100.0
No 4								100.0
No 8								98.9
No 10								98.9
No 16								97.2
No 40								95.3
No 50								93.3
No 100								91.0
No 200								85.0
pan								-------



Date 13/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.67 — Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0340	18.2000	-0.00306	1.0309	7.30	0.014016	0.0437	98.93	84.09
1	1.0335	18.2000	-0.00306	1.0304	7.45	0.014016	0.0383	97.34	82.73
2	1.0330	18.2000	-0.00306	1.0299	7.60	0.014016	0.0273	95.74	81.38
4	1.0325	18.2000	-0.00306	1.0294	7.70	0.014016	0.0195	94.14	80.02
8	1.0320	18.2000	-0.00306	1.0289	7.80	0.014016	0.0138	92.54	78.66
15	1.0310	18.0000	-0.0031	1.0279	8.10	0.013906	0.0102	89.21	75.83
30	1.0300	18.0000	-0.0031	1.0269	8.40	0.013906	0.0074	86.02	73.11
60	1.0300	17.8000	-0.00314	1.0269	8.40	0.013942	0.0052	85.89	73.00
120	1.0290	18.2000	-0.00306	1.0259	8.60	0.014016	0.0038	82.95	70.50
240	1.0285	19.0000	-0.0029	1.0256	8.90	0.013736	0.0026	81.86	69.58
480	1.0289	16.7000	-0.00336	1.0255	8.90	1.54	0.2097	81.51	69.28
1440	1.0285	17.3000	-0.00324	1.0253	8.60	0.014032	0.0011	80.77	68.66

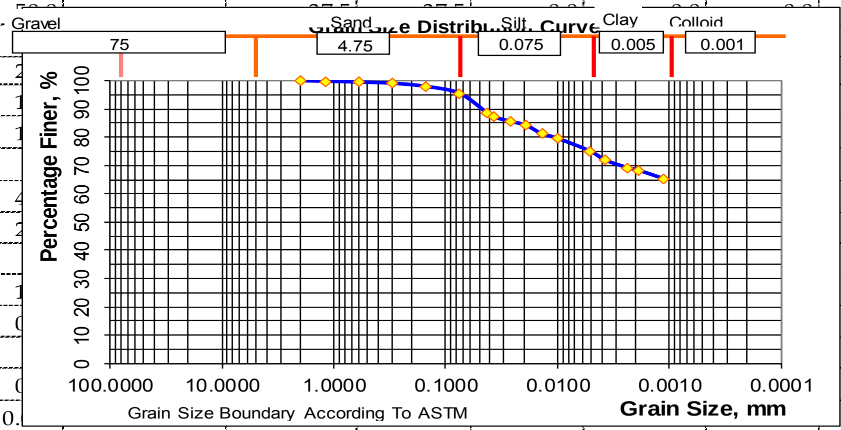
%Gravel	0.0
%Sand	15.1
%Silt	15.9
%Clay	69.0

Grain Size Analysis

Date	18/6/2015		
Location:	Wolliso		
Color ofsample:	Black		
Sample No :	Hospital 1	Sample Depth, m :	1.25m
Sample Type :	Expansive soil of Wolliso		

Sieve Analysis — Total mass of sample, 500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percenta ge (%)	Passing (%)
3''	75.0		50.0	50.0	0.0	0.0	0.0	100.0
2''	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
1.5''	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
1''	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
3/4''	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
1/2''	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
3.8''	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
No 4	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
No 8	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
No 10	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0
No 16	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99.8
No 40	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99.5
No 50	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99.1
No 100	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	98.0
No 200	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	95.5
pan	-------		0.0	477.7	477.7	95.5	100.0	-------



Date 20/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.76 — Test Temperature, deg.c

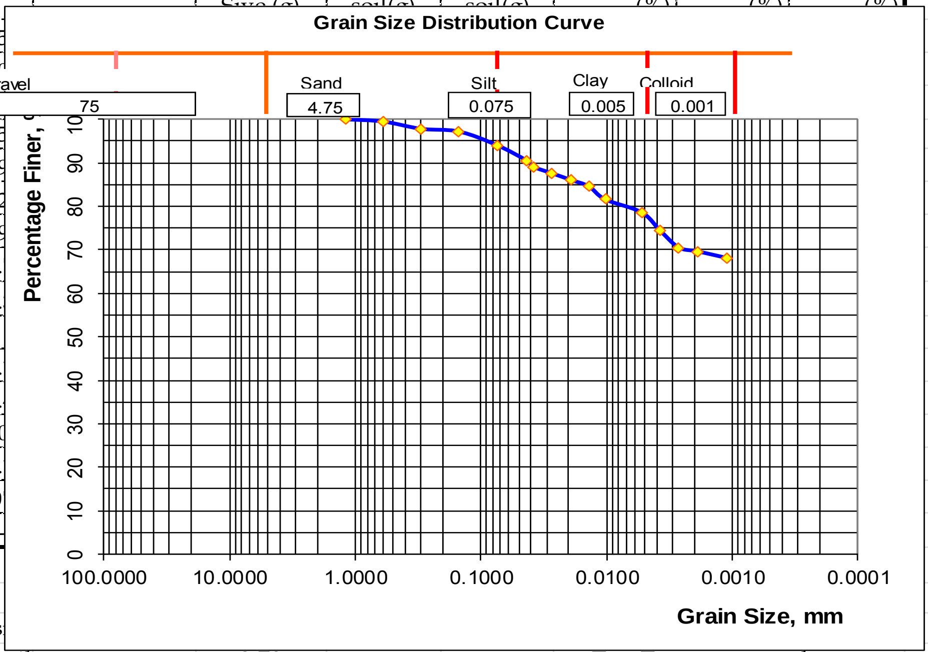
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0325	19.2000	-0.0029	1.0296	7.70	0.0133564	0.0428	92.84	88.66
1	1.0320	19.2000	-0.0029	1.0291	7.80	0.0133564	0.0373	91.27	87.16
2	1.0315	19.2000	-0.0029	1.0286	7.95	0.0133564	0.0266	89.70	85.66
4	1.0310	19.2000	-0.0029	1.0281	8.10	0.0133564	0.0190	88.13	84.17
8	1.0300	19.1000	-0.0029	1.0271	8.40	0.0133692	0.0137	85.00	81.17
15	1.0295	18.9000	-0.0029	1.0266	8.50	0.0133988	0.0101	83.43	79.67
30	1.0290	18.7000	-0.003	1.0260	8.60	0.0134324	0.0072	81.55	77.88
60	1.0280	18.9000	-0.0029	1.0251	8.90	0.013399	0.0052	78.72	75.18
120	1.0270	18.7000	-0.003	1.0240	9.20	0.0134324	0.0037	75.27	71.89
240	1.0260	19.2000	-0.0029	1.0231	7.40	0.0133564	0.0023	72.45	69.19
480	1.0255	19.9000	-0.0027	1.0228	9.55	0.0132668	0.0019	71.51	68.29
1440	1.0250	17.7000	-0.0032	1.0218	9.70	0.013584	0.0011	68.37	65.30

%Gravel	2.7
%Sand	4.5
%Silt	26.5
%Clay	69.0

Grain Size Analysis

Date	11/6/2015			
Location:	Wolliso			
Color ofsample:	Grey			
Sample No :	Hospital 2	Sample Depth, m :	2.5m	
Sample Type :	Expansive soil of Wolliso			
Sieve Analysis		Total mass of sample,	500	

Sieve No	Sieve Openinig (mm)		Mass of Sieve (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained(%)	Percentage (%)	Passing (%)
3''	75							
2''	5(							
1.5''								
1''	25							
3/4''	19							
1/2''	12							
3.8''	9							
No 4	4.							
No 8	2.							
No 10								
No 16	1.							
No 30	0.							
No 50	(							
No 100	0.							
No 200	0.0							
pan	-----							



Date 13/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.70 Test Temperature, deg.c

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0335	17.7	-0.0032	1.0303	7.45	0.013834	0.0436	96.25	90.57
1	1.0330	17.7	-0.0032	1.0298	7.60	0.013834	0.0381	94.66	89.07
2	1.0325	17.7	-0.0032	1.0293	7.70	0.013834	0.0271	93.07	87.58
4	1.0320	17.7	-0.0032	1.0288	7.80	0.013834	0.0193	91.48	86.08
8	1.0315	17.6000	-0.0032	1.0283	8.00	0.013852	0.0139	89.89	84.59
15	1.0305	17.5000	-0.0032	1.0273	8.25	0.01387	0.0103	86.72	81.60
30	1.0300	17.5000	-0.0032	1.0268	8.40	0.01387	0.0073	85.13	80.11
60	1.0295	17.7000	-0.0032	1.0263	8.70	0.013834	0.0053	83.54	78.61
120	1.0280	18.0000	-0.0031	1.0249	8.90	0.01378	0.0038	79.09	74.43
240	1.0265	19.2000	-0.0029	1.0236	9.30	0.013576	0.0027	74.96	70.54
480	1.0260	19.8000	0	1.0260	9.40	0.013474	0.0019	82.59	77.72
1440	1.0260	17.8000	-0.0032	1.0228	9.40	0.013816	0.0011	72.42	68.15

%Gravel	0.0
%Sand	5.9
%Silt	24.4
%Clay	70.0

Grain Size Analysis

Date 19/6/2015

Location: Wolliso

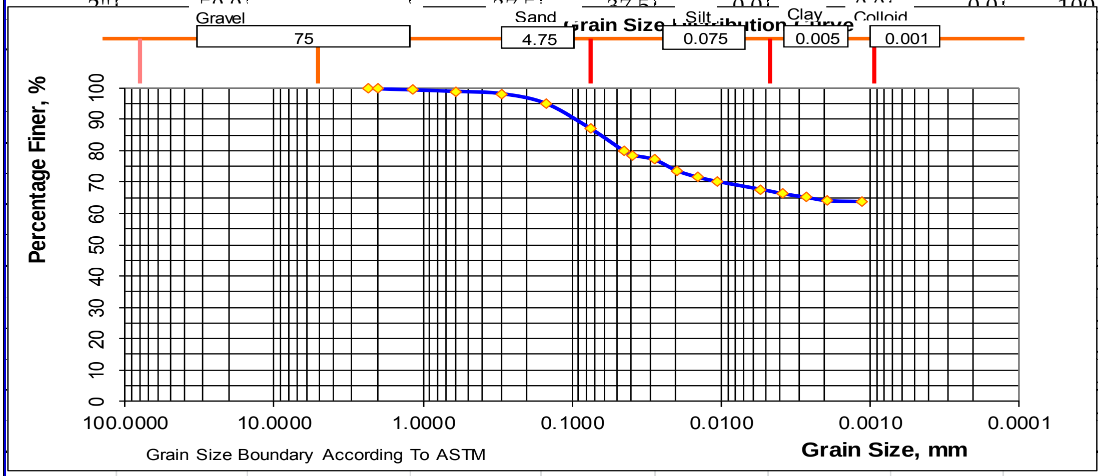
Color ofsample: Black

Sample No : Univesity inside 1 Sample Depth, m : 1.25m

Sample Type : Expansive soil of Wolliso

Sieve Analysis Total mass of sample, 500

Sieve No	Sieve Openinig (mm)	Mass of Sive (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentage (%)	Passing (%)
3''	75.0	50.0	50.0	0.0	0.0	0.0	100.0
2''	50.0		37.5	0.0		0.0	100.0



Date 21/06/2015

Hydrometer Analysis

Specific Gravity of soil 2.65 Test Temperature, deg.c

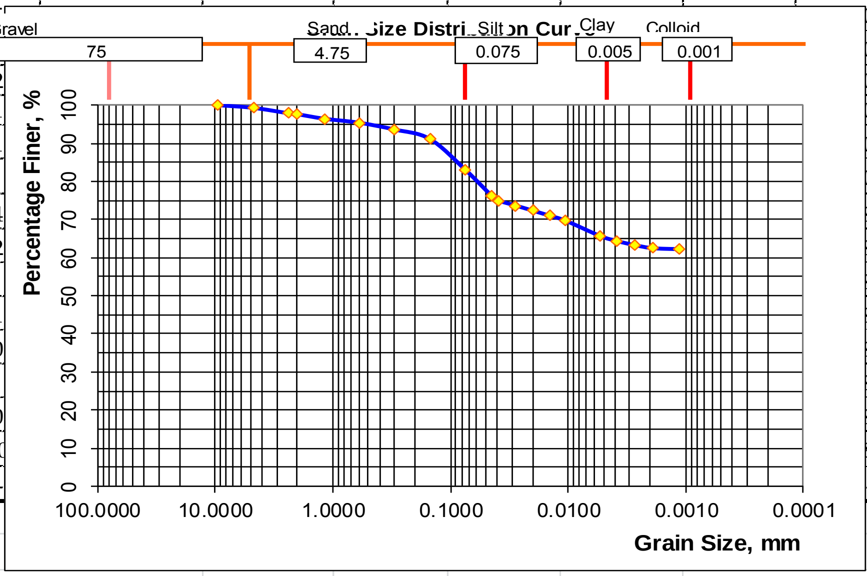
Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0315	19.1000	-0.0029	1.0286	7.95	0.013803	0.0449	91.87	79.97
1	1.0310	19.1000	-0.0029	1.0281	8.10	0.013803	0.0393	90.26	78.57
2	1.0305	19.1000	-0.0029	1.0276	8.25	0.013803	0.0280	88.65	77.17
4	1.0293	19.1000	-0.0029	1.0264	8.30	0.013803	0.0199	84.64	73.67
8	1.0285	19.1000	-0.0029	1.0256	8.75	0.013803	0.0144	82.23	71.58
15	1.0280	19.1000	-0.0029	1.0251	8.83	0.013803	0.0106	80.62	70.18
30	1.0275	19.3000	-0.0028	1.0247	8.90	0.013769	0.0075	79.34	69.06
60	1.0270	19.3000	-0.0028	1.0242	9.20	0.013769	0.0054	77.73	67.66
120	1.0265	19.3000	-0.0028	1.0237	9.30	0.013769	0.0038	76.13	66.26
240	1.0260	20.1000	0	1.0260	9.40	0.013633	0.0027	83.52	72.70
480	1.0255	20.5000	-0.0026	1.0229	9.55	0.013565	0.0019	73.56	64.03
1440	1.0260	17.5000	-0.0032	1.0228	9.40	0.01408	0.0011	73.24	63.75

%Gravel	0.7
%Sand	13.0
%Silt	23.0
%Clay	64.0

Grain Size Analysis

Date		19/6/2015	
Location:		Wolliso	
Color ofsample:	Grey		
Sample No :	Univesity inside 2	Sample Depth, m :	2.5m
Sample Type :	Expansive soil of Wolliso		
Sieve Analysis		Total mass of sample,	500

Sieve No	Sieve Openinig (mm)		Mass of Sive (g)	sieve + Retained soil(g)	Mass of Retined soil(g)	e Retained((%)	Percentage (%)	Passing (%) (%)
3''	75.0		1057.0	1057.0	0.0	0.0	0.0	100.0
2''								00.0
1.5''								00.0
1''	2							00.0
3/4''	1							00.0
1/2''	1							00.0
3.8''								00.0
No 4	4							99.3
No 8	2							97.9
No 10								97.6
No 16	1							96.4
No 40	0							95.4
No 50								93.6
No 100	0							91.2
No 200	0.0							83.1
pan	-----							--



Date 14/06/2015

Hydrometer Analysis

Specific Gravity of soil	2.65	Test Temperature, deg.c	

Elapsed time (min)	Actual Hydrometer reading	Temprature °c	Composite correction	Corrected Hydrometer	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer(%)	Perc. Finer Combined(%)
0.75	1.0315	18.9000	-0.0029	1.0286	7.95	0.013837	0.0451	91.87	76.35
1	1.0310	18.9000	-0.0029	1.0281	8.10	0.013837	0.0394	90.26	75.02
2	1.0305	18.9000	-0.0029	1.0276	8.25	0.013837	0.0281	88.65	73.68
4	1.0300	18.9000	-0.0029	1.0271	8.40	0.013837	0.0201	87.05	72.35
8	1.0295	19.0000	-0.0029	1.0266	8.70	0.01382	0.0144	85.44	71.01
15	1.0290	18.9000	-0.0029	1.0261	8.60	0.013837	0.0105	83.84	69.68
30	1.0285	19.2000	-0.0029	1.0256	8.70	0.013786	0.0074	82.23	68.35
60	1.0275	19.0000	-0.0029	1.0246	8.95	0.01382	0.0053	79.02	65.68
120	1.0270	18.9000	-0.0029	1.0241	9.20	0.013837	0.0038	77.41	64.34
240	1.0265	19.5000	-0.0028	1.0237	9.30	0.013735	0.0027	76.13	63.27
480	1.0260	20.5000	-0.0026	1.0234	9.40	0.013565	0.0019	75.16	62.47
1440	1.0265	17.4000	-0.0032	1.0233	9.30	0.01408	0.0011	74.84	62.20

%Gravel	0.7
%Sand	16.3
%Silt	20.0
%Clay	63.0

Free Swell Test

Test date: 4/2/2015

Location: Wolliso

Color of sample: Black

Sample No : University Old 1 — Sample Depth, m : 1.25m

Sample Type : Expansive soil of Wolliso

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	23.0	21.0	22.0	120

Free Swell Test

Test date: 3/2/2015

Location: Wolliso

Color ofsample: Grey

Sample No : University old 2 — Sample Depth, m : 2.3m

Sample Type : Expansive soil of Wolliso

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	20.0	21.0	20.5	105

Free Swell Test

Test date: 2/2/2015

Location: Wolliso

Color of sample: Black

Sample No : Ejersa1 — Sample Depth, m : 1.25m

Sample Type : Expansive soil of Wolliso

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	22.0	21.0	21.5	115

Free Swell Test

Test date: 2/2/2015

Location: Wolliso

Color ofsample: Grey

Sample No : Ejersa2 — Sample Depth, m : 2.5m

Sample Type : Expansive soil of Wolliso

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	19.0	21.0	20.0	100

Free Swell Test

Test date		16/03/2015		
Location:		Wolliso		
Color of the sample			Black	
Sample No :			Kidane mihret1	Sample Depth, m 1.25m
Type of sample			Expansive soil of Woliso	

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	20.0	22.0	21.0	110

Free Swell Test

Test date		16/03/2015		
Location:		Wolliso		
Color of the sample			Black	
Sample No :			Kidane mehret 2	Sample Depth, m 2.5m
Type of the sample			Expansive soil of Wolliso	

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	19.0	20.0	19.5	95

Free Swell Test

Date		24/6/2015		
Location:		Wolliso		
Color ofsample:		Black		
Sample No :			University Infront 1	Sample Depth, m 1.25m
Sample Type :			Expansive soil of Wolliso	

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	21.0	22.0	21.5	115

Free Swell Test

Date			24/6/2015	
Location:			Wolliso	
Color ofsample:		Grey		
Sample No :			University Infront 2	Sample Depth, m 2.5m
Sample Type :			Expansive soil of Wolliso	

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	22.0	23.0	22.5	125

Free Swell Test

Test date			24/06/2015	
Location:			Wolliso	
Color ofsample:		Black		
Sample No :			Michael 1	Sample Depth, m 1.25m
Sample Type :			Expansive soil of Wolliso	

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	20.0	18.0	19.0	90

Free Swell Test

Date			25/6/2015	
Location:			Wolliso	
Color ofsample:		Grey		
Sample No :			Michael 2	Sample Depth, m 2.5m
Sample Type :			Expansive soil of Wolliso	
Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	19.0	19.5	95

Free Swell Test

Date			25/6/2015	
Location:			Wolliso	
Color ofsample:		Grey		
Sample No :			Elementary 1	Sample Depth, m 1.25m
Sample Type :			Expansive soil of Wolliso	
Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.0	22.0	20.0	100

Free Swell Test

Date			25/6/2015	
Location:			Wolliso	
Color ofsample:		Grey		
Sample No :			Elementary2	Sample Depth, m 2.5m
Sample Type :			Expansive soil of Wolliso	
Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	21.0	23.0	22.0	120

Free Swell Test

Date			26/6/2015	
Location:			Wolliso	
Color ofsample:		Grey		
Sample No :			Hospital 1	Sample Depth, m 1.25m
Sample Type :			Expansive soil of Wolliso	
Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	18.0	19.0	90

Free Swell Test

Date			26/6/2015	
Location:			Wolliso	
Color ofsample:		Grey		
Sample No :			Hospital 2	Sample Depth, m 2.5m
Sample Type :			Expansive soil of Wolliso	
Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	18.0	19.0	90

Free Swell Test

Date 26/6/2015
Location: Wolliso

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	24.0	20.0	22.0	120

Free Swell Test

Date 27/6/2015
Location: Wolliso
Color ofsample: Grey
Sample No : Univesity inside 1 Sample Depth, m : 2.5m
Sample Type : Expansive soil of Wolliso

Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
10.0	22.0	21.0	21.5	115

Specific Gravity Test

Test date 2/2/2015
Location: Wolliso

Color ofsample: Grey
Sample No : University old 2 Sample Depth, m : 2.5m
Sample Type : Expansive soil of Wolliso

