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 AMBO TOWN

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

Nahom Debelo

Advisor

Messele Haile (Dr.-Ing.)

June, 2015

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Messele Haile (Dr.-Ing.) Advisor	Signature	20/07/15 Date
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Dedicated to my father Debelo Goju

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 _____

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Lists of Abbreviation and Symbols

% P_{200}	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. R^2	Adjusted R-square (Adjusted Coefficient of Determination)
ASTM	American Society for Testing and Materials
ATMB	Ambo town municipality bureaus
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
CES	Classification of expansive soils
CH	Inorganic clay of high compressibility
CL	Inorganic clay of low compressibility
C_L	Mean confidence level
CM	Inorganic clay of medium compressibility
CSS	Classification of swelling soils
CSTGG	Classification soil Texture Grades and Groups
DDL	Diffused double layer
ds/m	Decisiemens per meter
EBC	Exchangeable base capacity
EC	Electrical conductivity
ESCA	Expansive Soil Classification Based on Atterberg Limits
FS	Free swell

Gs	Specific gravity of solids
K	A constant=$3.6*10^{-5}$
K^+	Potassium ions
LI	Liquidity index
LL	Liquid limit
LLSC	Liquid Limit Range and Site Classification
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
Na^+	Sodium Ions
OH	Organic clay of high compressibility
PE	Potential expansiveness
PI	Plastic index
PL	Plastic limit
R^2	R-Square (coefficient of determination)
RF	Rainfall
SEPLP	Soil Expansivity Prediction by Liquid Limits and Plasticity Index
SPO	Swelling potential
SPR	Swelling pressure
Temp	Temperature
USCS	Unified Soil Classification System
Wl	Natural moisture content
$x_1, x_2, \ldots x_n$	Independent variable
Y	Dependent variable

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Abstract

A large surface area of Ambo town is covered by expansive soils which has a tendency to undergo volume change due to change in water content with seasonal moisture variation. Civil engineering structure constructed on such soils shows 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 Ambo town. Conducting swelling pressure and swelling potential tests are time taking and expensive when one compare with a simple index property tests. Therefore, it is very important and has engineering implication 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. Hence, a total of 20 disturbed and 20 undisturbed samples were collected from different parts of Ambo 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 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 new empirical correlation using single regression analysis results in a good determination coefficient of R-square (R^2) = 0.5258 and mean confidence level of (C_L) =99.99%, whereas multiple regression analysis gave comparatively a better correlation with determination coefficient of R-square (R^2) = 0.6401 with mean confidence level of (C_L) =99.73%. 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 soils.

Chapter-1

Introduction

1.1 General

The role and significance of developing correlation between index properties and swelling potential of expansive soils is quite often necessary for the geotechnical engineers to estimates the swelling potential from simple index properties tests. Obtaining the swelling characteristics such as swelling pressure, swell or collapse and related properties require undisturbed soil samples. Further, this requires more time and cost because of elaborative sampling and laboratory procedures. Therefore, it is desirable to make use of simpler and quicker methods of testing to assess the swelling potential and degree of expansiveness characters. The properties with respect to natural moisture content, dry density, liquid limit, plastic limit, plasticity index, liquidity index and grain size distribution are simpler to estimate for common soils and are important inferential soil tests with wide universal acceptance.

1.2 Back ground of the Thesis

Ambo town is located about 114 km to the West of Addis Ababa and has universities, educational institutes, mining of natural water, small factories, hotels, etc. There is great potential for investment expansion in the town and large surfaces area of the town is covered mainly with expansive soils. Such soils expand when subjected to moisture and shrink when they lose moisture. Thus, the alternate expansion and shrinking leads to structural distress within the system and finally facilitates failure of the structure. Since expansive soils are causing greater damage to those civil engineering structures constructed on them especially the light weight structures as they lack the counter balancing force as compared to the swelling pressure of such soils.

1.3 Objective of the study

The primary objectives of this research study are:

- ✓ To study and determine index properties of soils of the town
- ✓ To understand and evaluate expansiveness nature of soils of the town
- ✓ To study and determine some of the chemical analysis of soils of the town
- ✓ To study and determine swelling pressure and potential of soils of the town
- ✓ To correlates index properties with swelling potential of soils of the town

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 in general and soil index property is reviewed. Subsequently, previous works of different researchers with regard to prediction of swelling potential value from basic soil index properties are assessed.

To have satisfactory data for utilizing the correlations, laboratory tests are conducted on samples collected from different localities of Ambo town. After visual identification, expansive soil site investigation was conducted from 10 test pits for a total of 20 laboratory test samples. From 20 laboratory test samples10 samples were collected from an average depth of 1.44m and the other 10 samples are collected from same test pits, but from an average depth of 2.84m. Especially samples from places where structural damage and road failures occurred are given special attention. Each collected disturbed and undisturbed soil samples are tested based on ASTM standard. Moisture content, specific gravity, dry density, Atterberg limit and indices test, grain size analysis, swelling pressure and potential tests are done for the samples. A free swell test is conducted in accordance to Gibbs and Holtz, 1969, test Procedure and Chemical analysis was done based on Aluminum Acetate method.

Based on the above laboratory test, the results are analyzed and soils are grouped based on their similar behavior and classified using American Association of State Highway and Transportation Officials (AASHTO) system, Unified Soil Classification System (USCS) and Classification specific to expansive soils. To estimate the swelling characteristics from simple index properties tests, statistical regression analyses of test results were carried out and empirical correlations were developed. Finally discussions of the validity of the developed correlations are 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 Ambo town. In order to conduct the proposed correlation, only twenty laboratory test results are used in this research work. With regard to the regression analysis, depending on the trends of the scattering of test results the correlation is analyzed using a linear regression model. The required correlation is carried out by applying a single linear regression equation and multiple linear regression equations with the aid of Excel software. 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 consists of overall view of expansive soils of the world and Ethiopia and their behavior. Chapter 3 provides the impacts of environmental factors on the formation of different types of soils. Chapter 4 consists of sampling and laboratory test results. In Chapter 5, the different types of classification are discussed. Chapter 6 presents the development of empirical correlation techniques. In addition swelling potential prediction models and comparison of the existing and developed empirical equation are discussed. In Chapter 7, finally conclusion and recommendations are presented.

Chapter- 2

Literature Review

2.1 General

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 [10]. It has been ascertained that expansive clays cause billions of dollars 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). The problem is also widespread in many areas of Ethiopia but no detail statistics are available. 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

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 crack. Each year in the world, expansive soils cause billion dollars in damage to houses, other buildings, roads, pipelines, and other structures. Although expansive soils can be found in many countries, the problems related to expansive soils are the most severe and widespread in Ethiopia. Often, damage from expansive soils can be seen within the first few months or a year after a structure is constructed [9].

Figure 2.1: Distributions of expansive soils in Ethiopia [10]

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 [12].

2.2.2 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 stable 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 [12].

2.2.3 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 [12].

2.2.4 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[12].

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 soils are often clay like, becoming very sticky when wet and hard and brittle when dry [10].

2.3.1.1 Geological description

Geology provides good information about the method of forming a mass into size, shape and behavior (Lambe, T. W. and Whitman, R. V., 1996). Good well-documented geological information will facilitate quick decision for the selection of relevant methods and the extent of geotechnical site investigations. It is the base to judge the effectiveness of the test methods and assess the validity of the results. Geological description is usually obtained by the study of the site history and geological maps. Information on the maps can give valuable idea of the soil composition as the preliminary information for further investigation.

2.3.1.2 Geomorphological description

- ✓ **Ground water and moisture content**
- ✓ **Consistency**
- ✓ **In situ moisture content and density**
- ✓ **Soil groups**

2.3.2 Laboratory identification

In general, there are three different method of identifying expansive soil in the laboratory. These are [10]:-

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. Therefore, for this research purpose only the following tests were conducted for selected 10 samples taken from each pit [10].

- ✓ 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 mill equivalents 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 [21]. Different clay minerals have different CEC. See table 2.1.

Table 2.1: Cation Exchange Capacity of Principal Clay Minerals [8]

Clay Mineral	CEC (meq/100gm)
Kaolinite	3-15
Illite	10-40
Montmorilonite	70-80

2.3.2.1.4 Exchangeable Base Capacity (EBC)

Another test is also conducted to determine the Na^+ concentration in the soil of the study area. Na^+, K^+ Ca^{2+} and Ma^{2+} ions have their own role in the shrink-swell property of expansive soil. These cations balance the negative surface charge of clay particles. Especially the cation is held close to the surface in air-dry soil. But when water is available the hydration energy opposes the inter particle force which held these cation to the clay surface. As the amount of water increases in the soil, the cation start to enlarge and they tend to diffuse to the more dilute solution. But at the same time the negative surface force of the clay particle increases and this phenomenon attracts more cation towards the surface and cation accumulate around the clay particle. This accumulation of cation forms a layer, which is called diffused double layer (DDL). The DDL formed around every other clay particles overlaps and this overlapping produces repulsion force which is expressed as swelling pressure. The thicker the DDL the more is the swelling potential. The thickness of the DDL is governed by the presence of cation with low valance. Thus more swelling potential would occur in a soil having exchangeable sodium (N^+) cation than same soil with Potassium (K^+) or calcium (Ca^{2+}) or magnesium (mg^{2+}) cation (L.P.Van Reeuwijk, 2002).

2.3.2.2 Indirect measurement

There are several indirect measurement methods used to predict swell potential of expansive soils and these methods are summarized below [10].

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 [10].

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 [20].

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 [20].

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 stress condition. These factors are summarized below [9]:

2.6.1 Soil properties

The swell potential of an Expansive Soil may be affected by either the soil properties influencing the nature of the internal force field, the environmental factors those may change the internal force system or the state of stress present on the soil. Some physical factors such as initial water content, initial dry density, amount and type of compaction also influence the swell potential and swell parameters of soils (Baser, 2009)[9].

- ✓ **Clay Mineralogy**
- ✓ **Soil Water Chemistry**
- ✓ **Soil Suction**
- ✓ **Plasticity**
- ✓ **Soil Structure and Fabric**
- ✓ **Dry Density**

2.6.2 Environmental factors [9]

- ✓ **Initial Moisture Content**
- ✓ **Moisture Variations**
- ✓ **Climate**
- ✓ **Groundwater**
- ✓ **Drainage**
- ✓ **Vegetation**
- ✓ **Permeability**
- ✓ **Temperature**

2.6.3 Stress conditions [9]

- ✓ **Stress History**
- ✓ **In situ Conditions**
- ✓ **Loading**
- ✓ **Soil Profile**

2.7 Previous Works

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

1. [9]. For 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. [10]. 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, 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:

3. [19]. 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 from 14 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 5metres.
- ✓ 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 sub grade 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.

4. [16]. The laboratory test conducted to attain the objectives of study were: Moisture content determination, Atterberg limits, grain size analysis, free swell, specific gravity, and chemical analysis by collecting samples over Nejo-Mendi-Asossa and finally following conclusions were made after the study.

- ✓ The relationship between plasticity index and liquid limit suggested by Seed et al. (1964) is applicable only to lateritic soils at in-situ condition for soils studied under this thesis.
- ✓ The Atterberg limits determined for the lateritic soil plot anomalously below the Casagrande- line, despite the absence of Mica, Halloysite, Allophane or high organic matter content in the soil. This may be due to water retention in micro-aggregates. Because of this effect, Casagrande's classification system is inapplicable to these soils studied.

Chapter-3

Study Area

3.1 General

The formation of the different types of soils depends on 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. Consequently a considerable part of Ambo town is covered by expansive soils which pose sever problem for engineering works.

This chapter deals with the description of location, back ground, land cover and land use, geologic, climate, Geography, and Soil Characteristics which influence the formation of expansive soils in the town and the nearby area [4].

3.2 Location of the study area

The geographical (Astronomical) location of Ambo town is approximately between 8^{o} 56'30'' N- 8^{o} 59'30'' N latitude and between 37^{o}47'30" E - 37^{o} 55'15" E longitude (topographic map sheet obtained from Ethiopian Mapping Agency and topographic surveyed map). Relatively Ambo town is located 114 km far away West of Finfinne (Addis Ababa), 60kms North West of Weliso town and 12kms East of Guder town. Ambo town is a zonal town with the 2^{nd} grade (stage) of administrative status [4].

As information from the municipality shows, the town previously had three urban gendas (kebeles) such as kebele 01, kebele 02 and kebele 03. In addition to these three urban kebeles, now the town is expanded outwards and included certain farmers kebeles associations such as Awaro & Ilammu Mujja in the eastern direction, Sankelle Farisi in Western, Gosu Kora in the southern and Oddo Liban Kisose in the northern direction [4].

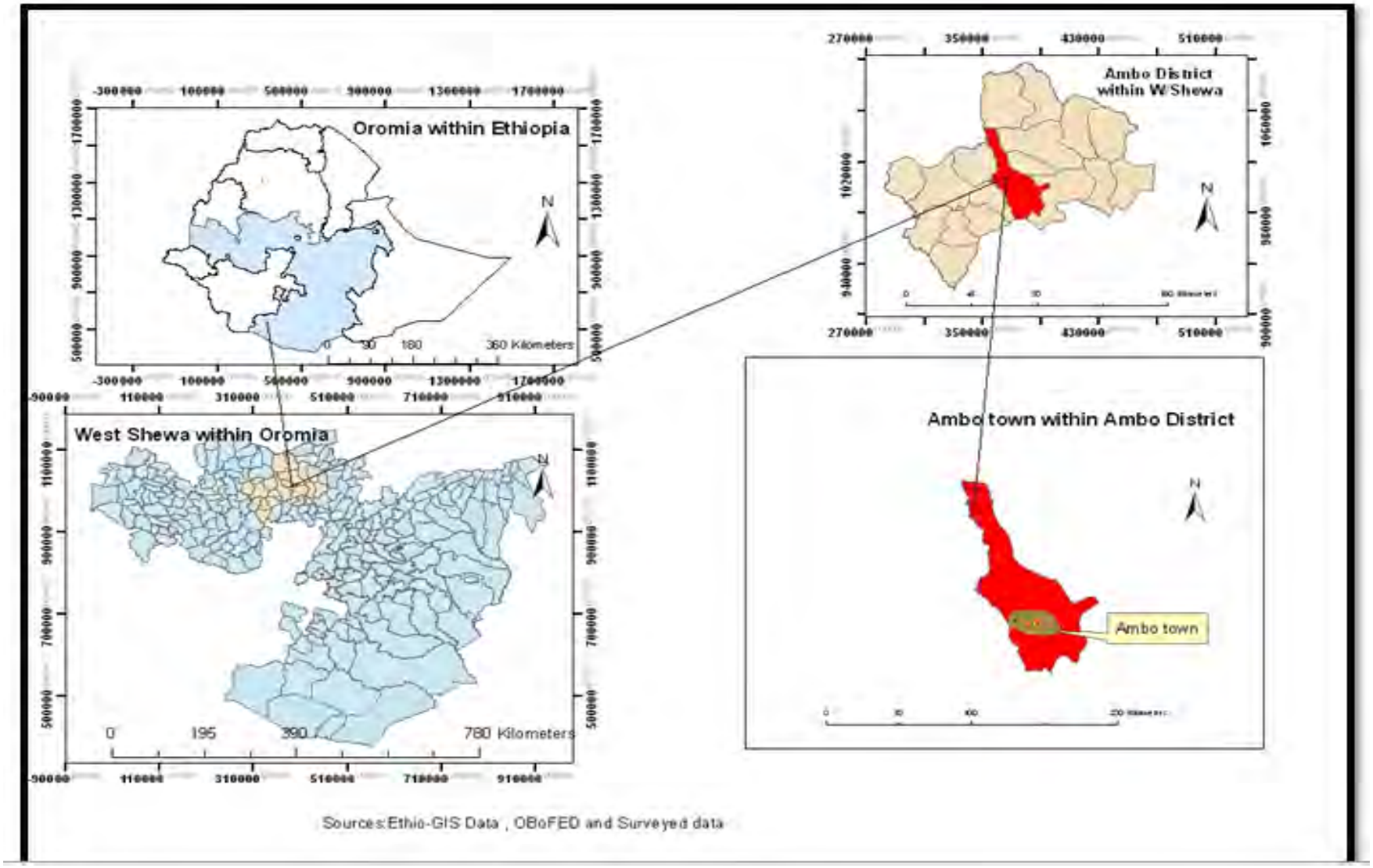

Figure 3.1: Location map-Absolute Location of Ambo town [4]

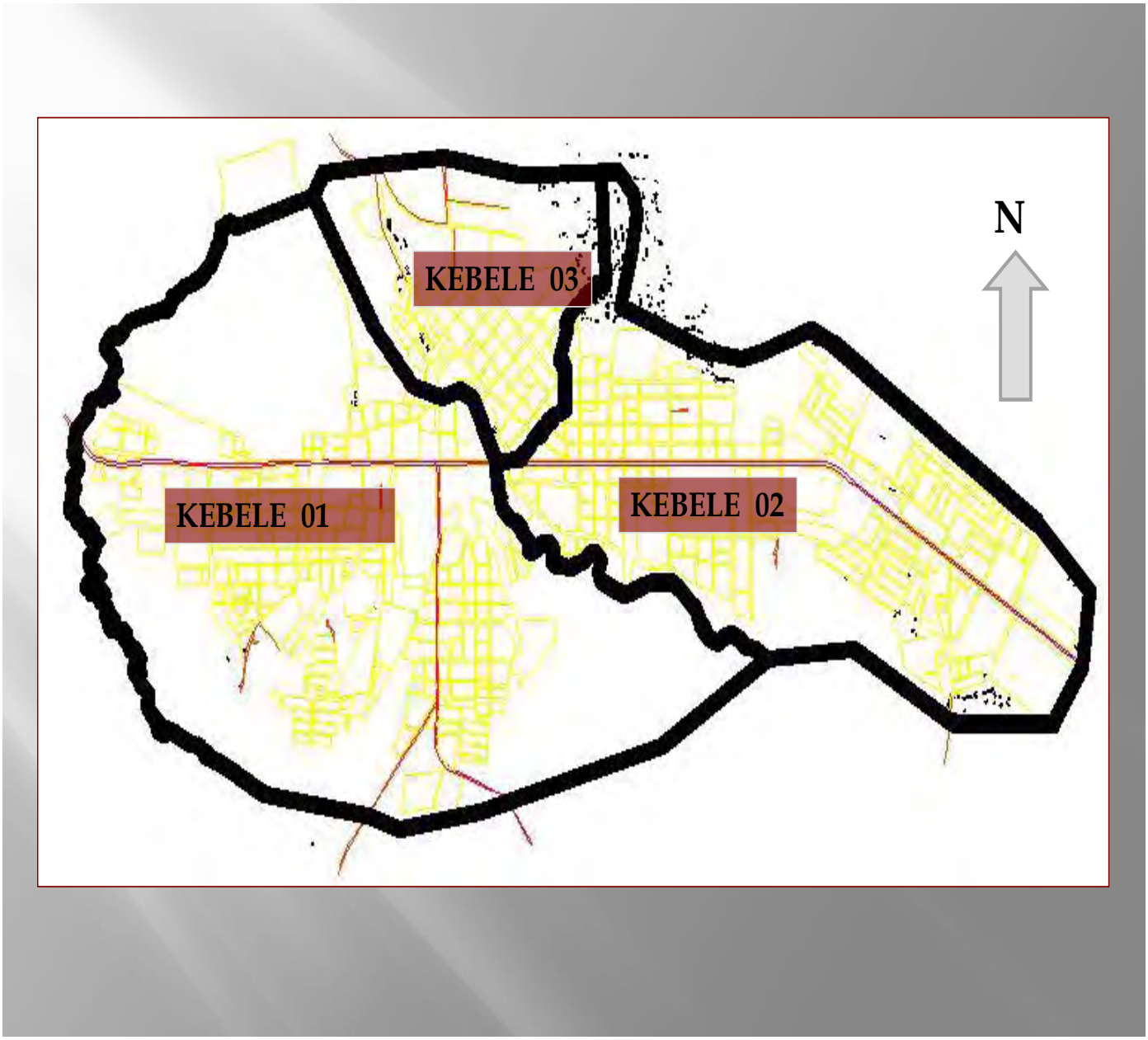

Figure 3.2: The previously existing kebeles (Gandas) and border in the town [4]

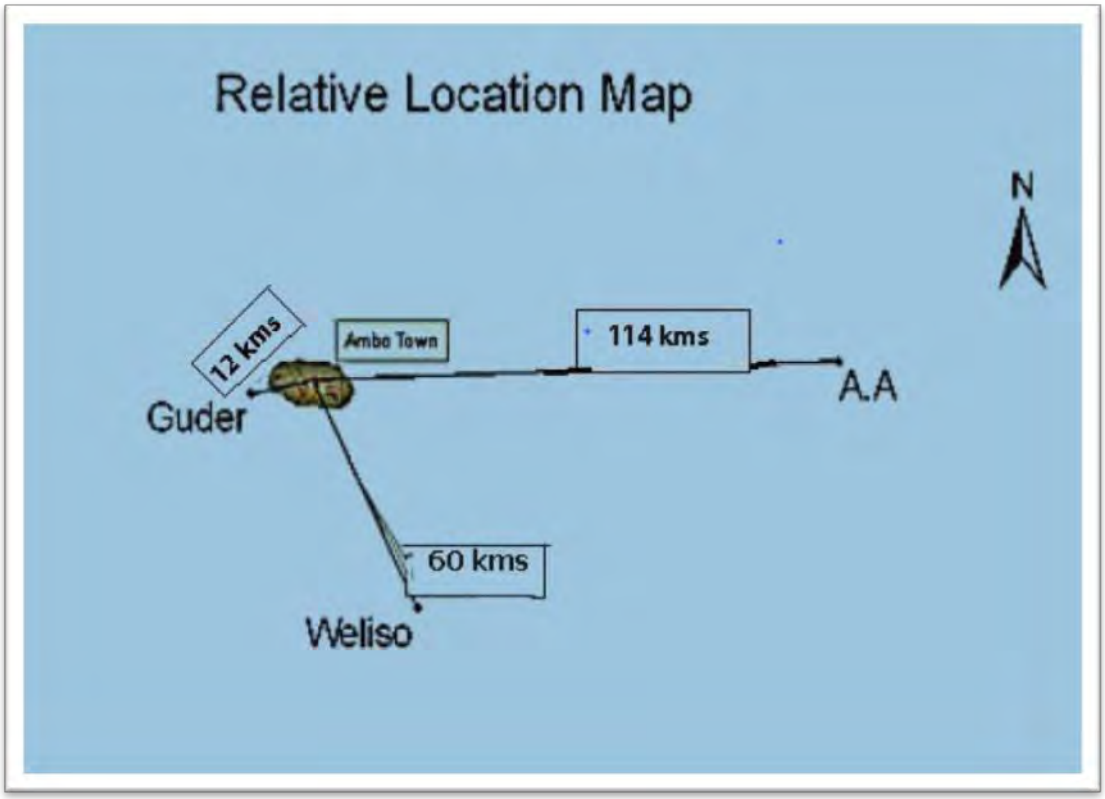

Figure 3.3: Relative location Map of Ambo town [4]

3.3 Back ground of the area

Looking at the natural resources and ethnographic character of the area may be the logical place to start writing about the history of its urbanization. In this connection Ambo area is known for its different natural resources including the abundant resources and attractive scenery. Above all, the Ambo mineral water (Hora Ambo) is one of the important natural resources, which have direct relation with urbanization of the area. It also took the name Xabala Ambo; after the establishment of Ambo Yesus Church. The area came under the Showan kingdom of Menelik after series of campaign waged. According to both oral and written sources, the name of the town was given by the imperial rule, two different names at different periods other than Ambo. These were Dingat Alem and Hagre Hiwot. According to the informants, the name Dingat Alam was given by Ras Tafari himself, as he himself, at some time was ill and cured using the Hora. But this name was dropped with the Italian invasions. According to the informants the name Hagere-Hiwot was awarded by Emperor Haile Sellassie when his spouse, empress Menen revived from her sickness at one time. Despite the Imperial attempt to change the name of the town, the popular name of town remained Ambo [4].

3.4 Area and Shape of the town

The area under administration of the town including the adjacent proposed expansion area is calculated to be about 8587.59 ha (85.88 km^2). To analyze the shape of the town it is important to consider the compactness index model. The compactness index of Ambo town is calculated by dividing the actual area of the town for a circle circumscribing the town. Thus, the area of a circle circumscribing Ambo town is 215.26 km^2 but the actual area of Ambo is 85.88 km^2. The value of compactness index indicates that the shape of Ambo town deviates from a perfectly compact shape (a circle) by 60% [4].

3.5 Land Cover and land use

In the study area there are almost no remains of endogenous natural vegetation cover. Ambo and its surrounding areas are dominated by eucalyptus trees, which are owned by the individuals. The eucalyptus trees are found distributed in all direction of the town and its surroundings. Other trees observed in the town and its surrounding areas are acacias, cordial (locally Wanza, Wadeessa), Tid/ scientifically Junipers / and coniferous forest trees are other trees found distributed in the town and its surrounding. Along the riverbanks, in the Ambo Palace, in the known hotels (Ambo Ethiopia

Hotel, Jibatena Mecha Hotel), in the churches and in some other governmental offices we find vegetations, which keep the urban environment to be green. Individuals and communities are engaged in planting eucalyptus and other trees for construction, energy, economical (to earn money after selling) and environmental purpose [4].

3.6 Geology

The land features of Ambo town are the results of the past geological history and tectonic movement. During the Mesozoic era sedimentary rock formation of Sandstone occurred in Ambo town [4].

3.7 Climate

According to the data obtained from National Meteorological Agency of Ambo branch which is located in Ambo University 10 years consecutive meteorological data was taken and the following result is observed on the temperature, rainfall, humidity and wind direction.

Temperature: - The mean annual temperature, the mean annual maximum and mean annual minimum temperatures of the town are reckoned to be about 18.87^{o}C, 19.63^{o}C & 18.24^{o}C, respectively, which is the characteristic of a warm temperate climate (Table 3.1 and Appendix C).

Rainfall: The mean annual rainfall is about 82.32mm. 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 & surrounding areas (Table 3.2 and Appendix C).

Humidity: The mean monthly relative humidity of the town varies from 64.6% in August to 35.8% in December, which is very comfortable for human life.

Wind direction: From the meteorological data obtained the prevailing winds of autumn, winter and spring seasons are Easterly and South Easterly Winds while that of summer season is Westerly and South Westerly Winds. Generally the most dominant prevailing wind of Ambo town is Easterly Wind. Therefore, industries and other urban activities which can pollute the town in terms of smoke, dust particles, noise and stench smell are recommended to be located opposite to the most dominant prevailing wind direction [4].

Table 3.1: Mean Monthly Average Temperature Condition of Ambo town

Year	Temperature (In Degree Celsius)												Mean Annual Temperature
	J	F	M	A	M	J	J	A	S	O	N	D	
Mean Monthly Average Temperature	19.38	20.37	20.77	20.79	19.71	18.19	17.39	17.31	17.23	18.06	18.14	18.87	18.87

Table 3.2: Monthly Average Rainfall Condition of Ambo town

Year	Monthly Rainfall (mm)												Mean Annual Rain Fall
	J	F	M	A	M	J	J	A	S	O	N	D	
Monthly Average Rain Fall	23.88	19.35	52.89	64.87	95.07	156.69	197.52	210.43	104.18	38.91	16.16	7.33	82.32

3.8 Geography

The town is located on the Shewa plateau. Most of the existing built up areas of the town is almost gentle slope & undulated while some hill slope and mountain are also seen in the town. Along the course of the rivers and streams steep slope & gullies are also observed. Concerning the altitude of the town, the town's altitude ranges from 1872 meter above sea level to 2362 m. As regard to the proposed expansion most of the areas are characterized by flat, gentle slopes and undulated plains towards Awaro & Illammu Mujja in the eastern direction, Oddo Liban Kisose in the Northern and Gosu Kora in the southern. But some of the slopes in the Sankalle Faris in Western direction have higher slopes and also has manmade barriers such as Ambo Mineral Water Factory, Sankalle Police Training Centre and Sankalle Gypsum Factory [4].

3.9 Soil Characteristics of Ambo

The soil types encountered in Ambo and its surrounding include black clay, red clay, sandy silts and silty clays. The dominant type of soil in Ambo town and its surrounding area is Vertisol soil. Pellic Vertisol soils which are dark, usually occupying vast areas that are water logged during the rainy season and shrink & have deep cracks in dry season. The Vertisol soils covers the gently slopes in the southern, eastern and northern part of the town. Dystric Nitosol soils are also observed in some part of Ambo especially in Western part around Sankalle and some parts Faris areas. These are deep clay red soils and have a uniform profile, porous and have stable structure. There are impacts (influences) of soil erosion on urban settlement like gully erosion, land degradation, road destruction, cracks when dry which can damage building, very sticky and plastic when wet that hinders driving vehicles and walking on the road. The silty clays and sandy silts mainly cover the central parts of the town. They usually occupy topographically flat parts of the town [4].

Chapter-4

Sampling and Laboratory Test Results

4.1 Sampling

Before the samples are taken, visual identification of the location of expansive soils is necessary. Since a major parts of Ambo town is mainly covered with expansive soil, sampling from such areas of the town is possible. All samples for this research purpose were taken during summer season and depth of excavation is dependent on the existing condition of the ground. In some pits aggregates was encountered before 3.0m. On the other hand in few test pits the soil color is changed before 1.5m reached. Generally as seen from all test pits the color of soil is changed from black to grey and black to darkly grey soil after an average depth of 1.44m. There are also test pits which are fully black or fully grey as a whole. Finally of 10 places (pits) were selected from different locations. As a result a total of 20 disturbed and 20 undisturbed representative samples were taken. Undisturbed samples were taken using a ring of sampler with diameter =11cm and height=20cm. On average, 10 samples were taken from depth of 1.44m whereas the other 10 samples were taken from an average depth of 2.84m. Especially samples from places of structural damage and roads failures were taken special attention. For this thesis undisturbed soil samples were used for:- natural moisture content, dry density, swelling potential and swelling pressure tests whereas disturbed soil samples were used for: - specific gravity, Atterberg limit and indices, grain size analysis, free swell tests and chemical analysis. For detail of sampling locations in the town see (figure 4.1).