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	44.3	45.2	
Weight of pycnometer + water, wpw (g)	143.5	144.7	
Observed temperature of water, Ti (oc)	19.4	19.5	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	159.1	160.5	
Temperature, Tx(oc)	22.1	20.9	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	143.48	144.63	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.66	2.70	
Average specific gravity of soil .		2.68	

Specific Gravity Test

Test date 2/2/2015
Location: Wolliso

Color of sample: Black
Sample No : Ejersa1 Sample Depth, m : 1.25m
Sample Type : Expansive soil of Wolliso

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	44.3	45.2	
Weight of pycnometer + water, wpw (g)	143.6	144.7	
Observed temperature of water, Ti (oc)	22.6	21.3	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	159.2	160.3	
Temperature, Tx(oc)	24.1	23.2	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	143.58	144.63	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.66	2.68	
Average specific gravity of soil .		2.67	

Specific Gravity Test

Test date	2/2/2015			
Location:	Wolliso			
Color ofsample:	Grey			
Sample No :	Ejersa2	Sample Depth, m :	2.5m	
Sample Type :	Expansive soil of Wolliso			

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	63.5	44.5	
Weight of pycnometer + water, wpw (g)	162.1	143.8	
Observed temperature of water, Ti (oc)	21.6	20.7	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	177.5	159.1	
Temperature, Tx(oc)	22.9	22.8	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.08	143.13	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.61	2.59	
Average specific gravity of soil .		2.60	

Specific Gravity Test

Test date	2/2/2015			
Location:	Wolliso			
Color of sample:	Black			
Sample No :	Geresu 1	Sample Depth, m :	1.25m	
Sample Type :	Expansive soil of Wolliso			

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	63.5	44.5	
Weight of pycnometer + water, wpw (g)	162	143.3	
Observed temperature of water, Ti (oc)	19.3	19.1	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	177.85	159.3	
Temperature, Tx(oc)	18.9	19.3	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	161.98	143.23	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.70	2.76	
Average specific gravity of soil .		2.73	

Specific Gravity Test

Test date	2/2/2015			
Location:	Wolliso			
Color of Sample :	Grey			
Sample No :	Geresu 2	Sample Depth, m :	1.9m	
Sample TYpe :	Expansive soil of Wolliso			

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	63.7	44.5	
Weight of pycnometer + water, wpw (g)	162.5	143.35	
Observed temperature of water, Ti (oc)	19.2	19.3	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	178	159.45	
Temperature, Tx(oc)	20.3	18.7	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.48	143.28	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.62	2.79	
Average specific gravity of soil .		2.70	

Specific Gravity Test

Test date	3/2/2015			
Location:	Wolliso			
Color of sample	Black			
Sample No :	Huluyimar 1	Sample Depth, m :	1.25m	
Type of sample:	Expansive soil of Wolliso			

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	45.4	49.6	
Weight of pycnometer + water, wpw (g)	142.9	146.5	
Observed temperature of water, Ti (oc)	23.3	23.6	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	159.05	162.5	
Temperature, Tx(oc)	25.4	26.1	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	142.88	146.44	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.83	2.80	
Average specific gravity of soil .		2.81	

Specific Gravity Test

Test date	3/2/2015	
Location:	Wolliso	
Color of sample No :	Grey	
Sample No :	Huluyimar 2.	Sample Depth, m 2.5m
Sample type :	Expansive soil from woliso	

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	45.4	49.6
Weight of pycnometer + water, wpw (g)	142.9	146.5
Observed temperature of water, Ti (oc)	23.3	23.6

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	159.05	162.5
Temperature, Tx(oc)	25.4	26.1
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	142.88	146.44
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.83	2.80
Average specific gravity of soil .		2.81

Specific Gravity Test

Test date	3/2/2015	
Location:	Wolliso	
Color of the sample	Black	
Sample No :	Kidane mihret1	Sample Depth, m 1.25m
Type of sample	Expansive soil of Woliso	

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	63.4	47.9
Weight of pycnometer + water, wpw (g)	162.3	146.2
Observed temperature of water, Ti (oc)	18.9	19.1

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	178.1	162.1
Temperature, Tx(oc)	20.9	21.3
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.28	146.13
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.70	2.72
Average specific gravity of soil .		2.71

Specific Gravity Test

Test date	3/2/2015		
Location:	Wolliso		
Color of the sample	Black		
Sample No :	Kidane mehret 2	Sample Depth, m	2.5m
Type of the sample	Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	44.45	45.2
Weight of pycnometer + water, wpw (g)	143.3	144.6
Observed temperature of water, Ti (oc)	19.2	19.9

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	159.3	160.5
Temperature, Tx(oc)	20.6	18.6
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	143.28	144.53
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.76	2.71
Average specific gravity of soil .		2.74

Specific Gravity Test

Test date	11/6/2015		
Location:	Wolliso		
Color ofsample:	Black		
Sample No :	University Infront 1	Sample Depth, m	1.25m
Sample Type :	Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	63.5	44.5
Weight of pycnometer + water, wpw (g)	162.1	143.2
Observed temperature of water, Ti (oc)	18	17.6

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	178.1	162.3
Temperature, Tx(oc)	18.9	18.8
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.28	146.73
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.70	2.61
Average specific gravity of soil .		2.65

Specific Gravity Test

Test date	11/6/2015		
Location:	Wolliso		
Color ofsample:	Grey		
Sample No :	University Infront 2	Sample Depth, m	2.5m
Sample Type :	Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	47.7	45.5	
Weight of pycnometer + water, wpw (g)	146.9	144.5	
Observed temperature of water, Ti (oc)	17.7	17.4	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	162.4	160.1	
Temperature, Tx(oc)	18.7	18.8	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	146.88	144.43	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.60	2.68	
Average specific gravity of soil .		2.64	

Specific Gravity Test

Test date	11/6/2015		
Location:	Wolliso		
Color ofsample:	Black		
Sample No :	Michael 1	Sample Depth, m	1.25m
Sample Type :	Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	45.4	47.7	
Weight of pycnometer + water, wpw (g)	144.8	147.1	
Observed temperature of water, Ti (oc)	17.3	17.8	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	160.5	163	
Temperature, Tx(oc)	17.8	18	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	144.78	147.03	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.69	2.77	
Average specific gravity of soil .		2.73	

Specific Gravity Test

Test date	4/6/2015			
Location:	Wolliso			
Color ofsample:		Grey		
Sample No :		Michael 2	Sample Depth, m	2.5m
Sample Type :		Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	63.5	44.3	
Weight of pycnometer + water, wpw (g)	162.8	143.4	
Observed temperature of water, Ti (oc)	17.45	17.7	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	179	159.1	
Temperature, Tx(oc)	17.7	18.3	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.78	143.33	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.79	2.65	
Average specific gravity of soil .		2.72	

Specific Gravity Test

Test date	12/6/2015			
Location:	Wolliso			
Color ofsample:		Grey		
Sample No :		Elementary 1	Sample Depth, m	1.25m
Sample Type :		Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2	
Weight of dry, clean pycnometer, wp (g)	63.5	47.5	
Weight of pycnometer + water, wpw (g)	163.1	146.8	
Observed temperature of water, Ti (oc)	18	18.1	

[B] Specific Gravity Determination

Determination No.	1	2	
Pycnometer No.	1	2	
Weight of pycnometer + soil + water, Wpws (g)	178.3	162.6	
Temperature, Tx(oc)	18.7	18.7	
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	163.08	146.73	
Weight of dry soil , ws (gm)	25	25	
Conversion factor , K	0.9996	0.9993	
Specific gravity of soil at 20°c.	2.54	2.72	
Average specific gravity of soil .		2.63	

Specific Gravity Test

Test date	12/6/2015
Location:	Wolliso
Color ofsample:	Grey
Sample No :	Elementary2
Sample Depth, m	2.5m
Sample Type :	Expansive soil of Wolliso

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	44.25	45.2
Weight of pycnometer + water, wpw (g)	143.5	144.7
Observed temperature of water, Ti (oc)	17.3	17.2

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	159.1	160.4
Temperature, Tx(oc)	19.65	19.65
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	143.48	144.63
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.66	2.67
Average specific gravity of soil .		2.67

Specific Gravity Test

Test date	5/6/2015
Location:	Wolliso
Color ofsample:	Grey
Sample No :	Hospital 1
Sample Depth, m	1.25m
Sample Type :	Expansive soil of Wolliso

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	45.5	48.1
Weight of pycnometer + water, wpw (g)	144.4	147.2
Observed temperature of water, Ti (oc)	18.3	17.8

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	160.4	163.3
Temperature, Tx(oc)	19.1	19.3
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	144.38	147.13
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.74	2.77
Average specific gravity of soil .		2.76

Specific Gravity Test

Test date	12/6/2015		
Location:	Wolliso		
Color ofsample:	Grey		
Sample No :	Hospital 2	Sample Depth, m	2.5m
Sample Type :	Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	63.7	44.5
Weight of pycnometer + water, wpw (g)	162.6	143.4
Observed temperature of water, Ti (oc)	18.5	17.7

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	178.1	159.5
Temperature, Tx(oc)	18.4	18.7
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.58	143.33
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.62	2.79
Average specific gravity of soil .		2.70

Specific Gravity Test

Test date	13/6/2015		
Location:	Wolliso		
Color ofsample:	Black		
Sample No :	Univesity inside 1	Sample Depth, m	1.25m
Sample Type :	Expansive soil of Wolliso		

[A] Calibration of pycnometer

Pycnometer No.	1	2
Weight of dry, clean pycnometer, wp (g)	63.5	47.8
Weight of pycnometer + water, wpw (g)	162.3	146.8
Observed temperature of water, Ti (oc)	17.5	17.5

[B] Specific Gravity Determination

Determination No.	1	2
Pycnometer No.	1	2
Weight of pycnometer + soil + water, Wpws (g)	178.1	162.3
Temperature, Tx(oc)	18.9	18.8
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.28	146.73
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9996	0.9993
Specific gravity of soil at 20°c.	2.70	2.61
Average specific gravity of soil .		2.65

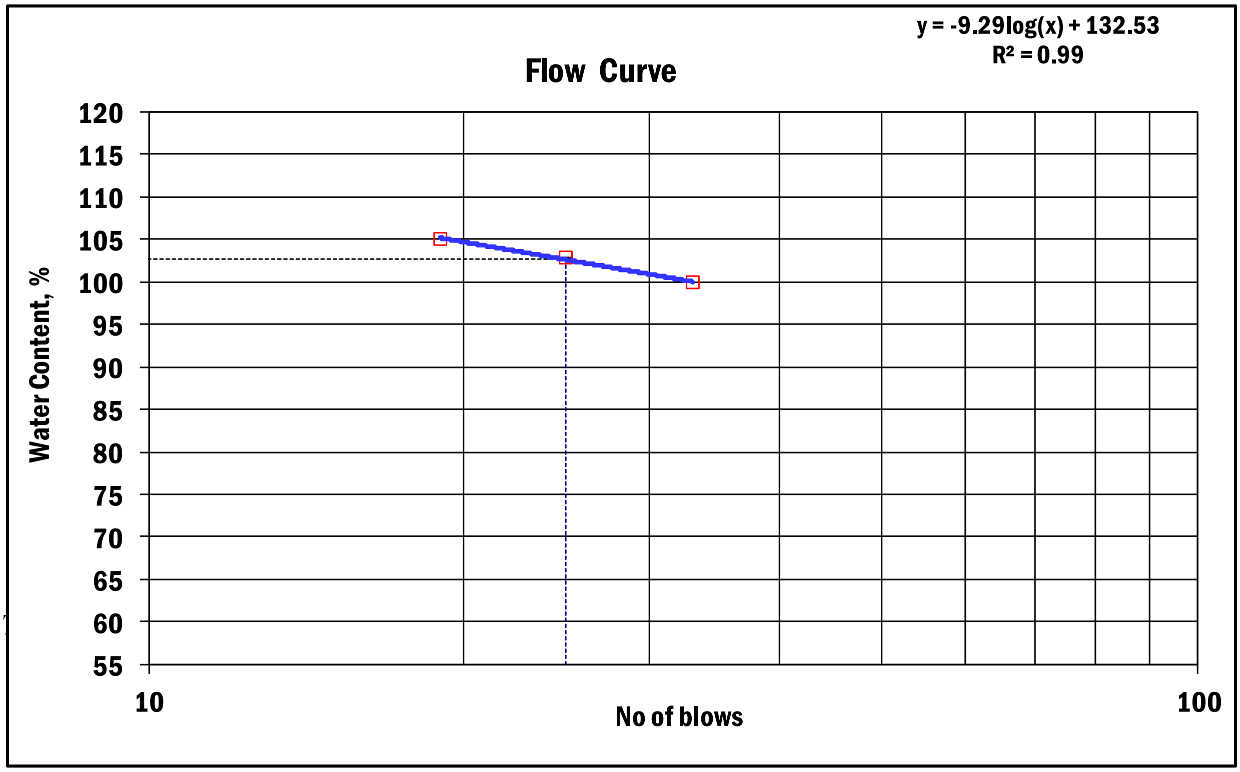
Liquid Limit and Plastic Limit Test

Date taste 3/2/2015
location Wolliso

Sample No : university old 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	M4	WA	AB		BS	ZQ
Mass of container, g	15.70	15.60	15.50		15.60	15.70
Mass of container + Wet soil, g	42.95	44.00	43.90		20.30	21.70
Mass of container + Dry soil, g	29.33	29.60	29.35		18.85	19.90
Mass of water, g	13.62	14.40	14.55		1.45	1.80
Mass of dry soil, g	13.63	14.00	13.85		3.25	4.20
Water content, %	99.93	102.86	105.05		44.62	42.86
No of blows	33	25	19		------	------

Liquid Limit, % = 103 Plastic Limit, % = 44 PI, %= 59



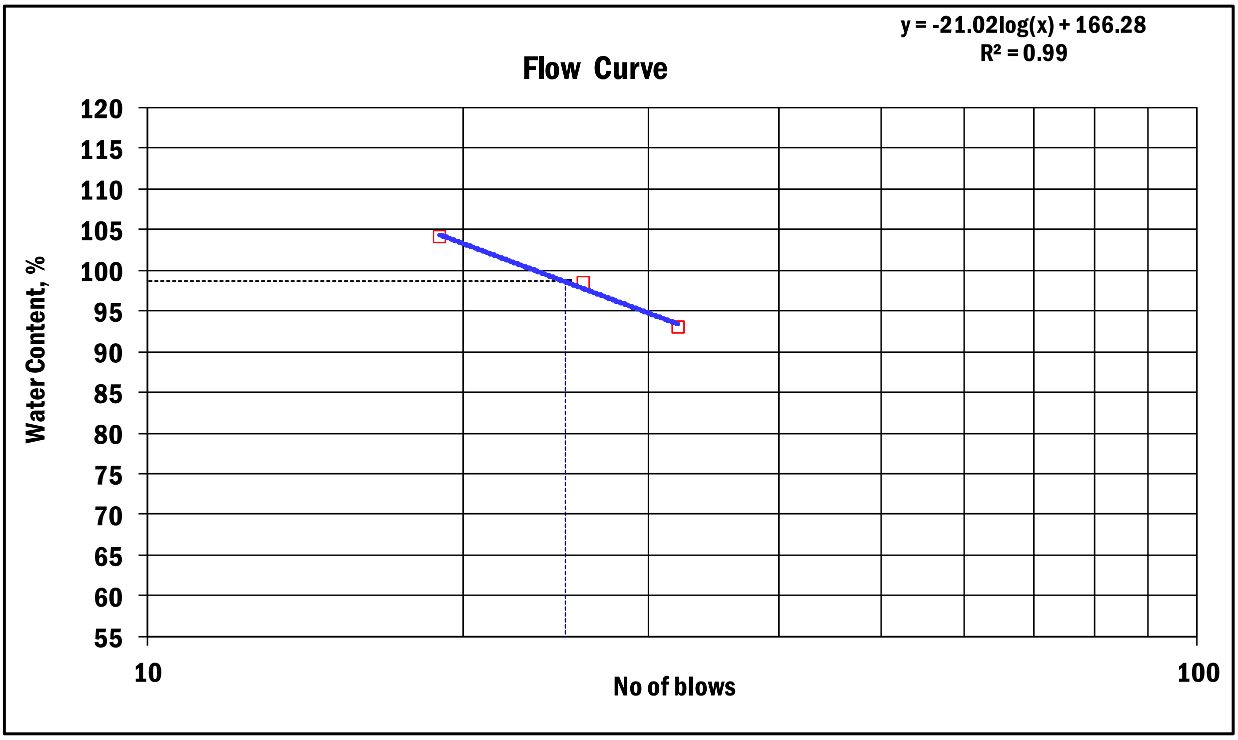
Liquid Limit and Plastic Limit Test

Date tasted 2/2/2015
location Wolliso

Sample No : Ejersa 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	G2	p23	GA		23	34
Mass of container, g	15.70	15.60	15.50		15.60	15.70
Mass of container + Wet soil, g	43.10	43.20	43.05		21.20	21.20
Mass of container + Dry soil, g	29.90	29.50	29.00		19.80	19.50
Mass of water, g	13.20	13.70	14.05		1.40	1.70
Mass of dry soil, g	14.20	13.90	13.50		4.20	3.80
Water content, %	92.96	98.56	104.07		33.33	0.00
No of blows	32	26	19		------	------

Liquid Limit, % = 99 Plastic Limit, % = 33 PI, %= 65



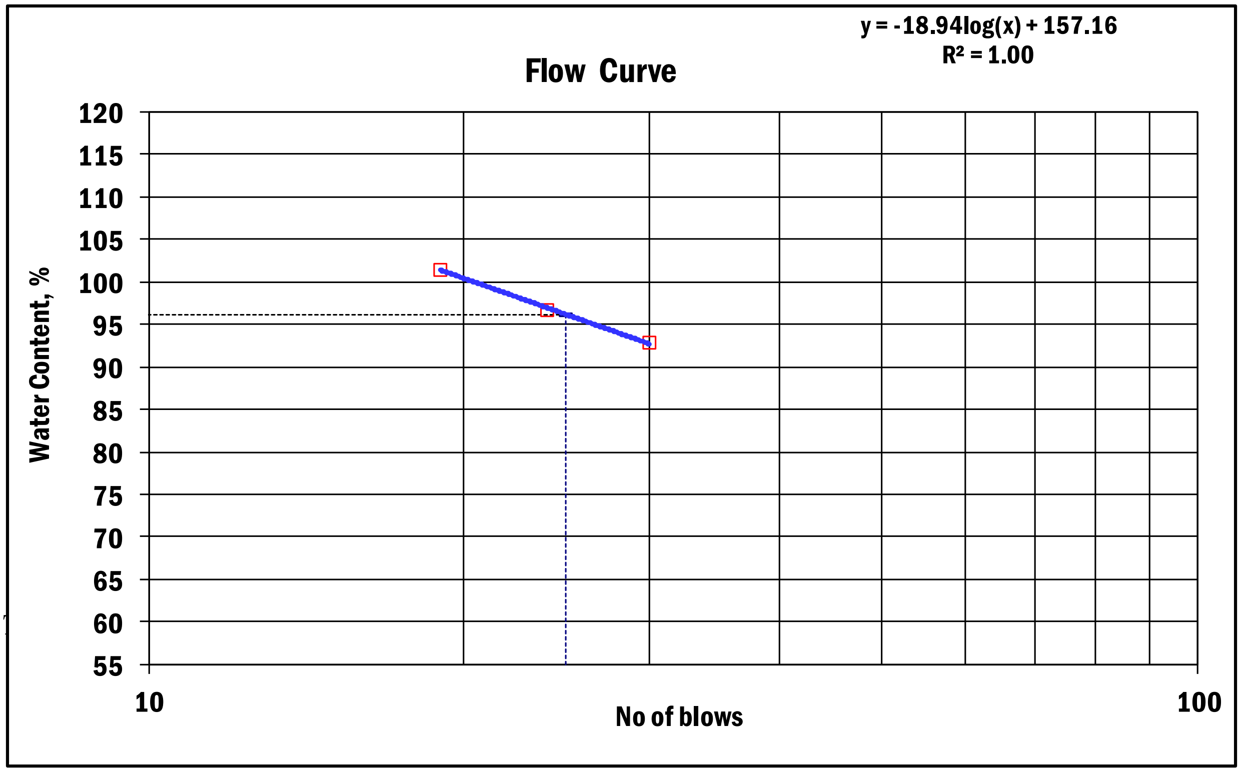
Liquid Limit and Plastic Limit Test

Date taste 5/2/2015
location Wolliso

Sample No : Ejersa 2 Sample Depth, m : 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3			2
Container No	65	32	24			T8
Mass of container, g	15.60	15.90	16.50			15.90
Mass of container + Wet soil, g	42.60	42.85	43.30			22.00
Mass of container + Dry soil, g	29.60	29.60	29.80			20.10
Mass of water, g	13.00	13.25	13.50			1.90
Mass of dry soil, g	14.00	13.70	13.30			4.20
Water content, %	92.86	96.72	101.50			45.24
No of blows	30	24	19		------	------

Liquid Limit, % = 96 Plastic Limit, % = 45 PI, %= 51



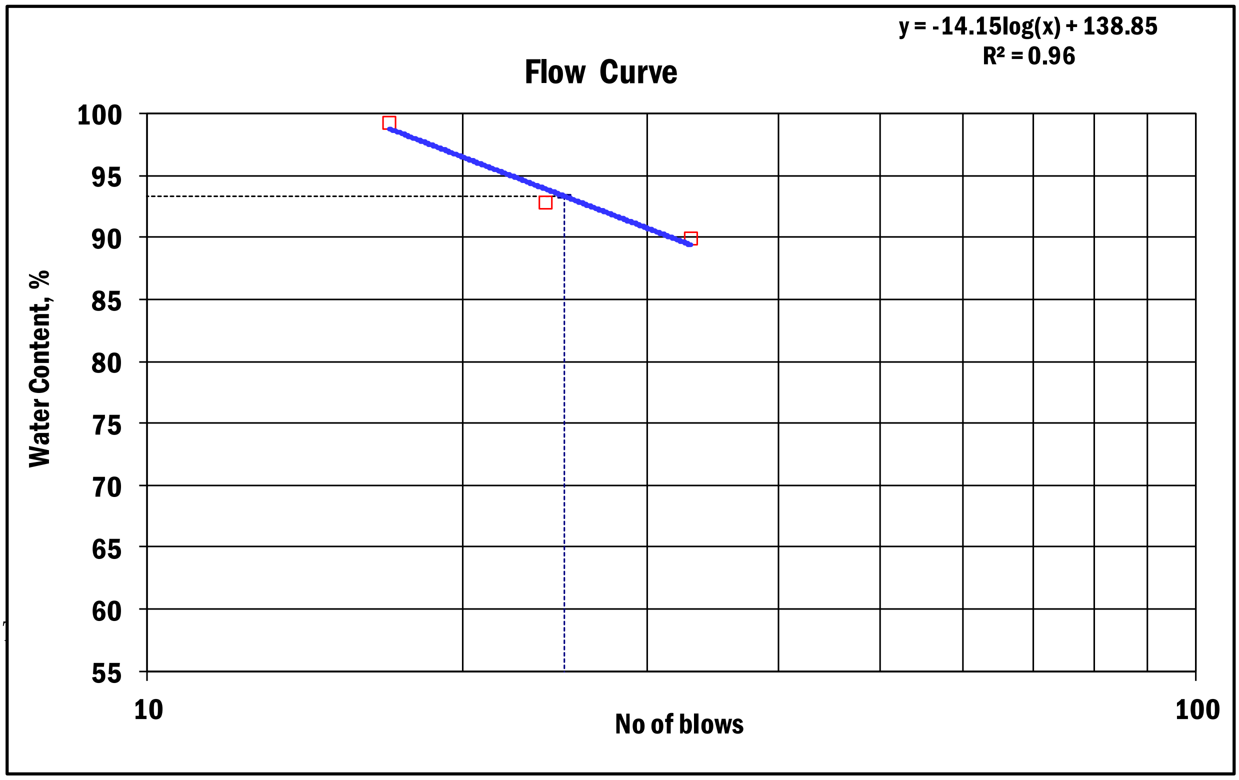
Liquid Limit and Plastic Limit Test

Date taste 15/03/2015
location Wolliso

Sample No : Geresu1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	wl	p33	a4		m10	16
Mass of container, g	15.70	15.90	15.50		15.70	15.80
Mass of container + Wet soil, g	42.10	42.90	42.80		21.90	22.70
Mass of container + Dry soil, g	29.60	29.90	29.20		20.00	20.60
Mass of water, g	12.50	13.00	13.60		1.90	2.10
Mass of dry soil, g	13.90	14.00	13.70		4.30	4.80
Water content, %	89.93	92.86	99.27		44.19	43.75
No of blows	33	24	17		------	------

Liquid Limit, % = 93 Plastic Limit, % = 44 PI, %= 48



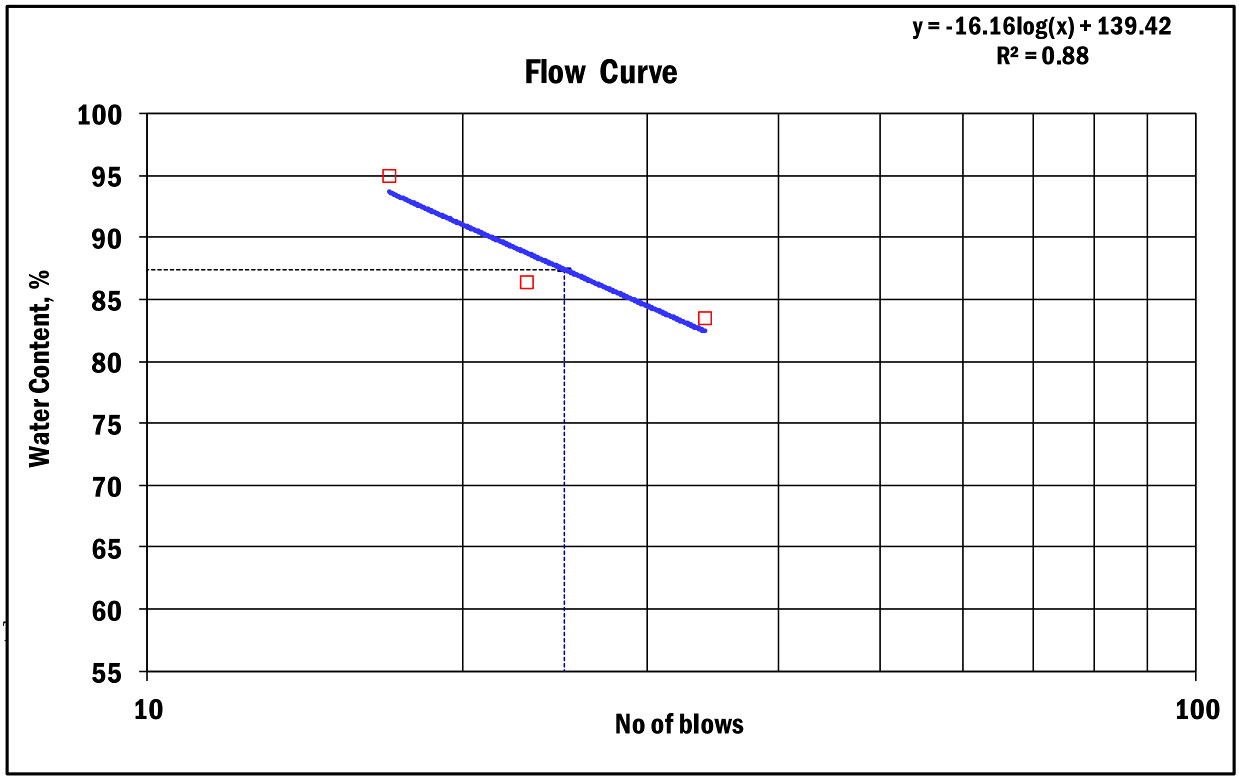
Liquid Limit and Plastic Limit Test

Date taste 15/03/2015
location Wolliso

Sample No : Geresu 2 Sample Depth, m : 1.9m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	Pl	M2	B4		M10	GA
Mass of container, g	15.50	15.60	16.10		15.60	15.80
Mass of container + Wet soil, g	41.90	43.00	43.20		20.80	21.80
Mass of container + Dry soil, g	29.89	30.30	30.00		19.20	20.00
Mass of water, g	12.01	12.70	13.20		1.60	1.80
Mass of dry soil, g	14.39	14.70	13.90		3.60	4.20
Water content, %	83.46	86.39	94.96		44.44	42.86
No of blows	34	23	17		------	------

Liquid Limit, % = 87 Plastic Limit, % = 44 PI, %= 44



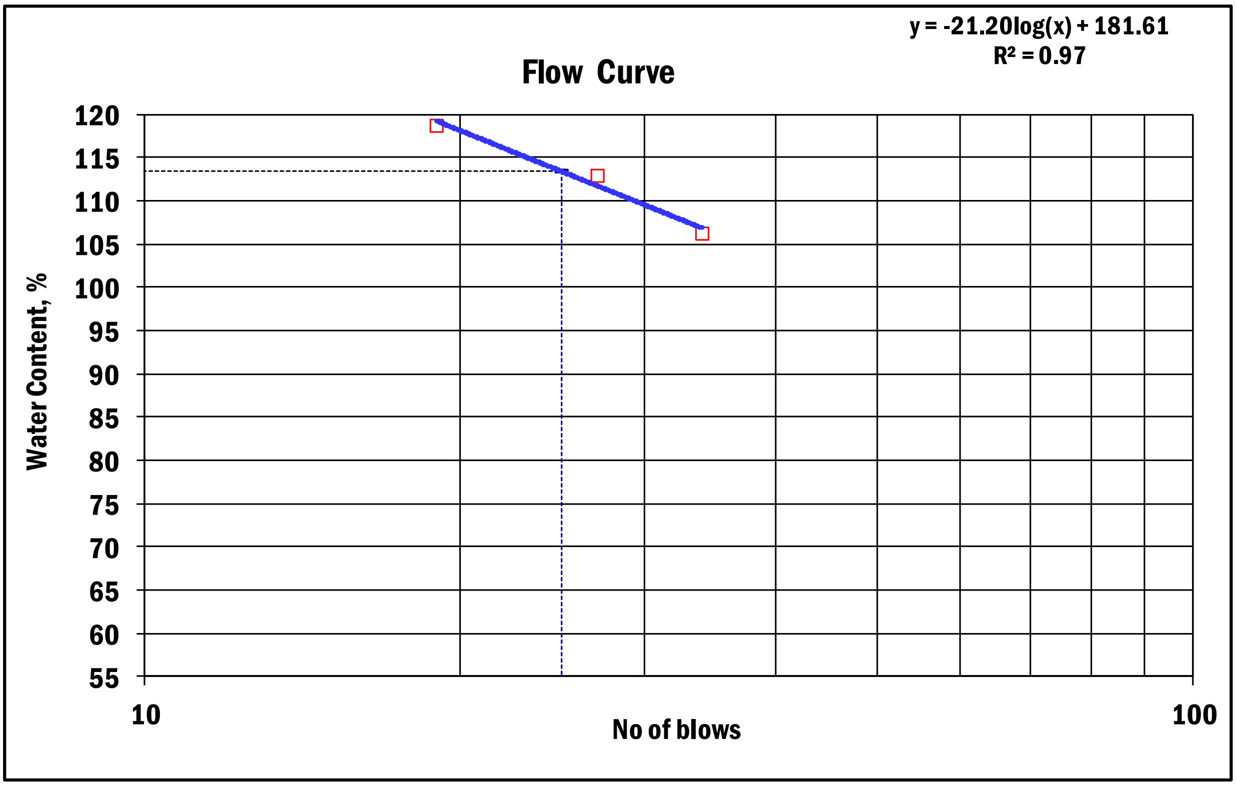
Liquid Limit and Plastic Limit Test

Date tasted 28/01/2015
location Wolliso

Sample No : huluyimar 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	60	28	M10		24	b10
Mass of container, g	15.60	15.80	16.60		15.60	15.80
Mass of container + Wet soil, g	42.60	42.10	43.50		22.70	23.20
Mass of container + Dry soil, g	28.70	28.15	28.90		20.40	20.80
Mass of water, g	13.90	13.95	14.60		2.30	2.40
Mass of dry soil, g	13.10	12.35	12.30		4.80	5.00
Water content, %	106.11	112.96	118.70		47.92	48.00
No of blows	34	27	19		------	------

Liquid Limit, % = 113 Plastic Limit, % = 48 PI, %= 65



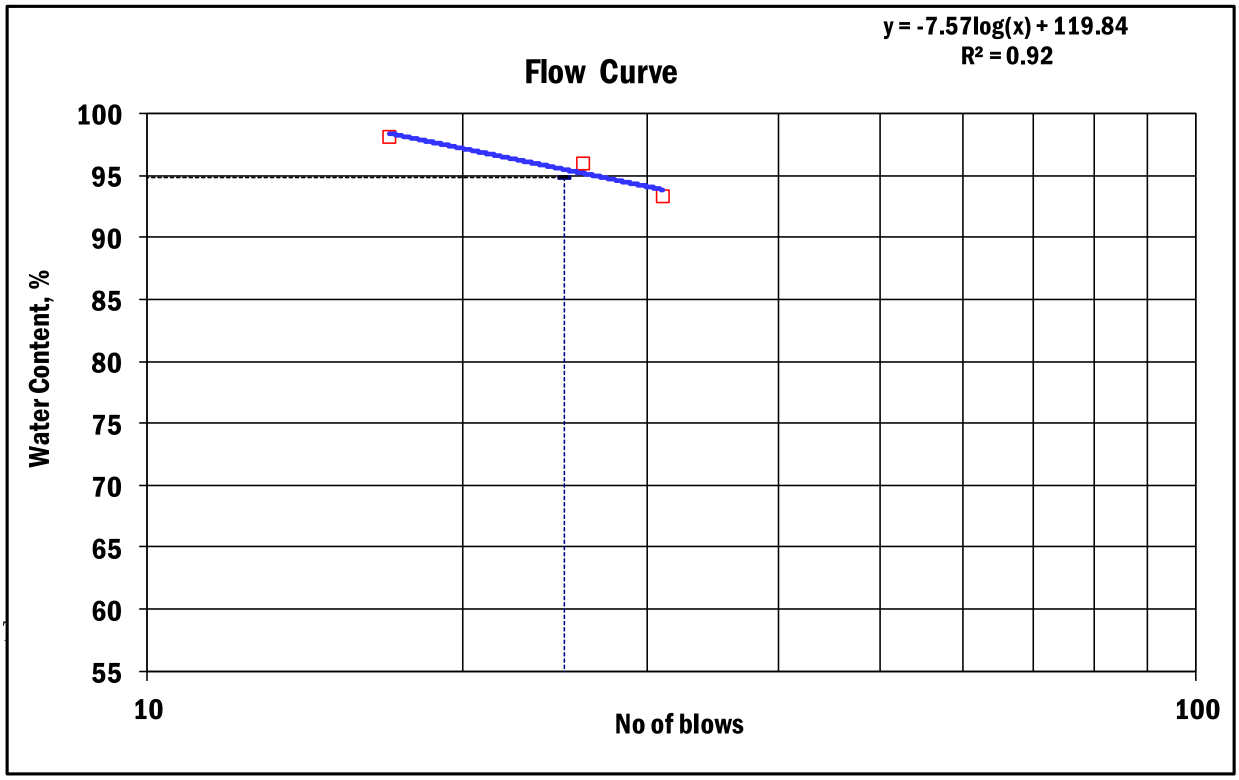
Liquid Limit and Plastic Limit Test

Date taste 28/01/2015
location Wolliso

Sample No : huluyimar 2 Sample Depth, m : 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	25	36	P10		60	58
Mass of container, g	15.70	16.60	15.80		15.70	15.90
Mass of container + Wet soil, g	43.15	43.25	42.95		23.80	23.50
Mass of container + Dry soil, g	29.90	30.20	29.50		21.30	21.10
Mass of water, g	13.25	13.05	13.45		2.50	2.40
Mass of dry soil, g	14.20	13.60	13.70		5.60	5.20
Water content, %	93.31	95.96	98.18		44.64	46.15
No of blows	31	26	17		------	------

Liquid Limit, % = 95 Plastic Limit, % = 45 PI, %= 50



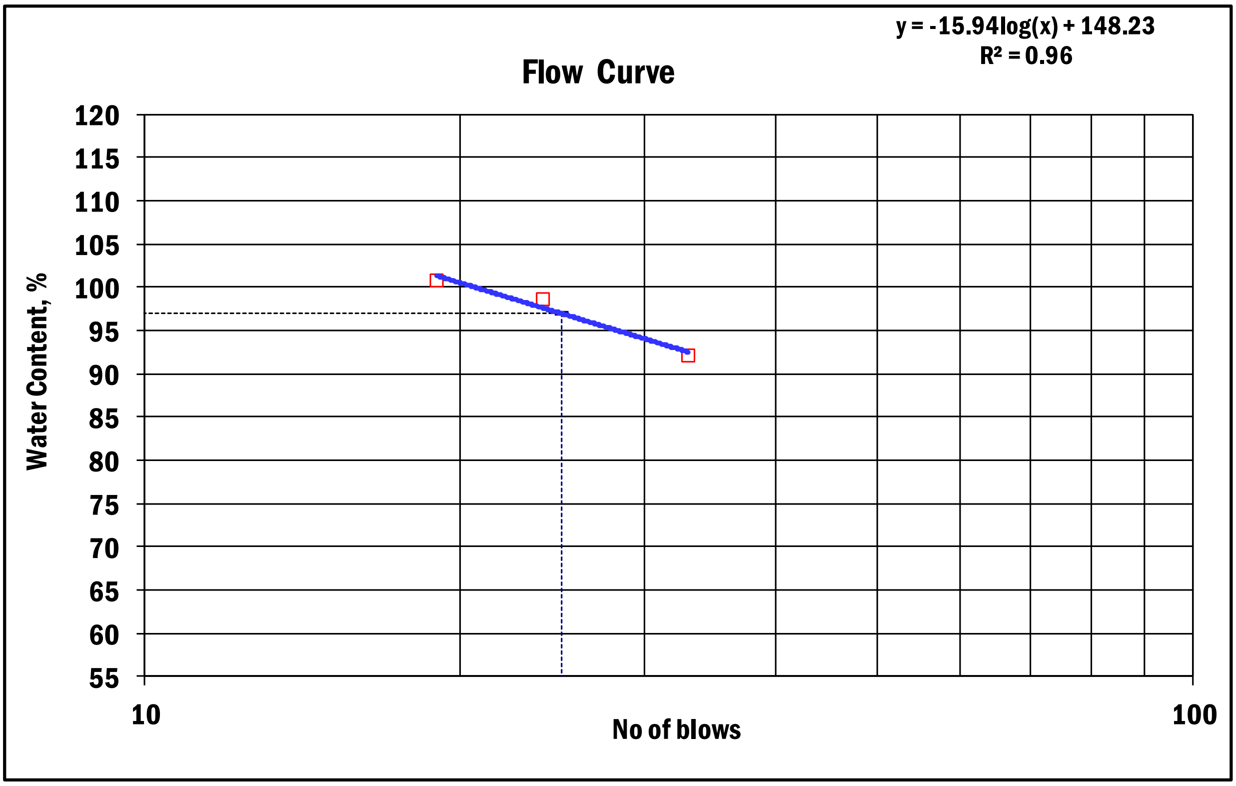
Liquid Limit and Plastic Limit Test

Date tasted 16/03/2015
location Wolliso

Sample No : Kidenemehiret 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	M1	LL	G4		28	32
Mass of container, g	15.70	15.60	15.70		15.60	15.70
Mass of container + Wet soil, g	42.40	43.00	43.00		20.90	21.90
Mass of container + Dry soil, g	29.60	29.40	29.30		19.20	20.00
Mass of water, g	12.80	13.60	13.70		1.70	1.90
Mass of dry soil, g	13.90	13.80	13.60		3.60	4.30
Water content, %	92.09	98.55	100.74			44.19
No of blows	33	24	19		------	------

Liquid Limit, % = 97 Plastic Limit, % = 44 PI, %= 53



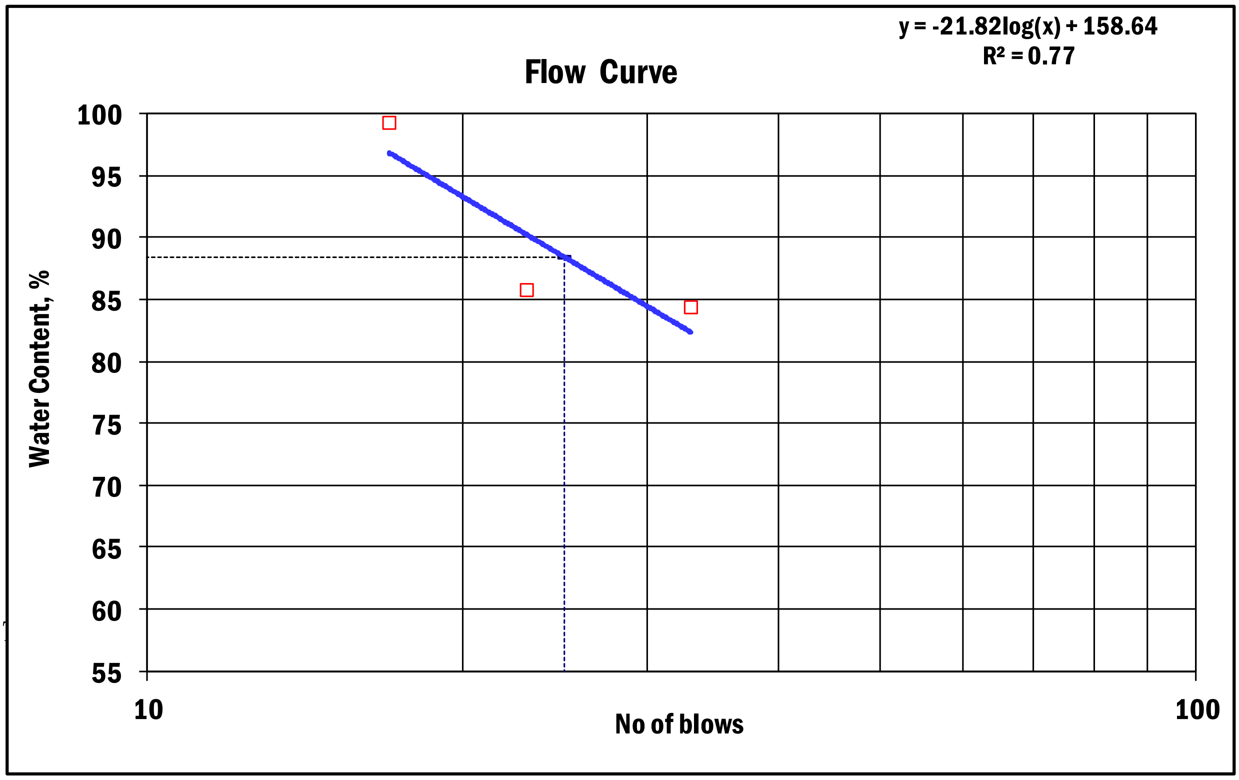
Liquid Limit and Plastic Limit Test

Date taste 16/03/2015
location Wolliso

Sample No : Kidane mehiret 2 Sample Depth, m : 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	M2	G4	pl		32	56
Mass of container, g	15.60	15.50	15.70		15.70	15.60
Mass of container + Wet soil, g	41.60	42.80	43.00		21.00	21.50
Mass of container + Dry soil, g	29.70	30.20	29.40		19.50	19.80
Mass of water, g	11.90	12.60	13.60		1.50	1.70
Mass of dry soil, g	14.10	14.70	13.70		3.80	4.20
Water content, %	84.40	85.71	99.27		39.47	40.48
No of blows	33	23	17		------	------