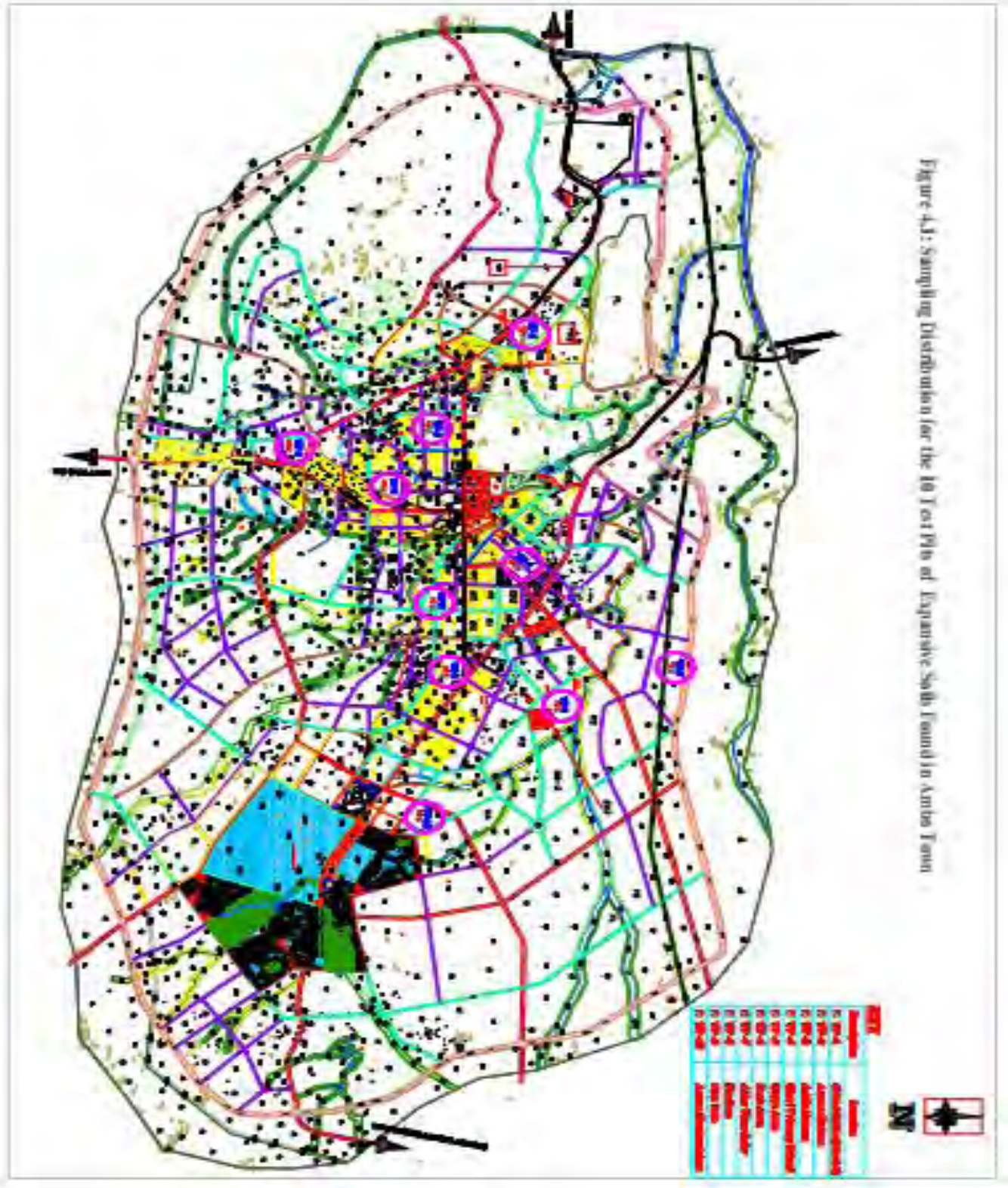

Figure 4.1 Sampling Distribution for the 10 Test Pits of Expansive Soils Found in Ambo Town

4.2 Laboratory Test Results

Laboratory tests are useful in providing reliable data for calculating swelling pressure and swelling potential of soils, strength of a soil, determining physical characteristics of soils and compactness 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 on 20 samples collected from10 different test pits. Such parameters are useful to provide correlations with engineering soil properties for the estimation of swelling potential of expansive soils.

4.2.1.1 Natural Moisture Content

The natural moisture content tests were carried out in laboratory as per the procedures of ASTM D 2216 - Standard Test Method. The laboratory test results show that, moisture contents of the study area falls in the range of (31.99-47.42) %.

Table 4.1: Natural Moisture Content Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth(m)	Moisture Content (%)
1	Geba Mishion	Test Pit-1	Grey	1.5m	42.61
2			Grey	3.0m	39.56
3	Awura Godana	Test Pit-2	Black	1.5m	32.43
4			Dark Grey	2.8m	36.76
5	Addis Ketema	Test Pit-3	Grey	1.4m	40.66
6			Grey	2.5m	43.79
7	Cheri Primary School	Test Pit-4	black	1.3m	47.42
8			Dark Grey	2.8m	45.53
9	Gossu	Test Pit-5	Grey	1.5m	31.99
10			Grey	3.0m	36.99
11	Faris	Test Pit-6	Dark Grey	1.5m	37.80
12			Grey	3.0m	36.76
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	43.46
14			Dark Grey	3.0m	47.18
15	Studium	Test Pit-8	Grey	1.5m	40.30
16			Dark Grey	2.8m	35.26
17	New Bole	Test Pit-9	Black	1.5m	42.64
18			Black	3.0m	38.20
19	Awro Condominium	Test Pit-10	Black	1.2m	32.53
20			Grey	2.5m	44.07

4.2.1.2 Dry density test

ASTM D 2937-00 – Standard Test Method was 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 (11.92-14.96) kN/m^3.

Table 4.2: Dry Density Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth(m)	Bulk unit Weight (kN/m^3)	Moisture Content (%)	Dry Density (kN/m^3)
1	Geba Mishion	Test Pit-1	Grey	1.5m	18.60	42.61	13.04
2			Grey	3.0m	17.04	39.56	12.21
3	Awura Godana	Test Pit-2	Black	1.5m	18.01	32.43	13.60
4			Dark Grey	2.8m	18.93	36.76	13.84
5	Addis Ketema	Test Pit-3	Grey	1.4m	17.99	40.66	12.79
6			Grey	2.5m	18.47	43.79	12.85
7	Cheri Primary School	Test Pit-4	black	1.3m	17.58	47.42	11.92
8			Dark Grey	2.8m	18.37	45.53	12.62
9	Gossu	Test Pit-5	Grey	1.5m	18.65	31.99	14.13
10			Grey	3.0m	17.91	36.99	13.07
11	Faris	Test Pit-6	Dark Grey	1.5m	17.91	37.80	13.00
12			Grey	3.0m	19.49	36.76	14.30
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	17.83	43.46	12.43
14			Dark Grey	3.0m	17.94	47.18	12.19
15	Studium	Test Pit-8	Grey	1.5m	18.50	40.30	13.18
16			Dark Grey	2.8m	20.23	35.26	14.96
17	New Bole	Test Pit-9	Black	1.5m	17.78	42.64	12.47
18			Black	3.0m	18.90	38.20	13.68
19	Awro Condominium	Test Pit-10	Black	1.2m	19.06	32.53	14.38
20			Grey	2.5m	19.49	44.07	13.53

4.2.1.3 Specific Gravity test

These tests were carried out in 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 (2.56-2.81).

Table 4.3: Specific Gravity Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth(m)	Spesific Gravity
1	Geba Mishion	Test Pit-1	Grey	1.5m	2.68
2			Grey	3.0m	2.61
3	Awura Godana	Test Pit-2	Black	1.5m	2.68
4			Dark Grey	2.8m	2.69
5	Addis Ketema	Test Pit-3	Grey	1.4m	2.63
6			Grey	2.5m	2.64
7	Cheri Primary School	Test Pit-4	black	1.3m	2.56
8			Dark Grey	2.8m	2.61
9	Gossu	Test Pit-5	Grey	1.5m	2.73
10			Grey	3.0m	2.68
11	Faris	Test Pit-6	Dark Grey	1.5m	2.66
12			Grey	3.0m	2.73
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	2.62
14			Dark Grey	3.0m	2.61
15	Studium	Test Pit-8	Grey	1.5m	2.68
16			Dark Grey	2.8m	2.81
17	New Bole	Test Pit-9	Black	1.5m	2.63
18			Black	3.0m	2.69
19	Awro Condominium	Test Pit-10	Black	1.2m	2.68
20			Grey	2.5m	2.69

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 (66.72-101.19) %; Plastic Limit (25.21-40.98) %; Plastic Index (37.12-60.66) % and Liquidity Index(-11.42-31.53) %.

Table 4.4: Atterberg Limits and Indices Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth(m)	Atterberg Limit and Indices test				
					Liquid Limit (LL) %	Plastic Limit (PL) (%)	Plastic Index (PI) (%)	Moisture Content (%)	Liquidity Index (LI) (%)
1	Geba Mishion	Test Pit-1	Grey	1.5m	74.65	30.48	44.17	42.61	27.46
2			Grey	3.0m	89.21	37.93	51.28	39.56	3.19
3	Awura Godana	Test Pit-2	Black	1.5m	96.01	38.95	57.06	32.43	-11.42
4			Dark Grey	2.8m	72.39	31.05	41.34	36.76	13.82
5	Addis Ketema	Test Pit-3	Grey	1.4m	89.25	39.03	50.22	40.66	3.24
6			Grey	2.5m	89.75	34.39	55.36	43.79	16.97
7	Cheri Primary School	Test Pit-4	black	1.3m	90.37	30.85	59.52	47.42	27.84
8			Dark Grey	2.8m	90.42	35.36	55.06	45.53	18.47
9	Gossu	Test Pit-5	Grey	1.5m	78.69	25.94	52.75	31.99	11.48
10			Grey	3.0m	66.72	25.21	41.51	36.99	28.37
11	Faris	Test Pit-6	Dark Grey	1.5m	92.36	36.91	55.45	37.80	1.61
12			Grey	3.0m	92.03	40.98	51.05	36.76	-8.26
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	101.19	40.53	60.66	43.46	4.83
14			Dark Grey	3.0m	93.37	39.03	54.34	47.18	15.00
15	Studium	Test Pit-8	Grey	1.5m	69.85	32.63	37.22	40.30	20.61
16			Dark Grey	2.8m	70.76	33.64	37.12	35.26	4.36
17	New Bole	Test Pit-9	Black	1.5m	77.79	29.03	48.76	42.64	27.91
18			Black	3.0m	78.94	35.53	43.41	38.20	6.16
19	Awro Condominium	Test Pit-10	Black	1.2m	69.29	29.36	39.93	32.53	7.94
20			Grey	2.5m	71.83	31.29	40.54	44.07	31.53

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 (0-5.99) %; Percent Sand (1.64-15.80) %; Percent Silt (14.15-38.53) %; Percent Clay (54.54-80.66) % and Percent finer than 0.075mm (82.14-98.18).

Table 4.5: Grain Size Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth (m)	Grain Size Analysis				
					Gravel (%)	Sand (%)	Silt (%)	Clay (%)	% P_{200}
1	Geba Mishion	Test Pit-1	Grey	1.5m	1.09	4.22	38.53	56.16	94.69
2			Grey	3.0m	0.92	2.69	21.74	74.65	96.39
3	Awura Godana	Test Pit-2	Black	1.5m	5.99	5.13	17.62	71.26	88.87
4			Dark Grey	2.8m	0.52	14.19	30.75	54.54	85.29
5	Addis Ketema	Test Pit-3	Grey	1.4m	0.18	1.64	21.03	77.15	98.18
6			Grey	2.5m	-	3.00	24.24	72.76	97.00
7	Cheri Primary School	Test Pit-4	black	1.3m	3.29	4.74	17.66	74.32	91.98
8			Dark Grey	2.8m	2.97	4.57	26.37	66.08	92.46
9	Gossu	Test Pit-5	Grey	1.5m	0.05	5.93	25.90	68.12	94.03
10			Grey	3.0m	0.17	4.77	28.37	66.69	95.07
11	Faris	Test Pit-6	Dark Grey	1.5m	0.82	3.33	15.96	79.88	95.85
12			Grey	3.0m	0.01	2.31	17.02	80.66	97.68
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	2.01	8.90	20.17	68.92	89.09
14			Dark Grey	3.0m	0.91	4.66	20.66	73.77	94.43
15	Studium	Test Pit-8	Grey	1.5m	0.13	4.00	28.90	66.97	95.87
16			Dark Grey	2.8m	0.61	5.29	26.31	67.79	94.10
17	New Bole	Test Pit-9	Black	1.5m	2.06	15.80	15.79	66.35	82.14
18			Black	3.0m	0.95	12.80	14.15	72.10	86.25
19	Awro Condominium	Test Pit-10	Black	1.2m	0.83	5.71	17.86	75.60	93.47
20			Grey	2.5m	0.19	5.21	18.55	76.05	94.60

4.2.3 Swelling characteristics

All swelling characteristics parameters were tested at Addis Ababa Institutes of Technology Geotechnical Engineering Laboratory on 20 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 (98-163) %.

Table 4.6: Free Swell Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth (m)	Free Swell (%)
1	Geba Mishion	Test Pit-1	Grey	1.5m	98
2			Grey	3.0m	143
3	Awura Godana	Test Pit-2	Black	1.5m	150
4			Dark Grey	2.8m	118
5	Addis Ketema	Test Pit-3	Grey	1.4m	145
6			Grey	2.5m	155
7	Cheri Primary School	Test Pit-4	black	1.3m	153
8			Dark Grey	2.8m	150
9	Gossu	Test Pit-5	Grey	1.5m	110
10			Grey	3.0m	110
11	Faris	Test Pit-6	Dark Grey	1.5m	163
12			Grey	3.0m	153
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	130
14			Dark Grey	3.0m	140
15	Studium	Test Pit-8	Grey	1.5m	135
16			Dark Grey	2.8m	130
17	New Bole	Test Pit-9	Black	1.5m	145
18			Black	3.0m	143
19	Awro Condominium	Test Pit-10	Black	1.2m	123
20			Grey	2.5m	105

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 (26.45-374.25) kPa.

Table 4.7: Swelling Pressure Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth(m)	Swelling Pressure (kPa)
1	Geba Mishion	Test Pit-1	Grey	1.5m	44.85
2			Grey	3.0m	110.80
3	Awura Godana	Test Pit-2	Black	1.5m	233.55
4			Dark Grey	2.8m	200.00
5	Addis Ketema	Test Pit-3	Grey	1.4m	86.55
6			Grey	2.5m	94.25
7	Cheri Primary School	Test Pit-4	black	1.3m	95.45
8			Dark Grey	2.8m	26.45
9	Gossu	Test Pit-5	Grey	1.5m	140.05
10			Grey	3.0m	90.75
11	Faris	Test Pit-6	Dark Grey	1.5m	334.23
12			Grey	3.0m	374.25
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	95.65
14			Dark Grey	3.0m	66.15
15	Studium	Test Pit-8	Grey	1.5m	58.90
16			Dark Grey	2.8m	191.15
17	New Bole	Test Pit-9	Black	1.5m	82.00
18			Black	3.0m	179.98
19	Awro Condominium	Test Pit-10	Black	1.2m	250.45
20			Grey	2.5m	93.25

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 (1.78-9.84) %.

Table 4.8: Swelling Potential Test Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth(m)	Swelling Potential (%)
1	Geba Mishion	Test Pit-1	Grey	1.5m	1.80
2			Grey	3.0m	3.26
3	Awura Godana	Test Pit-2	Black	1.5m	7.98
4			Dark Grey	2.8m	6.62
5	Addis Ketema	Test Pit-3	Grey	1.4m	4.99
6			Grey	2.5m	6.37
7	Cheri Primary School	Test Pit-4	black	1.3m	3.96
8			Dark Grey	2.8m	1.78
9	Gossu	Test Pit-5	Grey	1.5m	6.78
10			Grey	3.0m	5.20
11	Faris	Test Pit-6	Dark Grey	1.5m	9.73
12			Grey	3.0m	9.84
13	Abba Tesas Sefar	Test Pit-7	Black	1.5m	3.19
14			Dark Grey	3.0m	2.06
15	Studium	Test Pit-8	Grey	1.5m	2.06
16			Dark Grey	2.8m	7.38
17	New Bole	Test Pit-9	Black	1.5m	2.80
18			Black	3.0m	5.60
19	Awro Condominium	Test Pit-10	Black	1.2m	8.61
20			Grey	2.5m	4.05

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 pit-4 at 2.8m depth and pit-6 at 3.0m depth which showed great difference results of swelling characteristics. The first sample gave relatively the lowest swelling characteristics of 26.45 kPa and 1.78% swelling pressure and swelling potential respectively whereas; the second sample gave the highest swelling characteristics of 374.25 kPa and 9.84% swelling pressure and swelling potential respectively. This can be attributed to the fact that the first sample has relatively high natural moisture content and low dry density and the second sample has low natural moisture content and high dry density during sampling. Therefore the first sample has already swelled in situ to high extent than the second sample. Depending on the laboratory test results the whole samples are in the range of very high potential of expansiveness [8].

4.2.3.5 Analysis and Relations of Index Properties and Chemical analysis Results of study area

Mineralogical Identification Method:-

Depending on the chemical analysis results of study area, tables 4:9; clearly showed a minimum value of CEC of 50.64 meq/100g which is greater than the maximum values for Illites requirement which shows all samples contains Montmorilonite minerals. See table 2:1. Since the whole samples of the study area gave values greater than 40 meq/100g, therefore, the whole samples fall in the range of great potential of expansiveness.

Indirect Method:-

Again considering the index properties results of the study area, table 4:10; one can see that as the whole plastic index values of the soils of study area fall above (greater than) 35%. Since sample with plastic index values greater than 35% shows very high swelling potential [8]. Therefore, the whole samples are in the range of (very high swelling potential) great potential of expansiveness.

Final Analysis:-

From the above two methods, both the chemical analysis (mineralogical identification) and index properties (indirect) methods lead to the same conclusion with direct method(swelling characteristics) which is great potential of expansiveness.

4.2.4 Chemical Analysis

All chemical analysis parameters were tested at ministry of agriculture, national soil testing centre laboratory. This test was done on selected 10 samples collected from each 10 different test pits.

4.2.4.1 PH

The laboratory test results show that, PH tests of the study area falls in the range of (7.6-8.2). This shows the expansive soils of Ambo town is moderately alkaline soils. See (table 4.9)

4.2.4.2 Electrical Conductivity (EC)

The laboratory test results show that, EC tests of the study area falls in the range of (0.239-1.180) ds/m. The soluble salt content of soils of study area is in the range of low to medium. See (table 4.9)

4.2.4.3 Cation Exchange Capacity (CEC)

Chapman, (1965) ammonium acetate test method was used to test cation exchange capacity. The laboratory test results show that, CEC tests of the study area falls in the range of (50.64-64.14) meq/100g. Based on laboratory results Ambo expansive soils showed CEC greater than 40 meq/100g. See (table 4.9)

4.2.4.4 Exchangeable Base (EB)

Exchangeable base was tested according to Chapman, (1965) ammonium acetate test method. Readings of sodium and potassium ions were taken by flame photometer whereas calcium and magnesium ions were taken by atomic absorption spectro-photometer. The detail summary of laboratory test results of the exchangeable base of the study area falls in the ranges of:-Na^{+} (0.41-2.95) meq/100g, K^{+} (1.15-1.89) meq/100g, Ca^{2+} (21.66-34.85) meq/100g and Mg^{2+} (4.01-14.08) meq/100g. See (table 4.9)

4.2.4.5 Base saturation

Base saturation = Sum of Na+, K+, Ca++, and Mg++ divided by CEC. Base saturation of Ambo expansive soils falls in the range of (64.0-78.0) %. This shows the study area soils are moderately basic. See (table 4.9)

Table 4.9: Summary of All Chemical Analysis Results of Ambo expansive soil

Number of tests	Location	Test Pits	Color	Depth (m)	PH-H_2O	EC (ds/m) (Salt Content)	CEC (meq/100g)	EBC (meq/100g)				Base Saturation (%)
								Na^+	K^+	Ca^{2+}	Mg^{2+}	
1	Geba Mishion	Test Pit-1	Grey	1.5m	7.9	0.401	56.29	0.41	1.89	27.48	10.37	71
2	Awura Godana	Test Pit-2	Black	1.5m	8.0	0.715	57.61	2.56	1.15	31.43	9.04	77
3	Addis Ketema	Test Pit-3	Grey	1.4m	8.2	0.239	57.39	2.34	1.36	26.89	14.08	78
4	Cheri Primary School	Test Pit-4	black	1.3m	7.9	1.180	64.14	2.95	1.43	34.85	9.21	76
5	Gossu	Test Pit-5	Grey	1.5m	8.2	0.622	51.61	2.49	1.31	21.66	7.43	64
6	Faris	Test Pit-6	Dark Grey	1.5m	8.0	0.406	50.64	2.26	1.24	25.51	8.51	74
7	Abba Tesas Sefar	Test Pit-7	Black	1.5m	8.0	0.840	55.40	2.08	1.57	32.66	7.08	78
8	Studium	Test Pit-8	Grey	1.5m	7.6	0.887	54.47	0.89	1.37	31.48	5.09	71
9	New Bole	Test Pit-9	Black	1.5m	8.2	0.422	53.33	0.98	1.37	32.43	4.01	73
10	Awro Condominium	Test Pit-10	Black	1.2m	7.9	0.465	53.47	0.91	1.25	27.74	8.28	71

Table 4.10: Summary of All Index Properties and Swelling Characteristics Test Results of Ambo expansive soil

Location	Test Pits	Color	Depth (m)	Moisture Content (Wl) %	Dry Density (kN/m^3)	Specific Gravity	Atterbrg Limit				Grain size Analysis					Swelling Characteristics		
							LL (%)	PL (%)	PI (%)	LI (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	$\%P_{200}$	Free Swell (%)	Swelling Pressure (kPa)	Swelling Potential (%)
Geba Mishion	Pit-1	Grey	1.5m	42.61	13.04	2.68	74.65	30.48	44.17	27.46	1.09	4.22	38.53	56.16	94.69	98	44.85	1.80
		Grey	3.0m	39.56	12.21	2.61	89.21	37.93	51.28	3.19	0.92	2.69	21.74	74.65	96.39	143	110.80	3.26
Awura Godana	Pit-2	Black	1.5m	32.43	13.60	2.68	96.01	38.95	57.06	-11.42	5.99	5.13	17.62	71.26	88.87	150	233.55	7.98
		Dark Grey	2.8m	36.76	13.84	2.69	72.39	31.05	41.34	13.82	0.52	14.19	30.75	54.54	85.29	118	200.00	6.62
Addis Ketema	Pit-3	Grey	1.4m	40.66	12.79	2.63	89.25	39.03	50.22	3.24	0.18	1.64	21.03	77.15	98.18	145	86.55	4.99
		Grey	2.5m	43.79	12.85	2.64	89.75	34.39	55.36	16.97	-	3.00	24.24	72.76	97.00	155	94.25	6.37
Cheri Primary School	Pit-4	Black	1.3m	47.42	11.92	2.56	90.37	30.85	59.52	27.84	3.29	4.74	17.66	74.32	91.98	153	95.45	3.96
		Dark Grey	2.8m	45.53	12.62	2.61	90.42	35.36	55.06	18.47	2.97	4.57	26.37	66.08	92.46	150	26.45	1.78
Gossu	Pit-5	Grey	1.5m	31.99	14.13	2.73	78.69	25.94	52.75	11.48	0.05	5.93	25.90	68.12	94.03	110	140.05	6.78
		Grey	3.0m	36.99	13.07	2.68	66.72	25.21	41.51	28.37	0.17	4.77	28.37	66.69	95.07	110	90.75	5.20
Faris	Pit-6	Dark Grey	1.5m	37.80	13.00	2.66	92.36	36.91	55.45	1.61	0.82	3.33	15.96	79.88	95.85	163	334.23	9.73
		Grey	3.0m	36.76	14.30	2.73	92.03	40.98	51.05	-8.26	0.01	2.31	17.02	80.66	97.68	153	374.25	9.84
Abba Tesas Sefar	Pit-7	Black	1.5m	43.46	12.43	2.62	101.19	40.53	60.66	4.83	2.01	8.90	20.17	68.92	89.09	130	95.65	3.19
		Dark Grey	3.0m	47.18	12.19	2.61	93.37	39.03	54.34	15.00	0.91	4.66	20.66	73.77	94.43	140	66.15	2.06
Studium	Pit-8	Grey	1.5m	40.30	13.18	2.68	69.85	32.63	37.22	20.61	0.13	4.00	28.90	66.97	95.87	135	58.90	2.06
		Dark Grey	2.8m	35.26	14.96	2.81	70.76	33.64	37.12	4.36	0.61	5.29	26.31	67.79	94.10	130	191.15	7.38
New Bole	Pit-9	Black	1.5m	42.64	12.47	2.63	77.79	29.03	48.76	27.91	2.06	15.80	15.79	66.35	82.14	145	82.00	2.80
		Black	3.0m	38.20	13.68	2.69	78.94	35.53	43.41	6.16	0.95	12.80	14.15	72.10	86.25	143	179.98	5.60
Awro Condominium	Pit-10	Black	1.2m	32.53	14.38	2.68	69.29	29.36	39.93	7.94	0.83	5.71	17.86	75.60	93.47	123	250.45	8.61
		Grey	2.5m	44.07	13.53	2.69	71.83	31.29	40.54	31.53	0.19	5.21	18.55	76.05	94.60	105	93.25	4.05

Chapter -5

Classification

5.1 General

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

- AASHTO,
- USCS and

Also other soil classification specific to expansive soils are: -

- Classification Soil Texture Grades and Groups (CSTGG)
- Classification of Expansive Soils (CES)
- Soil Expansivity Prediction by Liquid Limits and Plasticity Index (SEPLP)
- Expansive Soil Classification based on Atterberg Limits (ESCA)
- Classification of Swelling Soils and (CSS)
- Liquid Limit range and Site Classification (LLSC)

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

According to this system of soil classification, the expansive soil of Ambo town is classified as A-7-5 and A-7-6 groups, which shows that a soil is silt-clay materials. See table (5.1). One can also see AASHTO classification from the following figure. Sixteen (16) samples, PI < LL-30 therefore, they classified as A-7-5 and the rest four (4) samples with PI >LL-30 are classified as A-7-6. See (figure 5.1).

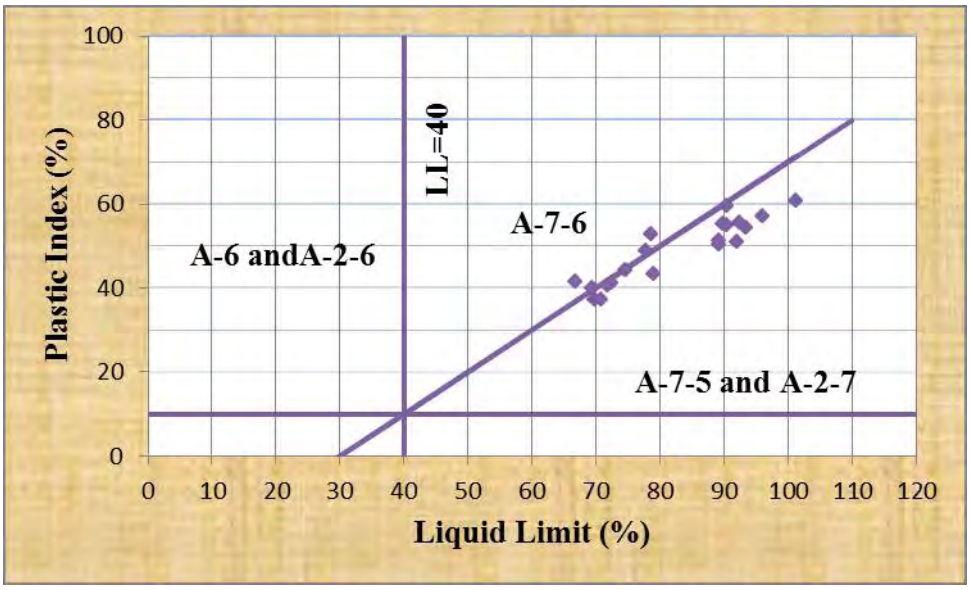

Figure 5.1: Scatter plots of Ambo expansive soils according to AASHTO classification

5.3 Engineering Unified Soil Classification System (USCS)

The classification of Ambo town expansive soil according to this classification system 2 samples are falls in MH whereas, 18 samples falls within CH region, which indicates that the soils is potentially expansive. See (Table 5.1).

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 (Figure 5.2).

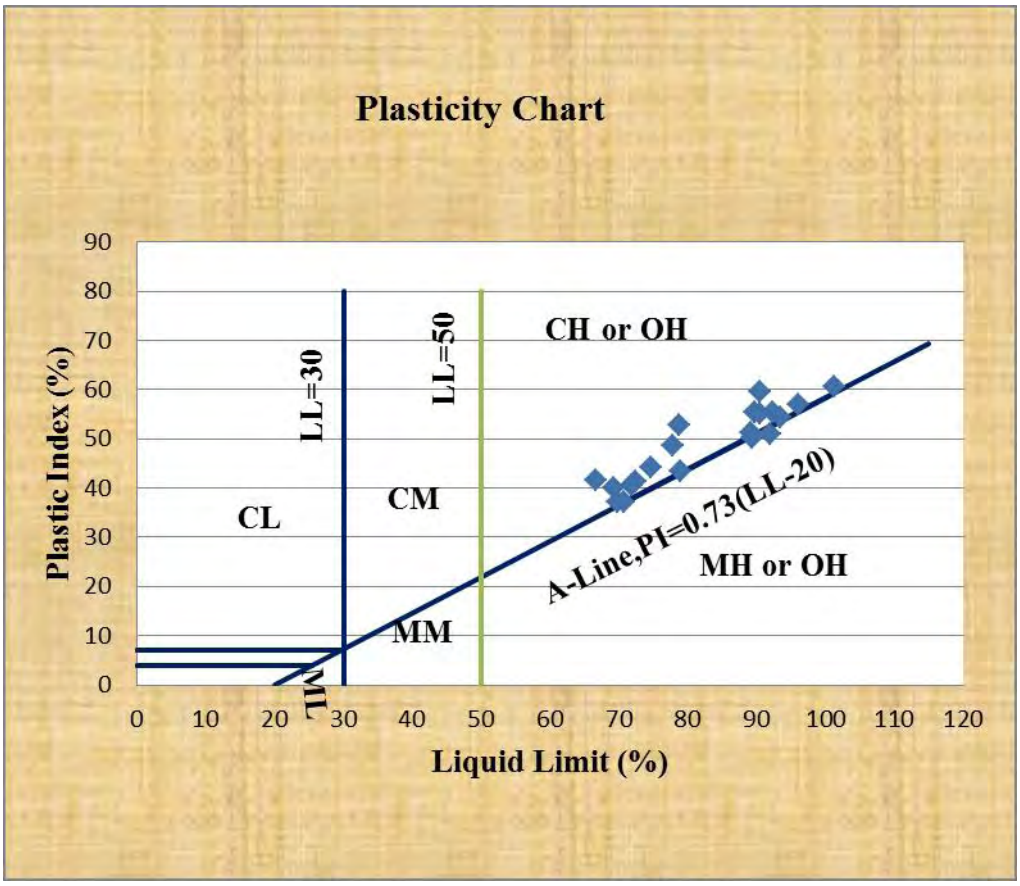

Figure 5.2: Scatter plots of Ambo expansive soils on Plasticity Chart according to (USCS)

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 Ambo town expansive soils are falls in the range of very high potential of expansiveness. See (Fig 5.3).

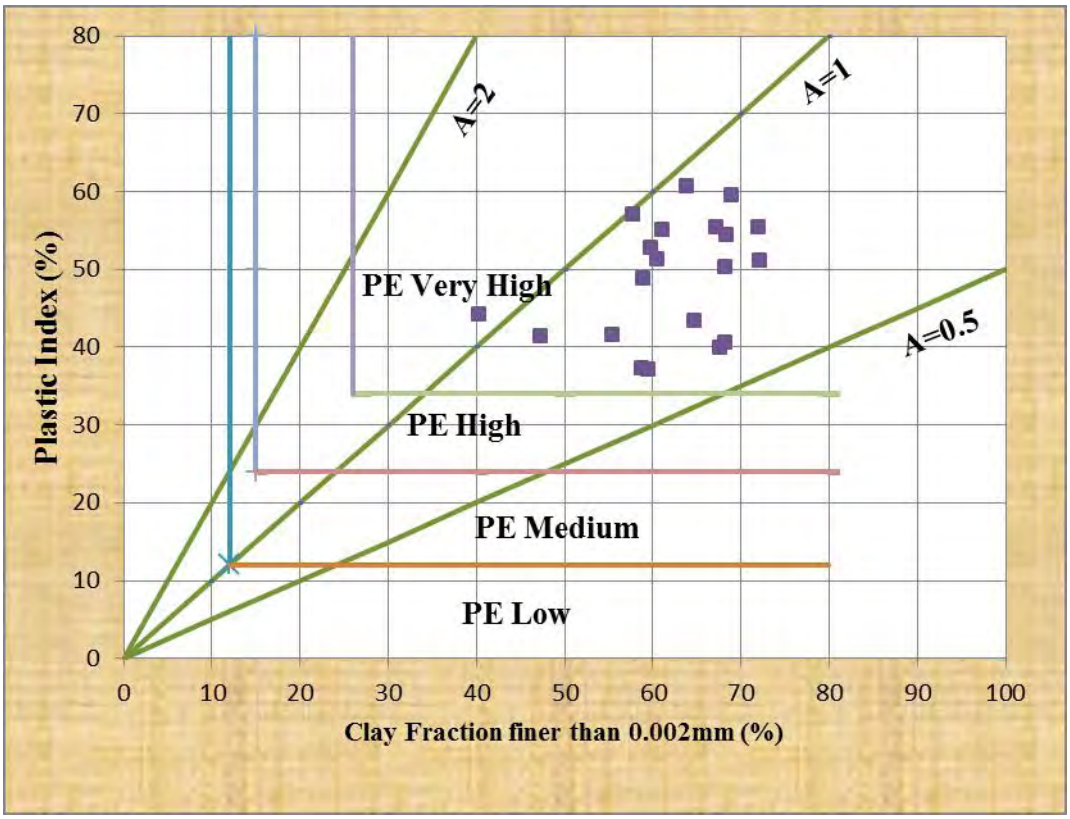

Figure 5.3: Scatter plots of Ambo expansive soils on Activity Chart using method of V.D. Merwe

5.4. Classification specific to expansive soil

In addition to the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) there are also other classification systems which may give a rough estimate that the soil may have expansive character and doesn't provide useful information. See table (5.2) the summary of classification of Ambo expansive soil according to these systems.