Liquid Limit, % = 88 Plastic Limit, % = 40 PI, %= 48



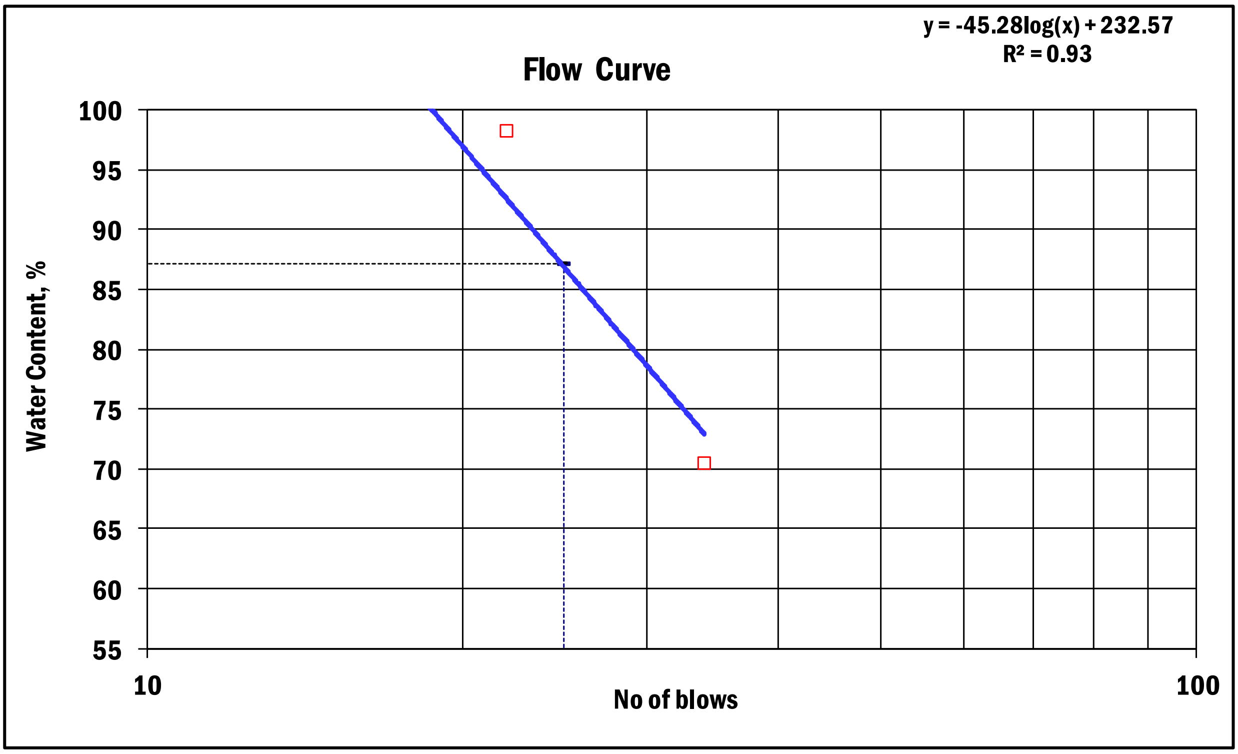
Liquid Limit and Plastic Limit Test

Date tasted 9/6/2015
location Wolliso

Sample No : university infront 1 Sample Depth, m : 1.25m

	Liquid Limit			Plastic Limit	
Trial No	1	2	3	1	2
Container No	6	M10	A31	24	P2
Mass of container, g	15.80	10.90	16.60	15.60	15.80
Mass of container + Wet soil, g	34.90	44.20	48.80	22.30	22.50
Mass of container + Dry soil, g	27.00	27.70	32.40	20.40	20.70
Mass of water, g	7.90	16.50	16.40	1.90	1.80
Mass of dry soil, g	11.20	16.80	15.80	4.80	4.90
Water content, %	70.54	98.21	103.80	39.58	36.73
No of blows	34	22	16	------	------

Liquid Limit, % = 87 Plastic Limit, % = 38 PI, %= 49



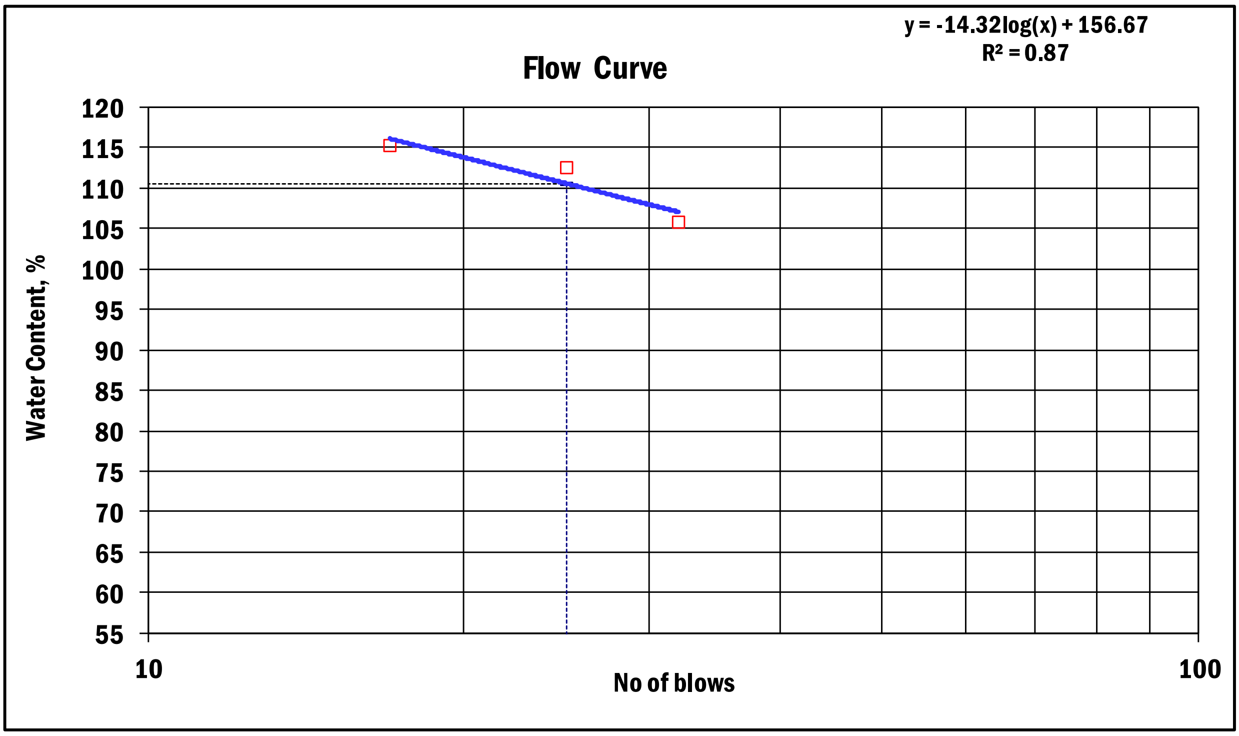
Liquid Limit and Plastic Limit Test

Date tasted 9/6/2015
location Wolliso

Sample No : university infront 2 Sample Depth, m : 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	
Container No	B11	28	32		85	
Mass of container, g	16.00	15.70	15.80		15.90	
Mass of container + Wet soil, g	40.70	42.70	45.30		22.40	
Mass of container + Dry soil, g	28.00	28.40	29.50		20.50	
Mass of water, g	12.70	14.30	15.80		1.90	
Mass of dry soil, g	12.00	12.70	13.70		4.60	
Water content, %	105.83	112.60	115.33		41.30	
No of blows	32	25	17		------	------

Liquid Limit, % = 111 Plastic Limit, % = 41 PI, %= 70



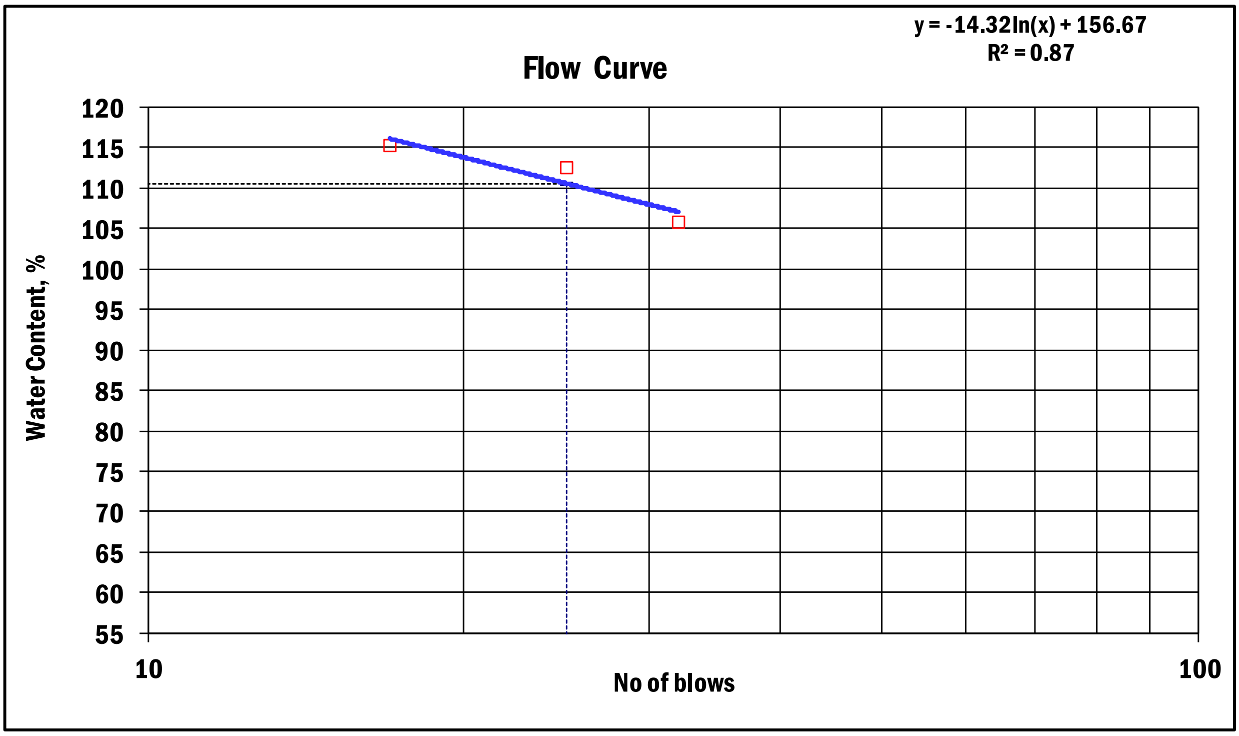
Liquid Limit and Plastic Limit Test

Date tasted 9/6/2015
location Wolliso

Sample No : University infront 2 Sample Depth, m : 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	
Container No	B11	28	32		85	
Mass of container, g	16.00	15.70	15.80		15.90	
Mass of container + Wet soil, g	40.70	42.70	45.30		22.40	
Mass of container + Dry soil, g	28.00	28.40	29.50		20.50	
Mass of water, g	12.70	14.30	15.80		1.90	
Mass of dry soil, g	12.00	12.70	13.70		4.60	
Water content, %	105.83	112.60	115.33		41.30	
No of blows	32	25	17		------	------

Liquid Limit, % = 111 Plastic Limit, % = 41 PI, %= 70



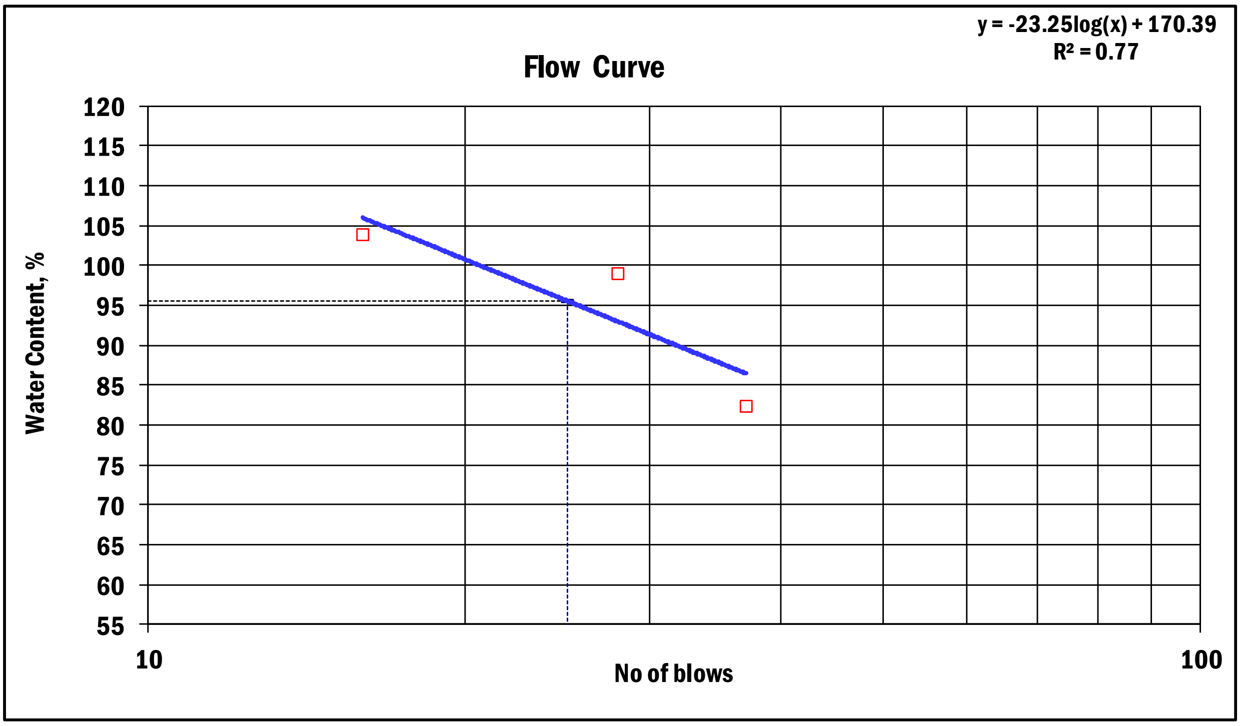
Liquid Limit and Plastic Limit Test

Date tasted 12/6/2015
location Wolliso

Sample No : university inside 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	B4	AB	40		AL3	M1
Mass of container, g	16.00	15.80	15.90		15.50	15.50
Mass of container + Wet soil, g	38.80	35.70	36.70		22.20	24.70
Mass of container + Dry soil, g	28.50	25.80	26.10		20.30	22.10
Mass of water, g	10.30	9.90	10.60		1.90	2.60
Mass of dry soil, g	12.50	10.00	10.20		4.80	6.60
Water content, %	82.40	99.00	103.92		39.58	39.39
No of blows	37	28	16		------	------

Liquid Limit, % = 96 Plastic Limit, % = 39 PI, %= 56



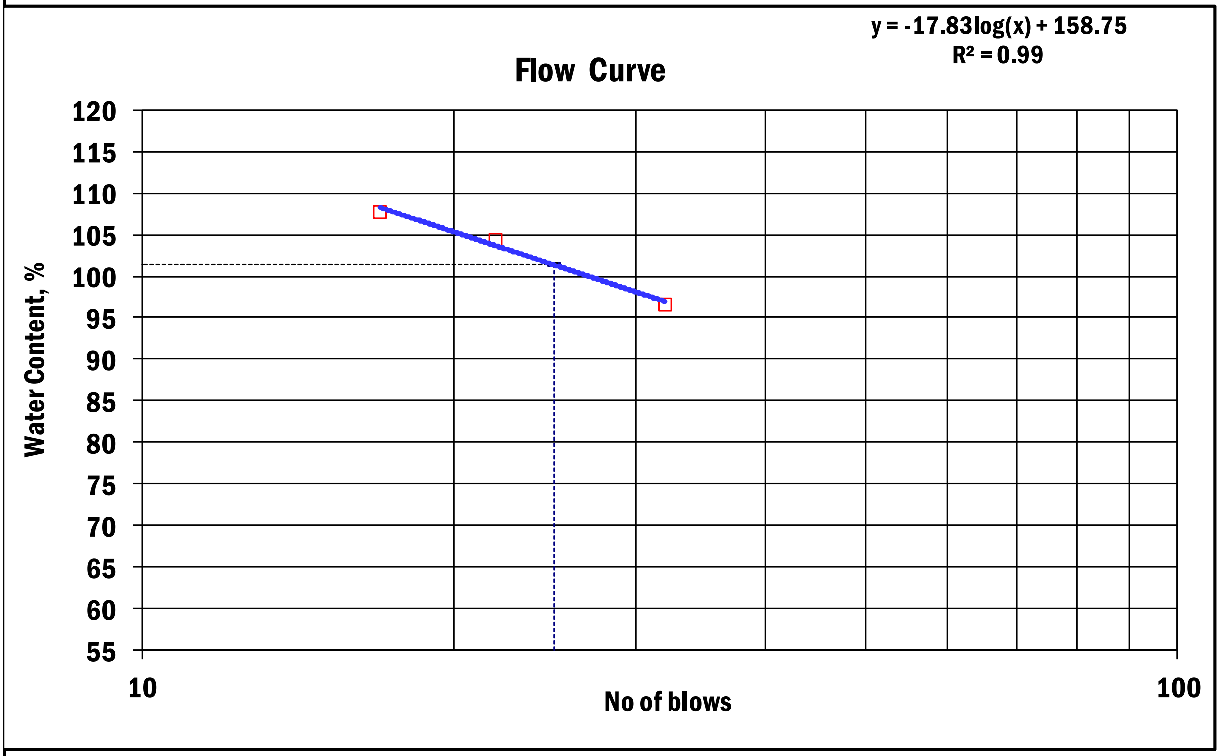
Liquid Limit and Plastic Limit Test

Date tasted 12/6/2015
location Wolliso

Sample No : Ambo inside 2 Sample Depth, 2.5m

	Liquid Limit			Plastic Limit	
Trial No	1	2	3	1	2
Container No	M2	PI-2	S4	Z	28
Mass of container, g	15.70	15.80	15.80	15.80	15.40
Mass of container + Wet soil, g	39.10	52.60	37.20	22.60	21.50
Mass of container + Dry soil, g	27.60	33.80	26.10	20.70	19.80
Mass of water, g	11.50	18.80	11.10	1.90	1.70
Mass of dry soil, g	11.90	18.00	10.30	4.90	4.40
Water content, %	96.64	104.44	107.77	38.78	38.64
No of blows	32	22	17	------	------