5.4.1 Classification Soil Texture Grades and Groups

This method is mainly focus on estimated clay contents to classify the expansive soils. Since this method use a single soil properties to classify, it is used only for rough estimates of potential expansiveness of expansive soils. According to this method the whole Ambo town expansive soils are classified as heavy clay. See table (5.2)

5.4.2 Classification of Expansive Soils

This method is focus plastic index, liquid limit and soil group to classify the expansive soils. Therefore it used only for rough estimates of potential expansiveness of expansive soils. According to this classification 9 samples are grouped under highly expansive whereas; the other 11 samples are classified as expansive clay stone. See table (5.2)

5.4.3 Soil Expansivity Prediction by Liquid Limits and Plasticity Index

Chen (1975) demonstrated that plasticity index and liquid limit are useful indices for determining the swelling characteristics of expansive soil. This method is focus plastic index and liquid limit to classify the expansive soils. Therefore it used only for rough estimates of potential expansiveness of expansive soils. According to this classification the whole samples are grouped under very highly expansive soils. See table (5.2).

5.4.4 Expansive Soil Classification based on Atterberg Limits

Snethen et al. (1977) re-evaluated the criteria for predicting soil swell behavior and found that the liquid limit, plasticity index, and soil suction at natural moisture content were good indicators of potential swell. According to this system the whole samples are grouped under high potential swell soils. See table (5.2).

5.4.5 Classification of Swelling Soils

If the liquid limit is less than 40 percent and the plasticity index is less than 15 percent are essentially non-expansive soils (Department of Army 1983).The Department of Army (1983) also classified the potential of swell according to their Atterberg limits and potential swell. Based on this method the whole samples are grouped under high swelling soils. See table (5.2).

5.4.6 Liquid Limit range and Site Classification

Kay (1990) showed that liquid limit is a sufficiently good indicator of shrink-swell response for natural soil in spite of the fact that the test is conducted on remolded soil. Since this system use one soil properties to classify, it is used only for rough estimates of potential expansiveness of expansive soils. According to this system 3 samples are classified as highly expansive and 17 samples are grouped under extremely expansive soils. See table (5.2).

Table 5.1: Summary of Classification of Ambo expansive soils according to AASHTO and USC system

Sample No.	Location	Depth (m)	Atterbrg Limit			Grain size Analysis					Classifications of Ambo Expansive Soils	
			LL (%)	PL (%)	PI (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	% P_{200}	AASHTO Class.	USCS Class.
1	Geba Mishion	1.5m	74.65	30.48	44.17	1.09	4.22	38.53	56.16	94.69	A-7-5	CH
2		3.0m	89.21	37.93	51.28	0.92	2.69	21.74	74.65	96.39	A-7-5	CH
3	Awura Godana	1.5m	96.01	38.95	57.06	5.99	5.13	17.62	71.26	88.87	A-7-5	CH
4		2.8m	72.39	31.05	41.34	0.52	14.19	30.75	54.54	85.29	A-7-5	CH
5	Addis Ketema	1.4m	89.25	39.03	50.22	0.18	1.64	21.03	77.15	98.18	A-7-5	MH
6		2.5m	89.75	34.39	55.36	-	3.00	24.24	72.76	97.00	A-7-5	CH
7	Cheri Primary School	1.3m	90.37	30.85	59.52	3.29	4.74	17.66	74.32	91.98	A-7-5	CH
8		2.8m	90.42	35.36	55.06	2.97	4.57	26.37	66.08	92.46	A-7-5	CH
9	Gossu	1.5m	78.69	25.94	52.75	0.05	5.93	25.90	68.12	94.03	A-7-6	CH
10		3.0m	66.72	25.21	41.51	0.17	4.77	28.37	66.69	95.07	A-7-6	CH
11	Faris	1.5m	92.36	36.91	55.45	0.82	3.33	15.96	79.88	95.85	A-7-5	CH
12		3.0m	92.03	40.98	51.05	0.01	2.31	17.02	80.66	97.68	A-7-5	MH
13	Abba Tesas Sefar	1.5m	101.19	40.53	60.66	2.01	8.90	20.17	68.92	89.09	A-7-5	CH
14		3.0m	93.37	39.03	54.34	0.91	4.66	20.66	73.77	94.43	A-7-5	CH
15	Studium	1.5m	69.85	32.63	37.22	0.13	4.00	28.90	66.97	95.87	A-7-5	CH
16		2.8m	70.76	33.64	37.12	0.61	5.29	26.31	67.79	94.10	A-7-5	CH
17	New Bole	1.5m	77.79	29.03	48.76	2.06	15.80	15.79	66.35	82.14	A-7-6	CH
18		3.0m	78.94	35.53	43.41	0.95	12.80	14.15	72.10	86.25	A-7-5	CH
19	Awro Condominium	1.2m	69.29	29.36	39.93	0.83	5.71	17.86	75.60	93.47	A-7-6	CH
20		2.5m	71.83	31.29	40.54	0.19	5.21	18.55	76.05	94.60	A-7-5	CH

Table 5.2: Summary of Classification of Ambo expansive soils according to Classification Specific to Expansive Soil

Sample No.	Location	Depth (m)	Atterbrg Limit			Clay (%)	SPO (%)	Classification of Ambo Expansive Soils					
			LL(%	PL(%)	PI(%)			CSTGG	CES	SEPLP	ESCA	CSS	LLSC
1	Geba Mishion	1.5m	74.65	30.48	44.17	56.16	1.80	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
2		3.0m	89.21	37.93	51.28	74.65	3.26	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
3	Awura Godana	1.5m	96.01	38.95	57.06	71.26	7.98	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
4		2.8m	72.39	31.05	41.34	54.54	6.62	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
5	Addis Ketema	1.4m	89.25	39.03	50.22	77.15	4.99	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
6		2.5m	89.75	34.39	55.36	72.76	6.37	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
7	Cheri Primary School	1.3m	90.37	30.85	59.52	74.32	3.96	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
8		2.8m	90.42	35.36	55.06	66.08	1.78	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
9	Gossu	1.5m	78.69	25.94	52.75	68.12	6.78	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
10		3.0m	66.72	25.21	41.51	66.69	5.20	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Highly Expansive
11	Faris	1.5m	92.36	36.91	55.45	79.88	9.73	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
12		3.0m	92.03	40.98	51.05	80.66	9.84	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
13	Abba Tesas Sefar	1.5m	101.19	40.53	60.66	68.92	3.19	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
14		3.0m	93.37	39.03	54.34	73.77	2.06	Heavy Clay	Expansive Clay Stone	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
15	Studium	1.5m	69.85	32.63	37.22	66.97	2.06	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Highly Expansive
16		2.8m	70.76	33.64	37.12	67.79	7.38	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
17	New Bole	1.5m	77.79	29.03	48.76	66.35	2.80	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
18		3.0m	78.94	35.53	43.41	72.10	5.60	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive
19	Awro Condominium	1.2m	69.29	29.36	39.93	75.60	8.61	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Highly Expansive
20		2.5m	71.83	31.29	40.54	76.05	4.05	Heavy Clay	Highly Expansive	Very Highly Expansive	High Potential Swell	High Swelling	Extremely Expansive

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 Ambo 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 in swelling potential.

6.2 Regression Analysis and Scatter plots

Regression analysis is an important technique in engineering and science to model and studying 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)) % see (Appendix).

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 statement 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).

6.2.1 Scatter Plot

In this paper, swelling potential is taken as the dependent variable whereas the moisture content, dry density, liquid limit, plastic limit, plastic index, percent finer than 0.075mm, clay content and CEC are independent variables. Earlier to carrying out the regression analysis using the twenty test results, a scatter plot is created by using the Excel Spreadsheet, in order to study the relationships developed between the dependent variable and the independent variables so as to determine the model that best suits the test results (see Appendix D).

6.2.2 Regression Analysis

In this paper, an attempt is made to apply single linear regression model and multiple linear regression models to distinguish 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:

$$Y = a_0 + a_1 x + c \quad (6.1)$$

$$Y = b_0 + b_1 x_1 + b_2 x_2 \ldots + b_n x_n + c \quad (6.2)$$

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 regression coefficients. The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model) plus the residual term, c [11]. 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 twenty laboratory test results of the independent and dependent variables are used in the following regression analysis.

6.2.2.1 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 (SPO) with Moisture Content (Wl)

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

SPO = 21.1669-0.4011*Wl, (R^2 = 0.5258, n = 20, C_L=99.99%)

The results of the statistical out-put shows that the relationship developed between SPO and Wl is reasonable (C_L=99.99%) because C_L>95% and this shows existence of strong relationship between the correlated variables. See the ANOVA analysis of Excel output in Appendix.

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

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

SPO = -22.9649+2.1324*γ_d, (R^2 = 04472, n = 20, C_L=99.63%)

The results of the statistical out-put shows that the relationship developed between SPO and γ_d is reasonable (C_L=99.63%) because C_L>95% and this shows existence of strong relationship between the correlated variables.

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

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

SPO = 5.6694-0.0096*PI, (R^2 = 0.0008, n = 20, C_L=45.64%)

The results of the statistical out-put shows that the relationship developed between SPO and PI is not reasonable (C_L=45.64%) because C_L<<95% and this shows existence of very weak relationship between the correlated variables.

Equation 4: Correlation of Swelling Potential (SPO) with Plastic Limit (PL)

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

SPO = 3.6139+0.0469*PL, (R^2 = 0.0071, n = 20, C_L=42.24%)

The results of the statistical out-put shows that the relationship developed between SPO and PL is not reasonable (C_L=42.24%) because C_L<<95% and this shows existence of very weak relationship between the correlated variables.

Equation 5: Correlation of Swelling Potential (SPO) with Liquid Limit (LL)

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

SPO = 5.5905-0.0046*LL, (R^2 = 0.0004, n = 20, C_L=41.82%)

The results of the statistical out-put shows that the relationship developed between SPO and LL is not reasonable (C_L=41.82%) because C_L<<95% and this shows existence of very weak relationship between the correlated variables.

Equation 6: Correlation of Swelling Potential (SPO) with % P_{200}

The output of regression analysis of correlating SPO with % P_{200} is given by the following single linear equation. The mean confidence level and determination coefficient is also given in the bracket:

SPO = –1.9782+0.0773*% P_{200}, (R^2 = 0.0165, n = 20, C_L=26.45%)

The results of the statistical out-put shows that the relationship developed between SPO and % P_{200} is not reasonable (C_L=26.45%) because C_L<<95% and this shows existence of very weak relationship between the correlated variables.

Equation 7: Correlation of Swelling Potential (SPO) with Clay Content

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

SPO = –5.7672+0.1556*Clay Content, (R^2 = 0.1623, n = 20, C_L=79.03%)

The results of the statistical out-put shows that the relationship developed between SPO and Clay Content is not reasonable (C_L=79.03%) because C_L<95% and this shows existence of weak relationship between the correlated variables.

Equation 8: Correlation of Swelling Potential (SPO) with Cation Exchange Capacity (CEC)

The output of regression analysis of correlating SPO with Cation Exchange Capacity is given by the following single linear equation. The mean confidence level and determination coefficient is also given in the bracket:

SPO = 19.6377-0.2606*CEC, (R^2 = 0.1192, n = 20, C_L=73.78%)

The results of the statistical out-put shows that the relationship developed between SPO and Cation Exchange Capacity (CEC) is not reasonable (C_L=73.78%) because C_L< 95% and this shows existence of weak relationship between the correlated variables.

6.2.2.2 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 SPO with PI and PL, n = 20

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

SPO = 2.7809-0.1125*PI+0.2581*PL, (R^2 = 0.0814, Adj.R^2 = -0.0267, C_L=54.18%)

The results of the statistical out-put shows that the relationship developed between SPO with PI and PL is not reasonable (C_L=54.18%) because C_L< 95% and this shows existence of weak relationship between the correlated variables, but the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Equation B: Correlation of SPO with γd and PI, n = 20

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

SPO = –45.1887+3.1226* γ_d +0.1872*PI, (R^2 = 0.6401, Adj.R^2 = 0.5977, C_L=99.73%)

The results of the statistical out-put shows that the relationship developed between SPO with γd and PI is reasonable (C_L=99.73%) because C_L> 95% and this shows existence of strong relationship between the correlated variables, in addition the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Equation C: Correlation of SPO with γd and LL, n = 20

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

SPO = –42.0376+2.8611* γ_d +0.1142*LL, (R^2 = 0.6082, Adj.R^2 = 0.5621, C_L=99.41%)

The results of the statistical out-put shows that the relationship developed between SPO with γd and LL is reasonable (C_L=99.41%) because C_L> 95% and this shows existence of strong relationship between the correlated variables, in addition the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Equation D: Correlation of SPO with γd, PI and LL, n = 20

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

SPO = –45.2815+3.1143* γ_d +0.1714*PI+0.0118*LL, (R^2 = 0.6404, Adj.R^2 = 0.5730, C_L=71.18%)

The results of the statistical out-put shows that the relationship developed between SPO with γ_d, PI and LL is not reasonable (C_L=71.18%) because C_L< 95% and this shows existence of weak relationship between the correlated variables, but the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Equation E: Correlation of SPO with γd, PL and Clay Content, n = 20

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

SPO = –35.9966+2.2101* γ_d +0.0113*PL+0.1649*Clay Content, (R^2 = 0.6371, Adj.R^2 = 0.5691, C_L=76.71%)

The results of the statistical out-put shows that the relationship developed between SPO with γ_d, PL and Clay Content is not reasonable (C_L=76.71%) because C_L< 95% and this shows existence of weak relationship between the correlated variables, but the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Equation F: Correlation of SPO with γd, LI and Clay Content, n = 20

The output of regression analysis of correlating SPO with γd, LI and Clay Content and is given by the following multiple linear equation. The mean confidence level, determination coefficient and Adj. R- square values are also given in the bracket:

SPO = –26.8695+1.8437* γ_d -0.0613*LI+0.1204*Clay Content, (R^2 = 0.6939, Adj.R^2 = 0.6365, C_L=95.61%)

The results of the statistical out-put shows that the relationship developed between SPO with γd, LI and Clay Content is reasonable (C_L=95.61%) because C_L> 95% and this shows existence of strong relationship between the correlated variables, but the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Equation G: Correlation of SPO with Wl, LI and CEC, n = 20

The output of regression analysis of correlating SPO with Wl, LI and CEC and is given by the following multiple linear equation. The mean confidence level, determination coefficient and Adj. R-square values are also given in the bracket:

SPO = 16.0402-0.2571*Wl-0.0888*LI+0.0055*CEC, (R^2 = 0.6382, Adj.R^2 = 0.4572, C_L=58.41%)

The results of the statistical out-put shows that the relationship developed between SPO with Wl, LI and CEC is not reasonable (C_L=58.41%) because C_L< 95% and this shows existence of weak relationship between the correlated variables, but the Adj.R^2 value of the multiple linear regression analysis is improved than the Adj.R^2 value of the single linear regression analysis.

Where for equations 1-8 and A-G above: -

SPO= Swelling potential (%)

Wl= Natural moisture content (%)

CEC=Cation exchange capacity

Clay fraction=Percentages of clay with equivalent diameters is than 0.005mm (%)

P_{200}=Percentages of finer than 0.075mm (%)

$\gamma_{d=}$ Dry density (kN/m^3),

PI = Plasticity index (%)

PL = Plasticity limit (%),

LL = Liquid limit (%) and

LI =Liquidity index (%)

SPR= Swelling pressure (kPa)

Table 6.1 Detail summaries of the developed correlations

No.	Types of regression	Number of samples	Developed Equations	R values	R square (R^2)	Adjusted R square (Adj. R_2)	Mean confidence level (C_L)	Standard error	Order of equation	Order of accuracy
1	Single	20	SPO = 21.1669-0.4011*Wl	0.7263	0.5258	0.5012	99.99%	1.8590	1	1st
2	Single	20	SPO = -22.9649+2.1324*γ_d	0.6687	0.4472	0.4165	99.63%	2.0108	1	2nd
3	Single	20	SPO = 5.6694-0.0096*PI	0.0274	0.0008	-0.0548	45.64%	2.7033	1	5th
4	Single	20	SPO = 3.6139+0.0469*PL	0.0840	0.0071	-0.0481	42.24%	2.6948	1	6th
5	Single	20	SPO = 5.5905-0.0046*LL	0.0204	0.0004	-0.0551	41.82%	2.7038	1	7th
6	Single	20	SPO = –1.9782+0.0773*% P_{200}	0.1284	0.0165	-0.0382	26.45%	2.6820	1	8th
7	Single	20	SPO = –5.7672+0.1556*Clay Content	0.4029	0.1623	0.1158	79.03%	2.4752	1	3rd
8	Single	20	SPO = 19.6377-0.2606*CEC	0.3452	0.1192	0.0091	73.78%	2.8769	1	4th
A	Multiple	20	SPO = 2.7809-0.1125*PI+0.2581*PL	0.2853	0.0814	-0.0267	54.18%	3.9311	2	7th
B	Multiple	20	SPO = –45.1887+3.1226*γ_d+0.1872*PI	0.8000	0.6401	0.5977	99.73%	1.6695	2	1st
C	Multiple	20	SPO = –42.0376+2.8611*γ_d+0.1142*LL	0.7799	0.6082	0.5621	99.41%	1.7419	2	`2nd
D	Multiple	20	SPO = –45.2815+3.1143*γ_d+0.1714*PI +0.0118*LL	0.8003	0.6404	0.5730	71.18%	1.7201	3	5th
E	Multiple	20	SPO = –35.9966+2.2101*γ_d+0.0113*PL +0.1649*Clay Content	0.7982	0.6371	0.5691	76.71%	1.7279	3	4th
F	Multiple	20	SPO = –26.8695+1.8437*γ_d -0.0613*LI +0.1204*Clay Content	0.8330	0.6939	0.6365	95.61%	1.5871	3	3rd
G	Multiple	20	SPO = 16.0402-0.2571*Wl-0.0888*LI +0.0055*CEC	0.7988	0.6382	0.4572	58.41%	2.1292	3	6th

6.3 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

$$SPO=0.23*PI-3.12, \quad (6.3)$$

2) Seed, Woodward and Lund green

$$SPO=60K\,(PI)^{2.44} \quad (6.4)$$

3) Seed et al

$$SPO=\frac{3.6*10^{-5}\,(PI^{2.44}\,C^{3.44})}{(C-n)^{2.44}} \quad (6.5)$$

Where: - SPO= 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 SPO from a single parameter. Whereas, in the previous section SPO was correlated with different index soils tests in different combination.

6.4 Discussion on the developed and existing correlation

6.4.1 Testing for the validity of developed equation

To test for validation of the developed correlation equation the comparison of actual laboratory test results with the calculated swelling potential is necessary. Depending on the swelling pressure test results and the formula developed between these two variables,

Equation (SPO =1.6072+0.0252*SPR) is preferably selected among the different alternatives to test the validity of developed correlation. The results are tabulated in (Table 6.2).

Table 6.2 Control test results and calculated Swelling Potential

Sample No.	Control Test Result		Calculated SPO Value (%)
	Actual SPR (kPa)	Actual SPO Value (%)	
1	44.85	1.80	2.74
2	110.80	3.26	4.40
3	233.55	7.98	7.49
4	200.00	6.62	6.65
5	86.55	4.99	3.79
6	94.25	6.37	3.98
7	95.45	3.96	4.01
8	26.45	1.78	2.27
9	140.05	6.78	5.14
10	90.75	5.20	3.89
11	334.23	9.73	10.03
12	374.25	9.84	11.04
13	95.65	3.19	4.02
14	66.15	2.06	3.27
15	58.90	2.06	3.09
16	191.15	7.38	6.42
17	82.00	2.80	3.67
18	179.98	5.60	6.14
19	250.45	8.61	7.92
20	93.25	4.05	3.96

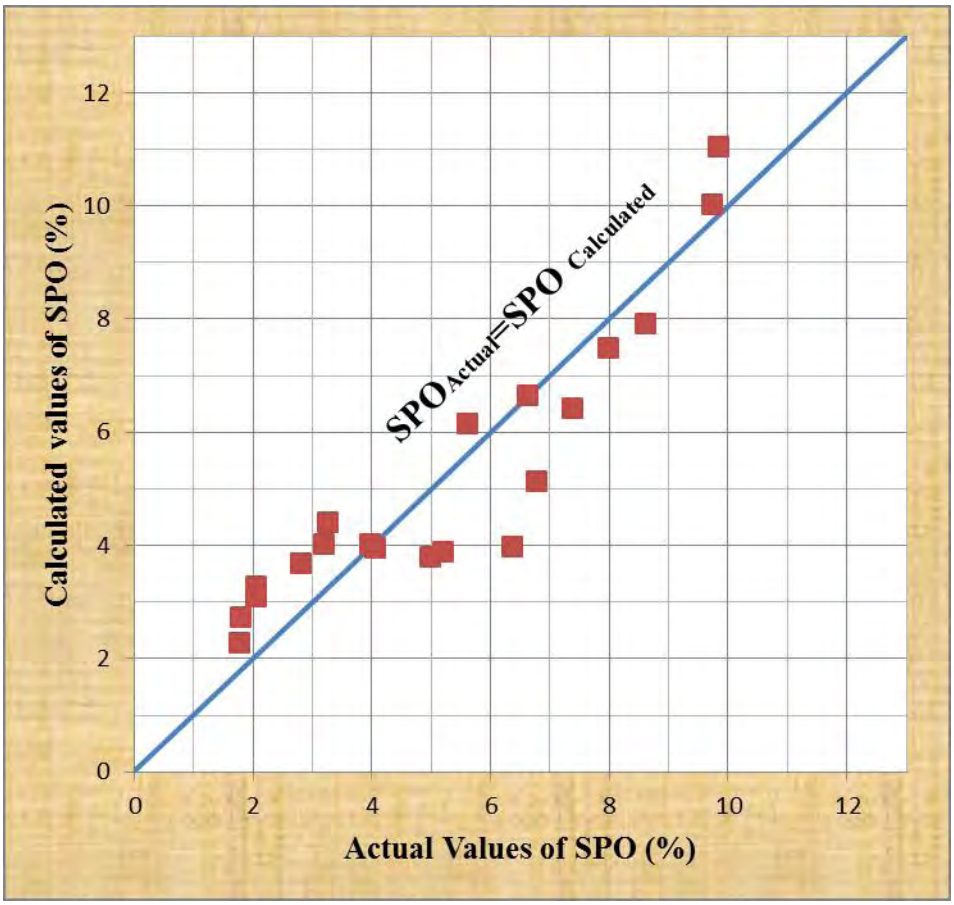

Figure 6.1: Control test results and calculated Swelling Potential

As one can see from the above graph a majority of the calculated values of swelling potential falls a little above or below, whereas some of them show variation from the actual SPO.

6.4.2 Relationship of developed with existing correlations

Tables 6.3, below shows the Anderson et al correlation resulted in an average difference from the actual by 110.63% over estimating the calculated SPO values. Also, the Seed, Woodward and Lund green correlation resulted in an average difference from the actual by 671.70% highly over estimating the calculated SPO value whereas, the Seed et al correlation resulted in an average difference from the actual by 876.37% extremely over estimating the calculated SPO value. Finally, the developed correlation estimates the calculated SPO value with average difference of 42.15% from the actual SPO value. At the end one can conclude that, as it is uneconomical (impossible) to predict (estimates) the swelling potential of the study area from the above existing correlations (swelling potential predicting models).

Table 6.3 Relashionship of developed and Existing Correlations

Sample No.	Actual (Control) Values				Developed Correlation		Existing Correlations					
							Anderson et al		Seed, Woodward and Lund green		Seed et al	
	SPO (%)	γ_d (KN/M^3)	PI (%)	Clay Finer than 0.001mm (%)	Calculated SPO (%)	Difference from Actual(%)	Calculated SPO (%)	Difference from Actual(%)	Calculated SPO (%)	Difference from Actual(%)	Calculated SPO (%)	Difference from Actual(%)
1	1.80	13.04	44.17	40.39	4.81	167.09	7.04	291.06	22.31	1,139.60	20.74	1,051.98
2	3.26	12.21	51.28	60.56	3.67	12.53	8.67	166.07	32.11	885.05	40.00	1,126.89
3	7.98	13.60	57.06	57.80	9.12	14.31	10.00	25.35	41.67	422.21	50.06	527.34
4	6.62	13.84	41.34	47.31	6.71	1.39	6.39	-3.50	18.99	186.80	19.66	196.99
5	4.99	12.79	50.22	68.26	5.25	5.18	8.43	68.95	30.52	511.64	41.80	737.76
6	6.37	12.85	55.36	67.24	6.46	1.48	9.61	50.91	38.71	507.73	52.39	722.38
7	3.96	11.92	59.52	68.91	4.43	11.74	10.57	166.91	46.20	1,066.64	63.77	1,510.23
8	1.78	12.62	55.06	61.09	5.69	219.86	9.54	436.17	38.20	2,046.22	47.91	2,591.41
9	6.78	14.13	52.75	59.85	9.89	45.94	9.01	32.91	34.40	407.42	42.46	526.21
10	5.20	13.07	41.51	55.44	4.37	-16.01	6.43	23.61	19.18	268.82	22.32	329.18
11	9.73	13.00	55.45	71.98	6.95	-28.61	9.63	-0.99	38.87	299.45	55.58	471.24
12	9.84	14.30	51.05	72.12	10.08	2.44	8.62	-12.38	31.77	222.83	45.50	362.40
13	3.19	12.43	60.66	63.94	6.23	95.28	10.83	239.55	48.39	1,416.86	62.90	1,871.75
14	2.06	12.19	54.34	68.44	4.22	104.93	9.38	355.30	37.00	1,696.20	50.79	2,365.49
15	2.06	13.18	37.22	58.74	3.85	86.72	5.44	164.08	14.69	613.22	17.87	767.52
16	7.38	14.96	37.12	59.58	9.33	26.36	5.42	-26.60	14.60	97.77	17.95	143.21
17	2.80	12.47	48.76	58.94	3.97	41.65	8.09	189.07	28.40	914.13	34.63	1,136.78
18	5.60	13.68	43.41	64.69	6.63	18.45	6.87	22.59	21.39	282.00	28.07	401.18
19	8.61	14.38	39.93	67.66	8.10	-5.96	6.06	-29.58	17.44	102.56	23.72	175.48
20	4.05	13.53	40.54	68.24	5.59	38.12	6.20	53.19	18.10	346.91	24.79	511.99
Average	5.20	13.21	48.84	62.06	6.27	42.15	8.11	110.63	29.65	671.70	38.14	876.37

Chapter-7

Conclusion and Recommendation

7.1 Conclusions

Based on the obtained test results to predict the SPO a single and multiple linear regressions were examined by testing the validity the developed correlation and finally the following conclusions are made:

1. After testing the suitability of the existing correlation with control test results, clearly one can see that from chapter-6, the existing SPO predicting models by different researchers' shows overestimation from the actual test results and are inadvisable (uneconomical) to calculate SPO from the above existing correlations.
2. 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.
3. From the single linear regression analysis developed above, the relationship between SPO with moisture content is the best among equations developed to calculate SPO from a single index property test.
4. From the multiple linear regression analysis developed above, 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.

7.2 Recommendation for future works

From this thesis, areas which need further improvement are identified. As a result the following recommendation is made:

1. The equations developed may be further improved by increasing numbers of samples collected from different locations of Ambo town especially from areas cannot covered in this paper.
2. It is also suggested to perform such a similar study in other parts of Ethiopia especially areas where expansive soils are abundant.