Liquid Limit, % = 101 Plastic Limit, % = 39 PI, %= 63



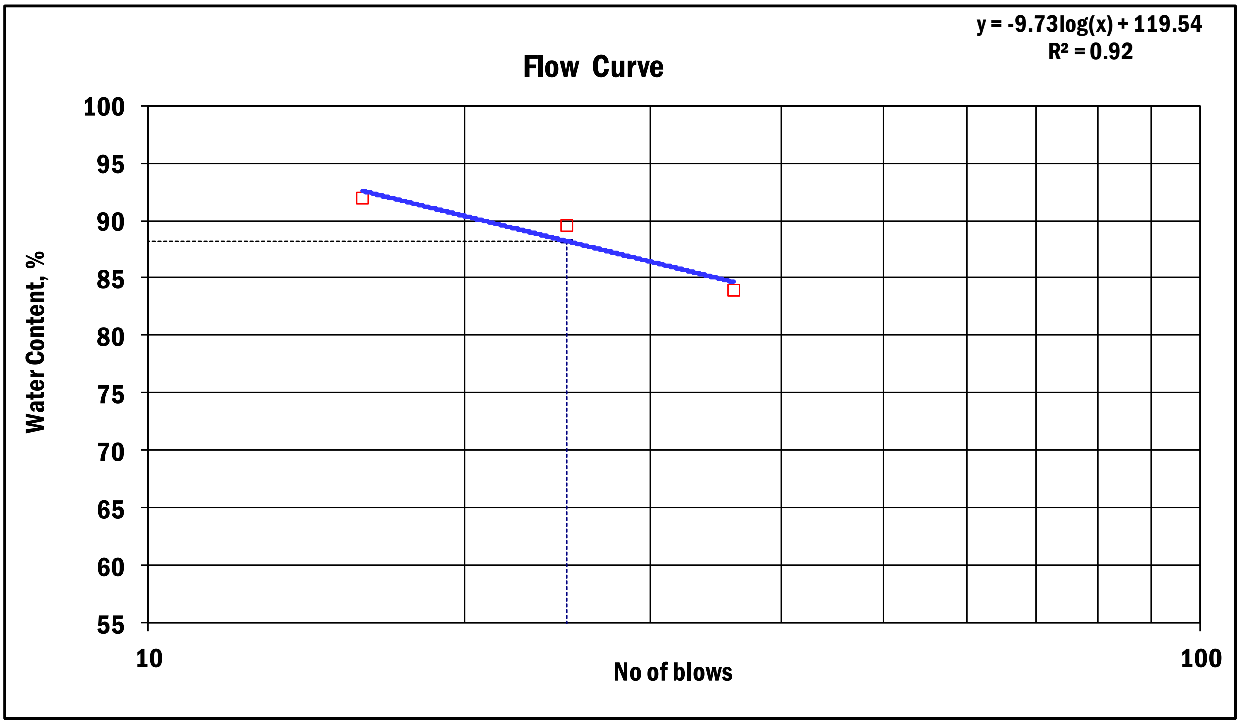
Liquid Limit and Plastic Limit Test

Date tasted 12/6/2015
location Wolliso

Sample No : Michael 1   Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	
Container No	AB	B11	28	28	32	
Mass of container, g	15.80	16.00	15.60	15.60	15.80	
Mass of container + Wet soil, g	43.20	43.30	46.50	46.50	22.90	
Mass of container + Dry soil, g	30.70	30.40	31.70	31.70	21.20	
Mass of water, g	12.50	12.90	14.80	14.80	1.70	
Mass of dry soil, g	14.90	14.40	16.10	16.10	5.40	
Water content, %	83.89	89.58	91.93	91.93	31.48	
No of blows	36	25	16	16	------	------

Liquid Limit, % = 88   Plastic Limit, % = 31   PI, %= 57



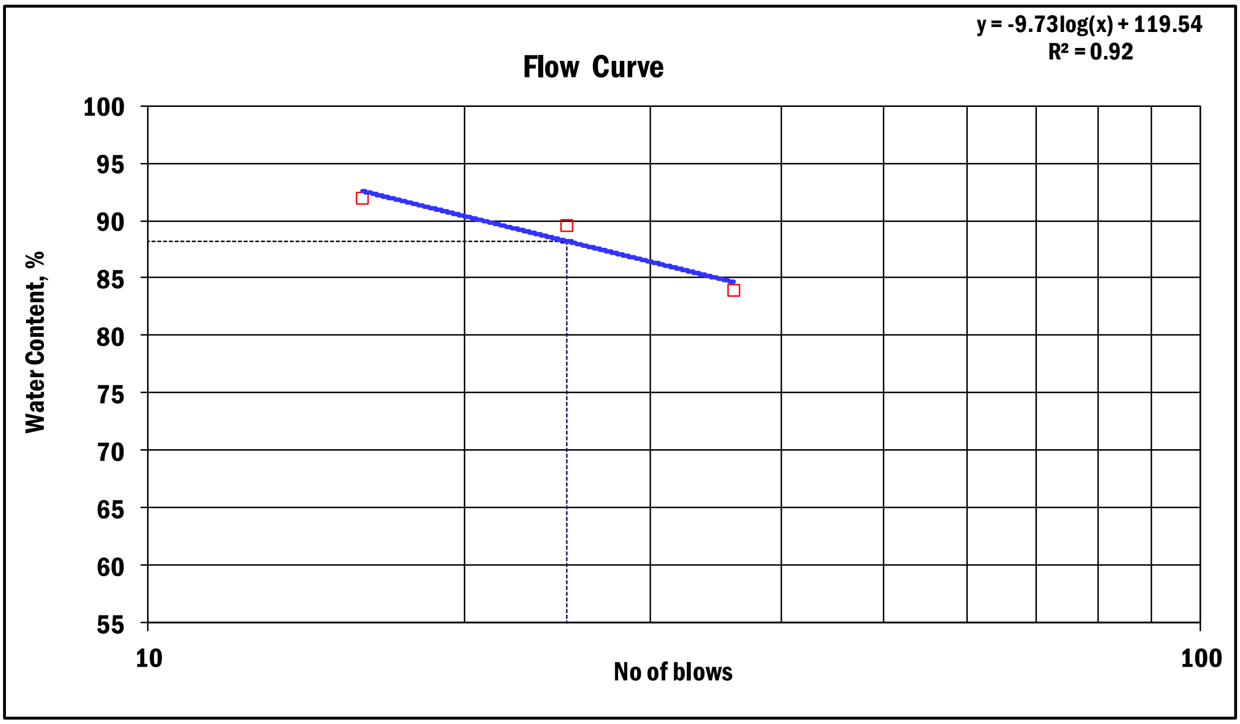
Liquid Limit and Plastic Limit Test

Date tasted 12/6/2015
location Wolliso

Sample No : Michael 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	
Container No	AB	B11	28	28	32	
Mass of container, g	15.80	16.00	15.60	15.60	15.80	
Mass of container + Wet soil, g	43.20	43.30	46.50	46.50	22.90	
Mass of container + Dry soil, g	30.70	30.40	31.70	31.70	21.20	
Mass of water, g	12.50	12.90	14.80	14.80	1.70	
Mass of dry soil, g	14.90	14.40	16.10	16.10	5.40	
Water content, %	83.89	89.58	91.93	91.93	31.48	
No of blows	36	25	16	16	------	------

Liquid Limit, % = 88 Plastic Limit, % = 31 PI, %= 57



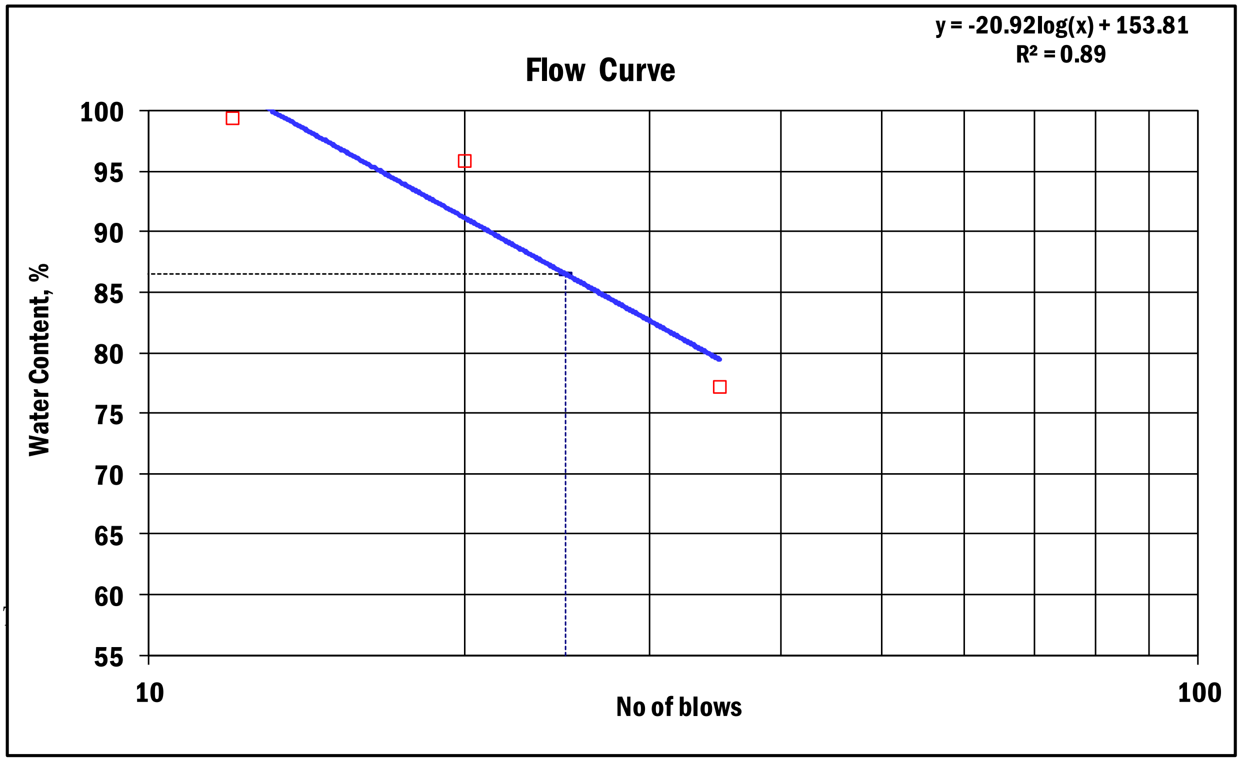
Liquid Limit and Plastic Limit Test

Date taste 12/6/2015
location Wolliso

Sample No : Michael 2 Sample Depth, m : 2.5m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3		1	2
Container No	2	SM3	A4		M1	32
Mass of container, g	16.10	15.50	15.30		15.90	15.90
Mass of container + Wet soil, g	47.20	38.80	48.00		24.10	23.90
Mass of container + Dry soil, g	33.65	27.40	31.70		21.80	21.70
Mass of water, g	13.55	11.40	16.30		2.30	2.20
Mass of dry soil, g	17.55	11.90	16.40		5.90	5.80
Water content, %	77.21	95.80	99.39		38.98	37.93
No of blows	35	20	12		------	------

Liquid Limit, % = 86 Plastic Limit, % = 38 PI, %= 48



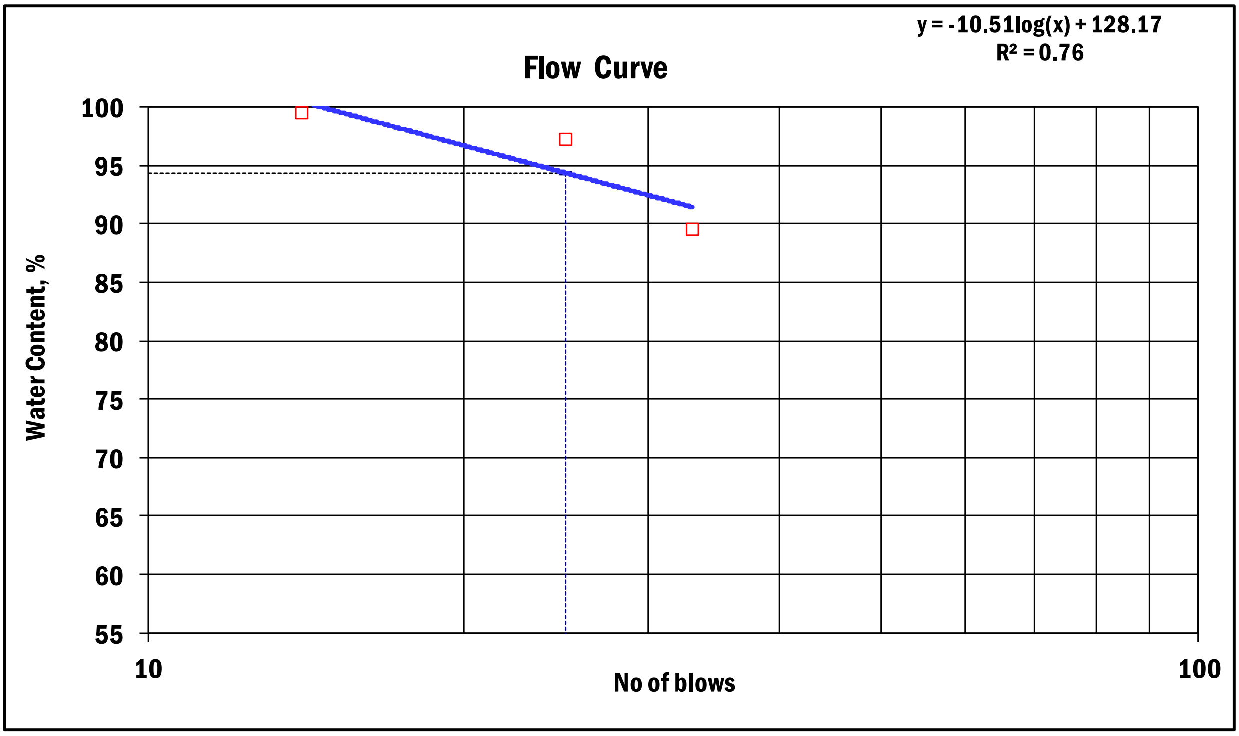
Liquid Limit and Plastic Limit Test

Date tasted 19/6/2015
location Wolliso

Sample No : Element 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	40	B11	GA		M55	Z1
Mass of container, g	15.90	16.10	15.60		16.00	15.50
Mass of container + Wet soil, g	37.50	37.60	55.90		23.60	23.90
Mass of container + Dry soil, g	27.30	27.00	35.80		21.20	21.30
Mass of water, g	10.20	10.60	20.10		2.40	2.60
Mass of dry soil, g	11.40	10.90	20.20		5.20	5.80
Water content, %	89.47	97.25	99.50		46.15	44.83
No of blows	33	25	14		------	------

Liquid Limit, % = 94 Plastic Limit, % = 45 PI, %= 49



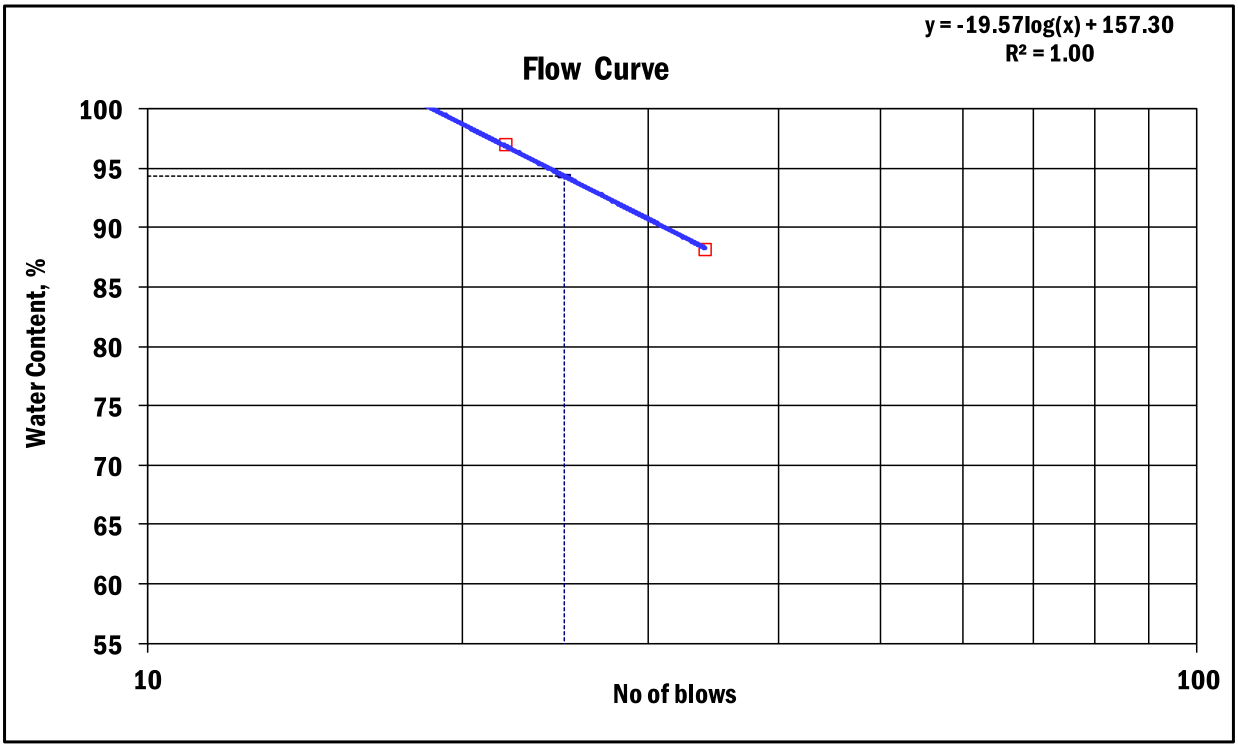
Liquid Limit and Plastic Limit Test

Date tasted 19/6/2015
location Wolliso

Sample No : Element Sample Depth, m : 2.5

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	S4	Z	AM	C18	S4	AM
Mass of container, g	15.90	15.50	15.60	20.03	15.50	15.70
Mass of container + Wet soil, g	49.40	48.60	45.40	42.94	22.50	25.10
Mass of container + Dry soil, g	33.70	32.30	30.60	33.19	20.70	22.60
Mass of water, g	15.70	16.30	14.80	9.75	1.80	2.50
Mass of dry soil, g	17.80	16.80	15.00	13.16	5.20	6.90
Water content, %	88.20	97.02	104.20	74.09	34.62	36.23
No of blows	34	22	15	16	------	------

Liquid Limit, % = 94 Plastic Limit, % = 35 PI, %= 59



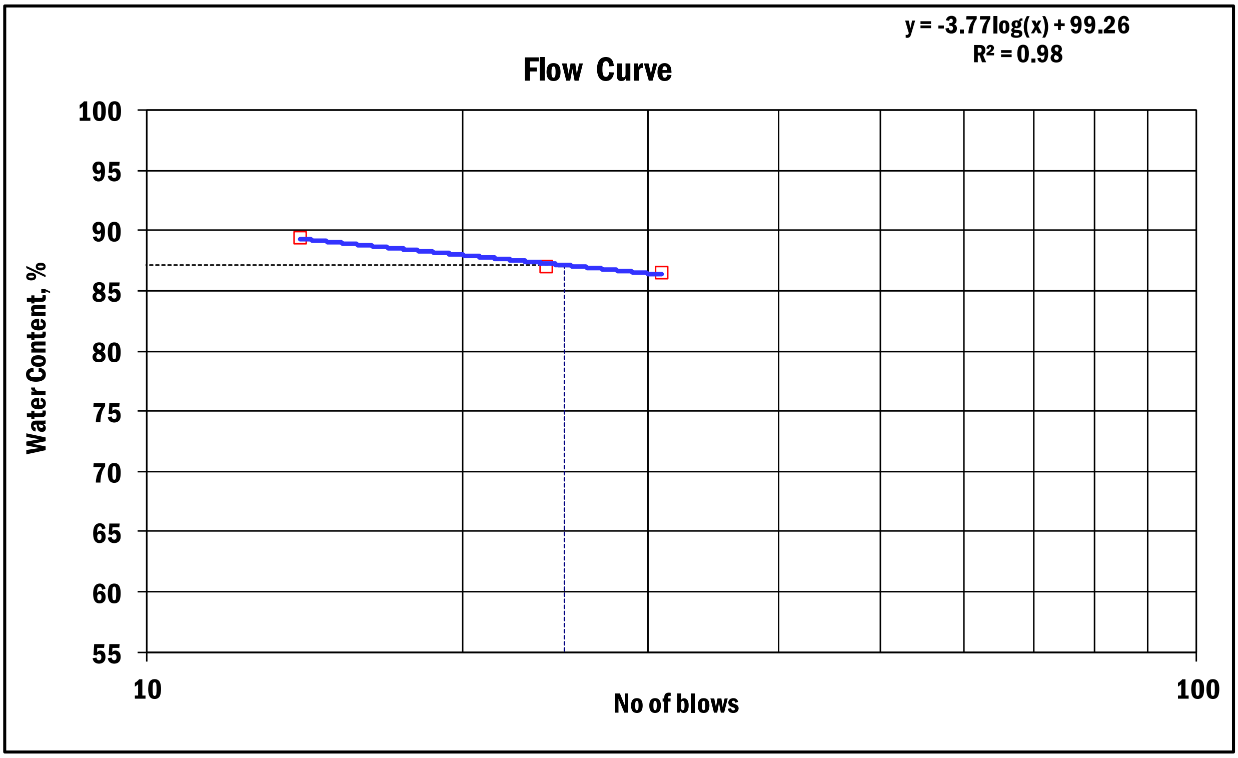
Liquid Limit and Plastic Limit Test

Date tasted 27/6/2015
location Wolliso

Sample No : Hospital 1 Sample Depth, m : 1.25m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	H1	A	P3	C18	32	24
Mass of container, g	15.70	15.40	14.00	20.03	15.90	15.70
Mass of container + Wet soil, g	36.40	35.60	39.00	42.94	22.70	23.20
Mass of container + Dry soil, g	26.80	26.20	27.20	33.19	20.80	21.10
Mass of water, g	9.60	9.40	11.80	9.75	1.90	2.10
Mass of dry soil, g	11.10	10.80	13.20	13.16	4.90	5.40
Water content, %	86.49	87.04	89.39	74.09	38.78	38.89
No of blows	31	24	14	16	------	------

Liquid Limit, % = 87 Plastic Limit, % = 39 PI, %= 48



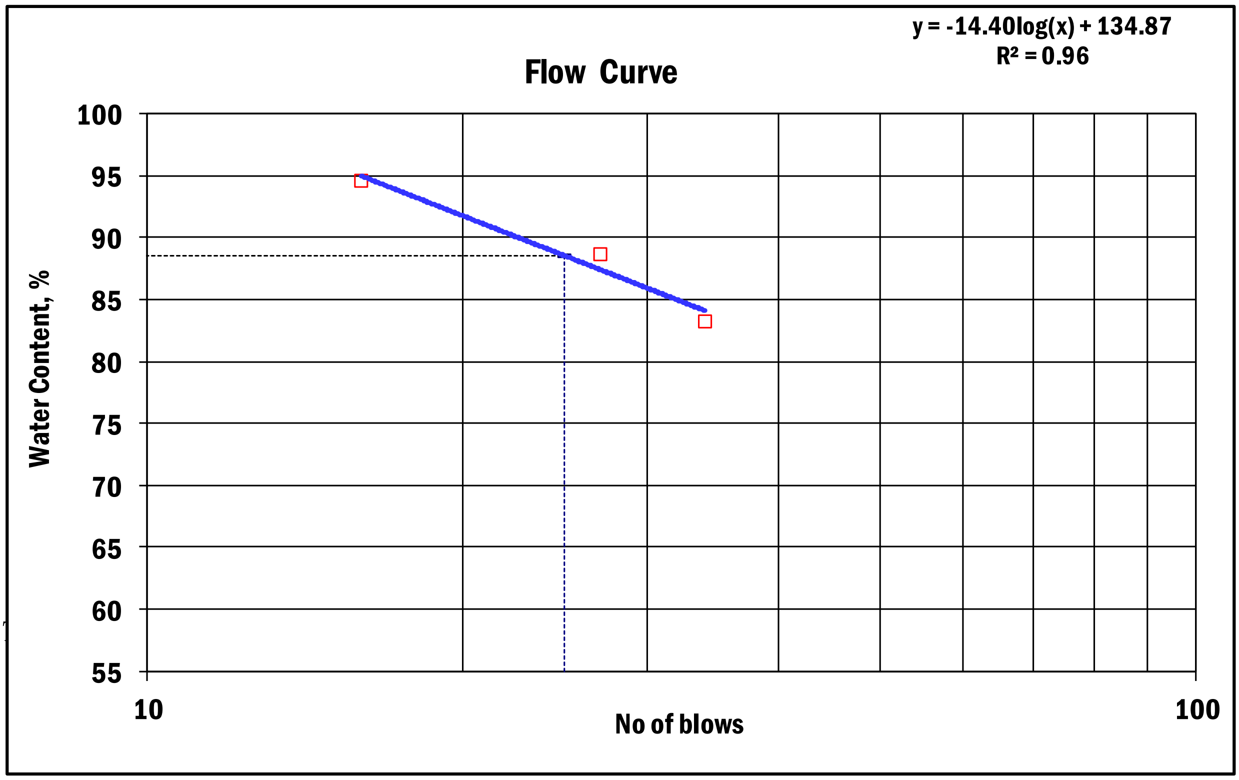
Liquid Limit and Plastic Limit Test

Date taste 27/6/2015
location Wolliso

Sample No : Hospital 2 Sample Depth, m : 2.5

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	F101	B11	32	C18	32	AL3
Mass of container, g	15.60	15.90	15.80	20.03	15.90	15.60
Mass of container + Wet soil, g	40.70	42.50	48.10	42.94	23.10	22.70
Mass of container + Dry soil, g	28.80	30.00	32.40	33.19	21.10	20.70
Mass of water, g	11.90	12.50	15.70	9.75	2.00	2.00
Mass of dry soil, g	13.20	14.10	16.60	13.16	5.20	5.10
Water content, %	83.25	88.65	94.58	74.09	38.46	39.22
No of blows	34	27	16	16	------	------

Liquid Limit, % = 89 Plastic Limit, % = 39 PI, %= 50



APPENDIX B1: Swell Tests

Swelling PressureTest

Date	05/2/2015-14/2/2015		
Location:	Wolliso		
Color ofsample:	Black		
Sample No :	University Old 1	Sample Depth, m :	1.25m
Sample Type :	Expansive soil of Wolliso		

$e = \frac{H - H_s}{H_s}$

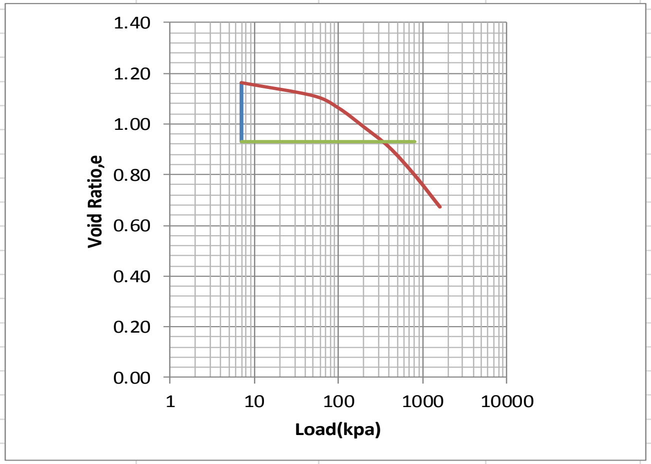
$H_s = \frac{M_s}{G*d_w*A}$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.16
Initial moisture content,%	30.15
Specific Gravity:	2.7
Wet density,g/cm3	2.03

[B] In the end of the test

Final Moisture Content,%	33.52
Dry specimen wt (m_s), gm:	54.9
Dry density,g/cm3	1.44
Height of Solids(H_s), mm	10.36
Final Void Ratio, e_f:	0.67



Determination of Initial Moisture Content

can no.	AB	GA
Wt. of can	22.1	22.3
Wt. of can+wet soil	52.9	52.8
Wt. of can+oven dry soil	45.7	45.8
Wt. of water	7.2	7
Wt of dry soil	23.6	23.5
Moist. Content	30.51	29.79
	30.15	

Determination of Final Moisture Content

can no.	E10
Wt. of can	37.60
Wt. of can+wet soil	110.90
Wt. of can+oven dry soil	92.50
Wt. of water	18.40
Wt of dry soil	54.90
Moist. Content	33.52
	33.52

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	140.20
Wt. of wet soil	72.40
Wet density	**2.03**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	92.50
Wt. can	37.60
Dry wt. of Specimen,gm	**54.9**

Determination of Dry Density

Initial initu wieght +wt of ring	142.20
Wieght of ring	68.70
Dry Density,g/cm3	1.44
Bulk density	1.87

Swelling PressureTest

Date	09/2/2015-19/2/2015
Location:	Wolliso
Color ofsample:	Grey
Sample No :	University Old 2
Sample Depth, m :	2.3m
Sample Type :	Expansive soil of Wolliso
Location:	Wolliso

$$e = \frac{H - H_s}{H_s}$$

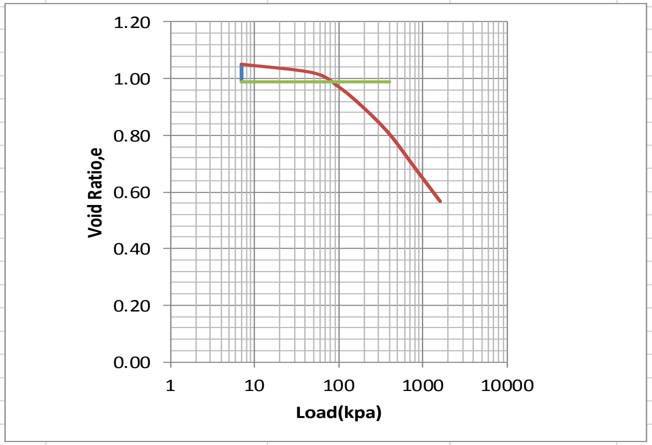
$$H_s = \frac{M_s}{G*d_w*A}$$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.05
Initial moisture content,%	39.39
Specific Gravity:	2.68
Wet density,g/cm3	2.26

[B] In the end of the test

Final Moisture Content,%	32.33
Dry specimen wt (m_s), gm:	52.9
Dry density,g/cm3	1.37
Height of Solids(H_s), mm	10.06
Final Void Ratio, e_f:	0.57



Determination of Initial Moisture Content

can no.	24	52
Wt. of can	22.3	22.1
Wt. of can+wet soil	53.2	65.9
Wt. of can+oven dry soil	44.7	53.2
Wt. of water	8.5	12.7
Wt of dry soil	22.4	31.1
Moist. Content	37.95	40.84
	39.39	

Determination of Final Moisture Content

can no.	M10
Wt. of can	35.60
Wt. of can+wet soil	105.60
Wt. of can+oven dry soil	88.50
Wt. of water	17.10
Wt of dry soil	52.90
Moist. Content	32.33
	32.33

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	137.20
Wt. of wet soil	69.40
Wet density	**2.26**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	88.50
Wt. can	35.60
Dry wt. of Specimen,gm	**52.9**

Determination of Dry Density

Initial initu wieght +wt of ring	143.50
Wieght of ring	68.70
Dry Density,g/cm3	1.37
Bulk density	1.91

Swelling PressureTest

Date	20/2/2015-26/2/2015
Location:	Wolliso
Color ofsample:	Black
Sample No :	Ejersa1
Sample Depth, m :	1.25m
Sample Type :	Expansive soil of Wolliso

$$e = \frac{H - H_s}{H_s}$$

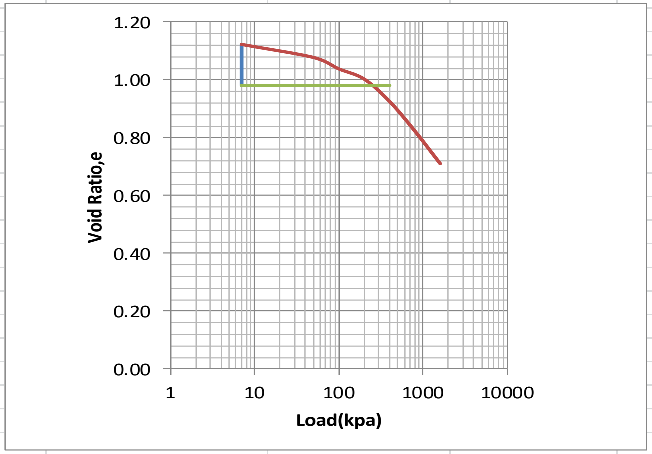
$$H_s = \frac{M_s}{G*d_w*A}$$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.12
Initial moisture content,%	34.52
Specific Gravity:	2.67
Wet density,g/cm3	2.11

[B] In the end of the test

Final Moisture Content,%	34.22
Dry specimen wt (m_s), gm:	52.9
Dry density,g/cm3	1.35
Height of Solids(H_s), mm	10.10
Final Void Ratio, e_f:	0.71



Determination of Initial Moisture Content

can no.	22	36
Wt. of can	22.2	22.3
Wt. of can+wet soil	52.9	52.8
Wt. of can+oven dry soil	45.2	44.8
Wt. of water	7.7	8
Wt of dry soil	23	22.5
Moist. Content	33.48	35.56
	34.52	

Determination of Final Moisture Content

can no.	E10
Wt. of can	36.60
Wt. of can+wet soil	107.60
Wt. of can+oven dry soil	89.50
Wt. of water	18.10
Wt of dry soil	52.90
Moist. Content	34.22
	34.22

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	139.20
Wt. of wet soil	71.40
Wet density	**2.11**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	89.50
Wt. can	36.60
Dry wt. of Specimen,gm	**52.9**

Determination of Dry Density

Initial initu wieght +wt of ring	140.20
Wieght of ring	68.70
Dry Density,g/cm3	1.35
Bulk density	1.82

Swelling PressureTest

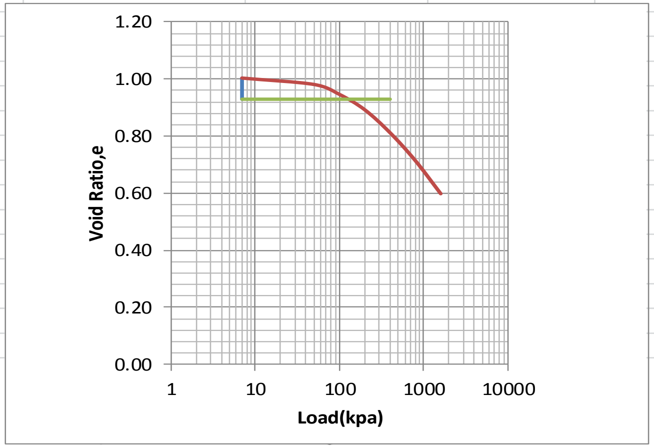
Date	20/2/2015-26/2/2015		
Location:	Wolliso		
Color ofsample:	Grey		
Sample No :	Ejersa2	Sample Depth, m :	2.5m
Sample Type :	Expansive soil of Wolliso		

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.00
Initial moisture content,%	38.26
Specific Gravity:	2.6
Wet density,g/cm3	2.13

[B] In the end of the test

Final Moisture Content,%	35.92
Dry specimen wt (m_s), gm:	52.9
Dry density,g/cm3	1.32
Height of Solids(H_s), mm	10.37
Final Void Ratio, e_f:	0.89



[C]Calculation table:

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Height (mm)	(mm)		
Loading						
7	4.510	0.00	20.00	9.63	0.93	
7	5.278	0.77	20.77	10.40	1.00	0.93
50	5.046	0.54	20.54	10.17	0.98	0.93
100	4.688	0.18	20.18	9.81	0.95	0.93
200	4.129	-0.38	19.62	9.25	0.89	0.93
400	3.294	-1.22	18.78	8.42	0.81	0.93
800	2.278	-2.23	17.77	7.40	0.71	1.00
1600	1.078	-3.43	16.57	6.20	0.60	0.98
Unloading						

Determination of Initial Moisture Content

can no.	GA	38
Wt. of can	22.1	22.4
Wt. of can+wet soil	49.9	51.7
Wt. of can+oven dry soil	42.2	43.6
Wt. of water	7.7	8.1
Wt of dry soil	20.1	21.2
Moist. Content	38.31	38.21
	38.26	

Determination of Final Moisture Content

can no.	E10
Wt. of can	38.70
Wt. of can+wet soil	110.60
Wt. of can+oven dry soil	91.60
Wt. of water	19.00
Wt of dry soil	52.90
Moist. Content	35.92
	35.92

Volume of Ring,cm3

2		39.25
2.301029996		
0.95	**Determination of Wet Density, gm/cm3**	
0.89	Wt of ring + initial wet soil	137.20
0.053918667	Wt. of wet soil	69.40
-0.301029996	Wet density	**2.13**
-0.179113936		
2.095855705		
	Determination of Dry Weight of Specimen	
	Oven Dry wt+wt can	91.60
124.6969139	Wt. can	38.70
	Dry wt. of Specimen,gm	**52.9**

Determination of Dry Density

Initial initu wieght +wt of ring	140.60
Wieght of ring	68.70
Dry Density,g/cm3	1.32
Bulk density	1.83

Swelling PressureTest

Date	27/2/2015-04/03/2015		
Location:	Wolliso		
Color of sample:	Black		
Sample No :	Geresu 1	Sample Depth, m :	1.25m
Sample Type :	Expansive soil of Wolliso		

$$e = \frac{H - H_s}{H_s}$$

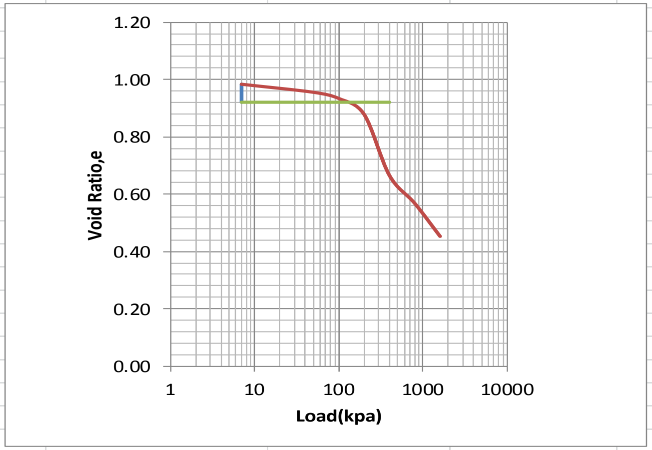
$$H_s = \frac{M_s}{G*d_w*A}$$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	0.98
Initial moisture content,%	30.72
Specific Gravity:	2.73
Wet density,g/cm3	2.09

[B] In the end of the test

Final Moisture Content,%	33.87
Dry specimen wt (m_s), gm:	55.8
Dry density,g/cm3	1.45
Height of Solids(H_s), mm	10.42
Final Void Ratio, e_f:	0.45



Determination of Initial Moisture Content

can no.	AB	ML
Wt. of can	22.4	22.6
Wt. of can+wet soil	47.4	53.8
Wt. of can+oven dry soil	41.5	46.5
Wt. of water	5.9	7.3
Wt of dry soil	19.1	23.9
Moist. Content	30.89	30.54
	30.72	

Determination of Final Moisture Content

can no.	B4
Wt. of can	37.60
Wt. of can+wet soil	112.30
Wt. of can+oven dry soil	93.40
Wt. of water	18.90
Wt of dry soil	55.80
Moist. Content	33.87
	33.87

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	137.20
Wt. of wet soil	69.40
Wet density	**2.09**

Determination of Dry Weight of Specimen

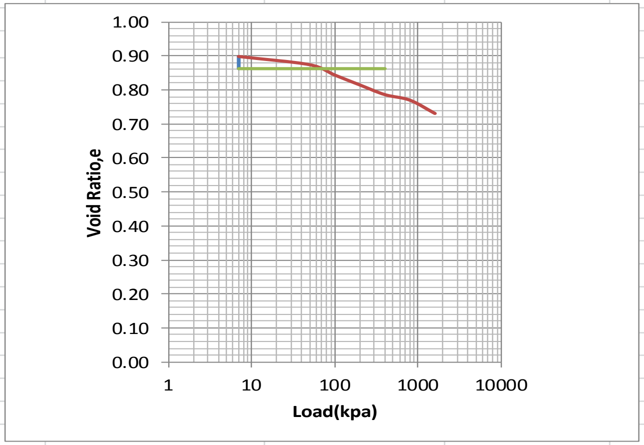
Oven Dry wt+wt can	93.40
Wt. can	37.60
Dry wt. of Specimen,gm	**55.8**

Determination of Dry Density

Initial initu wieght +wt of ring	143.20
Wieght of ring	68.70
Dry Density,g/cm3	1.45
Bulk density	1.90

Swelling PressureTest

Date	05/03/2015-10/03/2015	
Location:	Wolliso	
Color of Sample :	Grey	
Sample No :	Geresu 2	Sample Depth, m : 1.9m
Sample TYpe :	Expansive soil of Wolliso	



[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	0.90
Initial moisture content,%	31.84
Specific Gravity:	2.7
Wet density,g/cm3	2.04

[B] In the end of the test

Final Moisture Content,%	33.57
Dry specimen wt (m_s), gm:	56.9
Dry density,g/cm3	1.46
Height of Solids(H_s), mm	10.74
Final Void Ratio, e_f:	0.73

H_s

$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	LL	PL
Wt. of can	22.1	23.2
Wt. of can+wet soil	65.4	63.4
Wt. of can+oven dry soil	55.15	53.5
Wt. of water	10.25	9.9
Wt of dry soil	33.05	30.3
Moist. Content	31.01	32.67
	31.84	

Determination of Final Moisture Content

can no.	M2
Wt. of can	35.60
Wt. of can+wet soil	111.60
Wt. of can+oven dry soil	92.50
Wt. of water	19.10
Wt of dry soil	56.90
Moist. Content	33.57
	33.57

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	142.20
Wt. of wet soil	74.40
Wet density	**2.04**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	92.50
Wt. can	35.60
Dry wt. of Specimen,gm	**56.9**

Determination of Dry Density

Initial initu wieght +wt of ring	144.50
Wieght of ring	68.70
Dry Density,g/cm3	1.46
Bulk density	1.93

Swelling PressureTest

Date	11/03/2015-20/03/2015
Location:	Wolliso
Color of sample	Black
Sample No :	Huluyimar 1
Sample Depth, m :	1.25m
Type of sample:	Expansive soil of Wolliso