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APPENDIXA: Findings of the ANOVA Excel Analysis Outputs

APPENDIX1: The Outputs of Single Linear Analysis

Equation 1: Correlation of swelling potential (SPO) with moisture content (Wl)

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.726277					
R Square	0.527478					
Adjusted R Square	0.501227					
Standard Error	1.858986					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	69.43950383	69.43950383	20.0934	0.000287858	
Residual	18	62.20491617	3.455828676			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	21.1669	3.585504493	5.903465679	1.4E-05	13.6340373	28.69976813
X Variable 1	-0.40112	0.089484639	-4.482571262	0.00029	-0.58912152	-0.21312102
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	4.074672	-2.27467234	-1.25713898		2.5	1.78
2	5.296776	-2.036775955	-1.125661222		7.5	1.8
3	8.156948	-0.176948038	-0.097793547		12.5	2.06
4	6.42108	0.198919648	0.109936556		17.5	2.06
5	4.857494	0.132506264	0.073231993		22.5	2.8
6	3.602915	2.767085139	1.529279856		27.5	3.19
7	2.145263	1.814736565	1.00294712		32.5	3.26
8	2.903609	-1.12360936	-0.620983119		37.5	3.96
9	8.333046	-1.553046378	-0.858319286		42.5	4.05
10	6.331139	-1.131138665	-0.625144326		47.5	4.99
11	6.004041	3.725959263	2.059219055		52.5	5.2
12	6.42108	3.418919648	1.889528035		57.5	5.6
13	3.734374	-0.544373641	-0.300857979		62.5	6.37
14	2.240277	-0.1802766	-0.099633137		67.5	6.62
15	5.001045	-2.941044837	-1.625421842		72.5	6.78
16	7.024304	0.355696438	0.196582097		77.5	7.38
17	4.063351	-1.263350799	-0.698213763		82.5	7.98
18	5.842763	-0.242762563	-0.134167139		87.5	8.61
19	8.117623	0.492376835	0.272121		92.5	9.73
20	3.488201	0.561799376	0.310488628		97.5	9.84

Equation 2: Correlation of swelling potential (SPO) with dry density (γ_d)

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.66871246					
R Square	0.44717636					
Adjusted R Square	0.41646393					
Standard Error	2.01075093					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	58.86827235	58.86827235	14.56011	0.0012661	
Residual	18	72.77614765	4.043119314			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-22.964887	7.395643642	-3.10519117	0.00611	-38.5025581	-7.427217
X Variable 1	2.13239618	0.558837485	3.815771556	0.001266	0.958322191	3.3064702
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	4.84155885	-3.041558848	-1.554098326		2.5	1.78
2	3.07167002	0.188329982	0.096228061		7.5	1.8
3	6.03570071	1.944299292	0.993448566		12.5	2.06
4	6.54747579	0.072524209	0.037056574		17.5	2.06
5	4.3084598	0.681540197	0.348236063		22.5	2.8
6	4.43640357	1.933596427	0.987979888		27.5	3.19
7	2.45327513	1.506724874	0.769867927		32.5	3.26
8	3.94595245	-2.165952452	-1.106703256		37.5	3.96
9	7.16587068	-0.385870683	-0.197162381		42.5	4.05
10	4.90553073	0.294469267	0.150460411		47.5	4.99
11	4.756263	4.973737	2.54135354		52.5	5.2
12	7.52837803	2.311621966	1.181133757		57.5	5.6
13	3.54079718	-0.350797178	-0.179241413		62.5	6.37
14	3.02902209	-0.969022095	-0.495126246		67.5	6.62
15	5.14009431	-3.080094313	-1.573788197		72.5	6.78
16	8.93575951	-1.555759513	-0.794922398		77.5	7.38
17	3.62609303	-0.826093025	-0.422095988		82.5	7.98
18	6.2062924	-0.606292403	-0.30978786		87.5	8.61
19	7.69896973	0.911030272	0.465495061		92.5	9.73
20	5.88643298	-1.836432976	-0.938333781		97.5	9.84

Equation 3: Correlation of swelling potential (SPO) with plastic index (PI)

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.027436					
R Square	0.000753					
Adjusted R Square	-0.05476					
Standard Error	2.703345					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	0.099096803	0.099096803	0.01356	0.908587655	
Residual	18	131.5453232	7.308073511			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5.669408	4.050682445	1.399618008	0.17863	-2.84075993	14.179576
X Variable 1	-0.00955	0.082014088	-0.116447017	0.90859	-0.1818555	0.1627549
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	5.247576	-3.447575569	-1.310246139		2.5	1.78
2	5.179693	-1.919693483	-0.729576749		7.5	1.8
3	5.124495	2.855504935	1.085230546		12.5	2.06
4	5.274586	1.345413967	0.511322644		17.5	2.06
5	5.189792	-0.199792233	-0.075930751		22.5	2.8
6	5.140704	1.229296288	0.467192287		27.5	3.19
7	5.100974	-1.140974481	-0.433625712		32.5	3.26
8	5.143569	-3.363568801	-1.278319488		37.5	3.96
9	5.165669	1.61433087	0.613524127		42.5	4.05
10	5.27295	-0.072949623	-0.0277244		47.5	4.99
11	5.139841	4.590158645	1.744483195		52.5	5.2
12	5.181861	4.658139296	1.770319144		57.5	5.6
13	5.090087	-1.900087144	-0.722125388		62.5	6.37
14	5.150408	-3.090407637	-1.17450498		67.5	6.62
15	5.313966	-3.253965676	-1.236664978		72.5	6.78
16	5.31493	2.065069912	0.784826852		77.5	7.38
17	5.203769	-2.403769427	-0.913549116		82.5	7.98
18	5.254799	0.345200522	0.131192962		87.5	8.61
19	5.288086	3.321914119	1.262488686		92.5	9.73
20	5.282244	-1.232244481	-0.468312744		97.5	9.84

Equation 4: Correlation of swelling potential (SPO) with plastic limit (PL)

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.0840498					
R Square	0.0070644					
Adjusted R Square	-0.048099					
Standard Error	2.6947937					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	0.929984697	0.929984697	0.12806	0.72461059	
Residual	18	130.7144353	7.261913072			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.6138858	4.481307903	0.806435515	0.43052	-5.8009927	13.02876
X Variable 1	0.0468682	0.130968291	0.357859358	0.72461	-0.22828594	0.322022
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	5.0424294	-3.242429449	-1.236190951		2.5	1.78
2	5.3915978	-2.131597751	-0.812681322		7.5	1.8
3	5.4394033	2.540596656	0.968614011		12.5	2.06
4	5.0691443	1.55085566	0.591270763		17.5	2.06
5	5.4431528	-0.453152802	-0.172766564		22.5	2.8
6	5.2256842	1.144315777	0.436275586		27.5	3.19
7	5.0597707	-1.099770694	-0.419292571		32.5	3.26
8	5.2711464	-3.491146404	-1.331015419		37.5	3.96
9	4.8296477	1.950352308	0.743580674		42.5	4.05
10	4.7954339	0.404566114	0.154242668		47.5	4.99
11	5.3437922	4.386207842	1.672261657		52.5	5.2
12	5.5345458	4.305454152	1.641473946		57.5	5.6
13	5.5134551	-2.323455145	-0.885827824		62.5	6.37
14	5.4431528	-3.383152802	-1.289842368		67.5	6.62
15	5.1431961	-3.083196141	-1.175482529		72.5	6.78
16	5.1905331	2.189466949	0.834744216		77.5	7.38
17	4.9744705	-2.174470518	-0.829026759		82.5	7.98
18	5.279114	0.320885997	0.122339243		87.5	8.61
19	4.989937	3.620062966	1.380165444		92.5	9.73
20	5.0803927	-1.030392714	-0.392841901		97.5	9.84

Equation 5: Correlation of swelling potential (SPO) with liquid limit (LL)

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.02040331					
R Square	0.00041629					
Adjusted R Square	-0.0551161					
Standard Error	2.70379997					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*ignificance F*	
Regression	1	0.054802896	0.054802896	0.0075	0.9319597	
Residual	18	131.5896171	7.310534284			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5.59053954	4.516634548	1.237766635	0.23171	-3.898558	15.07964
X Variable 1	-0.0046391	0.053580387	-0.086581916	0.93196	-0.117207	0.107929
RESIDUAL OUTPUT					PROBABILITY OUTPU	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	5.24423325	-3.44423325	-1.308755573		2.5	1.78
2	5.17669803	-1.916698029	-0.728315722		7.5	1.8
3	5.14515331	2.834846687	1.077198067		12.5	2.06
4	5.2547094	1.365290597	0.518789393		17.5	2.06
5	5.16713471	-0.177134707	-0.06730846		22.5	2.8
6	5.16091273	1.209087266	0.459434534		27.5	3.19
7	5.15841256	-1.198412555	-0.455378308		32.5	3.26
8	5.15741403	-3.377414026	-1.283365297		37.5	3.96
9	5.22550837	1.554491634	0.590682872		42.5	4.05
10	5.28100681	-0.081006811	-0.03078134		47.5	4.99
11	5.16207158	4.567928419	1.735742425		52.5	5.2
12	5.16360153	4.676398468	1.776959372		57.5	5.6
13	5.09655547	-1.906555475	-0.724461708		62.5	6.37
14	5.15736932	-3.097369316	-1.176952622		67.5	6.62
15	5.26650845	-3.206508448	-1.21842381		72.5	6.78
16	5.26229143	2.117708569	0.80469663		77.5	7.38
17	5.22968093	-2.429680934	-0.923241323		82.5	7.98
18	5.22431487	0.375685126	0.14275456		87.5	8.61
19	5.26910707	3.340892928	1.269487842		92.5	9.73
20	5.25731614	-1.207316141	-0.458761533		97.5	9.84

Equation 6: Correlation of swelling potential (SPO) with % P_{200}

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.128406					
R Square	0.016488					
Adjusted R Square	-0.038152					
Standard Error	2.681976					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	2.170551667	2.170551667	0.30176	0.589532449	
Residual	18	129.4738683	7.192992685			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.978205	13.08650183	-0.151163771	0.88153	-29.4719251	25.51552
X Variable 1	0.077324	0.140762239	0.549326126	0.58953	-0.21840612	0.373055
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	5.343898	-3.5438979	-1.357584716		2.5	1.78
2	5.474834	-2.214833842	-0.848451241		7.5	1.8
3	4.89387	3.086129966	1.182224486		12.5	2.06
4	4.617049	2.00295123	0.767283949		17.5	2.06
5	5.613244	-0.623244474	-0.238750437		22.5	2.8
6	5.522259	0.847740541	0.32474965		27.5	3.19
7	5.133833	-1.173833346	-0.449668206		32.5	3.26
8	5.170949	-3.390949046	-1.298993574		37.5	3.96
9	5.292348	1.487651684	0.569884699		42.5	4.05
10	5.372766	-0.172765666	-0.066182502		47.5	4.99
11	5.433079	4.296921321	1.646050444		52.5	5.2
12	5.574582	4.265417714	1.633982146		57.5	5.6
13	4.910366	-1.720365901	-0.659032094		62.5	6.37
14	5.323794	-3.263793562	-1.25028327		67.5	6.62
15	5.434883	-3.374882915	-1.292839013		72.5	6.78
16	5.298277	2.081723482	0.797459764		77.5	7.38
17	4.373219	-1.573219239	-0.602663636		82.5	7.98
18	4.690765	0.909235325	0.348306869		87.5	8.61
19	5.249047	3.360953334	1.287502915		92.5	9.73
20	5.336939	-1.286938706	-0.492996234		97.5	9.84

Equation 7: Correlation of swelling potential (SPO) with clay content

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.4028876					
R Square	0.1623184					
Adjusted R Square	0.1157805					
Standard Error	2.4751667					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	21.36831234	21.36831234	3.48788	0.0781905	
Residual	18	110.2761077	6.126450426			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-5.767239	5.900037078	-0.977492022	0.34128	-18.1627571	6.628279
X Variable 1	0.1556241	0.08332902	1.867586172	0.07819	-0.01944365	0.330692
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	2.9732487	-1.17324869	-0.486996863		2.5	1.78
2	5.8500833	-2.590083254	-1.075102347		7.5	1.8
3	5.3218451	2.658154851	1.103357784		12.5	2.06
4	2.7207405	3.899259475	1.618520566		17.5	2.06
5	6.2384562	-1.248456169	-0.518214291		22.5	2.8
6	5.5565437	0.813456323	0.337652777		27.5	3.19
7	5.7983367	-1.838336716	-0.763064321		32.5	3.26
8	4.5169206	-2.736920575	-1.136052183		37.5	3.96
9	4.8343242	1.945675849	0.807619087		42.5	4.05
10	4.6117773	0.588222696	0.244161882		47.5	4.99
11	6.6647885	3.065211541	1.27232054		52.5	5.2
12	6.7847407	3.055259284	1.268189516		57.5	5.6
13	4.9583983	-1.76839827	-0.734033984		62.5	6.37
14	5.7134393	-3.653439271	-1.516484511		67.5	6.62
15	4.6555865	-2.595586468	-1.077386644		72.5	6.78
16	4.7825609	2.597439101	1.078155642		77.5	7.38
17	4.5587884	-1.758788433	-0.730045094		82.5	7.98
18	5.4527382	0.147261764	0.061126015		87.5	8.61
19	5.9982772	2.611722775	1.084084568		92.5	9.73
20	6.0684058	-2.018405814	-0.837808138		97.5	9.84

Equation 8: Correlation of swelling potential (SPO) with CEC

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.3452346					
R Square	0.1191869					
Adjusted R Square	0.0090853					
Standard Error	2.8769432					
Observations	10					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	8.959783053	8.959783053	1.08252	0.328555184	
Residual	8	66.21441695	8.276802118			
Total	9	75.1742				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	19.637648	13.9158514	1.411171141	0.19588	-12.45236297	51.72766
X Variable 1	-0.260623	0.250493024	-1.040441007	0.32856	-0.838261164	0.317015
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	4.9671672	-3.167167152	-1.167658808		5	1.8
2	4.6231445	3.356855491	1.237592363		15	2.06
3	4.6804816	0.309518384	0.114112028		25	2.8
4	2.9212749	1.038725082	0.382953104		35	3.19
5	6.1868838	0.593116205	0.218667764		45	3.96
6	6.4396883	3.290311687	1.213059254		55	4.99
7	5.1991218	-2.009121813	-0.740715178		65	6.78
8	5.4415014	-3.381501402	-1.246678721		75	7.98
9	5.7386119	-2.938611866	-1.083395938		85	8.61
10	5.7021246	2.907875384	1.072064132		95	9.73

APPENDIX2: The Outputs of Multiple Linear Analysis

Equation A: Correlation of SPO with PI and PL

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.28525898					
R Square	0.08137268					
Adjusted R Square	-0.0267011					
Standard Error	3.93111045					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	23.27119581	11.6355979	0.75294	0.486053997	
Residual	17	262.7116992	15.45362936			
Total	19	285.982895				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.78091512	7.246194908	0.38377592	0.7059	-12.5072198	18.06905
X Variable 1	-0.112453	0.135468113	-0.830106629	0.41798	-0.39826571	0.17335976
X Variable 2	0.25810932	0.217015479	1.18935901	0.25065	-0.19975332	0.71597195
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	5.68108661	-3.881086611	-1.043735436		2.5	1.78
2	6.80470194	-3.544701936	-0.953271955		7.5	1.8
3	6.41802221	1.561977794	0.420060601		12.5	2.06
4	6.14625217	0.473747829	0.127404371		17.5	2.06
5	7.2075331	-2.217533104	-0.596358214		22.5	2.8
6	5.43189757	0.938102431	0.252282633		27.5	3.19
7	4.0503862	-0.0903862	-0.02430744		32.5	3.26
8	5.7159995	-3.935999499	-1.058503085		37.5	3.96
9	3.54483706	3.23516294	0.870028046		42.5	4.05
10	4.61962535	0.580374648	0.156079379		47.5	4.99
11	6.07217895	7.14782105	1.922253963		52.5	5.2
12	7.61745397	7.042546029	1.893942492		57.5	6.37
13	6.42068798	-3.230687978	-0.868824601		62.5	6.62
14	6.74378673	-4.683786727	-1.259604505		67.5	6.78
15	7.01775295	-4.957752948	-1.333281875		72.5	7.98
16	7.28979913	2.750200867	0.739607844		77.5	8.61
17	4.79101884	-1.991018841	-0.535442036		82.5	10.04
18	7.06959886	4.310401145	1.15919042		87.5	11.38
19	5.86900566	2.740994337	0.737131944		92.5	13.22
20	6.29837523	-2.248375227	-0.604652545		97.5	14.66

Equation B: Correlation of SPO with γ_d and PI

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.800043					
R Square	0.640069					
Adjusted R Square	0.597724					
Standard Error	1.669499					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	84.26154725	42.13077363	15.1157	0.00016899	
Residual	17	47.38287275	2.787227809			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-45.1887	9.587337686	-4.713369658	0.0002	-65.416181	-24.961152
X Variable 1	3.122594	0.568254128	5.495066502	3.9E-05	1.92368281	4.32150564
X Variable 2	0.18723	0.062030082	3.018374505	0.00775	0.05635798	0.31810205
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	3.799833	-1.999832748	-1.266367576		2.5	1.78
2	2.538883	0.721117292	0.456637965		7.5	1.8
3	7.961433	0.018566744	0.011757145		12.5	2.06
4	5.768378	0.851622028	0.539278359		17.5	2.06
5	4.152005	0.837994892	0.530649156		22.5	2.8
6	5.301723	1.068276945	0.676472213		27.5	3.19
7	3.176587	0.783412698	0.496085705		32.5	3.26
8	4.527357	-2.747357378	-1.739727638		37.5	3.96
9	8.809206	-2.029205881	-1.284967724		42.5	4.05
10	3.396062	1.803938385	1.142320068		47.5	4.99
11	5.787018	3.942981623	2.496840842		52.5	5.2
12	9.022617	0.817382916	0.517596896		57.5	5.6
13	4.982553	-1.792552578	-1.135110156		62.5	6.37
14	3.050569	-0.990569006	-0.627264691		67.5	6.62
15	2.935442	-0.87544245	-0.554362326		72.5	6.78
16	8.474753	-1.094753225	-0.693237967		77.5	7.38
17	2.878757	-0.078757236	-0.049871976		82.5	7.98
18	5.656671	-0.056670988	-0.035886152		87.5	8.61
19	7.189919	1.420080683	0.899247267		92.5	9.73
20	4.650233	-0.600232717	-0.380089411		97.5	9.84

Equation C: Correlation of SPO with γ_d and LL

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.779866					
R Square	0.608191					
Adjusted R Square	0.562096					
Standard Error	1.741862					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	80.0649788	40.0324894	13.19426	0.000347641	
Residual	17	51.5794412	3.034084776			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-42.03757	9.649595072	-4.35640725	0.00043	-62.3964319	-21.6787
X Variable 1	2.861057	0.557098484	5.135639623	8.26E-05	1.685681989	4.036432
X Variable 2	0.114178	0.043197842	2.643141034	0.017082	0.023038509	0.205317
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*andard Residuals*		*Percentile*	*Y*
1	3.793957	-1.993956507	-1.210191686		2.5	1.78
2	3.081465	0.178534633	0.108357994		7.5	1.8
3	7.834718	0.145282409	0.088176228		12.5	2.06
4	5.824962	0.795038381	0.48253251		17.5	2.06
5	4.745739	0.244260751	0.148249136		22.5	2.8
6	4.974492	1.395508334	0.846975637		27.5	3.19
7	2.384499	1.575501036	0.956218578		32.5	3.26
8	4.392948	-2.612947798	-1.585875966		37.5	3.96
9	7.373368	-0.593368127	-0.360132817		42.5	4.05
10	2.974712	2.225287774	1.350593533		47.5	4.99
11	5.701689	4.028311388	2.444902351		52.5	5.2
12	9.383407	0.456592607	0.277119674		57.5	5.6
13	5.079044	-1.889043901	-1.146517096		62.5	6.37
14	3.499965	-1.439965191	-0.87395783		67.5	6.62
15	3.646264	-1.586264233	-0.962751083		72.5	6.78
16	8.842736	-1.462735576	-0.887777856		77.5	7.38
17	2.521318	0.278682403	0.169140664		82.5	7.98
18	6.115267	-0.515266853	-0.312730824		87.5	8.61
19	7.015575	1.594425005	0.967704099		92.5	9.73
20	4.873877	-0.823876533	-0.500035245		97.5	9.84

Equation D: Correlation of SPO with γ_d, PI and LL

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.8002557					
R Square	0.6404092					
Adjusted R Square	0.5729859					
Standard Error	1.7200677					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	84.30629641	28.1020988	9.49834	0.000769559	
Residual	16	47.33812359	2.958632724			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-45.28154	9.906560066	-4.57086433	0.00031	-66.28251121	-24.28057
X Variable 1	3.1142599	0.589375349	5.284000868	7.4E-05	1.864839931	4.3636798
X Variable 2	0.1714683	0.143211862	1.197305202	0.24863	-0.132127278	0.4750639
X Variable 3	0.011756	0.095589693	0.122983514	0.90365	-0.190885141	0.2143971
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	3.7796662	-1.97966619	-1.254189749		2.5	1.78
2	2.5847432	0.675256754	0.427799446		7.5	1.8
3	7.9845478	-0.0045478	-0.002881195		12.5	2.06
4	5.759574	0.860425978	0.54511081		17.5	2.06
5	4.2101991	0.77980094	0.494031948		22.5	2.8
6	5.2842797	1.085720268	0.687842848		27.5	3.19
7	3.1086149	0.851385081	0.539383077		32.5	3.26
8	4.524436	-2.74443596	-1.738698913		37.5	3.96
9	8.6922282	-1.91222817	-1.21146534		42.5	4.05
10	3.324334	1.875666029	1.188301906		47.5	4.99
11	5.7975882	3.932411797	2.49132434		52.5	5.2
12	9.0878235	0.752176527	0.476530889		57.5	5.6
13	5.0195608	-1.82956076	-1.159092562		62.5	6.37
14	3.0972442	-1.0372442	-0.657131512		67.5	6.62
15	2.9672309	-0.9072309	-0.574763413		72.5	6.78
16	8.5039845	-1.12398453	-0.712084633		77.5	7.38
17	2.8279212	-0.02792118	-0.017689075		82.5	7.98
18	5.693568	-0.09356799	-0.05927869		87.5	8.61
19	7.1624096	1.447590413	0.917100603		92.5	9.73
20	4.6500461	-0.60004609	-0.380150786		97.5	9.84

Equation E: Correlation of SPO with $\gamma_{d,}$ PL and Clay Content

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.7981995					
R Square	0.6371224					
Adjusted R Square	0.5690829					
Standard Error	1.7279107					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	83.87361118	27.95787039	9.364	0.000825878	
Residual	16	47.77080882	2.985675551			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-35.99658	8.092037472	-4.448394519	0.0004	-53.1509283	-18.842222
X Variable 1	2.2100808	0.489764367	4.512539045	0.00035	1.171826751	3.2483349
X Variable 2	0.0113447	0.096327338	0.117772022	0.90771	-0.19286017	0.2155495
X Variable 3	0.1648539	0.065571912	2.514092507	0.02301	0.025847609	0.3038601
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*andard Residuals*		*Percentile*	*Y*
1	2.4275315	-0.627531457	-0.395759186		2.5	1.78
2	3.7251355	-0.465135503	-0.293342503		7.5	1.8
3	6.2491527	1.730847348	1.091576733		12.5	2.06
4	3.9345787	2.685421297	1.693588641		17.5	2.06
5	5.430868	-0.440867984	-0.278037942		22.5	2.8
6	4.7884783	1.581521655	0.997402945		27.5	3.19
7	2.9490763	1.01092368	0.637549446		32.5	3.26
8	3.1898832	-1.40988319	-0.889157377		37.5	3.96
9	6.7564666	0.023533416	0.014841592		42.5	4.05
10	4.1697537	1.030246316	0.649735466		47.5	4.99
11	6.3225514	3.4074486	2.148942607		52.5	5.2
12	9.3688956	0.471104372	0.297106831		57.5	5.6
13	3.2962805	-0.106280531	-0.067026913		62.5	6.37
14	3.548665	-1.488664978	-0.938841923		67.5	6.62
15	4.5434474	-2.483447383	-1.566211708		72.5	6.78
16	8.6233544	-1.243354375	-0.784134262		77.5	7.38
17	2.8309103	-0.030910284	-0.019493889		82.5	7.98
18	6.5258164	-0.925816434	-0.583875684		87.5	8.61
19	8.5807701	0.029229851	0.018434107		92.5	9.73
20	6.7983844	-2.748384414	-1.73329698		97.5	9.84

Equation F: Correlation of SPO with γ_d, LI and Clay Content

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.8329773					
R Square	0.6938512					
Adjusted R Square	0.6364483					
Standard Error	1.5871118					
Observations	20					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	91.34163925	30.44721308	12.0874	0.0002198	
Residual	16	40.30278075	2.518923797			
Total	19	131.64442				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-26.86947	8.760161256	-3.06723484	0.00737	-45.440184	-8.29876
X Variable 1	1.843737	0.487208297	3.784289033	0.00163	0.8109016	2.876572
X Variable 2	-0.061362	0.035538767	-1.726618004	0.10349	-0.1367007	0.013977
X Variable 3	0.1204124	0.060283142	1.997447354	0.06307	-0.0073821	0.248207
RESIDUAL OUTPUT					PROBABILITY OUTPU	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	2.2504145	-0.450414539	-0.309258536		2.5	1.78
2	4.4357445	-1.175744502	-0.80727639		7.5	1.8
3	7.4861683	0.49383172	0.33906915		12.5	2.06
4	4.3675825	2.252417537	1.54652945		17.5	2.06
5	5.8020873	-0.812087258	-0.557586167		22.5	2.8
6	4.5425944	1.827405604	1.254712564		27.5	3.19
7	2.3482095	1.6117905	1.106669361		32.5	3.26
8	3.2222737	-1.442273677	-0.990277637		37.5	3.96
9	6.6809694	0.099030587	0.067995261		42.5	4.05
10	3.5181904	1.681809598	1.154745081		47.5	4.99
11	6.6196296	3.110370382	2.135607327		52.5	5.2
12	9.7149757	0.125024347	0.085842803		57.5	5.6
13	4.0506802	-0.860680215	-0.590950513		62.5	6.37
14	3.5679928	-1.50799278	-1.035400944		67.5	6.62
15	4.2306834	-2.170683352	-1.490410048		72.5	6.78
16	8.6081894	-1.228189351	-0.843285479		77.5	7.38
17	2.3987863	0.401213723	0.275476828		82.5	7.98
18	6.6563318	-1.056331815	-0.725286602		87.5	8.61
19	8.2594208	0.350579234	0.240710748		92.5	9.73
20	5.2990757	-1.249075743	-0.857626257		97.5	9.84

Equation G: Correlation of SPO with Wl, LI and CEC

Summary output

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.79884997					
R Square	0.63816128					
Adjusted R Square	0.45724191					
Standard Error	2.12919925					
Observations	10					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	47.97326334	15.99108778	3.52732	0.088360564	
Residual	6	27.20093666	4.533489443			
Total	9	75.1742				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	16.0402359	10.44869847	1.535142004	0.17565	-9.5268082	41.60728
X Variable 1	-0.2571442	0.204954242	-1.254642196	0.25627	-0.7586492	0.2443607
X Variable 2	-0.0888128	0.069763574	-1.273054117	0.2501	-0.25951812	0.0818925
X Variable 3	0.00550468	0.226936418	0.024256505	0.98143	-0.54978873	0.5607981
RESIDUAL OUTPUT					PROBABILITY OUTPUT	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*		*Percentile*	*Y*
1	2.9540884	-1.154088405	-0.66384762		5	1.8
2	9.03139477	-1.051394774	-0.604776823		15	2.06
3	5.613028	-0.623027999	-0.358374327		25	2.8
4	1.72667751	2.233322486	1.284637998		35	3.19
5	7.07744366	-0.297443657	-0.171093707		45	3.96
6	6.45564579	3.274354212	1.883453852		55	4.99
7	4.74086992	-1.550869918	-0.892081837		65	6.78
8	4.14630127	-2.086301274	-1.200069362		75	7.98
9	2.89057095	-0.090570948	-0.052097663		85	8.61
10	7.26397972	1.346020277	0.774249489		95	9.73

APPENDIXB: Analysis of Laboratory Test Results

APPENDIX1: Analysis of Index Properties Test Results

MOISTURE CONTENT TEST

Date of Tested:- 12/08/2014, Tuesday @ 5:30AM

Pit no:- 1

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*GA*	*61*	*CRS*
Mass of container, g	*15.50*	*15.80*	*15.80*
Mass of container + Wet soil, g	*45.10*	*56.50*	*48.60*
Mass of container + Dry soil, g	*36.20*	*44.80*	*38.50*
Mass of water, g	*8.90*	*11.70*	*10.10*
Mass of dry soil, g	*20.70*	*29.00*	*22.70*
Water content, %	*43.00*	*40.34*	*44.49*
Ave. moisture content,% =		*42.61*	

MOISTURE CONTENT TEST

Date of Tested:- 28/08/2014, Thursday @ 5:00AM

Pit no:- 1

Depth:- @ 3.0m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*G2*	*A2*	*P51*
Mass of container, g	*15.70*	*15.60*	*15.20*
Mass of container + Wet soil, g	*68.90*	*68.10*	*62.70*
Mass of container + Dry soil, g	*54.00*	*53.30*	*49.00*
Mass of water, g	*14.90*	*14.80*	*13.70*
Mass of dry soil, g	*38.30*	*37.70*	*33.80*
Water content, %	*38.90*	*39.26*	*40.53*
Ave. moisture content,% =		*39.56*	

MOISTURE CONTENT TEST

Date of Tested:- 16/08/2014, Saturday @ 3:40AM

Pit no:- 2

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*A301*	*19A*	*P9*
Mass of container, g	*15.50*	*15.60*	*15.60*
Mass of container + Wet soil, g	*52.70*	*51.10*	*54.00*
Mass of container + Dry soil, g	*43.60*	*42.30*	*44.70*
Mass of water, g	*9.10*	*8.80*	*9.30*
Mass of dry soil, g	*28.10*	*26.70*	*29.10*
Water content, %	*32.38*	*32.96*	*31.96*
Ave. moisture content,% =	*32.43*		

MOISTURE CONTENT TEST

Date of Tested:- 16/08/2014, Saturday @ 4:10AM

Pit no:- 2

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*E2*	*GA*	*G8*
Mass of container, g	*15.60*	*15.50*	*20.90*
Mass of container + Wet soil, g	*53.60*	*56.30*	*62.60*
Mass of container + Dry soil, g	*43.50*	*45.30*	*51.30*
Mass of water, g	*10.10*	*11.00*	*11.30*
Mass of dry soil, g	*27.90*	*29.80*	*30.40*
Water content, %	*36.20*	*36.91*	*37.17*
Ave. moisture content,% =	*36.76*		

MOISTURE CONTENT TEST

Date of Tested:- 25/08/2014, Monday @ 6:50PM

Pit no:- 3

Depth:- @1.4m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*D25*	*GA*	*117*
Mass of container, g	*16.00*	*15.50*	*10.90*
Mass of container + Wet soil, g	*61.20*	*64.90*	*57.80*
Mass of container + Dry soil, g	*48.20*	*50.70*	*44.10*
Mass of water, g	*13.00*	*14.20*	*13.70*
Mass of dry soil, g	*32.20*	*35.20*	*33.20*
Water content, %	*40.37*	*40.34*	*41.27*
Ave. moisture content,% =		*40.66*	

MIOSTURE CONTENT TEST

Date of Tested:- 01/09/2014,Monday @ 10:00PM

Pit no:- 3

Depth:- @2.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*E2*	*AL4*	*54*
Mass of container, g	*15.60*	*15.60*	*15.60*
Mass of container + Wet soil, g	*61.40*	*65.20*	*72.50*
Mass of container + Dry soil, g	*47.60*	*50.00*	*55.10*
Mass of water, g	*13.80*	*15.20*	*17.40*
Mass of dry soil, g	*32.00*	*34.40*	*39.50*
Water content, %	*43.13*	*44.19*	*44.05*
Ave. moisture content,% =		*43.79*	

MOISTURE CONTENT TEST

Date of Tested:- 20/08/2014, Wednesday @ 6:25PM

Pit no:- 4

Depth:- @1.3m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Black

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*H2O*	*T3*	*G8*
Mass of container, g	*15.60*	*15.60*	*20.90*
Mass of container + Wet soil, g	*56.30*	*57.60*	*57.90*
Mass of container + Dry soil, g	*43.10*	*44.20*	*46.00*
Mass of water, g	*13.20*	*13.40*	*11.90*
Mass of dry soil, g	*27.50*	*28.60*	*25.10*
Water content, %	*48.00*	*46.85*	*47.41*
Ave. moisture content,% =		*47.42*	

MOISTURE CONTENT TEST

Date of Tested:- 25/08/2014, Monday @ 7:20PM

Pit no:- 4

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*T9*	*P4*	*T3*
Mass of container, g	*15.40*	*15.60*	*15.40*
Mass of container + Wet soil, g	*69.70*	*62.30*	*61.20*
Mass of container + Dry soil, g	*52.90*	*47.50*	*46.90*
Mass of water, g	*16.80*	*14.80*	*14.30*
Mass of dry soil, g	*37.50*	*31.90*	*31.50*
Water content, %	*44.80*	*46.39*	*45.40*
Ave. moisture content,% =		*45.53*	

MOISTURE CONTENT TEST

Date of Tested:- 28/08/2014, Thursday @ 6:00PM

Pit no:- 5

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*A303*	*P33*	*18A*
Mass of container, g	*15.40*	*15.70*	*15.50*
Mass of container + Wet soil, g	*58.60*	*72.20*	*66.60*
Mass of container + Dry soil, g	*48.50*	*58.60*	*53.70*
Mass of water, g	*10.10*	*13.60*	*12.90*
Mass of dry soil, g	*33.10*	*42.90*	*38.20*
Water content, %	*30.51*	*31.70*	*33.77*
Ave. moisture content,% =	*31.99*		

MOISTURE CONTENT TEST

Date of Tested:- 04/09/2014, Thursday @ 8:00PM

Pit no:- 5

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*B4*	*N4*	*D25*
Mass of container, g	*15.70*	*15.40*	*15.90*
Mass of container + Wet soil, g	*67.40*	*68.70*	*78.20*
Mass of container + Dry soil, g	*53.60*	*54.30*	*61.20*
Mass of water, g	*13.80*	*14.40*	*17.00*
Mass of dry soil, g	*37.90*	*38.90*	*45.30*
Water content, %	*36.41*	*37.02*	*37.53*
Ave. moisture content,% =	*36.99*		

MOISTURE CONTENT TEST

Date of Tested:- 04/09/2014, Thursday @ 8:30PM

Pit no:- 6

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*BBC*	*D30*	*H5*
Mass of container, g	*11.00*	*15.80*	*15.50*
Mass of container + Wet soil, g	*56.90*	*65.20*	*71.10*
Mass of container + Dry soil, g	*44.20*	*51.90*	*55.70*
Mass of water, g	*12.70*	*13.30*	*15.40*
Mass of dry soil, g	*33.20*	*36.10*	*40.20*
Water content, %	*38.25*	*36.84*	*38.31*
Ave. moisture content,% =	*37.80*		

MOISTURE CONTENT TEST

Date of Tested:- 06/09/2014, Saturday @ 4:50AM

Pit no:- 6

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*G30*	*H7*	*BBC*
Mass of container, g	*15.80*	*15.50*	*11.00*
Mass of container + Wet soil, g	*65.90*	*68.40*	*65.70*
Mass of container + Dry soil, g	*52.60*	*54.30*	*51.10*
Mass of water, g	*13.30*	*14.10*	*14.60*
Mass of dry soil, g	*36.80*	*38.80*	*40.10*
Water content, %	*36.14*	*36.34*	*36.41*
Ave. moisture content,% =	*36.30*		

MOISTURE CONTENT TEST

Date of Tested:- 13/09/2014, Saturday @ 7:00PM

Pit no:- 7

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*C44*	*H2S*	*CRS*
Mass of container, g	*15.70*	*15.00*	*15.80*
Mass of container + Wet soil, g	*85.80*	*90.95*	*71.10*
Mass of container + Dry soil, g	*65.20*	*67.20*	*54.40*
Mass of water, g	*20.60*	*23.75*	*16.70*
Mass of dry soil, g	*49.50*	*52.20*	*38.60*
Water content, %	*41.62*	*45.50*	*43.26*
Ave. moisture content,% =		*43.46*	

MOISTURE CONTENT TEST

Date of Tested:- 18/09/2014, Thursday @ 4:00AM

Pit no:- 7

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*100*	*S1M*	*C44*
Mass of container, g	*15.60*	*15.30*	*15.70*
Mass of container + Wet soil, g	*81.20*	*83.50*	*72.10*
Mass of container + Dry soil, g	*60.70*	*61.30*	*53.85*
Mass of water, g	*20.50*	*22.20*	*18.25*
Mass of dry soil, g	*45.10*	*46.00*	*38.15*
Water content, %	*45.45*	*48.26*	*47.84*
Ave. moisture content,% =		*47.18*	

MOISTURE CONTENT TEST

Date of Tested:- 18/09/2014, Thursday @ 4:30AM

Pit no:- 8

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*6*	*CNN*	*H2S*
Mass of container, g	*15.70*	*15.50*	*15.00*
Mass of container + Wet soil, g	*83.60*	*86.70*	*83.40*
Mass of container + Dry soil, g	*64.10*	*66.35*	*63.65*
Mass of water, g	*19.50*	*20.35*	*19.75*
Mass of dry soil, g	*48.40*	*50.85*	*48.65*
Water content, %	*40.29*	*40.02*	*40.60*
Ave. moisture content,% =		*40.30*	

MOISTURE CONTENT TEST

Date of Tested:- 18/09/2014, Thurday @ 5:00AM

Pit no:- 8

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*CRS*	*52*	*T15*
Mass of container, g	*15.80*	*15.10*	*15.70*
Mass of container + Wet soil, g	*82.40*	*76.10*	*80.10*
Mass of container + Dry soil, g	*65.00*	*60.20*	*63.35*
Mass of water, g	*17.40*	*15.90*	*16.75*
Mass of dry soil, g	*49.20*	*45.10*	*47.65*
Water content, %	*35.37*	*35.25*	*35.15*
Ave. moisture content,% =		*35.26*	

MOISTURE CONTENT TEST

Date of Tested:- 24/09/2014, Wednesday @ 4:30AM

Pit no:- 9

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*M2O*	*D31*	*CRS*
Mass of container, g	*15.70*	*15.50*	*15.80*
Mass of container + Wet soil, g	*96.55*	*88.30*	*90.85*
Mass of container + Dry soil, g	*72.60*	*65.70*	*69.10*
Mass of water, g	*23.95*	*22.60*	*21.75*
Mass of dry soil, g	*56.90*	*50.20*	*53.30*
Water content, %	*42.09*	*45.02*	*40.81*
Ave. moisture content,% =		*42.64*	

MOISTURE CONTENT TEST

Date of Tested:- 24/09/2014, Wednesday @ 5:00AM

Pit no:- 9

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*T15*	*CNN*	*52*
Mass of container, g	*15.60*	*15.50*	*15.10*
Mass of container + Wet soil, g	*70.75*	*76.70*	*84.60*
Mass of container + Dry soil, g	*55.50*	*60.00*	*65.15*
Mass of water, g	*15.25*	*16.70*	*19.45*
Mass of dry soil, g	*39.90*	*44.50*	*50.05*
Water content, %	*38.22*	*37.53*	*38.86*
Ave. moisture content,% =		*38.20*	

MOISTURE CONTENT TEST

Date of Tested:- 01/10/2014, Wednesday @ 3:00AM

Pit no:- 10

Depth:- @1.2m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*CNN*	*140*	*6*
Mass of container, g	*15.60*	*15.60*	*15.70*
Mass of container + Wet soil, g	*89.60*	*81.70*	*90.10*
Mass of container + Dry soil, g	*71.50*	*65.10*	*72.20*
Mass of water, g	*18.10*	*16.60*	*17.90*
Mass of dry soil, g	*55.90*	*49.50*	*56.50*
Water content, %	*32.38*	*33.54*	*31.68*
Ave. moisture content,% =		*32.53*	

MOISTURE CONTENT TEST

Date of Tested:- 01/10/2014, Wednesday @ 3:30AM

Pit no:- 10

Depth:- @2.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

Trial No	*1*	*2*	*3*
Container No	*D31*	*M2O*	*52*
Mass of container, g	*15.50*	*15.70*	*15.10*
Mass of container + Wet soil, g	*78.60*	*84.60*	*89.50*
Mass of container + Dry soil, g	*59.10*	*63.50*	*67.00*
Mass of water, g	*19.50*	*21.10*	*22.50*
Mass of dry soil, g	*43.60*	*47.80*	*51.90*
Water content, %	*44.72*	*44.14*	*43.35*
Ave. moisture content,% =		*44.07*	

DRY DENSITY TEST

Date of Tested:- 12/08/2014,Tuesday @ 5:30AM

Pit no:- 1

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*142.90*
Weight of sand, (g)	*73.00*
Unit Weight of sand, (KN/M^3)	*18.60*
Dry Density,(KN/M3)	*13.04*

DRY DENSITY TEST

Date of Tested:- 28/08/2014,Thursday @ 5:00AM

Pit no:- 1

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*135.60*
Weight of sand, (g)	*66.90*
Unit Weight of sand, (KN/M^3)	*17.04*
Dry Density,(KN/M3)	*12.21*

DRY DENSITY TEST

Date of Tested:- 16/08/2014,Saturday @ 3:40AM
Pit no:- 2
Depth:- @1.5 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*140.60*
Weight of sand, (g)	*70.70*
Unit Weight of sand, (KN/M^3)	*18.01*
Dry Density,(KN/M3)	*13.60*

DRY DENSITY TEST

Date of Tested:- 16/08/2014,Saturday @ 4:10AM
Pit no:- 2
Depth:- @2.8 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*143.00*
Weight of sand, (g)	*74.30*
Unit Weight of sand, (KN/M^3)	*18.93*
Dry Density,(KN/M3)	*13.84*

DRY DENSITY TEST

Date of Tested:- 25/08/2014,Monday @ 6:30PM
Pit no:- 3
Depth:- @1.4m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*140.50*
Weight of sand, (g)	*70.60*
Unit Weight of sand, (KN/M^3)	*17.99*
Dry Density,(KN/M3)	*12.79*

DRY DENSITY TEST

Date of Tested:- 01/09/2014,Monday @10:00 PM
Pit no:- 3
Depth:- @2.5 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*37.60*
Weight of cylinder+sand, (g)	*110.10*
Weight of sand, (g)	*72.50*
Unit Weight of sand, (KN/M^3)	*18.47*
Dry Density,(KN/M3)	*12.85*

DRY DENSITY TEST

Date of Tested:- 20/08/2014, Wednesday @ 6:40PM

Pit no:- 4

Depth:- @1.3 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*137.70*
Weight of sand, (g)	*69.00*
Unit Weight of sand, (KN/M^3)	*17.58*
Dry Density,(KN/M3)	*11.92*

DRY DENSITY TEST

Date of Tested:- 25/08/2014, Monday @ 7:20PM

Pit no:- 4

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*140.80*
Weight of sand, (g)	*72.10*
Unit Weight of sand, (KN/M^3)	*18.37*
Dry Density,(KN/M3)	*12.62*

DRY DENSITY TEST

Date of Tested:- 28/08/2014, Thursday @ 6:00PM

Pit no:- 5

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*143.10*
Weight of sand, (g)	*73.20*
Unit Weight of sand, (KN/M^3)	*18.65*
Dry Density,(KN/M3)	*14.13*

DRY DENSITY TEST

Date of Tested:- 04/09/2014, Thursday @ 8:00PM

Pit no:- 5

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*140.20*
Weight of sand, (g)	*70.30*
Unit Weight of sand, (KN/M^3)	*17.91*
Dry Density,(KN/M3)	*13.07*

DRY DENSITY TEST

Date of Tested:- 04/09/2014, Thursday @ 8:30PM
Pit no:- 6
Depth:- @1.5 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*139.00*
Weight of sand, (g)	*70.30*
Unit Weight of sand, (KN/M^3)	*17.91*
Dry Density,(KN/M3)	*13.00*

DRY DENSITY TEST

Date of Tested:- 06/09/2014, Saturday @ 4:50AM
Pit no:- 6
Depth:- @3.0 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*37.60*
Weight of cylinder+sand, (g)	*114.10*
Weight of sand, (g)	*76.50*
Unit Weight of sand, (KN/M^3)	*19.49*
Dry Density,(KN/M3)	*14.30*

DRY DENSITY TEST

Date of Tested:- 13/09/2014, Saturday @ 7:00PM
Pit no:- 7
Depth:- @1.5 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*139.90*
Weight of sand, (g)	*70.00*
Unit Weight of sand, (KN/M^3)	*17.83*
Dry Density,(KN/M3)	*12.43*

DRY DENSITY TEST

Date of Tested:- 18/09/2014, Thursday @ 4:00AM
Pit no:- 7
Depth:- @3.0 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*139.10*
Weight of sand, (g)	*70.40*
Unit Weight of sand, (KN/M^3)	*17.94*
Dry Density,(KN/M3)	*12.19*

DRY DENSITY TEST

Date of Tested:- 18/09/2014, Thursday @ 4:30AM

Pit no:- 8

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*142.50*
Weight of sand, (g)	*72.60*
Unit Weight of sand, (KN/M^3)	*18.50*
Dry Density,(KN/M3)	*13.18*

DRY DENSITY TEST

Date of Tested:- 18/09/2014, Thursday @ 5:00AM

Pit no:- 8

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*37.60*
Weight of cylinder+sand, (g)	*117.00*
Weight of sand, (g)	*79.40*
Unit Weight of sand, (KN/M^3)	*20.23*
Dry Density,(KN/M3)	*14.96*

DRY DENSITY TEST

Date of Tested:- 24/09/2014, Wednesday @ 4:30AM

Pit no:- 9

Depth:- @1.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*138.50*
Weight of sand, (g)	*69.80*
Unit Weight of sand, (KN/M^3	*17.78*
Dry Density,(KN/M3)	*12.47*

DRY DENSITY TEST

Date of Tested:- 24/09/2014, Wednesday @ 5:00AM

Pit no:- 9

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*69.90*
Weight of cylinder+sand, (g)	*144.10*
Weight of sand, (g)	*74.20*
Unit Weight of sand, (KN/M^3	*18.90*
Dry Density,(KN/M3)	*13.68*

DRY DENSITY TEST

Date of Tested:- 01/10/2014, Wednesday @ 3:00AM

Pit no:- 10

Depth:- @1.2 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*68.70*
Weight of cylinder+sand, (g)	*143.50*
Weight of sand, (g)	*74.80*
Unit Weight of sand, (KN/M^3)	*19.06*
Dry Density,(KN/M3)	*14.38*

DRY DENSITY TEST

Date of Tested:- 01/10/2014, Wednesday @ 3:30AM

Pit no:- 10

Depth:- @2.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 2937-00 – Standard Test for Density of Soil in Place by the DriveCylinder Method

Diameter of sample, (cm)	*5.000*
Area of sample, (cm^2)	*19.63*
Length of sample, (cm)	*2.00*
Volume of sample ,(cm^3)	*39.25*
Weight of cylinder, (g)	*37.60*
Weight of cylinder+sand, (g)	*114.10*
Weight of sand, (g)	*76.50*
Unit Weight of sand, (KN/M^3)	*19.49*
Dry Density,(KN/M3)	*13.53*

SPECIC GRAVITY TEST

Date of Tested:- 26/08/14,Tuesday @8:20PM
Pit no:- 1
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.70*
Temperature, $T_x(^oc)$	*21.8*	*22*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.32*
Weight of dry soil , w_s (gm)	*10.00*	*10.20*
Conversion factor , K	*0.9996*	*0.9996*
Specific gravity of soil at 20°c.	*2.69*	*2.67*
Average specific gravity of soil .	*2.68*	

SPECIC GRAVITY TEST

Date of Tested:- 26/08/14,Tuesday @8:30PM
Pit no:- 1
Depth:- @3.0 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.50*	*150.60*
Temperature, $T_x(^oc)$	*21.6*	*22.4*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.32*
Weight of dry soil , w_s (gm)	*10.10*	*10.10*
Conversion factor , K	*0.9996*	*0.9996*
Specific gravity of soil at 20°c.	*2.58*	*2.64*
Average specific gravity of soil .	*2.61*	

SPECIC GRAVITY TEST

Date of Tested:- 26/08/14,Tuesday @8:40PM
Pit no:- 2
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.70*	*150.70*
Temperature, $T_x(^oc)$	*22.3*	*23.2*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.30*
Weight of dry soil , w_s (gm)	*10.20*	*10.20*
Conversion factor , K	*0.9996*	*0.9993*
Specific gravity of soil at 20°c.	*2.67*	*2.69*
Average specific gravity of soil .	*2.68*	

SPECIC GRAVITY TEST

Date of Tested:- 02/09/14,Tuesday @4:50AM
Pit no:- 2
Depth:- @2.8m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.70*	*144.70*
Observed temperature of water, T_i (oc)	*18.1*	*18.1*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*151.00*	*151.00*
Temperature, $T_x(^oc)$	*19.8*	*20.8*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.66*	*144.64*
Weight of dry soil , w_s (gm)	*10.10*	*10.10*
Conversion factor , K	*1*	*0.9998*
Specific gravity of soil at 20°c.	*2.69*	*2.70*
Average specific gravity of soil .	*2.69*	

SPECIC GRAVITY TEST

Date of Tested:- 02/09/14,Tuesday @5:10AM
Pit no:- 3
Depth:- @1.4m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.60*
Temperature, $T_x(^oc)$	*20.6*	*21.2*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.34*	*144.34*
Weight of dry soil , w_s (gm)	*10.10*	*10.10*
Conversion factor , K	*0.9998*	*0.9998*
Specific gravity of soil at 20°c.	*2.63*	*2.63*
Average specific gravity of soil .	*2.63*	

SPECIC GRAVITY TEST

Date of Tested:- 02/09/14,Tuesday @5:30AM
Pit no:- 3
Depth:- @2.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18.1*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.70*
Temperature, $T_x(^oc)$	*21.4*	*21.4*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.34*	*144.34*
Weight of dry soil , w_s (gm)	*10.10*	*10.20*
Conversion factor , K	*0.9998*	*0.9998*
Specific gravity of soil at 20°c.	*2.63*	*2.66*
Average specific gravity of soil .	*2.64*	

SPECIC GRAVITY TEST

Date of Tested:- 02/09/14,Tuesday @5:50AM

Pit no:- 4

Depth:- @1.3m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.50*	*150.60*
Temperature, $T_x(^oc)$	*21.9*	*21.2*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (	*144.32*	*144.34*
Weight of dry soil , w_s (gm)	*10.20*	*10.20*
Conversion factor , K	*0.9996*	*0.9998*
Specific gravity of soil at 20°c.	*2.54*	*2.59*
Average specific gravity of soil .	*2.56*	

SPECIC GRAVITY TEST

Date of Tested:- 02/09/14,Tuesday @6:00PM

Pit no:- 4

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.50*	*150.60*
Temperature, $T_x(^oc)$	*21.5*	*21.6*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (	*144.32*	*144.32*
Weight of dry soil , w_s (gm)	*10.00*	*10.20*
Conversion factor , K	*0.9996*	*0.9996*
Specific gravity of soil at 20°c.	*2.62*	*2.60*
Average specific gravity of soil .	*2.61*	

SPECIC GRAVITY TEST

Date of Tested:- 05/09/14,Friday @4:00AM
Pit no:- 5
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.80*	*150.80*
Temperature, $T_x(^oc)$	*21.1*	*21.1*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.34*	*144.34*
Weight of dry soil , w_s (gm)	*10.20*	*10.20*
Conversion factor , K	*0.9998*	*0.9998*
Specific gravity of soil at 20°c.	*2.73*	*2.73*
Average specific gravity of soil .	*2.73*	

SPECIC GRAVITY TEST

Date of Tested:- 05/09/14,Friday @4:20AM
Pit no:- 5
Depth:- @3.0 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.70*	*150.60*
Temperature, $T_x(^oc)$	*22.1*	*22.1*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.32*
Weight of dry soil , w_s (gm)	*10.10*	*10.10*
Conversion factor , K	*0.9996*	*0.9996*
Specific gravity of soil at 20°c.	*2.72*	*2.64*
Average specific gravity of soil .	*2.68*	

SPECIC GRAVITY TEST

Date of Tested:-07/09/14,Sunday @2:30AM
Pit no:- 6
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.70*
Temperature, $T_x(^oc)$	*21.9*	*21.9*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.32*
Weight of dry soil , w_s (gm)	*10.10*	*10.20*
Conversion factor , K	*0.9996*	*0.9996*
Specific gravity of soil at 20°c.	*2.64*	*2.67*
Average specific gravity of soil .	*2.66*	

SPECIC GRAVITY TEST

Date of Tested:- 07/09/14,Sunday @2:50AM
Pit no:- 6
Depth:- @3.0 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.70*
Temperature, $T_x(^oc)$	*21.7*	*21.7*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.32*
Weight of dry soil , w_s (gm)	*10.00*	*10.00*
Conversion factor , K	*0.9996*	*0.9996*
Specific gravity of soil at 20°c.	*2.69*	*2.76*
Average specific gravity of soil .	*2.73*	

SPECIC GRAVITY TEST

Date of Tested:- 09/09/14,Tuesday @4:30AM

Pit no:- 7

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.60*
Temperature, $T_x(^oc)$	*21*	*22.2*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.34*	*144.32*
Weight of dry soil , w_s (gm)	*10.20*	*10.10*
Conversion factor , K	*0.9998*	*0.9996*
Specific gravity of soil at 20°c.	*2.59*	*2.64*
Average specific gravity of soil .	*2.62*	

SPECIC GRAVITY TEST

Date of Tested:- 09/09/14,Tuesday @4:50AM

Pit no:- 7

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.60*
Temperature, $T_x(^oc)$	*22.4*	*20*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.32*	*144.36*
Weight of dry soil , w_s (gm)	*10.10*	*10.20*
Conversion factor , K	*0.9996*	*1*
Specific gravity of soil at 20°c.	*2.64*	*2.57*
Average specific gravity of soil .	*2.61*	

SPECIC GRAVITY TEST

Date of Tested:- 10/09/14,Wednesday @5:00AM
Pit no:- 8
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.60*
Temperature, $T_x(^oc)$	*21.1*	*22*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.34*	*144.32*
Weight of dry soil , w_s (gm)	*10.00*	*10.00*
Conversion factor , K	*0.9998*	*0.9996*
Specific gravity of soil at 20°c.	*2.67*	*2.69*
Average specific gravity of soil .	*2.68*	

SPECIC GRAVITY TEST

Date of Tested:- 10/09/14,Wednesday @5:20AM
Pit no:- 8
Depth:- @2.8m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.80*	*150.80*
Temperature, $T_x(^oc)$	*21.2*	*21.9*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.34*	*144.32*
Weight of dry soil , w_s (gm)	*10.00*	*10.10*
Conversion factor , K	*0.9998*	*0.9996*
Specific gravity of soil at 20°c.	*2.82*	*2.79*
Average specific gravity of soil .	*2.81*	

SPECIC GRAVITY TEST

Date of Tested:- 15/09/14,Monday @5:00AM
Pit no:- 9
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18.1*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.50*	*150.60*
Temperature, $T_x(^oc)$	*22.5*	*23.8*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.30*	*144.27*
Weight of dry soil , w_s (gm)	*10.00*	*10.20*
Conversion factor , K	*0.9993*	*0.9991*
Specific gravity of soil at 20°c.	*2.63*	*2.63*
Average specific gravity of soil .	*2.63*	

SPECIC GRAVITY TEST

Date of Tested:- 15/09/14,Monday @5:20AM
Pit no:- 9
Depth:- @3.0 m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18.1*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.70*	*150.60*
Temperature, $T_x(^oc)$	*23.2*	*25.3*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.30*	*144.25*
Weight of dry soil , w_s (gm)	*10.20*	*10.10*
Conversion factor , K	*0.9993*	*0.9989*
Specific gravity of soil at 20°c.	*2.69*	*2.69*
Average specific gravity of soil .	*2.69*	

SPECIC GRAVITY TEST

Date of Tested:- 15/09/14,Monday @5:40AM
Pit no:- 10
Depth:- @1.2m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18.1*

[B] Specific Gravity Determination

Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.60*	*150.60*
Temperature, $T_x(^oc)$	*24*	*23.9*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.27*	*144.27*
Weight of dry soil , w_s (gm)	*10.10*	*10.10*
Conversion factor , K	*0.9991*	*0.9991*
Specific gravity of soil at 20°c.	*2.68*	*2.68*
Average specific gravity of soil .	*2.68*	

SPECIC GRAVITY TEST

Date of Tested:- 15/09/14,Monday @6:00PM
Pit no:- 10
Depth:- @2.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

[A] Calibration of pycnometer

Pycnometer No.	*P1*	*P1*
Weight of dry, clean pycnometer, w_p (g)	*45.30*	*45.30*
Weight of pycnometer + water, w_{pw} (g)	*144.40*	*144.40*
Observed temperature of water, T_i (oc)	*18.1*	*18.1*

[B] Specific Gravity Determination

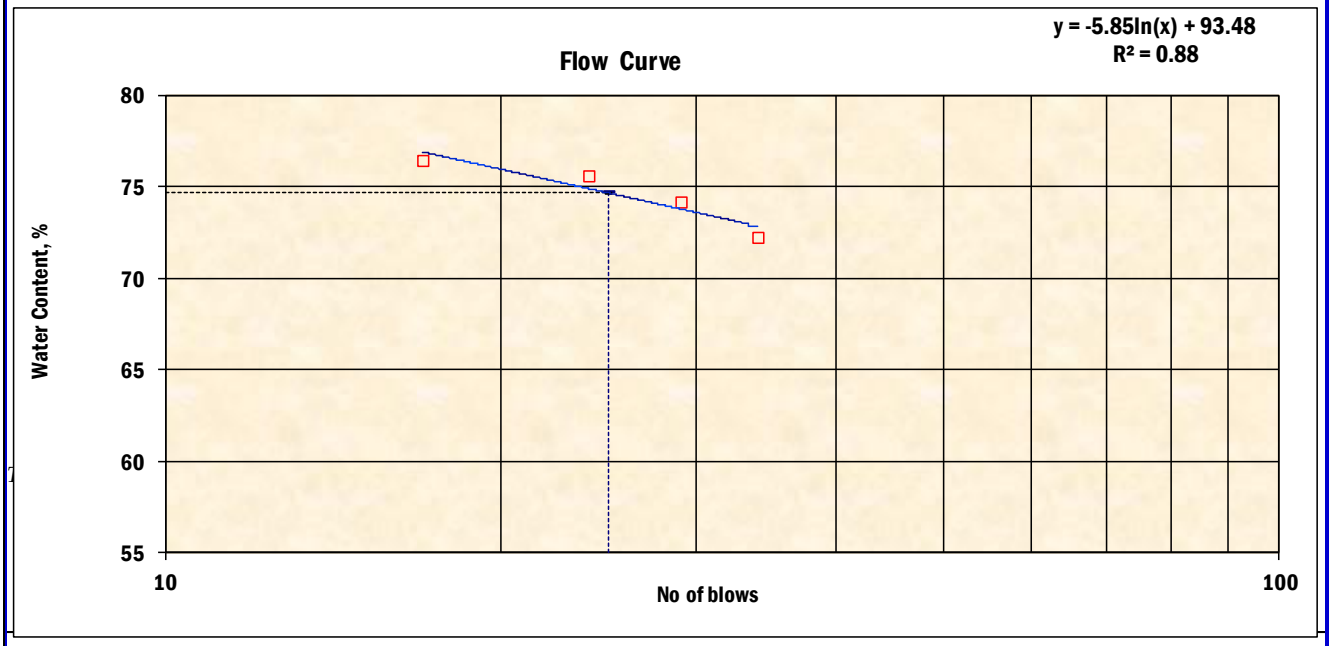
Determination No.	*1*	*1*
Pycnometer No.	*P1*	*P1*
Weight of pycnometer + soil + water, W_{pws} (g)	*150.70*	*150.70*
Temperature, $T_x(^oc)$	*23.5*	*23*
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	*144.27*	*144.30*
Weight of dry soil , w_s (gm)	*10.20*	*10.20*
Conversion factor , K	*0.9991*	*0.9993*
Specific gravity of soil at 20°c.	*2.70*	*2.69*
Average specific gravity of soil .	*2.69*	

ATTERBERG LIMIT TESTS

Date of Tested:-28/08/2014, Thursday @ 8:30PM
Pit no:- 1
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	2	A22	T9	72	P9	CA
Mass of container, g	15.30	15.60	15.50	15.70	15.60	29.90
Mass of container + Wet soil, g	37.00	36.50	36.40	33.70	22.50	36.70
Mass of container + Dry soil, g	27.90	27.60	27.40	25.90	20.90	35.10
Mass of water, g	9.10	8.90	9.00	7.80	1.60	1.60
Mass of dry soil, g	12.60	12.00	11.90	10.20	5.30	5.20
Water content, %	72.22	74.17	75.63	76.47	30.19	30.77
No of blows	34	29	24	17	------	------

Liquid Limit, % 74.65 Plastic Limit, % = 30.48 PI, %= 44.17

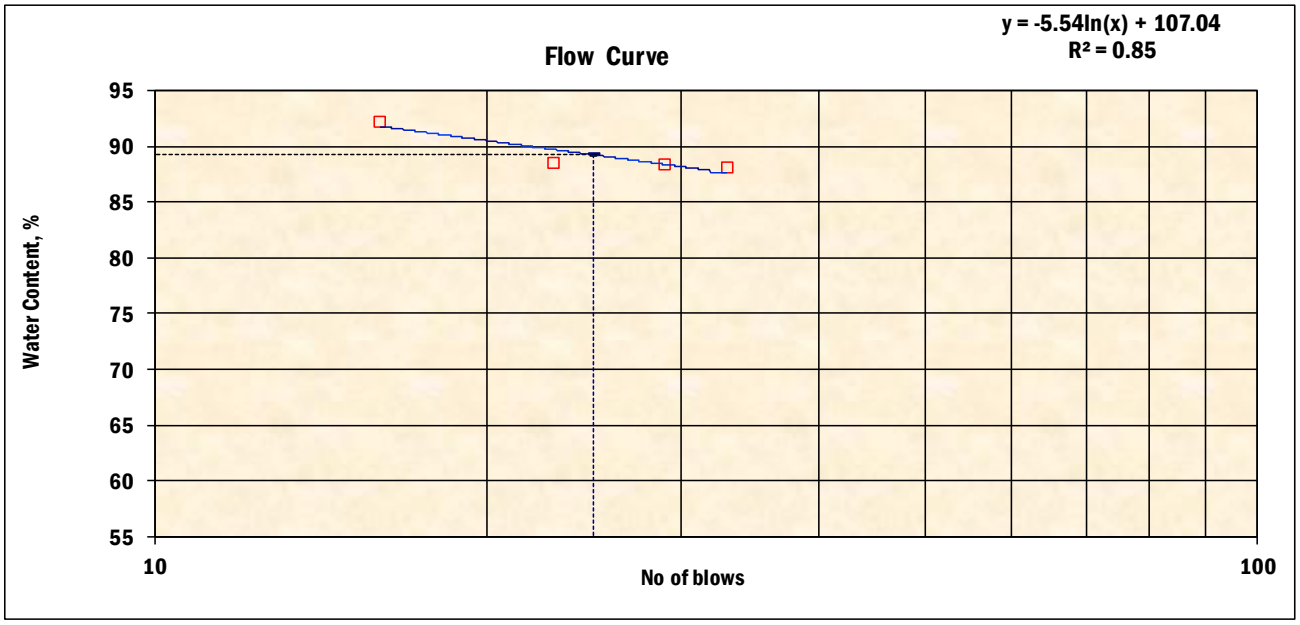


ATTERBERG LIMIT TESTS

Date of Tested:-28/08/2014, Thursday @ 9:30PM
Pit no:- 1
Depth:- @3.0m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	3M	AL4	AT8	54	ES	A98
Mass of container, g	10.50	15.50	15.50	15.70	15.70	15.20
Mass of container + Wet soil, g	31.20	38.30	32.10	30.50	22.70	23.10
Mass of container + Dry soil, g	21.50	27.60	24.30	23.40	20.80	20.90
Mass of water, g	9.70	10.70	7.80	7.10	1.90	2.20
Mass of dry soil, g	11.00	12.10	8.80	7.70	5.10	5.70
Water content, %	88.18	88.43	88.64	92.21	37.25	38.60
No of blows	33	29	23	16	------	------

Liquid Limit, % 89.21 Plastic Limit, % = 37.93 PI, %= 51.28

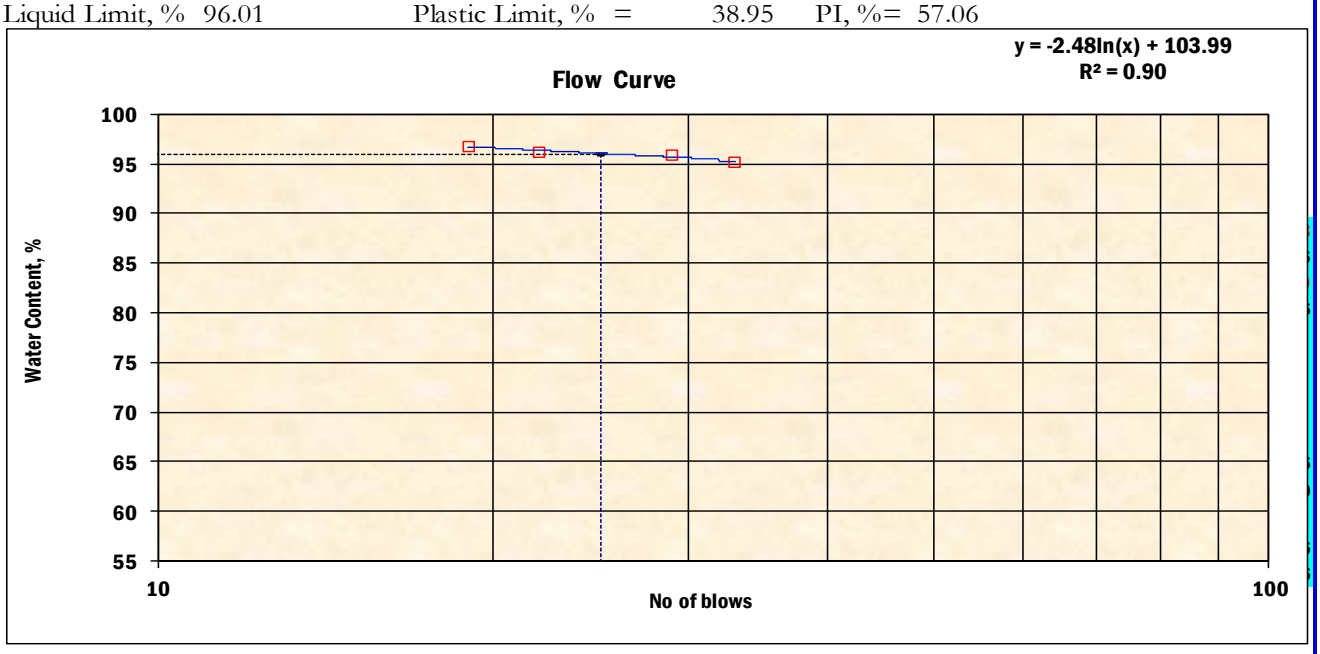


ATTERBERG LIMIT TESTS

Date of Tested:-28/08/2014, Thursday @ 10:00PM
Pit no:- 2
Depth:- @1.50m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	DC2	N29	N4	BBC	E2	DAS
Mass of container, g	15.50	15.70	15.40	11.00	15.60	15.50
Mass of container + Wet soil, g	27.60	34.90	36.00	29.10	22.20	22.10
Mass of container + Dry soil, g	21.70	25.50	25.90	20.20	20.35	20.25
Mass of water, g	5.90	9.40	10.10	8.90	1.85	1.85
Mass of dry soil, g	6.20	9.80	10.50	9.20	4.75	4.75
Water content, %	95.16	95.92	96.19	96.74	38.95	38.95
No of blows	33	29	22	19	------	------