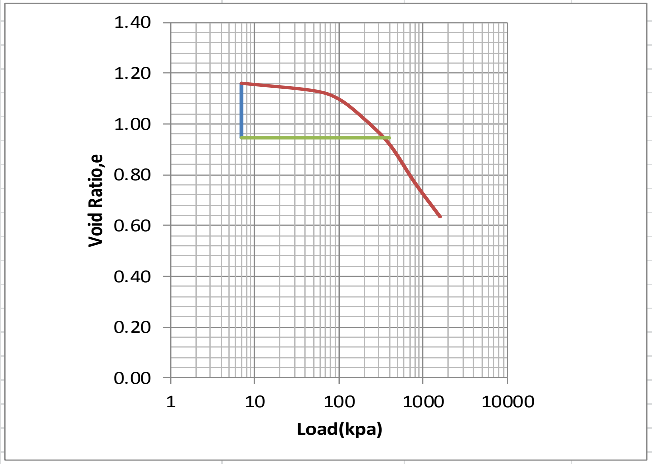
$$H_s = \frac{M_s}{G*d_w*A}$$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.16
Initial moisture content,%	34.29
Specific Gravity:	2.81
Wet density,g/cm3	2.16

[B] In the end of the test

Final Moisture Content,%	31.75
Dry specimen wt (m_s), gm:	56.7
Dry density,g/cm3	1.42
Height of Solids(H_s), mm	10.28
Final Void Ratio, e_f:	1.02



Determination of Initial Moisture Content

can no.	T9	p23
Wt. of can	22.2	22.3
Wt. of can+wet soil	47.9	41.7
Wt. of can+oven dry soil	41.4	36.7
Wt. of water	6.5	5
Wt of dry soil	19.2	14.4
Moist. Content	33.85	34.72
	34.29	

Determination of Final Moisture Content

can no.	24
Wt. of can	38.90
Wt. of can+wet soil	113.60
Wt. of can+oven dry soil	95.60
Wt. of water	18.00
Wt of dry soil	56.70
Moist. Content	31.75
	31.75

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	139.20
Wt. of wet soil	71.40
Wet density	**2.16**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	95.60
Wt. can	38.90
Dry wt. of Specimen,gm	**56.7**

Determination of Dry Density

Initial initu wieght +wt of ring	143.50
Wieght of ring	68.70
Dry Density,g/cm3	1.42
Bulk density	1.91

Swelling PressureTest

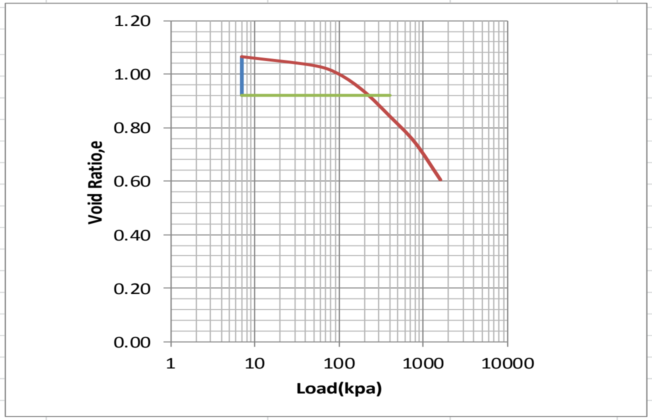
Date	21/03/2015-27/03/2015	
Location:	Wolliso	
Color of sample No :	Grey	
Sample No :	Huluyimar 2.	Sample Depth, m : 2.5m
Sample type :	Expansive soil from woliso	

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.06
Initial moisture content,%	37.77
Specific Gravity:	2.74
Wet density,g/cm3	2.07

[B] In the end of the test

Final Moisture Content,%	33.93
Dry specimen wt (m_s), gm:	56
Dry density,g/cm3	1.39
Height of Solids(H_s), mm	10.41
Final Void Ratio, e_f:	0.60



$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	GA	T1
Wt. of can	22.3	22.1
Wt. of can+wet soil	47.6	51.8
Wt. of can+oven dry soil	40.8	43.5
Wt. of water	6.8	8.3
Wt of dry soil	18.5	21.4
Moist. Content	36.76	38.79
	37.77	

Determination of Final Moisture Content

can no.	m4
Wt. of can	35.60
Wt. of can+wet soil	110.60
Wt. of can+oven dry soil	91.60
Wt. of water	19.00
Wt of dry soil	56.00
Moist. Content	33.93
	33.93

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	136.20
Wt. of wet soil	68.40
Wet density	**2.07**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	91.60
Wt. can	35.60
Dry wt. of Specimen,gm	**56**

Determination of Dry Density

Initial initu wieght +wt of ring	144.00
Wieght of ring	68.70
Dry Density,g/cm3	1.39
Bulk density	1.92

Swelling PressureTest

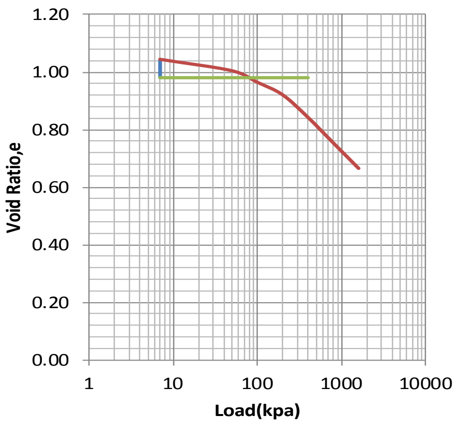
Date	28/03/2015-02/04/2015		
Location:	Wolliso		
Color of the sample	Black		
Sample No :	Kidane mehret 2	Sample Depth, m :	2.5m
Type of the sample	Expansive soil of Wolliso		

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.04
Initial moisture content,%	34.43
Specific Gravity:	2.74
Wet density,g/cm3	2.19

[B] In the end of the test

Final Moisture Content,%	36.83
Dry specimen wt (m_s), gm:	54.3
Dry density,g/cm3	1.41
Height of Solids(H_s), mm	10.10
Final Void Ratio, e_f:	0.67



$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	M1	T9
Wt. of can	22.2	22.3
Wt. of can+wet soil	49.6	62.8
Wt. of can+oven dry soil	42.6	52.4
Wt. of water	7	10.4
Wt of dry soil	20.4	30.1
Moist. Content	34.31	34.55
	34.43	

Determination of Final Moisture Content

can no.	m4
Wt. of can	35.30
Wt. of can+wet soil	109.60
Wt. of can+oven dry soil	89.60
Wt. of water	20.00
Wt of dry soil	54.30
Moist. Content	36.83
	36.83

usally initial moist is greater than final mois.

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	140.20
Wt. of wet soil	72.40
Wet density	**2.19**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	89.60
Wt. can	35.30
Dry wt. of Specimen,gm	**54.3**

Determination of Dry Density

Initial initu wieght +wt of ring	143.00
Wieght of ring	68.70
Dry Density,g/cm3	1.41
Bulk density	1.89

Swelling PressureTest

Date	28/03/2015-02/04/2015		
Location:	Wolliso		
Color of the sample	Black		
Sample No :	Kidane mehret 1	Sample Depth, m :	1.25m
Type of the sample	Expansive soil of Wolliso		

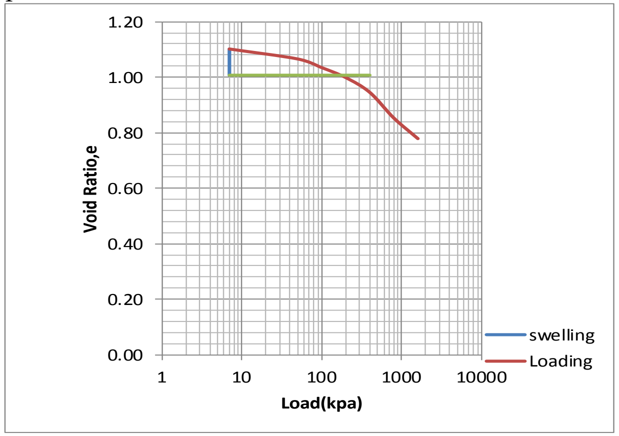
Test Pit No **Kidane Mehret 1**
Depth, m **1.5m**

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.10
Initial moisture content,%	31.26
Specific Gravity:	2.71
Wet density,g/cm3	2.08

[B] In the end of the test

Final Moisture Content,%	37.74
Dry specimen wt (m_s), gm:	53
Dry density,g/cm3	1.36
Height of Solids(H_s), mm	9.97
Final Void Ratio, e_f:	0.78



$$e = \frac{H - H_s}{H_s}$$

$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	G4	PL
Wt. of can	22.6	22.1
Wt. of can+wet soil	38.6	57.8
Wt. of can+oven dry soil	34.7	49.5
Wt. of water	3.9	8.3
Wt of dry soil	12.1	27.4
Moist. Content	32.23	30.29
	31.26	

Determination of Final Moisture Content

can no.	P4
Wt. of can	140.60
Wt. of can+wet soil	213.60
Wt. of can+oven dry soil	193.60
Wt. of water	20.00
Wt of dry soil	53.00
Moist. Content	37.74
	37.74

usally initial moist is greater than final mois.

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	140.20
Wt. of wet soil	72.40
Wet density	**2.08**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	193.60
Wt. can	140.60
Dry wt. of Specimen,gm	**53**

Determination of Dry Density

Initial initu wieght +wt of ring	138.60
Wieght of ring	68.70
Dry Density,g/cm3	1.36
Bulk density	1.78

Swelling PressureTest

`		19/6/2015-27/6/2015
Location:		Wolliso
Color ofsample:	Black	Sample Depth, m :
Sample No :	University Insidet 1	1.25m
Sample Type :	Expansive soil of Wolliso(undistutbed)	

Test Pit Ambo inide 1

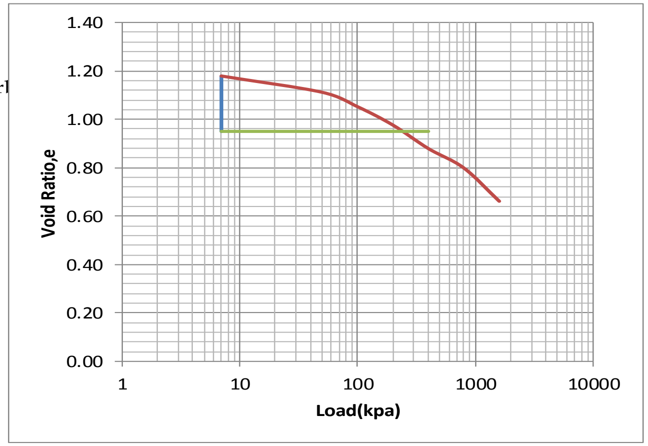
Depth, m	**1.50**

[A] In the beginning of the test

Sample type :	Undisturl
Ring Area,cm[2]:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.18
Initial moisture content,%	31.33
Specific Gravity:	2.65
Wet density,g/cm3	2.22

[B] In the end of the test

Final Moisture Content,%	38.80
Dry specimen wt (m_s), gm:	53.35
Dry density,g/cm3	1.44
Height of Solids(H_s), mm	10.26
Final Void Ratio, e_f:	0.66



Determination of Initial Moisture Content

can no.	28	GA
Wt. of can	15.8	15.9
Wt. of can+wet soil	39.7	42.3
Wt. of can+oven dry soil	34	36
Wt. of water	5.7	6.3
Wt of dry soil	18.2	20.1
Moist. Content	31.32	31.34
	31.33	

Determination of Final Moisture Content

can no.	D11
Wt. of can	17.95
Wt. of can+wet soil	92.00
Wt. of can+oven dry soil	71.30
Wt. of water	20.7
Wt of dry soil	53.35
Moist. Content	38.80
	38.80

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	143.00
Wt. of wet soil	74.30
Wet density	**2.22**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	71.30
Wt. can	17.95
Dry wt. of Specimen,gm	**53.35**

Determination of Dry Density

Initial initu wieght +wt of ring	142.90
Wieght of ring	68.70
Dry Density,g/cm3	1.44
Bulk density	1.89

Swelling PressureTest

`	29/6/2015-4/6/2015	
Location:	Wolliso	
Color ofsample: Black		Sample Depth, m :
Sample No :	University Infront 1	1.25m
Sample Type :	Expansive soil of Wolliso(undistutbed)	

$$e = \frac{H - H_s}{H_s}$$

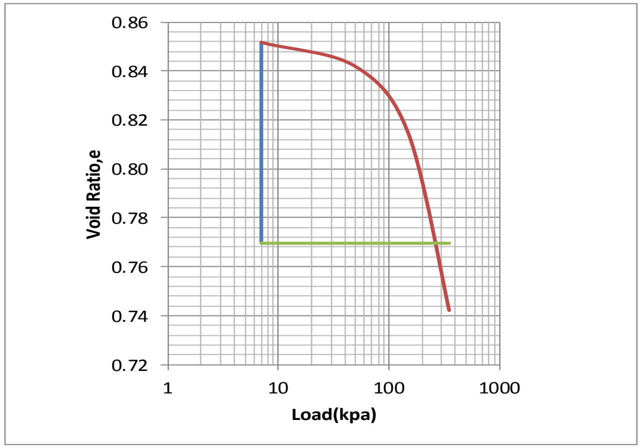
$$H_s = \frac{M_s}{G*d_w*A}$$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	0.85
Initial moisture content,%	40.54
Specific Gravity:	2.66
Wet density,g/cm3	1.85

[B] In the end of the test

Final Moisture Content,%	37.29
Dry specimen wt (m_s), gm:	59
Dry density,g/cm3	1.23
Height of Solids(H_s), mm	11.30
Final Void Ratio, e_f:	0.74



Determination of Initial Moisture Content

can no.	B16	T1
Wt. of can	16.6	15.3
Wt. of can+wet soil	46.4	36.8
Wt. of can+oven dry soil	37.8	30.6
Wt. of water	8.6	6.2
Wt of dry soil	21.2	15.3
Moist. Content	40.57	40.52
	40.54	

Determination of Final Moisture Content

can no.	D11
Wt. of can	36.60
Wt. of can+wet soil	117.60
Wt. of can+oven dry soil	95.60
Wt. of water	22
Wt of dry soil	59.00
Moist. Content	37.29
	37.29

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	139.20
Wt. of wet soil	71.40
Wet density	**1.85**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	95.60
Wt. can	36.60
Dry wt. of Specimen,gm	**59**

Determination of Dry Density

Initial initu wieght +wt of ring	136.50
Wieght of ring	68.70
Dry Density,g/cm3	1.23
Bulk density	1.73

Swelling PressureTest

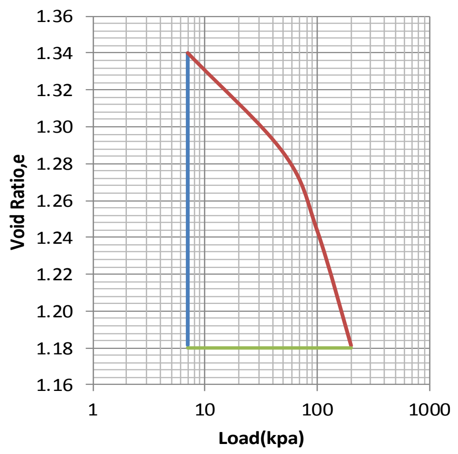
`	06/7/2015-13/7/2015		
Location:	Wolliso		
Color ofsample:	Black	Sample Depth, m :	
Sample No :	University Infront 2	2.5m	
Sample Type :	Expansive soil of Wolliso(undistutbed)		

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.34
Initial moisture content,%	39.79
Specific Gravity:	2.64
Wet density,g/cm3	1.80

[B] In the end of the test

Final Moisture Content,%	46.95
Dry specimen wt (m_s), gm:	47.5
Dry density,g/cm3	1.24
Height of Solids(H_s), mm	9.17
Final Void Ratio, e_f:	1.18



$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	GA	MT14
Wt. of can	15.5	15.7
Wt. of can+wet soil	50	39.3
Wt. of can+oven dry soil	40.3	32.5
Wt. of water	9.7	6.8
Wt of dry soil	24.8	16.8
Moist. Content	39.11	40.48
	39.79	

Determination of Final Moisture Content

can no.	D11
Wt. of can	18.00
Wt. of can+wet soil	87.80
Wt. of can+oven dry soil	65.50
Wt. of water	22.3
Wt of dry soil	47.50
Moist. Content	46.95
	46.95

usally initial moist is greater than final mois.

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	139.20
Wt. of wet soil	70.50
Wet density	**1.80**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	65.50
Wt. can	18.00
Dry wt. of Specimen,gm	**47.5**

Determination of Dry Density

Initial initu wieght +wt of ring	136.50
Wieght of ring	68.70
Dry Density,g/cm3	1.24
Bulk density	1.73

Swelling PressureTest

`	14/7/2015-21/7/2015		
Location:	Wolliso		
Color ofsample:	Black	Sample Depth, m :	
Sample No :	Elementary 1	1.25m	
Sample Type :	Expansive soil of Wolliso(undistutbed)		

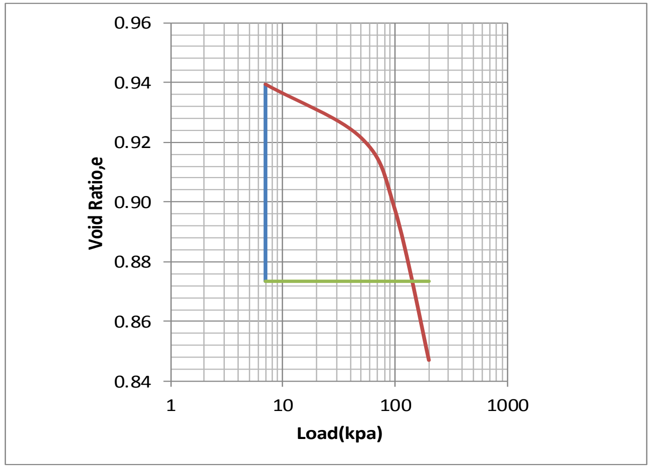
$H_s = \frac{M_s}{G*d_w*A}$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	0.94
Initial moisture content,%	35.21
Specific Gravity:	2.63
Wet density,g/cm3	1.97

[B] In the end of the test

Final Moisture Content,%	38.48
Dry specimen wt (m_s), gm:	55.1
Dry density,g/cm3	1.42
Height of Solids(H_s), mm	10.68
Final Void Ratio, e_f:	0.85



Determination of Initial Moisture Content

can no.	wsp	a27
Wt. of can	22.2	20.7
Wt. of can+wet soil	40.8	47.7
Wt. of can+oven dry soil	35.8	40.9
Wt. of water	5	6.8
Wt of dry soil	13.6	20.2
Moist. Content	36.76	33.66
	35.21	

Determination of Final Moisture Content

can no.	D11
Wt. of can	48.80
Wt. of can+wet soil	125.10
Wt. of can+oven dry soil	103.90
Wt. of water	21.2
Wt of dry soil	55.10
Moist. Content	38.48
	38.48

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	146.95
Wt. of wet soil	77.15
Wet density	**1.97**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	103.90
Wt. can	48.80
Dry wt. of Specimen,gm	**55.1**

Determination of Dry Density

Initial initu wiegght +wt of ring	145.20
Wieght of ring	69.80
Dry Density,g/cm3	1.42
Bulk density	1.92

Swelling PressureTest

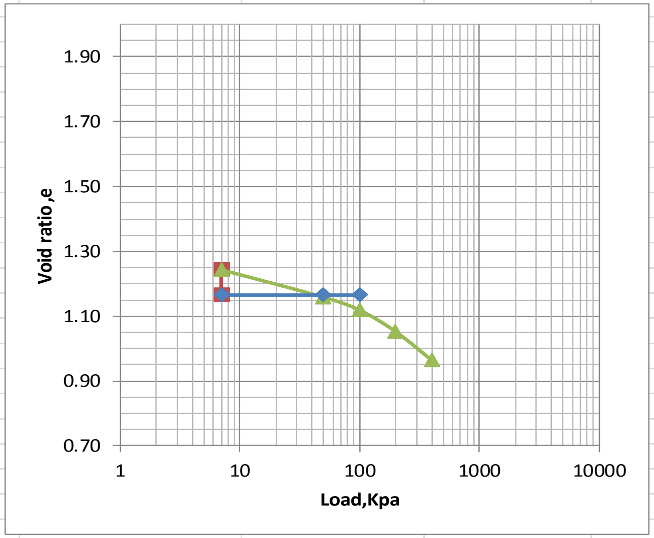
`	22/7/2015-29/7/2015	
Location:	Wolliso	
Color ofsample:	Black	Sample Depth, m :
Sample No :	Elementary 2	2.5m
Sample Type :	Expansive soil of Wolliso(undistutbed)	

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.24
Initial moisture content,%	39.32
Specific Gravity:	2.67
Wet density,g/cm3	2.06

[B] In the end of the test

Final Moisture Content,%	42.06
Dry specimen wt (m_s), gm:	48.4
Dry density,g/cm3	1.33
Height of Solids(H_s), mm	9.24
Final Void Ratio, e_f:	0.00



$G*d_w*A$

Determination of Initial Moisture Content

can no.	23	MT9
Wt. of can	22.1	22.3
Wt. of can+wet soil	36.4	52.5
Wt. of can+oven dry soil	32.4	43.9
Wt. of water	4	8.6
Wt of dry soil	10.3	21.6
Moist. Content	38.83	39.81
	39.32	

Determination of Final Moisture Content

can no.	A17
Wt. of can	245.40
Wt. of can+wet soil	317.00
Wt. of can+oven dry soil	295.80
Wt. of water	21.2
Wt of dry soil	50.40
Moist. Content	42.06
	42.06

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	142.00
Wt. of wet soil	73.30
Wet density	**2.06**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	93.30
Wt. can	44.90
Dry wt. of Specimen,gm	**48.4**

Determination of Dry Density

Initial initu wieght +wt of ring	141.20
Wieght of ring	68.70
Dry Density,g/cm3	1.33
Bulk density	1.85

Swelling PressureTest

`	30/7/2015-06/8/2015		
Location:	Wolliso		
Color	Grey	Sample Depth, m :	
Sample No :	Hospital 2	2.5m	
Sample Type :	Expansive soil of Wolliso(undistutbed)		

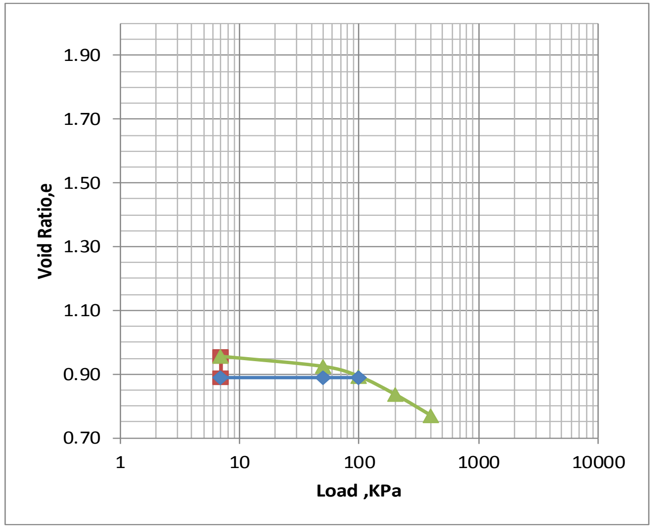
$H_s = \frac{M_s}{G*d_w*A}$

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	0.96
Initial moisture content,%	35.22
Specific Gravity:	2.7
Wet density,g/cm3	2.16

[B] In the end of the test

Final Moisture Content,%	39.57
Dry specimen wt (m_s), gm:	56.1
Dry density,g/cm3	1.48
Height of Solids(H_s), mm	10.59
Final Void Ratio, e_f:	0.00



Determination of Initial Moisture Content

can no.	W19	C14
Wt. of can	21.5	22.1
Wt. of can+wet soil	54.6	66.9
Wt. of can+oven dry soil	46	55.2
Wt. of water	8.6	11.7
Wt of dry soil	24.5	33.1
Moist. Content	35.10	35.35
	35.22	

Determination of Final Moisture Content

can no.	A17
Wt. of can	55.20
Wt. of can+wet soil	133.50
Wt. of can+oven dry soil	111.30
Wt. of water	22.2
Wt of dry soil	56.10
Moist. Content	39.57
	39.57

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	117.00
Wt. of wet soil	79.40
Wet density	**2.16**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	111.30
Wt. can	55.20
Dry wt. of Specimen,gm	**56.1**

Determination of Dry Density

Initial initu wieght +wt of ring	116.20
Wieght of ring	37.60
Dry Density,g/cm3	1.48
Bulk density	2.00

Swelling PressureTest

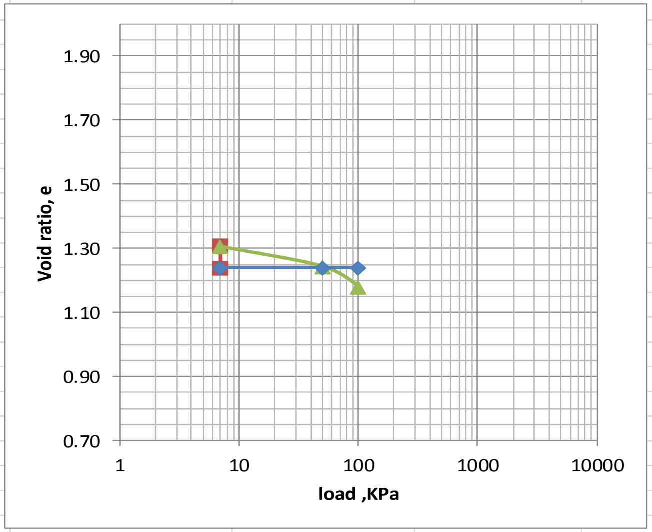
`	7/08/2015-11/8/2015		
Location:	Wolliso		
Color	Black	Sample Depth, m :	
Sample No :	Hospital 1	1.25m	
Sample Type :	Expansive soil of Wolliso(undistutbed)		

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.31
Initial moisture content,%	31.97
Specific Gravity:	2.76
Wet density,g/cm3	1.84

[B] In the end of the test

Final Moisture Content,%	44.08
Dry specimen wt (m_s), gm:	48.4
Dry density,g/cm3	1.36
Height of Solids(H_s), mm	8.94
Final Void Ratio, e_f:	0.00



$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	23	GA
Wt. of can	22.1	22.3
Wt. of can+wet soil	54.4	54.3
Wt. of can+oven dry soil	48.5	44.9
Wt. of water	5.9	9.4
Wt of dry soil	26.4	22.6
Moist. Content	22.35	41.59
	31.97	

Determination of Final Moisture Content

can no.	A17
Wt. of can	48.50
Wt. of can+wet soil	119.10
Wt. of can+oven dry soil	97.50
Wt. of water	21.6
Wt of dry soil	49.00
Moist. Content	44.08
	44.08

Volume of Ring,cm3

39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	141.10
Wt. of wet soil	71.30
Wet density	**1.84**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	93.30
Wt. can	44.90
Dry wt. of Specimen,gm	**48.4**

Determination of Dry Density

Initial initu wieght +wt of ring	139.20
Wieght of ring	68.90
Dry Density,g/cm3	1.36
Bulk density	1.79

Swelling PressureTest

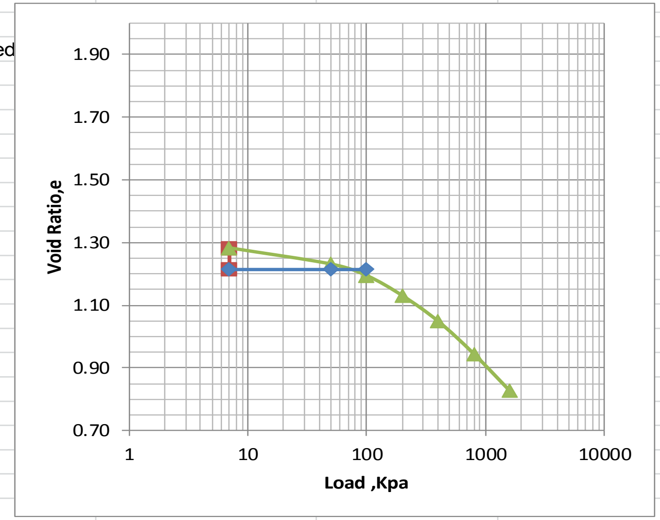
`	12/08/2015-20/8/2015	
Location:	Wolliso	
Color	Black	Sample Depth, m :
Sample No :	Michael 1	1.25m
Sample Type :	Expansive soil of Wolliso(undistutbed)	

[A] In the beginning of the test

Sample type :	Undisturbed
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.28
Initial moisture content,%	32.72
Specific Gravity:	2.73
Wet density,g/cm3	2.06

[B] In the end of the test

Final Moisture Content,%	36.98
Dry specimen wt (m_s), gm:	48.4
Dry density,g/cm3	1.36
Height of Solids(H_s), mm	9.03
Final Void Ratio, e_f:	0.83



$$H_s = \frac{M_s}{G*d_w*A}$$

Determination of Initial Moisture Content

can no.	62	6G
Wt. of can	22.1	22.3
Wt. of can+wet soil	56.9	65.2
Wt. of can+oven dry soil	48.1	54.9
Wt. of water	8.8	10.3
Wt of dry soil	26	32.6
Moist. Content	33.85	31.60
	32.72	

Determination of Final Moisture Content

can no.	A17
Wt. of can	44.90
Wt. of can+wet soil	111.20
Wt. of can+oven dry soil	93.30
Wt. of water	17.9
Wt of dry soil	48.40
Moist. Content	36.98
	36.98

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	135.60
Wt. of wet soil	66.90
Wet density	**2.06**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	93.30
Wt. can	44.90
Dry wt. of Specimen,gm	**48.4**

Determination of Dry Density

Initial initu wieght +wt of ring	140.70
Wieght of ring	69.80
Dry Density,g/cm3	1.36
Bulk density	1.81

Swelling PressureTest

`	21/08/2015-26/8/2015	
Location:	Wolliso	
Color	Grey	Sample Depth, m :
Sample No :	Michael 2	2.5m
Sample Type :	Expansive soil of Wolliso(undistutbed)	

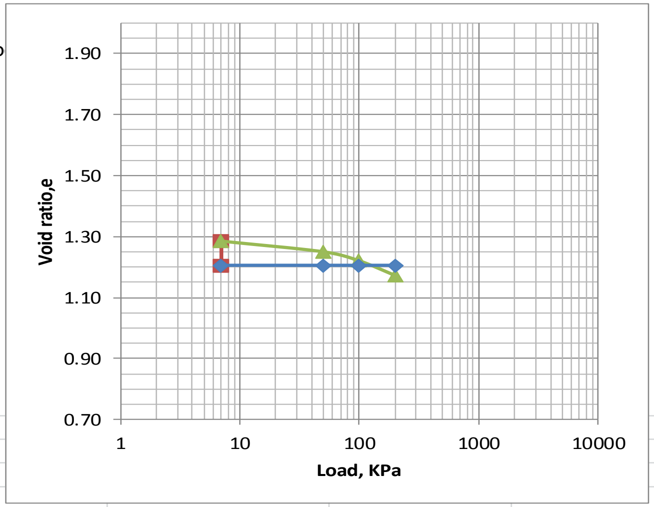
$H_s = \frac{M_s}{G*d_w*A}$

[A] In the beginning of the test

Sample type :	Undisturb
Ring Area,cm^2:	19.625
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, e_o:	1.28
Initial moisture content,%	39.40
Specific Gravity:	2.72
Wet density,g/cm3	1.86

[B] In the end of the test

Final Moisture Content,%	44.08
Dry specimen wt (m_s), gm:	48.4
Dry density,g/cm3	1.29
Height of Solids(H_s), mm	9.07
Final Void Ratio, e_f:	0.00



Determination of Initial Moisture Content

can no.	AD	T9
Wt. of can	15.9	16.5
Wt. of can+wet soil	29.2	49.6
Wt. of can+oven dry soil	25.5	40.1
Wt. of water	3.7	9.5
Wt of dry soil	9.6	23.6
Moist. Content	38.54	40.25
	39.40	

Determination of Final Moisture Content

can no.	A17
Wt. of can	48.50
Wt. of can+wet soil	119.10
Wt. of can+oven dry soil	97.50
Wt. of water	21.6
Wt of dry soil	49.00
Moist. Content	44.08
	44.08

Volume of Ring,cm3
39.25

Determination of Wet Density, gm/cm3

Wt of ring + initial wet soil	140.40
Wt. of wet soil	71.80
Wet density	**1.86**

Determination of Dry Weight of Specimen

Oven Dry wt+wt can	93.30
Wt. can	44.90
Dry wt. of Specimen,gm	**48.4**

Determination of Dry Density

Initial initu wieght +wt of ring	139.00
Wieght of ring	68.60
Dry Density,g/cm3	1.29
Bulk density	1.79

APPENDIX C: Scatter Plots Swelling potential with Index properties

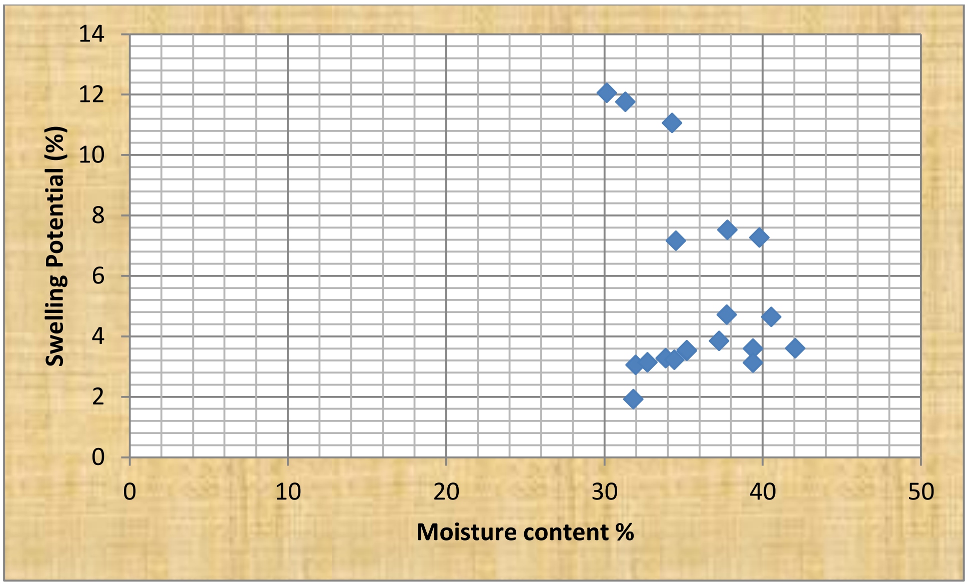


Figure: Scatter plots of SP vs. Moisture content

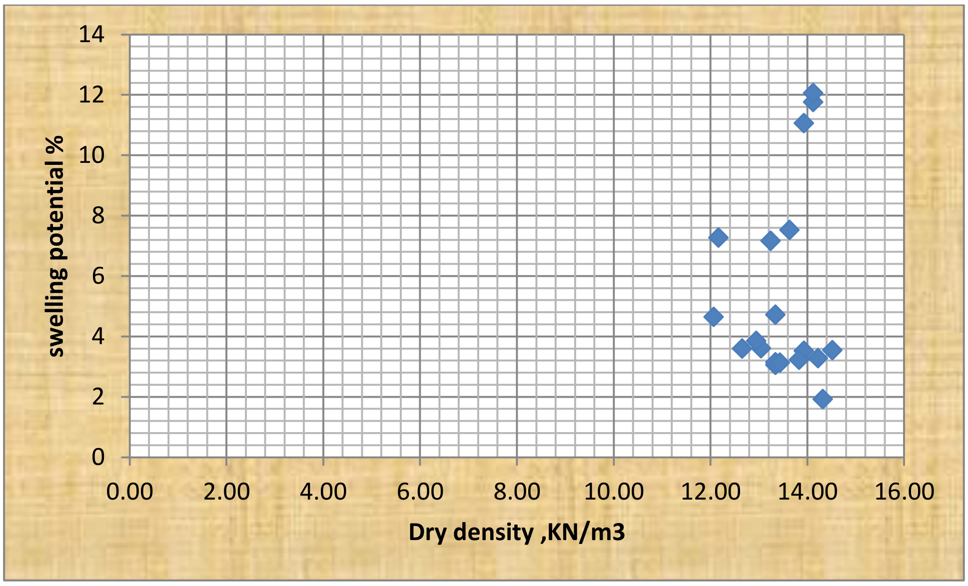


Figure: Scatter plots of SP vs. Dry density

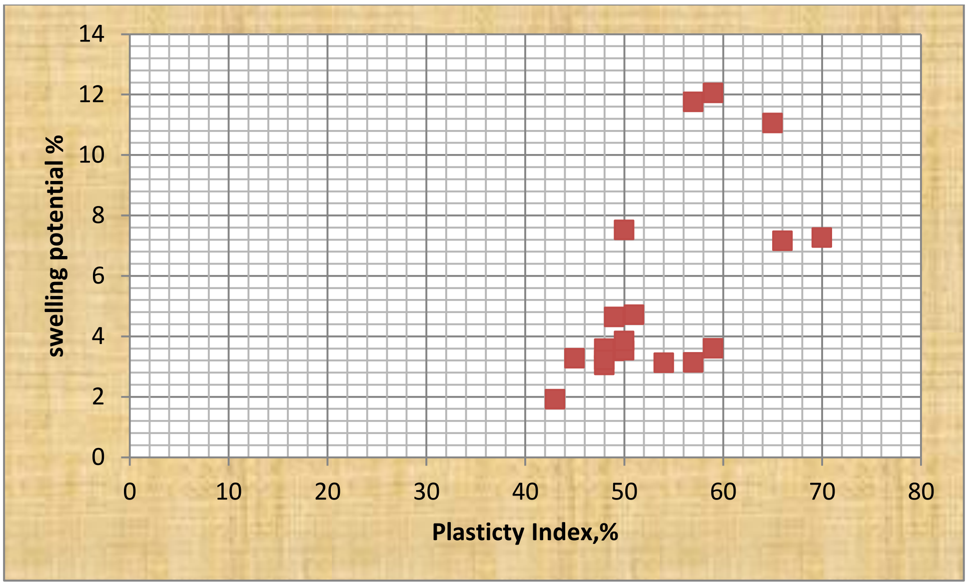


Figure: Scatter plots of SP vs. Plasticity Index

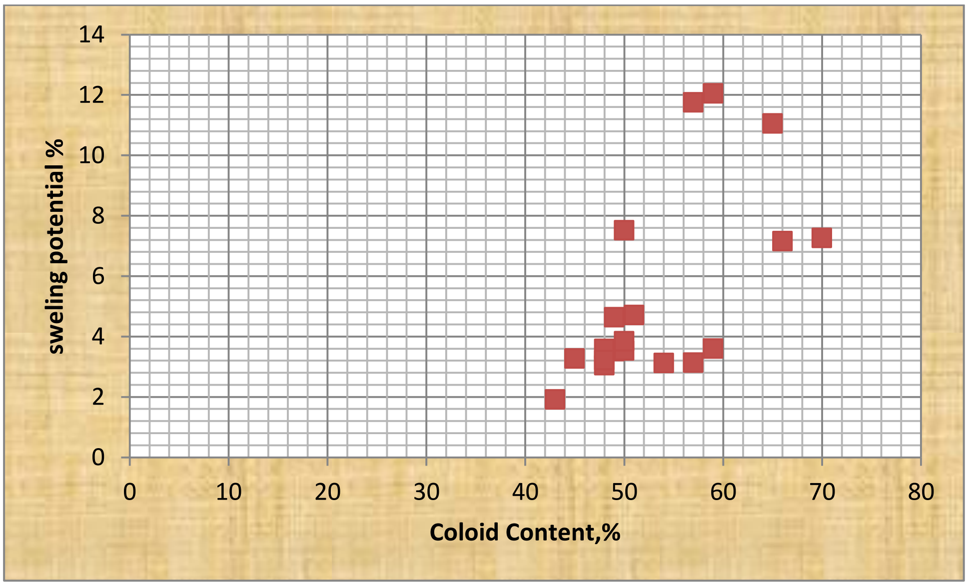


Figure: Scatter plots of SP vs. Clay content

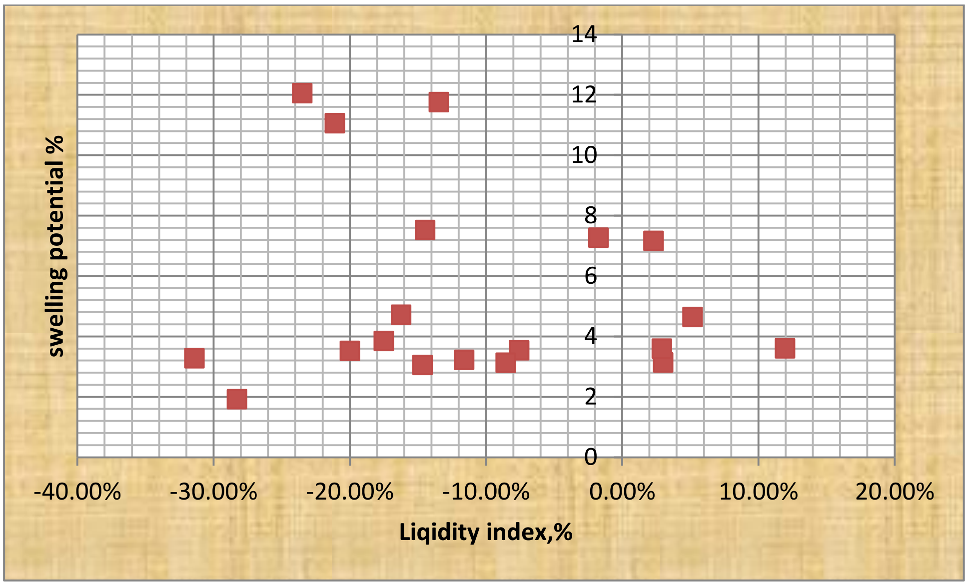


Figure: Scatter plots of SP vs. Liquidity index