Liquid Limit, % 96.01 Plastic Limit, % = 38.95 PI, %= 57.06

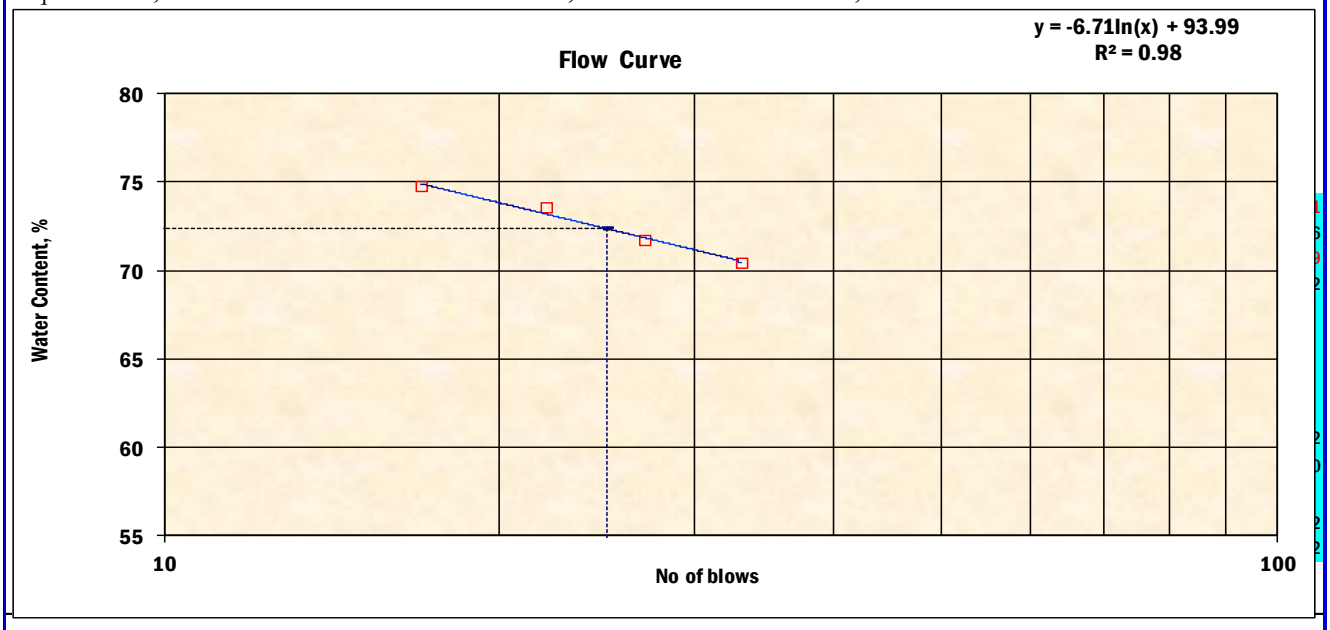


ATTERBERG LIMIT TESTS

Date of Tested:-02/09/2014, Tuesday @ 8:00PM
Pit no:- 2
Depth:- @2.8m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	24A	TB6	D1	T15	27A	BL
Mass of container, g	15.30	15.80	15.50	15.60	15.80	15.60
Mass of container + Wet soil, g	33.20	32.80	31.30	35.70	22.10	22.60
Mass of container + Dry soil, g	25.80	25.70	24.60	27.10	20.60	20.95
Mass of water, g	7.40	7.10	6.70	8.60	1.50	1.65
Mass of dry soil, g	10.50	9.90	9.10	11.50	4.80	5.35
Water content, %	70.48	71.72	73.63	74.78	31.25	30.84
No of blows	33	27	22	17	------	------

Liquid Limit, % 72.39 Plastic Limit, % = 31.05 PI, %= 41.35

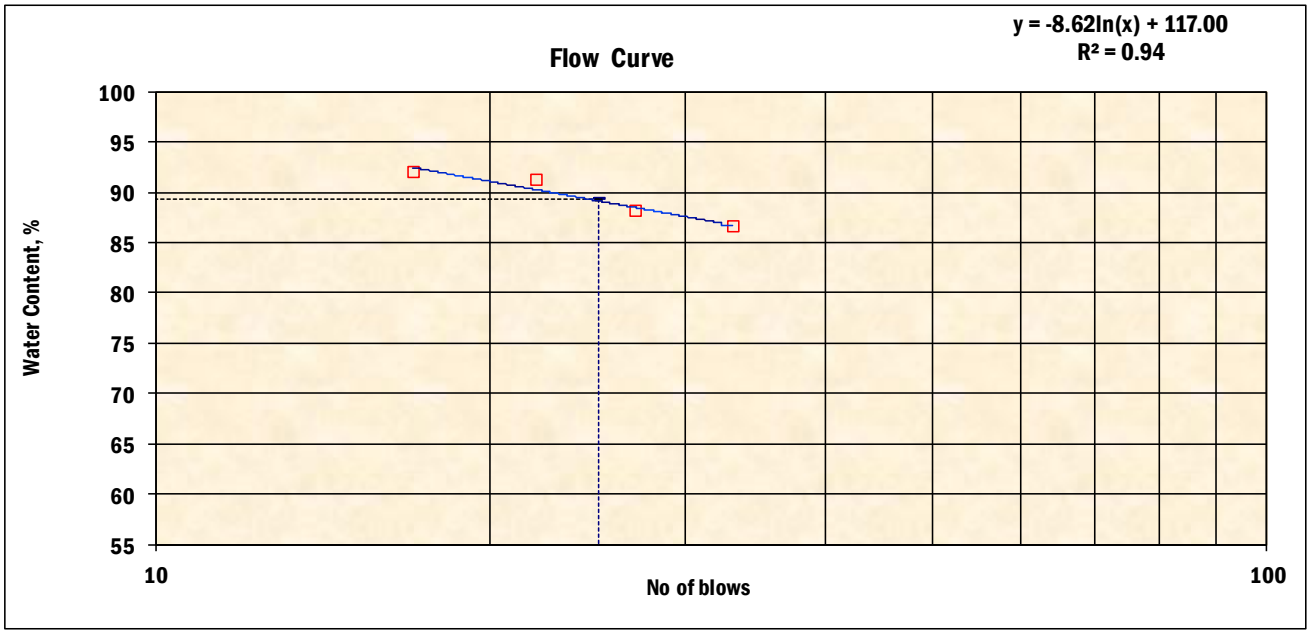


ATTERBERG LIMIT TESTS

Date of Tested:-02/09/2014, Tuesday @ 9:00PM
Pit no:- 3
Depth:- @1.4m
Sample discription:- Ambo Expanssive Soil
Color of sample:-Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	T13	47	DAB	G8	IL6	TL3
Mass of container, g	15.30	15.40	15.50	20.80	15.60	15.70
Mass of container + Wet soil, g	33.60	31.40	30.80	40.30	22.60	23.30
Mass of container + Dry soil, g	25.10	23.90	23.50	30.95	20.65	21.15
Mass of water, g	8.50	7.50	7.30	9.35	1.95	2.15
Mass of dry soil, g	9.80	8.50	8.00	10.15	5.05	5.45
Water content, %	86.73	88.24	91.25	92.12	38.61	39.45
No of blows	33	27	22	17	------	------

Liquid Limit, % 89.25 Plastic Limit, % = 39.03 PI, %= 50.22

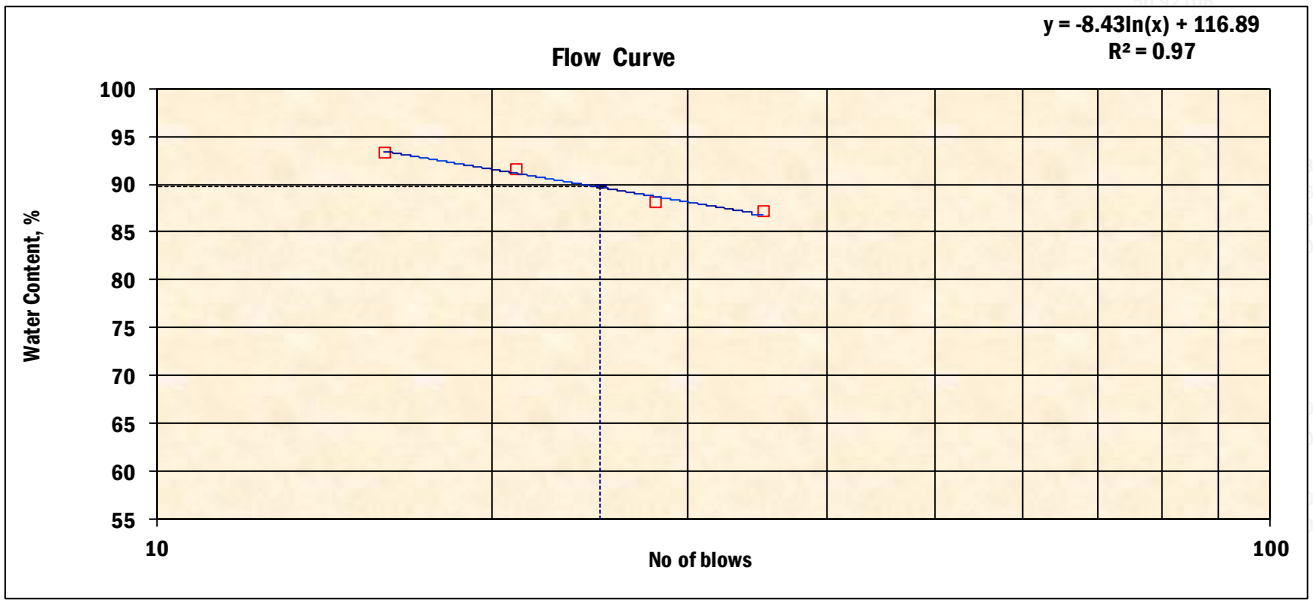


ATTERBERG LIMIT TESTS

Date of Tested:-02/09/2014, Tuesday @ 10:00PM
Pit no:- 3
Depth:- @2.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	DA	AT8	D31	72	60	PR
Mass of container, g	15.70	15.50	15.50	15.80	15.50	15.30
Mass of container + Wet soil, g	33.30	33.00	31.50	33.50	21.80	21.70
Mass of container + Dry soil, g	25.10	24.80	23.85	24.95	20.20	20.05
Mass of water, g	8.20	8.20	7.65	8.55	1.60	1.65
Mass of dry soil, g	9.40	9.30	8.35	9.15	4.70	4.75
Water content, %	87.23	88.17	91.62	93.44	34.04	34.74
No of blows	35	28	21	16	------	------

Liquid Limit, % 89.75 Plastic Limit, % = 34.39 PI, %= 55.37

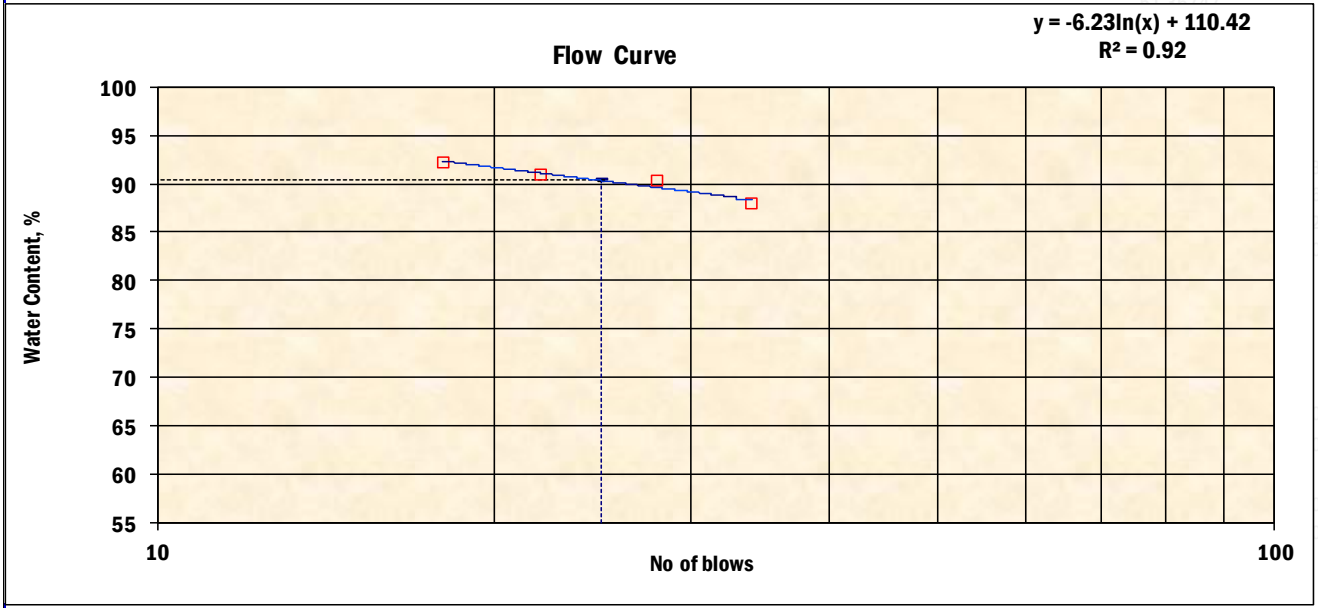


ATTERBERG LIMIT TESTS

Date of Tested:-02/09/2014, Tuesday @ 11:00PM
Pit no:- 4
Depth:- @1.3m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	2	H7	DC2	P21	2DA	A14
Mass of container, g	15.20	15.60	15.50	15.90	15.70	11.40
Mass of container + Wet soil, g	29.30	29.50	32.50	30.90	21.90	17.50
Mass of container + Dry soil, g	22.70	22.90	24.40	23.70	20.40	16.10
Mass of water, g	6.60	6.60	8.10	7.20	1.50	1.40
Mass of dry soil, g	7.50	7.30	8.90	7.80	4.70	4.70
Water content, %	88.00	90.41	91.01	92.31	31.91	29.79
No of blows	34	28	22	18	------	------

Liquid Limit, % 90.37 Plastic Limit, % = 30.85 PI, %= 59.52

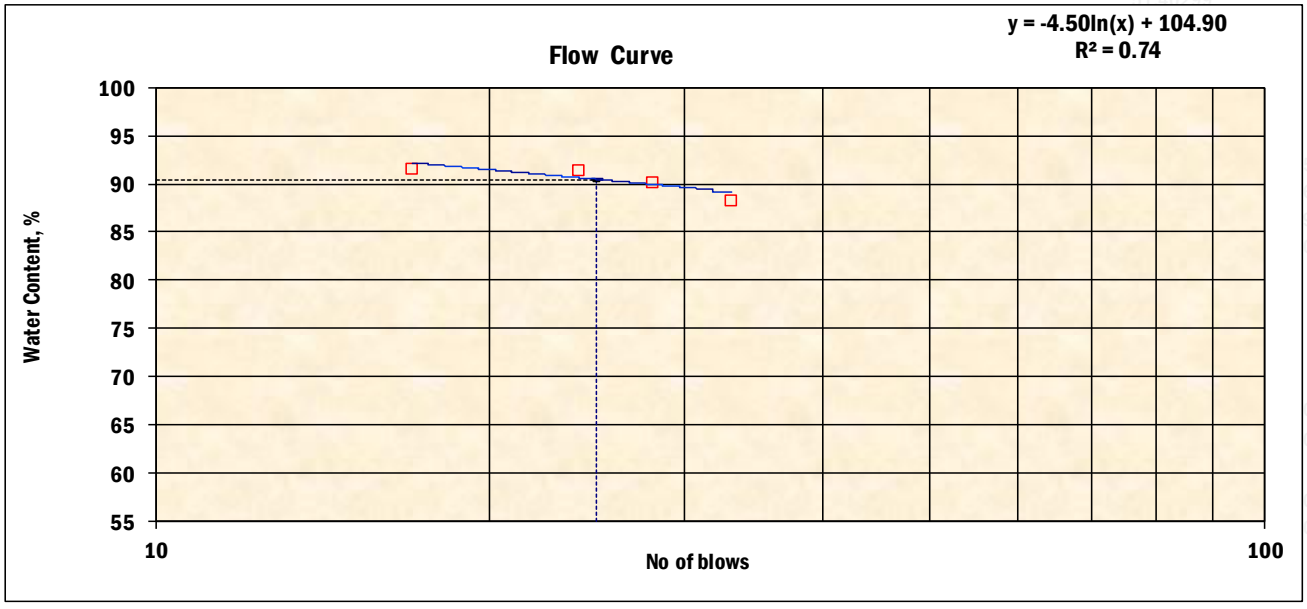


ATTERBERG LIMIT TESTS

Date of Tested:-02/09/2014, Tuesday @ 11:30PM
Pit no:- 4
Depth:- @2.8m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	117	B1	70	100	C44	TM
Mass of container, g	10.90	15.70	15.50	15.50	15.70	15.60
Mass of container + Wet soil, g	28.80	35.20	35.70	33.80	22.60	22.10
Mass of container + Dry soil, g	20.40	25.95	26.05	25.05	20.80	20.40
Mass of water, g	8.40	9.25	9.65	8.75	1.80	1.70
Mass of dry soil, g	9.50	10.25	10.55	9.55	5.10	4.80
Water content, %	88.42	90.24	91.47	91.62	35.29	35.42
No of blows	33	28	24	17	------	------

Liquid Limit, % 90.42 Plastic Limit, % = 35.36 PI, %= 55.06

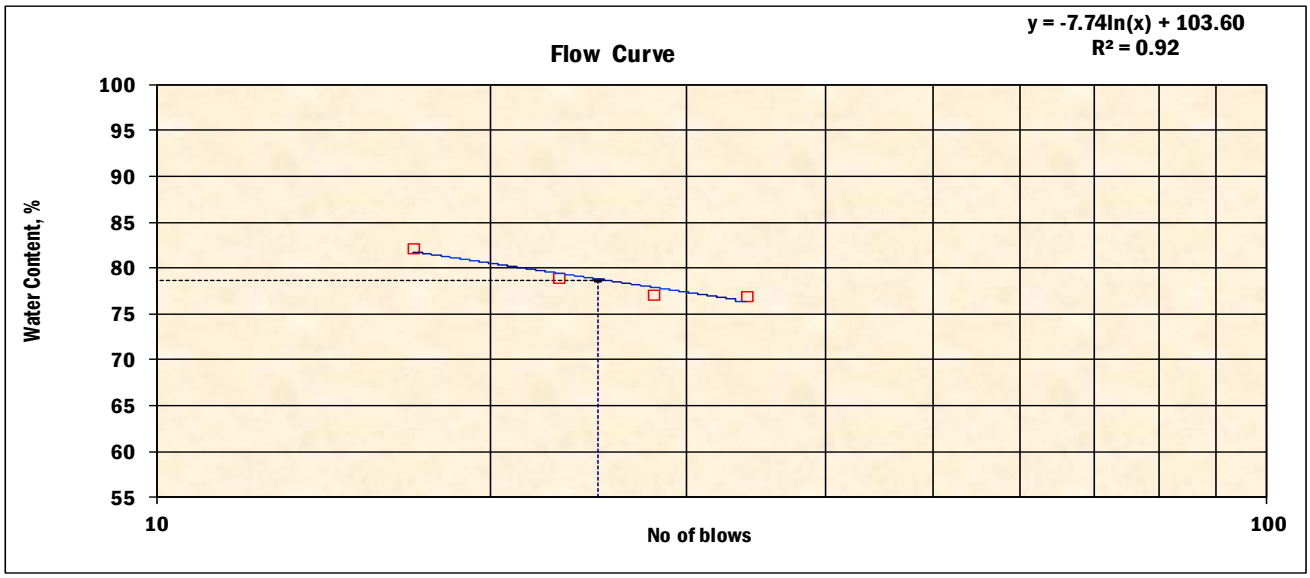


ATTERBERG LIMIT TESTS

Date of Tested:-05/09/2014, Friday @ 4:00AM
Pit no:- 5
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	M2O	T15	S1M	C1	ES	T-8
Mass of container, g	15.70	15.60	15.30	10.90	15.70	15.60
Mass of container + Wet soil, g	35.70	34.20	34.80	33.30	22.20	22.70
Mass of container + Dry soil, g	27.00	26.10	26.20	23.20	20.85	21.25
Mass of water, g	8.70	8.10	8.60	10.10	1.35	1.45
Mass of dry soil, g	11.30	10.50	10.90	12.30	5.15	5.65
Water content, %	76.99	77.14	78.90	82.11	26.21	25.66
No of blows	34	28	23	17	------	------

Liquid Limit, % 78.69 Plastic Limit, % = 25.94 PI, %= 52.75

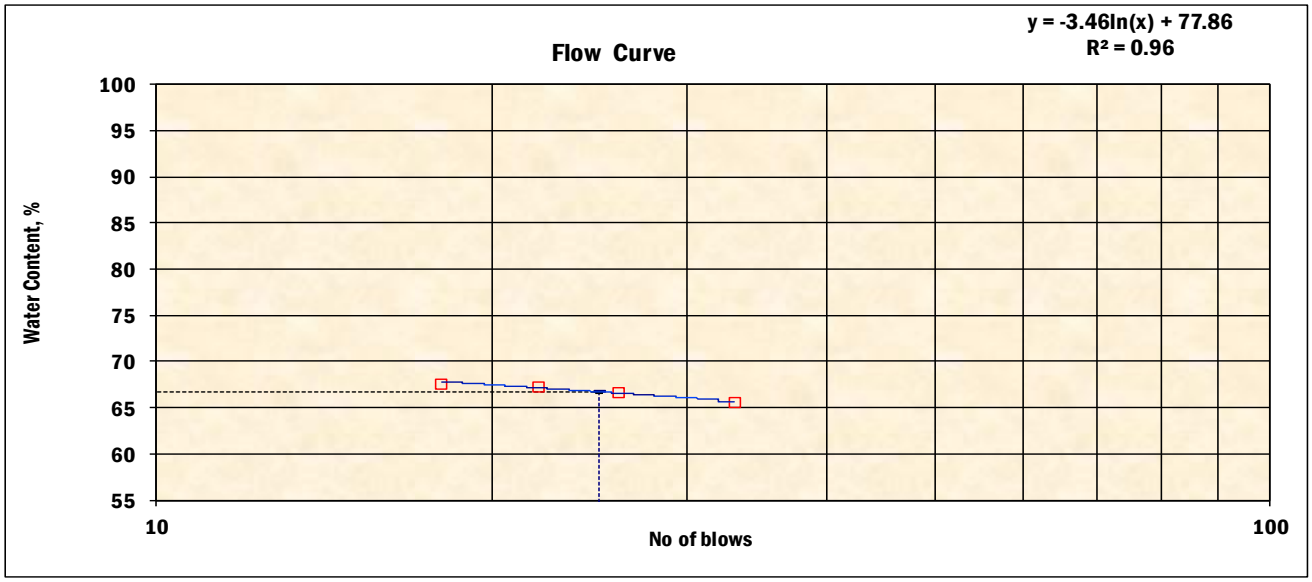


ATTERBERG LIMIT TESTS

Date of Tested:-05/09/2014, Friday @ 5:20AM
Pit no:- 5
Depth:- @3.0m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	CNN	H2S	14	57	3M	IL6
Mass of container, g	15.50	15.00	15.30	15.80	10.50	15.60
Mass of container + Wet soil, g	37.20	35.00	38.90	37.60	17.00	23.00
Mass of container + Dry soil, g	28.60	27.00	29.40	28.80	15.70	21.50
Mass of water, g	8.60	8.00	9.50	8.80	1.30	1.50
Mass of dry soil, g	13.10	12.00	14.10	13.00	5.20	5.90
Water content, %	65.65	66.67	67.38	67.69	25.00	25.42
No of blows	33	26	22	18	------	------

Liquid Limit, % 66.72 Plastic Limit, % = 25.21 PI, %= 41.51

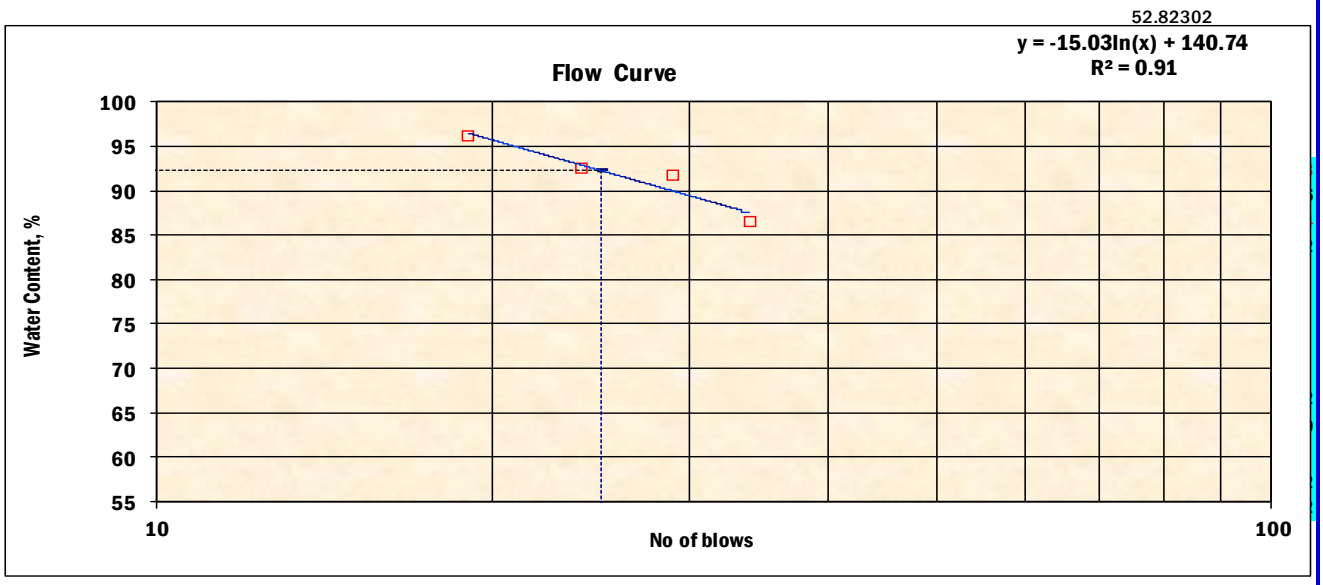


ATTERBERG LIMIT TESTS

Date of Tested:-07/09/2014, Sunday @ 2:30AM
Pit no:- 6
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	6	M2O	C44	IL6	117	S1M
Mass of container, g	15.60	15.60	15.70	15.50	10.90	15.30
Mass of container + Wet soil, g	32.40	32.10	33.80	33.95	17.70	22.60
Mass of container + Dry soil, g	24.60	24.20	25.10	24.90	15.85	20.65
Mass of water, g	7.80	7.90	8.70	9.05	1.85	1.95
Mass of dry soil, g	9.00	8.60	9.40	9.40	4.95	5.35
Water content, %	86.67	91.86	92.55	96.28	37.37	36.45
No of blows	34	29	24	19	------	------

Liquid Limit, % 92.36 Plastic Limit, % = 36.91 PI, %= 55.45

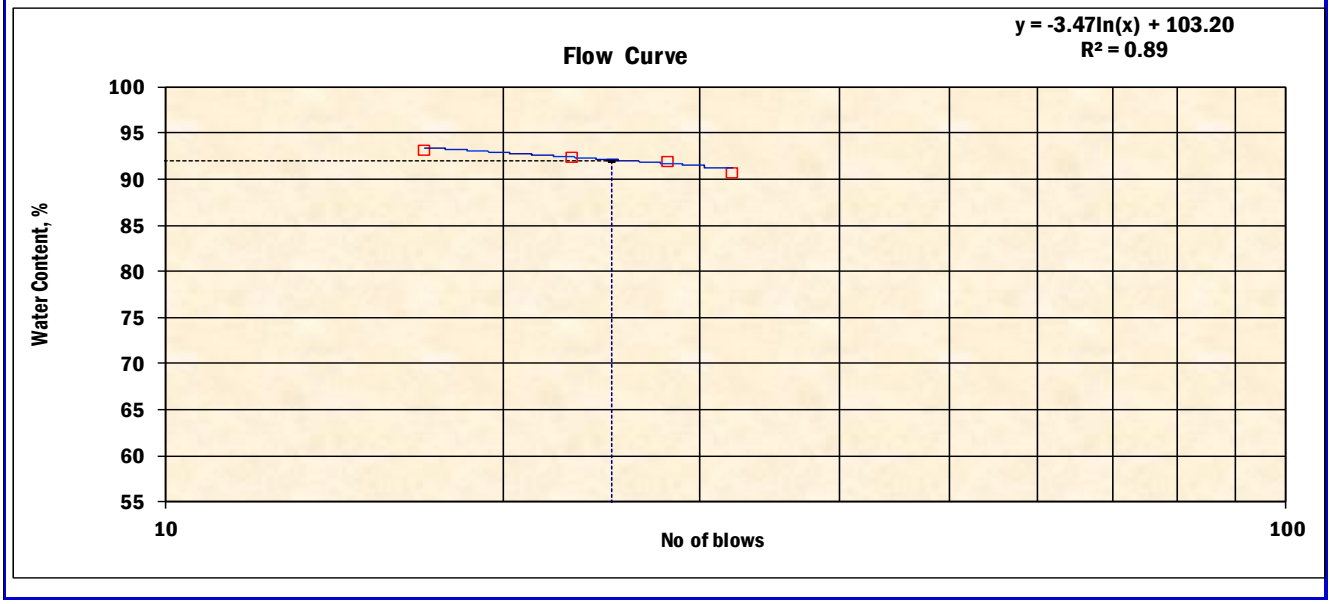


ATTERBERG LIMIT TESTS

Date of Tested:-07/09/2014, Sunday @ 4:20AM
Pit no:- 6
Depth:- @3.0m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	H2S	14	CNN	T-8	T15	C1
Mass of container, g	15.00	15.30	15.50	15.80	15.60	10.90
Mass of container + Wet soil, g	33.70	34.50	36.10	35.70	22.40	18.20
Mass of container + Dry soil, g	24.80	25.30	26.20	26.10	20.45	16.05
Mass of water, g	8.90	9.20	9.90	9.60	1.95	2.15
Mass of dry soil, g	9.80	10.00	10.70	10.30	4.85	5.15
Water content, %	90.82	92.00	92.52	93.20	40.21	41.75
No of blows	32	28	23	17	------	------

Liquid Limit, % 92.03 Plastic Limit, % = 40.98 PI, %= 51.05

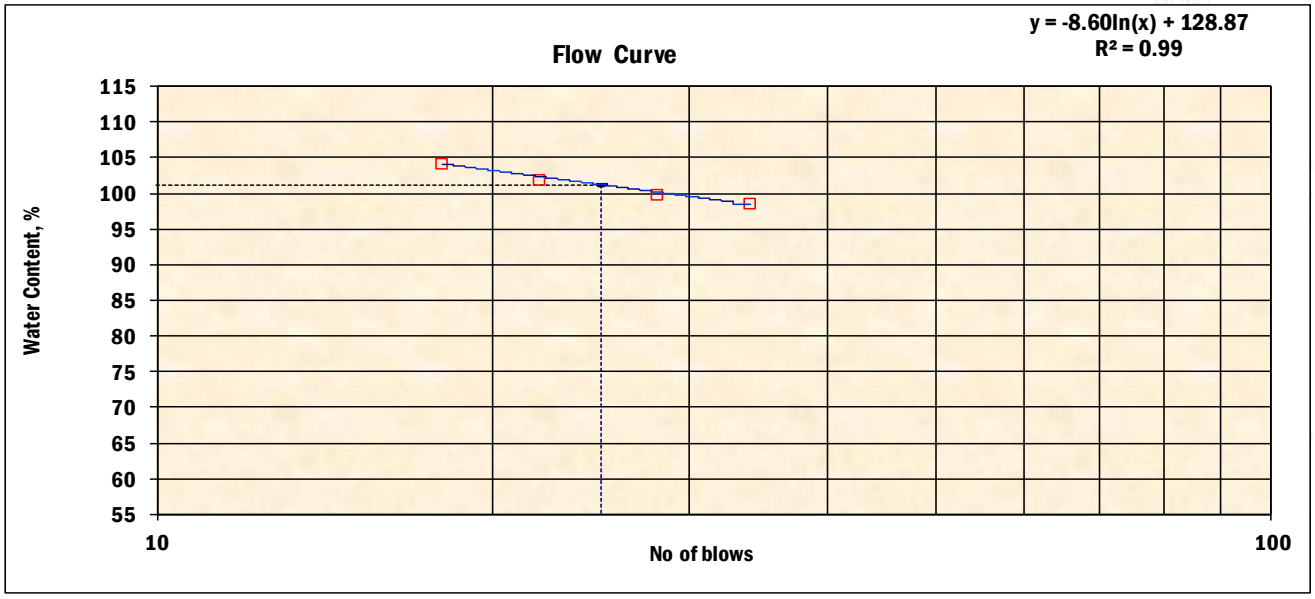


ATTERBERG LIMIT TESTS

Date of Tested:-09/09/2014, Tuesday @ 4:30AM
Pit no:- 7
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	6	G5	H2	140	D31	T13
Mass of container, g	15.70	15.50	15.00	15.50	15.50	15.30
Mass of container + Wet soil, g	31.60	34.60	34.90	34.80	22.30	22.20
Mass of container + Dry soil, g	23.70	25.05	24.85	24.95	20.30	20.25
Mass of water, g	7.90	9.55	10.05	9.85	2.00	1.95
Mass of dry soil, g	8.00	9.55	9.85	9.45	4.80	4.95
Water content, %	98.75	100.00	102.03	104.23	41.67	39.39
No of blows	34	28	22	18	------	------

Liquid Limit, % 101.19 Plastic Limit, % = 40.53 PI, %= 60.66

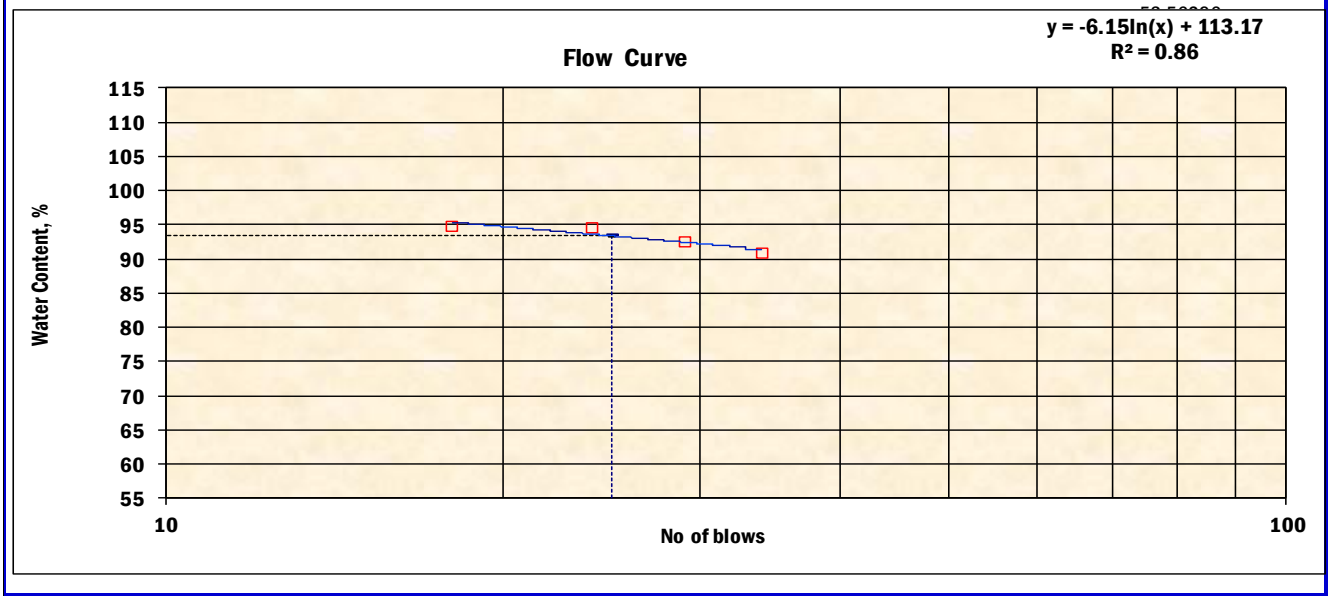


ATTERBERG LIMIT TESTS

Date of Tested:-09/09/2014, Tuesday @ 5:20AM
Pit no:- 7
Depth:- @3.0m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	CNN	52	CRS	T15	S1M	C44
Mass of container, g	15.50	15.10	15.80	15.60	15.30	15.70
Mass of container + Wet soil, g	36.70	33.10	33.70	34.50	22.30	23.30
Mass of container + Dry soil, g	26.60	24.45	25.00	25.30	20.35	21.15
Mass of water, g	10.10	8.65	8.70	9.20	1.95	2.15
Mass of dry soil, g	11.10	9.35	9.20	9.70	5.05	5.45
Water content, %	90.99	92.51	94.57	94.85	38.61	39.45
No of blows	34	29	24	18	------	------

Liquid Limit, % 93.37 Plastic Limit, % = 39.03 PI, %= 54.34

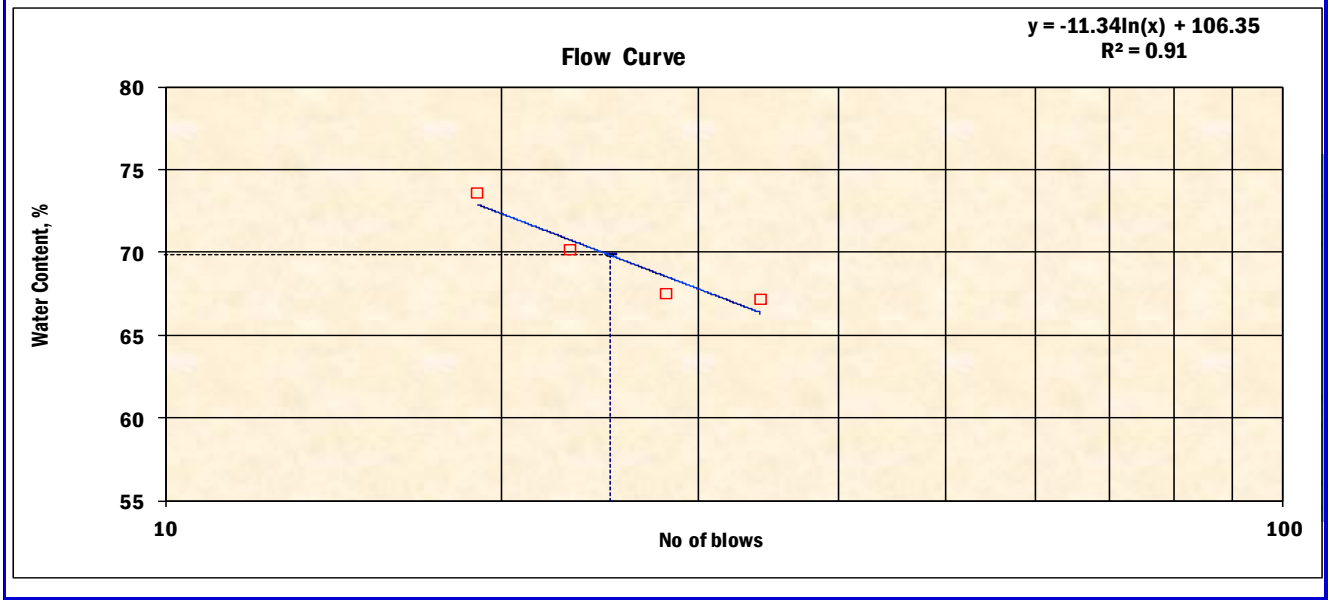


ATTERBERG LIMIT TESTS

Date of Tested:-10/09/2014, Wednesday @ 5:00AM
Pit no:- 8
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	F101	B6	3M	M2O	B4	117
Mass of container, g	15.50	15.60	10.50	15.70	15.70	10.90
Mass of container + Wet soil, g	36.90	34.20	31.10	38.10	22.00	17.20
Mass of container + Dry soil, g	28.30	26.70	22.60	28.60	20.45	15.65
Mass of water, g	8.60	7.50	8.50	9.50	1.55	1.55
Mass of dry soil, g	12.80	11.10	12.10	12.90	4.75	4.75
Water content, %	67.19	67.57	70.25	73.64	32.63	32.63
No of blows	34	28	23	19	------	------

Liquid Limit, % 69.85 Plastic Limit, % = 32.63 PI, %= 37.22

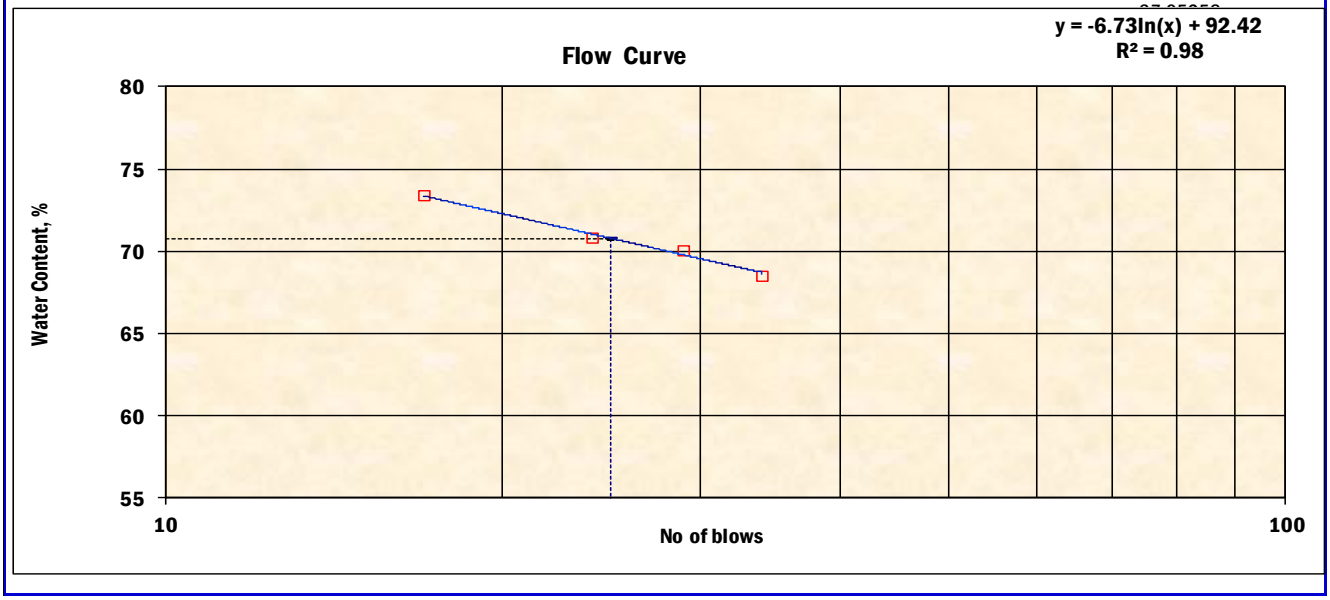


ATTERBERG LIMIT TESTS

Date of Tested:-10/09/2014, Wednesday @ 6:10PM
Pit no:- 8
Depth:- @2.8m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Dark Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	T15	52	C1	H5	100	ES
Mass of container, g	15.60	15.20	10.90	15.50	15.60	15.60
Mass of container + Wet soil, g	30.60	35.10	30.20	37.00	24.00	22.90
Mass of container + Dry soil, g	24.50	26.90	22.20	27.90	21.90	21.05
Mass of water, g	6.10	8.20	8.00	9.10	2.10	1.85
Mass of dry soil, g	8.90	11.70	11.30	12.40	6.30	5.45
Water content, %	68.54	70.09	70.80	73.39	33.33	33.94
No of blows	34	29	24	17	------	------

Liquid Limit, % 70.76 Plastic Limit, % = 33.64 PI, %= 37.12

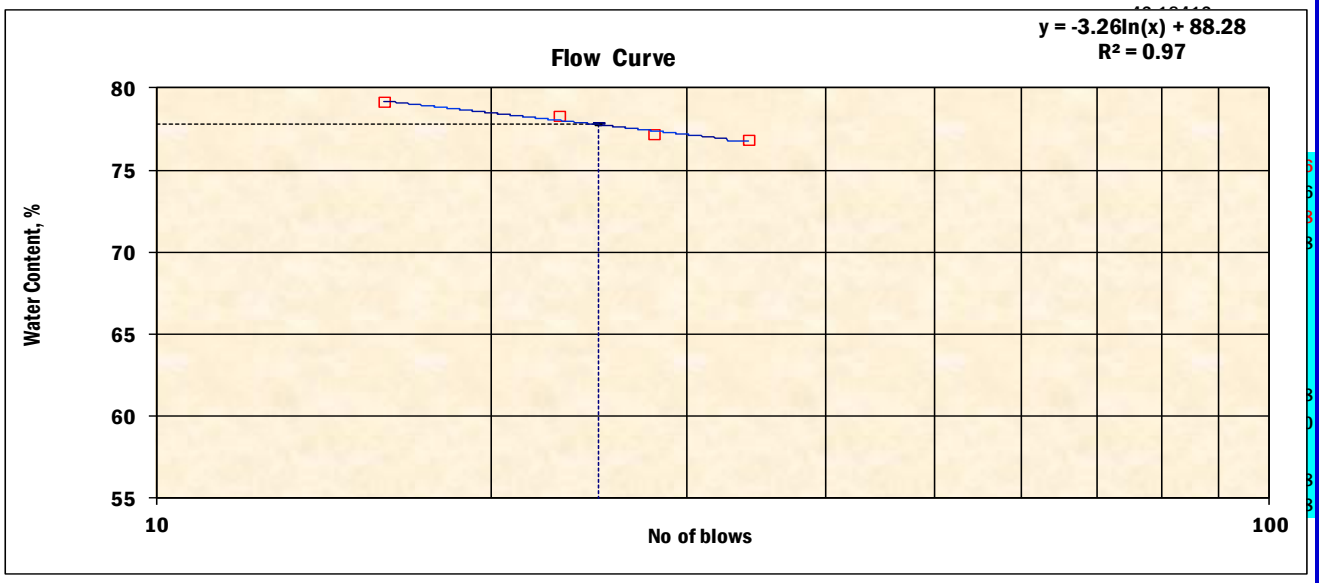


ATTERBERG LIMIT TESTS

Date of Tested:-15/09/2014, Monday @ 5:00AM
Pit no:- 9
Depth:- @1.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	CRS	52	140	T15	C44	D31
Mass of container, g	15.80	15.10	15.50	15.60	15.70	15.40
Mass of container + Wet soil, g	34.10	33.00	34.40	41.40	22.00	22.00
Mass of container + Dry soil, g	26.15	25.20	26.10	30.00	20.55	20.55
Mass of water, g	7.95	7.80	8.30	11.40	1.45	1.45
Mass of dry soil, g	10.35	10.10	10.60	14.40	4.85	5.15
Water content, %	76.81	77.23	78.30	79.17	29.90	28.16
No of blows	34	28	23	16	------	------

Liquid Limit, % 77.79 Plastic Limit, % = 29.03 PI, %= 48.76

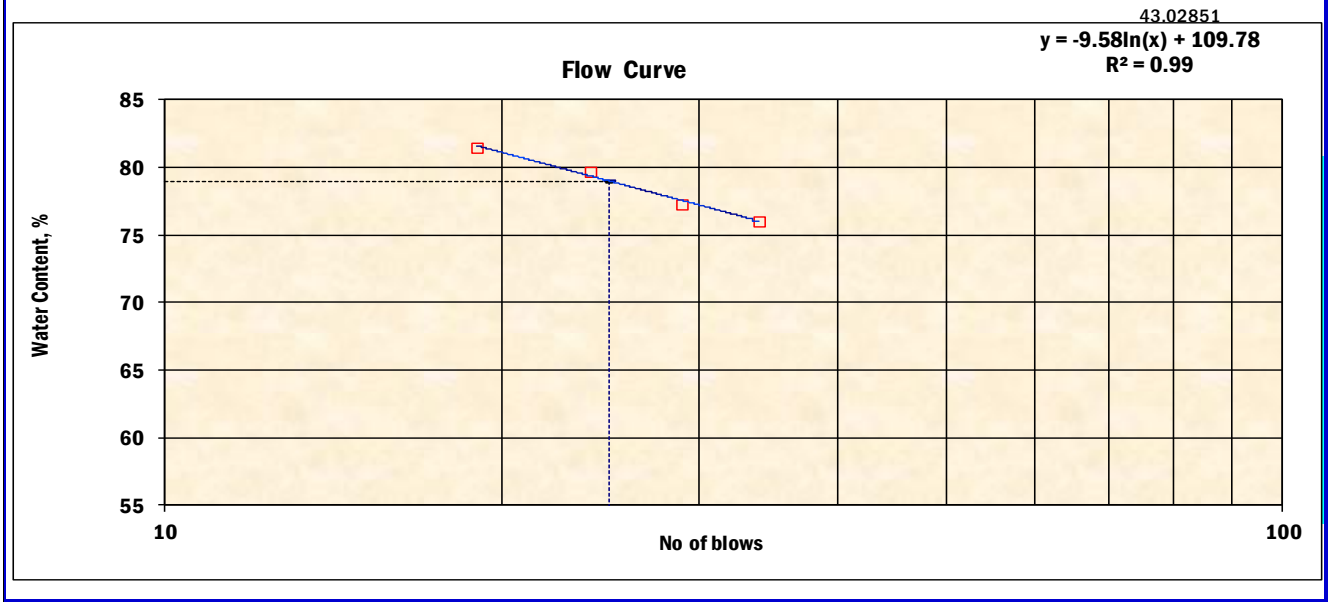


ATTERBERG LIMIT TESTS

Date of Tested:-15/09/2014, Monday @ 5:55AM
Pit no:- 9
Depth:- @3.0m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	T13	6	H2S	3M	CNN	S1M
Mass of container, g	15.20	15.60	15.00	10.40	15.50	15.30
Mass of container + Wet soil, g	35.80	38.20	37.10	32.90	22.10	22.80
Mass of container + Dry soil, g	26.90	28.35	27.30	22.80	20.40	20.80
Mass of water, g	8.90	9.85	9.80	10.10	1.70	2.00
Mass of dry soil, g	11.70	12.75	12.30	12.40	4.90	5.50
Water content, %	76.07	77.25	79.67	81.45	34.69	36.36
No of blows	34	29	24	19	------	------

Liquid Limit, % 78.94 Plastic Limit, % = 35.53 PI, %= 43.41

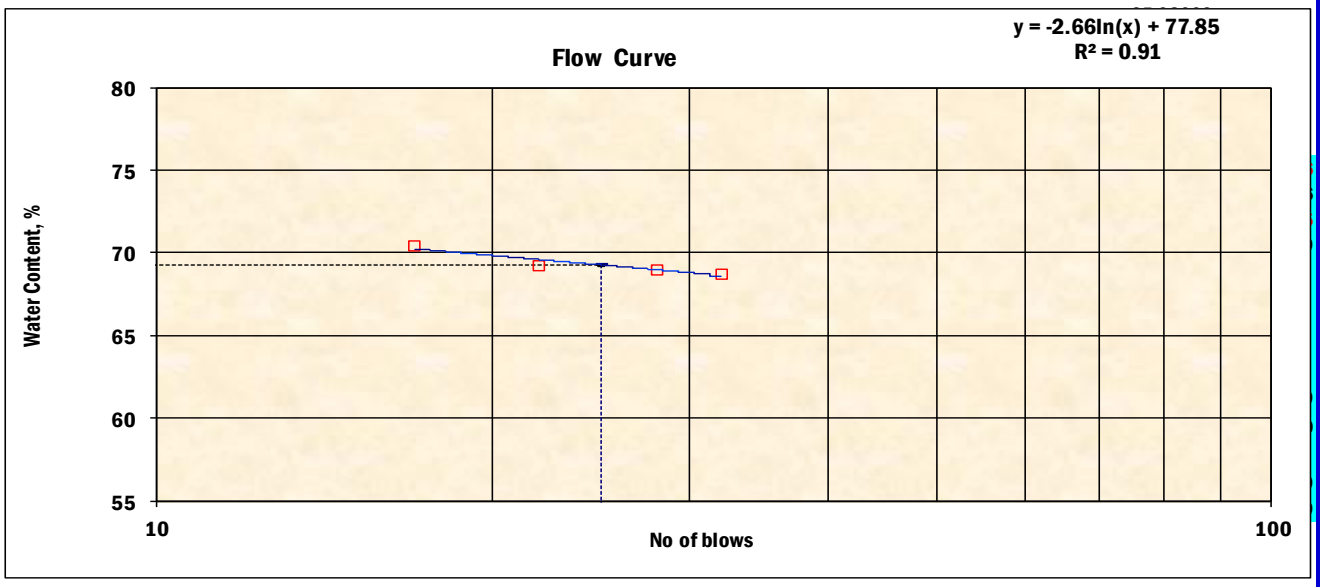


ATTERBERG LIMIT TESTS

Date of Tested:-15/09/2014, Monday @ 7:10PM
Pit no:- 10
Depth:- @1.2m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Black
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	B4	100	H5	117	M2O	ES
Mass of container, g	15.70	15.60	15.40	10.90	15.70	15.70
Mass of container + Wet soil, g	40.00	37.40	39.10	34.60	22.30	23.20
Mass of container + Dry soil, g	30.10	28.50	29.40	24.80	20.80	21.50
Mass of water, g	9.90	8.90	9.70	9.80	1.50	1.70
Mass of dry soil, g	14.40	12.90	14.00	13.90	5.10	5.80
Water content, %	68.75	68.99	69.29	70.50	29.41	29.31
No of blows	32	28	22	17	------	------

Liquid Limit, % 69.29 Plastic Limit, % = 29.36 PI, %= 39.93

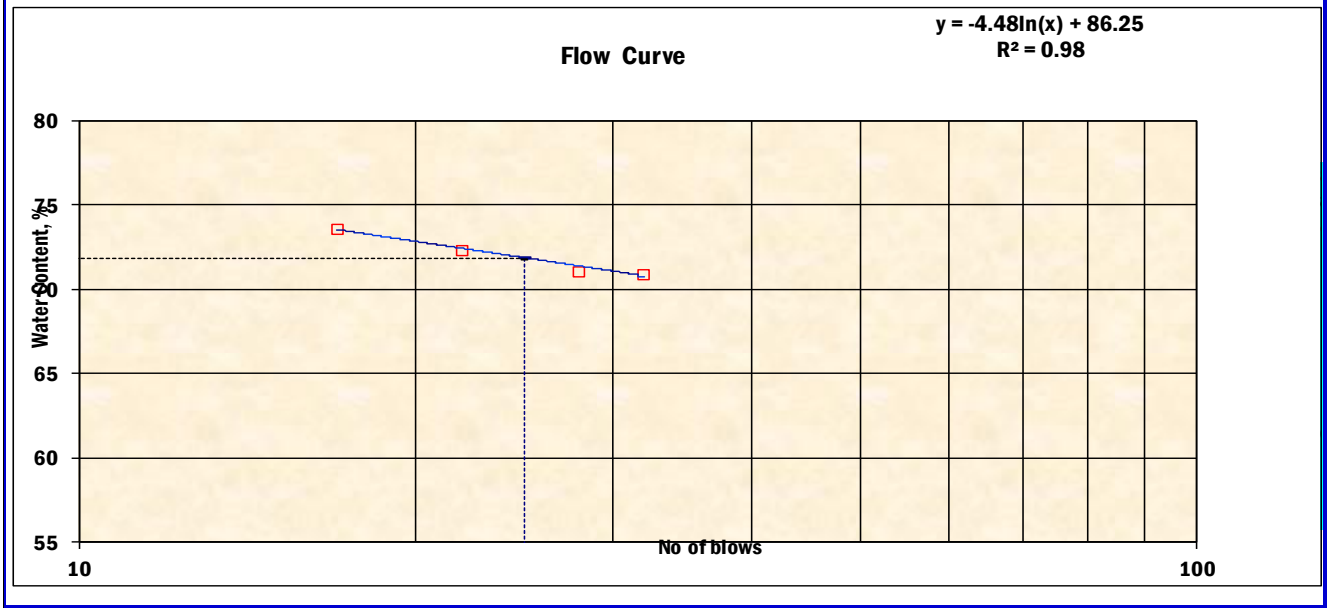


ATTERBERG LIMIT TESTS

Date of Tested:-15/09/2014, Monday @ 8:50PM
Pit no:- 10
Depth:- @2.5m
Sample discription:- Ambo Expanssive Soil
Color of sample:- Grey
Standard Referance:-ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	H2S	G5	6	D31	T13	140
Mass of container, g	15.00	15.50	15.70	15.50	15.30	15.50
Mass of container + Wet soil, g	39.10	37.40	40.00	34.60	22.30	23.20
Mass of container + Dry soil, g	29.10	28.30	29.80	26.50	20.60	21.40
Mass of water, g	10.00	9.10	10.20	8.10	1.70	1.80
Mass of dry soil, g	14.10	12.80	14.10	11.00	5.30	5.90
Water content, %	70.92	71.09	72.34	73.64	32.08	30.51
No of blows	32	28	22	17	------	------

Liquid Limit, % 71.83 Plastic Limit, % = 31.29 PI, %= 40.54



GRAIN SIZE ANLYSIS

Date of Tested:-25/08/2014, Monday @3:05 AM

Pit no:- 1

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

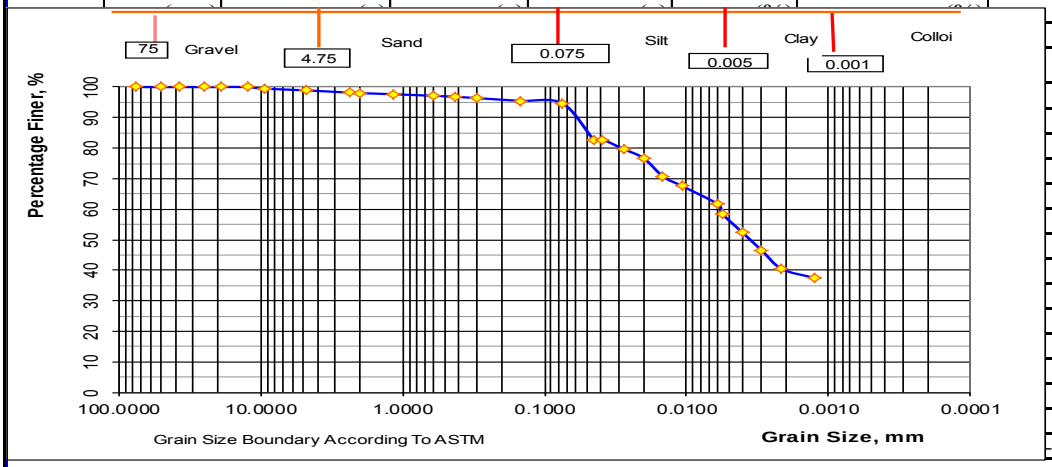
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.49
							98.91
							98.17
							98.02
							97.66
							97.13
							96.81
							96.39
							95.49
							94.69



Hydrometer Analysis

Specific Gravity of sc 2.68 — Test Temperature, deg.c 20.43

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0300	0.002615	1.0274	8.36	0.013457	0.0449	87.39	82.75
1	1.0300	0.002615	1.0274	8.36	0.013457	0.0389	87.39	82.75
2	1.0290	0.002615	1.0264	8.63	0.013457	0.0280	84.19	79.73
4	1.0280	0.002615	1.0254	8.89	0.013457	0.0201	81.00	76.71
8	1.0260	0.002615	1.0234	9.42	0.013457	0.0146	74.62	70.66
15	1.0250	0.002615	1.0224	9.69	0.013457	0.0108	71.43	67.64
30	1.0230	0.002615	1.0204	10.22	0.013457	0.0079	65.05	61.60
60	1.0220	0.002615	1.0194	10.48	0.013457	0.0056	61.86	58.58
120	1.0200	0.002615	1.0174	11.01	0.013457	0.0041	55.48	52.53
240	1.0180	0.002615	1.0154	11.54	0.013457	0.0030	49.09	46.49
480	1.0160	0.002615	1.0134	12.07	0.013457	0.0021	42.71	40.45
1440	1.0150	0.002615	1.0124	12.33	0.013457	0.0012	39.52	37.42

% Gravel= 1.09%

% Sand= 4.22%

% Silt= 38.56%

% Clay= 56.14%

GRAIN SIZE ANLYSIS

Date of Tested:-25/08/2014, Monday @3:36 AM

Pit no:- 1

Depth:- @3.0m

Sample discription:- Ambo Expansive Soil

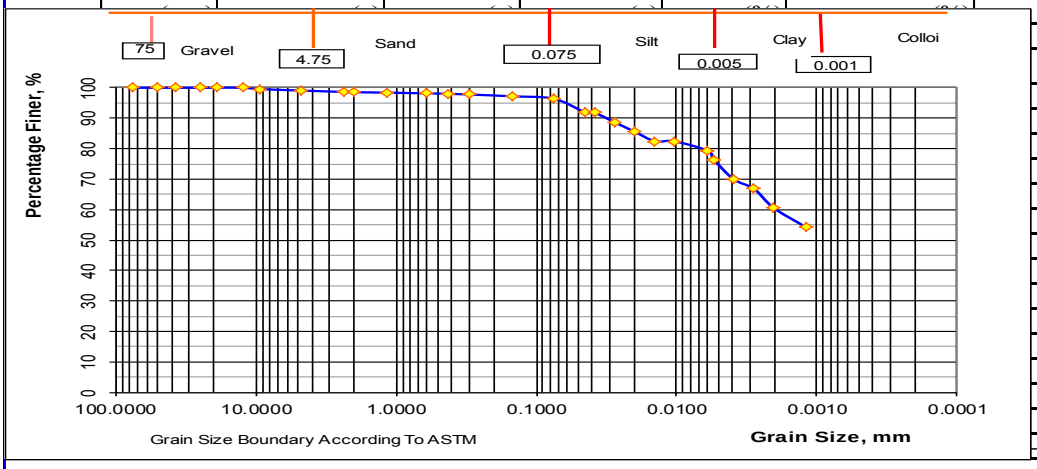
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.57
							99.08
							98.63
							98.55
							98.39
							98.16
							98.01
							97.78
							97.19
							96.39



Hydrometer Analysis

Specific Gravity of sc 2.61 — Test Temperature, deg.c 20.40

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0320	0.00262	1.0294	7.84	0.013749	0.0444	95.25	91.81
1	1.0320	0.00262	1.0294	7.84	0.013749	0.0385	95.25	91.81
2	1.0310	0.00262	1.0284	8.10	0.013749	0.0277	92.01	88.68
4	1.0300	0.00262	1.0274	8.36	0.013749	0.0199	88.77	85.56
8	1.0290	0.00262	1.0264	8.63	0.013749	0.0143	85.52	82.43
15	1.0290	0.00262	1.0264	8.63	0.013749	0.0104	85.52	82.43
30	1.0280	0.00262	1.0254	8.89	0.013749	0.0075	82.28	79.31
60	1.0270	0.00262	1.0244	9.16	0.013749	0.0054	79.04	76.18
120	1.0250	0.00262	1.0224	9.69	0.013749	0.0039	72.56	69.93
240	1.0240	0.00262	1.0214	9.95	0.013749	0.0028	69.31	66.81
480	1.0220	0.00262	1.0194	10.48	0.013749	0.0020	62.83	60.56
1440	1.0200	0.00262	1.0174	11.01	0.013749	0.0012	56.35	54.31

% Gravel= 0.92%
% Sand= 2.69%
% Silt= 21.79%
% Clay= 74.60%

GRAIN SIZE ANLYSIS

Date of Tested:-25/08/2014, Monday @3:46 AM

Pit no:- 2

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

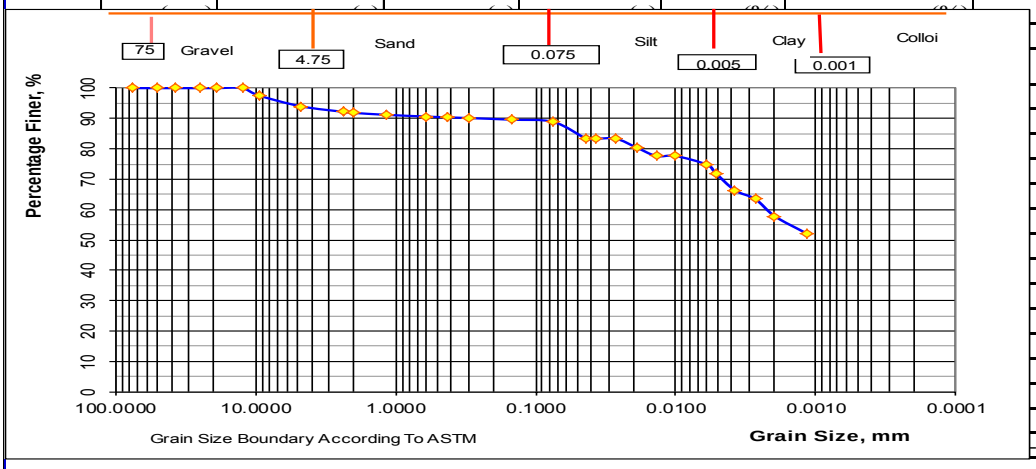
Color of sample:- Black

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening ( )	Mass of Sieve ( )	Mass of sieve + Retained soil ( )	Mass of Retained soil ( )	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							97.57
							94.01
							92.19
							91.86
							91.21
							90.63
							90.38
							90.14
							89.61
							88.87



Hydrometer Analysis

Specific Gravity of sc 2.68 — Test Temperature, deg.c 20.43

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0320	0.002615	1.0294	7.84	0.013454	0.0435	93.75	83.32
1	1.0320	0.002615	1.0294	7.84	0.013454	0.0377	93.75	83.32
2	1.0320	0.002615	1.0294	7.84	0.013454	0.0266	93.75	83.32
4	1.0310	0.002615	1.0284	8.10	0.013454	0.0191	90.56	80.49
8	1.0300	0.002615	1.0274	8.36	0.013454	0.0138	87.37	77.65
15	1.0300	0.002615	1.0274	8.36	0.013454	0.0100	87.37	77.65
30	1.0290	0.002615	1.0264	8.63	0.013454	0.0072	84.18	74.81
60	1.0280	0.002615	1.0254	8.89	0.013454	0.0052	80.99	71.98
120	1.0260	0.002615	1.0234	9.42	0.013454	0.0038	74.61	66.31
240	1.0250	0.002615	1.0224	9.69	0.013454	0.0027	71.42	63.47
480	1.0230	0.002615	1.0204	10.22	0.013454	0.0020	65.04	57.80
1440	1.0210	0.002615	1.0184	10.75	0.013454	0.0012	58.66	52.13

% Gravel= 5.99%

% Sand= 5.13%

% Silt= 17.62%

% Clay= 71.26%

GRAIN SIZE ANLYSIS

Date of Tested:-06/09/2014, Saturday @6:30PM

Pit no:- 1

Depth:- @2.8m

Sample discription:- Ambo Expansive Soil

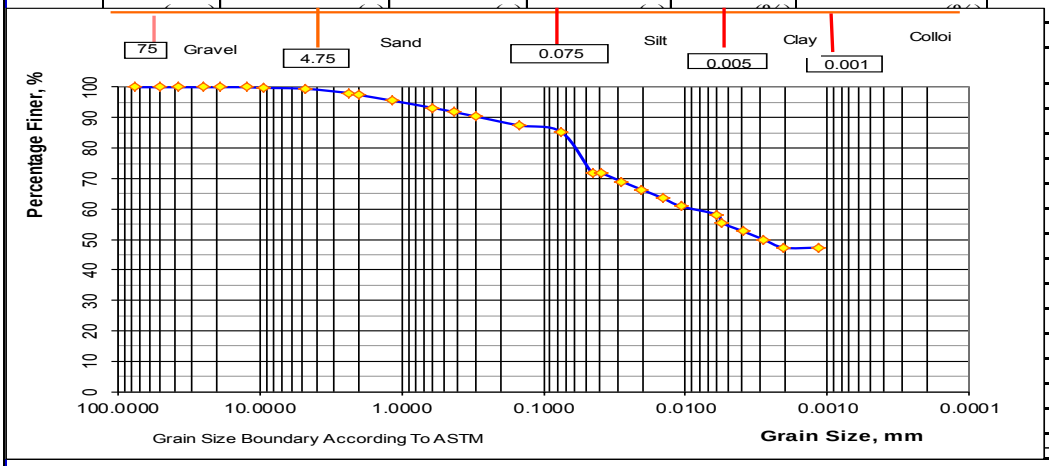
Color of sample:- Dark Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.79
							99.48
							98.07
							97.46
							95.63
							93.18
							91.82
							90.37
							87.48
							85.29



Hydrometer Analysis

Specific Gravity of sc 2.69 — Test Temperature, deg.c 20.58

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0290	0.002583333	1.0264	8.63	0.013393	0.0454	84.12	71.75
1	1.0290	0.002583333	1.0264	8.63	0.013393	0.0393	84.12	71.75
2	1.0280	0.002583333	1.0254	8.89	0.013393	0.0282	80.94	69.03
4	1.0270	0.002583333	1.0244	9.16	0.013393	0.0203	77.75	66.32
8	1.0260	0.002583333	1.0234	9.42	0.013393	0.0145	74.57	63.60
15	1.0250	0.002583333	1.0224	9.69	0.013393	0.0108	71.38	60.89
30	1.0240	0.002583333	1.0214	9.95	0.013393	0.0077	68.20	58.17
60	1.0230	0.002583333	1.0204	10.22	0.013393	0.0055	65.01	55.45
120	1.0220	0.002583333	1.0194	10.48	0.013393	0.0040	61.83	52.74
240	1.0210	0.002583333	1.0184	10.75	0.013393	0.0028	58.65	50.02
480	1.0200	0.002583333	1.0174	11.01	0.013393	0.0020	55.46	47.31
1440	1.0200	0.002583333	1.0174	11.01	0.013393	0.0012	55.46	47.31

% Gravel= 0.52%

% Sand= 14.19%

% Silt= 30.75%

% Clay= 54.54%

GRAIN SIZE ANLYSIS

Date of Tested:-06/09/2014, Saturday @6:30PM

Pit no:- 3

Depth:- @1.4m

Sample discription:- Ambo Expansive Soil

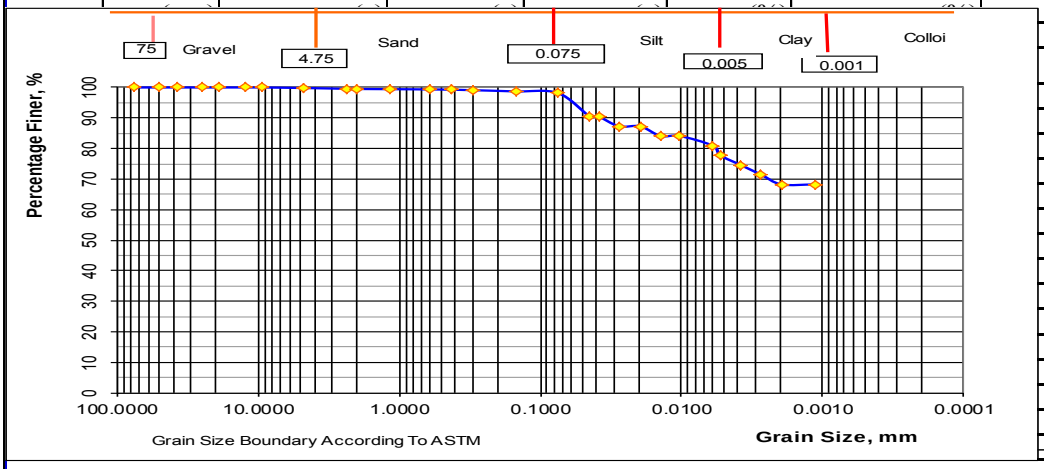
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.82
							99.55
							99.50
							99.45
							99.35
							99.26
							99.10
							98.70
							98.18



Hydrometer Analysis

Specific Gravity of sc 2.63 — Test Temperature, deg.c 21.16

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0310	0.002468333	1.0285	8.10	0.01355	0.0445	92.13	90.45
1	1.0310	0.002468333	1.0285	8.10	0.01355	0.0386	92.13	90.45
2	1.0300	0.002468333	1.0275	8.36	0.01355	0.0277	88.90	87.28
4	1.0300	0.002468333	1.0275	8.36	0.01355	0.0196	88.90	87.28
8	1.0290	0.002468333	1.0265	8.63	0.01355	0.0141	85.67	84.11
15	1.0290	0.002468333	1.0265	8.63	0.01355	0.0103	85.67	84.11
30	1.0280	0.002468333	1.0255	8.89	0.01355	0.0074	82.44	80.94
60	1.0270	0.002468333	1.0245	9.16	0.01355	0.0053	79.21	77.77
120	1.0260	0.002468333	1.0235	9.42	0.01355	0.0038	75.98	74.60
240	1.0250	0.002468333	1.0225	9.69	0.01355	0.0027	72.75	71.43
480	1.0240	0.002468333	1.0215	9.95	0.01355	0.0020	69.52	68.26
1440	1.0240	0.002468333	1.0215	9.95	0.01355	0.0011	69.52	68.26

% Gravel= 0.18%

% Sand= 1.64%

% Silt= 21.03%

% Clay= 77.15%

GRAIN SIZE ANLYSIS

Date of Tested:-06/09/2014, Saturday @6:30PM

Pit no:- 3

Depth:- @2.5m

Sample discription:- Ambo Expansive Soil

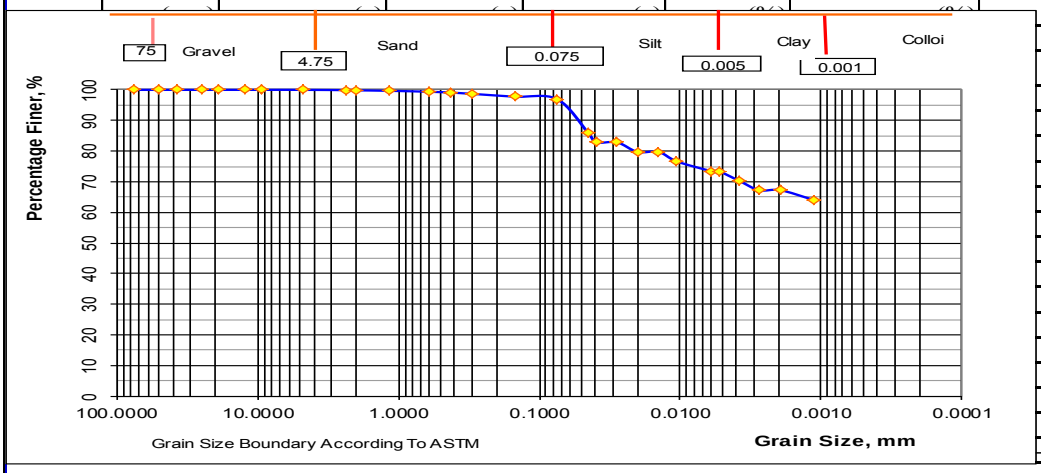
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.90
							99.84
							99.69
							99.37
							99.10
							98.69
							97.76
							97.00



Hydrometer Analysis

Specific Gravity of sc 2.64 — Test Temperature, deg.c 21.16

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0300	0.002468333	1.0275	8.36	0.013495	0.0451	88.63	85.97
1	1.0290	0.002468333	1.0265	8.63	0.013495	0.0396	85.41	82.85
2	1.0290	0.002468333	1.0265	8.63	0.013495	0.0280	85.41	82.85
4	1.0280	0.002468333	1.0255	8.89	0.013495	0.0201	82.19	79.73
8	1.0280	0.002468333	1.0255	8.89	0.013495	0.0142	82.19	79.73
15	1.0270	0.002468333	1.0245	9.16	0.013495	0.0105	78.97	76.60
30	1.0260	0.002468333	1.0235	9.42	0.013495	0.0076	75.75	73.48
60	1.0260	0.002468333	1.0235	9.42	0.013495	0.0053	75.75	73.48
120	1.0250	0.002468333	1.0225	9.69	0.013495	0.0038	72.53	70.36
240	1.0240	0.002468333	1.0215	9.95	0.013495	0.0027	69.32	67.24
480	1.0240	0.002468333	1.0215	9.95	0.013495	0.0019	69.32	67.24
1440	1.0230	0.002468333	1.0205	10.22	0.013495	0.0011	66.10	64.11

% Gravel=	0.00%
% Sand=	3.00%
% Silt=	24.24%
% Clay=	72.76%

GRAIN SIZE ANLYSIS

Date of Tested:-06/09/2014, Saturday @6:30PM

Pit no:- 4

Depth:- @1.3m

Sample discription:- Ambo Expansive Soil

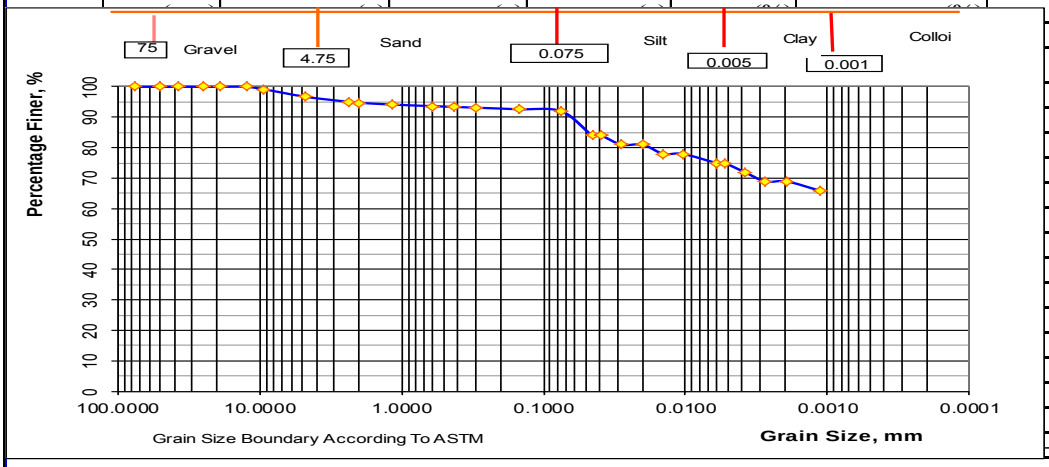
Color of sample:- Black

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.25
							96.71
							95.06
							94.76
							94.17
							93.64
							93.40
							93.14
							92.62
							91.98



Hydrometer Analysis

Specific Gravity of sc 2.56 — Test Temperature, deg.c 22.60

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0300	0.00218	1.0278	8.36	0.013608	0.0454	91.34	84.01
1	1.0300	0.00218	1.0278	8.36	0.013608	0.0394	91.34	84.01
2	1.0290	0.00218	1.0268	8.63	0.013608	0.0283	88.06	80.99
4	1.0290	0.00218	1.0268	8.63	0.013608	0.0200	88.06	80.99
8	1.0280	0.00218	1.0258	8.89	0.013608	0.0143	84.77	77.97
15	1.0280	0.00218	1.0258	8.89	0.013608	0.0105	84.77	77.97
30	1.0270	0.00218	1.0248	9.16	0.013608	0.0075	81.49	74.95
60	1.0270	0.00218	1.0248	9.16	0.013608	0.0053	81.49	74.95
120	1.0260	0.00218	1.0238	9.42	0.013608	0.0038	78.21	71.93
240	1.0250	0.00218	1.0228	9.69	0.013608	0.0027	74.93	68.91
480	1.0250	0.00218	1.0228	9.69	0.013608	0.0019	74.93	68.91
1440	1.0240	0.00218	1.0218	9.95	0.013608	0.0011	71.64	65.89

% Gravel= 3.29%

% Sand= 4.74%

% Silt= 17.66%

% Clay= 74.32%

GRAIN SIZE ANLYSIS

Date of Tested:-06/09/2014, Saturday @6:30PM

Pit no:- 4

Depth:- @2.8m

Sample discription:- Ambo Expansive Soil

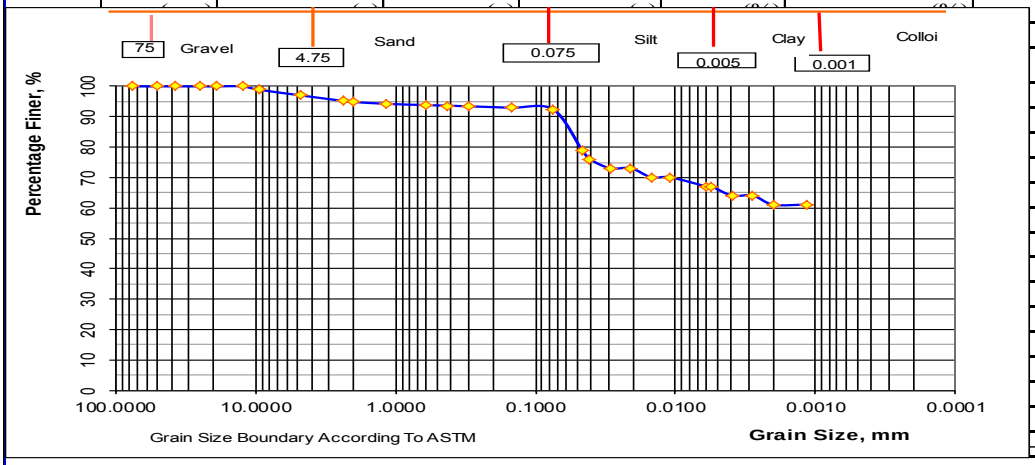
Color of sample:- Dark Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							98.91
							97.03
							95.21
							94.87
							94.27
							93.83
							93.65
							93.43
							92.98
							92.46



Hydrometer Analysis

Specific Gravity of sc 2.61 — Test Temperature, deg.c 20.43

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0290	0.002615	1.0264	8.63	0.01374	0.0466	85.52	79.07
1	1.0280	0.002615	1.0254	8.89	0.01374	0.0410	82.28	76.07
2	1.0270	0.002615	1.0244	9.16	0.01374	0.0294	79.04	73.07
4	1.0270	0.002615	1.0244	9.16	0.01374	0.0208	79.04	73.07
8	1.0260	0.002615	1.0234	9.42	0.01374	0.0149	75.80	70.08
15	1.0260	0.002615	1.0234	9.42	0.01374	0.0109	75.80	70.08
30	1.0250	0.002615	1.0224	9.69	0.01374	0.0078	72.55	67.08
60	1.0250	0.002615	1.0224	9.69	0.01374	0.0055	72.55	67.08
120	1.0240	0.002615	1.0214	9.95	0.01374	0.0040	69.31	64.08
240	1.0240	0.002615	1.0214	9.95	0.01374	0.0028	69.31	64.08
480	1.0230	0.002615	1.0204	10.22	0.01374	0.0020	66.07	61.09
1440	1.0230	0.002615	1.0204	10.22	0.01374	0.0012	66.07	61.09

% Gravel= 2.97%
% Sand= 4.57%
% Silt= 26.37%
% Clay= 66.08%

GRAIN SIZE ANLYSIS

Date of Tested:-07/09/2014, Sunday @6:00PM

Pit no:- 5

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

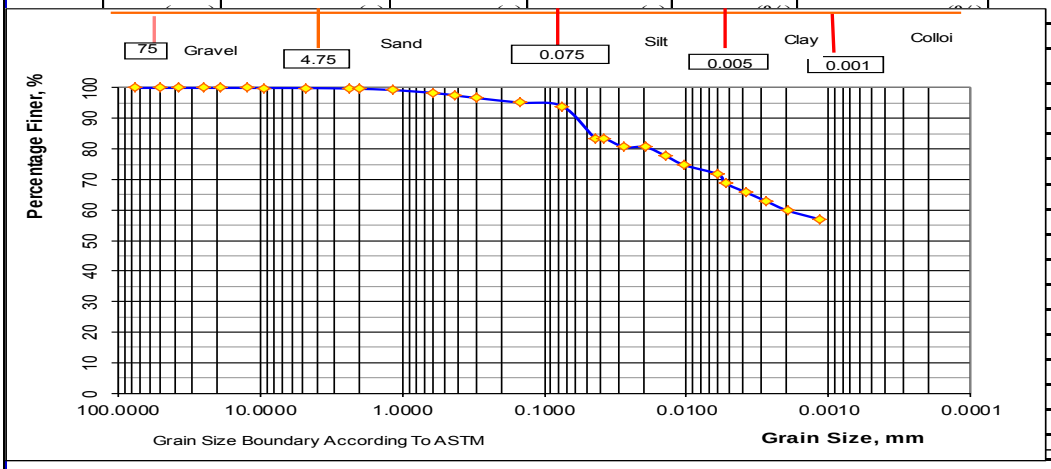
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.96
							99.95
							99.79
							99.69
							99.32
							98.33
							97.52
							96.69
							95.19
							94.03



Hydrometer Analysis

Specific Gravity of sc 2.73 — Test Temperature, deg.c 19.41

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0310	0.002818333	1.0282	8.10	0.013414	0.0441	88.88	83.57
1	1.0310	0.002818333	1.0282	8.10	0.013414	0.0382	88.88	83.57
2	1.0300	0.002818333	1.0272	8.36	0.013414	0.0274	85.73	80.61
4	1.0300	0.002818333	1.0272	8.36	0.013414	0.0194	85.73	80.61
8	1.0290	0.002818333	1.0262	8.63	0.013414	0.0139	82.57	77.64
15	1.0280	0.002818333	1.0252	8.89	0.013414	0.0103	79.42	74.68
30	1.0270	0.002818333	1.0242	9.16	0.013414	0.0074	76.27	71.71
60	1.0260	0.002818333	1.0232	9.42	0.013414	0.0053	73.11	68.75
120	1.0250	0.002818333	1.0222	9.69	0.013414	0.0038	69.96	65.78
240	1.0240	0.002818333	1.0212	9.95	0.013414	0.0027	66.80	62.81
480	1.0230	0.002818333	1.0202	10.22	0.013414	0.0020	63.65	59.85
1440	1.0220	0.002818333	1.0192	10.48	0.013414	0.0011	60.50	56.88

% Gravel= 0.05%

% Sand= 5.93%

% Silt= 25.90%

% Clay= 68.12%

GRAIN SIZE ANLYSIS

Date of Tested:-07/09/2014, Sunday @6:00PM

Pit no:- 5

Depth:- @3.0m

Sample discription:- Ambo Expansive Soil

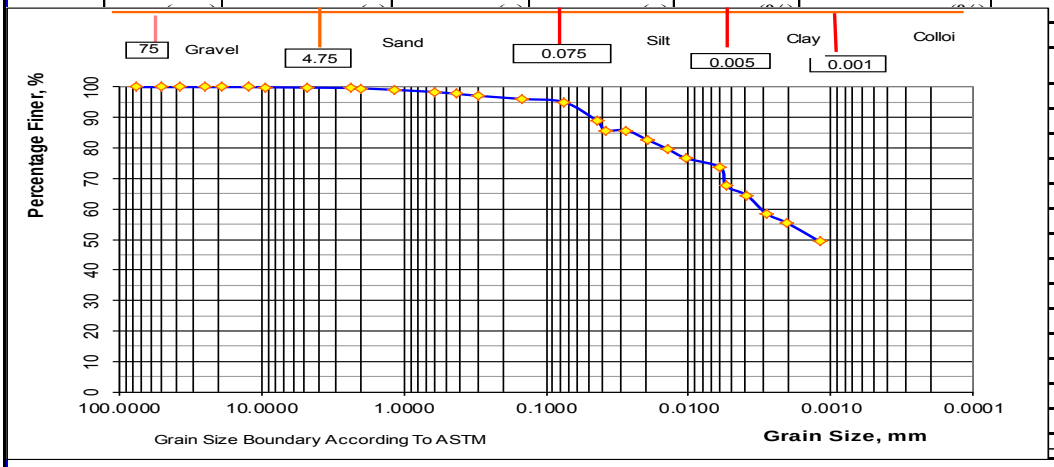
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.94
							99.83
							99.70
							99.57
							99.11
							98.36
							97.78
							97.15
							96.12
							95.07



Hydrometer Analysis

Specific Gravity of sc 2.68 — Test Temperature, deg.c 19.80

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0320	0.00274	1.0293	7.84	0.013578	0.0439	93.45	88.84
1	1.0310	0.00274	1.0283	8.10	0.013578	0.0386	90.26	85.81
2	1.0310	0.00274	1.0283	8.10	0.013578	0.0273	90.26	85.81
4	1.0300	0.00274	1.0273	8.36	0.013578	0.0196	87.06	82.77
8	1.0290	0.00274	1.0263	8.63	0.013578	0.0141	83.87	79.73
15	1.0280	0.00274	1.0253	8.89	0.013578	0.0105	80.68	76.70
30	1.0270	0.00274	1.0243	9.16	0.013578	0.0075	77.48	73.66
60	1.0250	0.00274	1.0223	9.69	0.013578	0.0055	71.10	67.59
120	1.0240	0.00274	1.0213	9.95	0.013578	0.0039	67.90	64.55
240	1.0220	0.00274	1.0193	10.48	0.013578	0.0028	61.51	58.48
480	1.0210	0.00274	1.0183	10.75	0.013578	0.0020	58.32	55.44
1440	1.0190	0.00274	1.0163	11.27	0.013578	0.0012	51.93	49.37

% Gravel= 0.17%

% Sand= 4.77%

% Silt= 28.37%

% Clay= 66.69%

GRAIN SIZE ANLYSIS

Date of Tested:-09/09/2014, Tuesday @8:30PM

Pit no:- 6

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

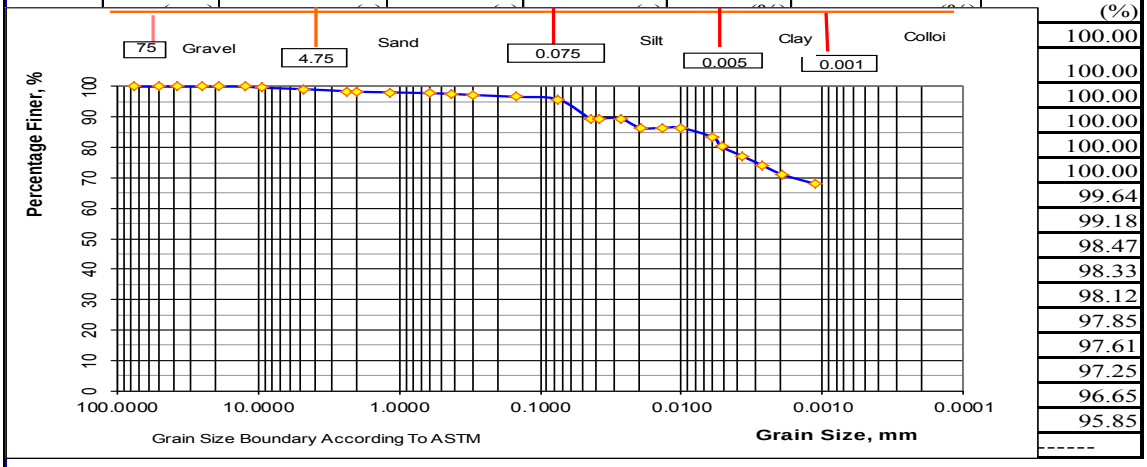
Color of sample:- Dark Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.64
							99.18
							98.47
							98.33
							98.12
							97.85
							97.61
							97.25
							96.65
							95.85



Hydrometer Analysis

Specific Gravity of sc 2.66 — Test Temperature, deg.c 19.28

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0320	0.002843333	1.0292	7.84	0.013722	0.0444	93.40	89.52
1	1.0320	0.002843333	1.0292	7.84	0.013722	0.0384	93.40	89.52
2	1.0320	0.002843333	1.0292	7.84	0.013722	0.0272	93.40	89.52
4	1.0310	0.002843333	1.0282	8.10	0.013722	0.0195	90.20	86.45
8	1.0310	0.002843333	1.0282	8.10	0.013722	0.0138	90.20	86.45
15	1.0310	0.002843333	1.0282	8.10	0.013722	0.0101	90.20	86.45
30	1.0300	0.002843333	1.0272	8.36	0.013722	0.0072	86.99	83.38
60	1.0290	0.002843333	1.0262	8.63	0.013722	0.0052	83.79	80.31
120	1.0280	0.002843333	1.0252	8.89	0.013722	0.0037	80.59	77.24
240	1.0270	0.002843333	1.0242	9.16	0.013722	0.0027	77.38	74.17
480	1.0260	0.002843333	1.0232	9.42	0.013722	0.0019	74.18	71.10
1440	1.0250	0.002843333	1.0222	9.69	0.013722	0.0011	70.98	68.03

% Gravel= 0.82%

% Sand= 3.33%

% Silt= 15.96%

% Clay= 79.88%

GRAIN SIZE ANLYSIS

Date of Tested:-09/09/2014, Tuesday @8:30PM

Pit no:- 6

Depth:- @3.0m

Sample discription:- Ambo Expansive Soil

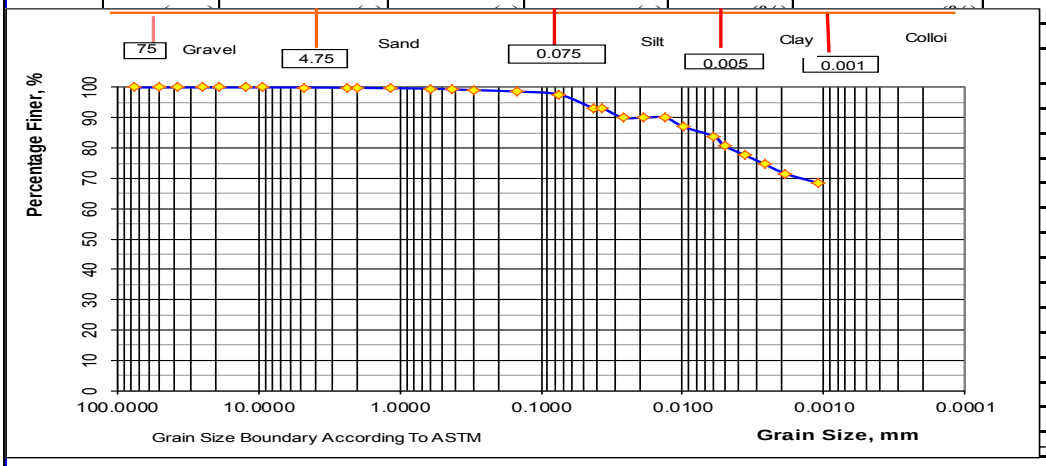
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.99
							99.89
							99.85
							99.75
							99.57
							99.36
							99.12
							98.65
							97.68



Hydrometer Analysis

Specific Gravity of sc 2.73 — Test Temperature, deg.c 19.68

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0330	0.002763333	1.0302	7.57	0.013362	0.0425	95.33	93.12
1	1.0330	0.002763333	1.0302	7.57	0.013362	0.0368	95.33	93.12
2	1.0320	0.002763333	1.0292	7.84	0.013362	0.0264	92.18	90.04
4	1.0320	0.002763333	1.0292	7.84	0.013362	0.0187	92.18	90.04
8	1.0320	0.002763333	1.0292	7.84	0.013362	0.0132	92.18	90.04
15	1.0310	0.002763333	1.0282	8.10	0.013362	0.0098	89.03	86.96
30	1.0300	0.002763333	1.0272	8.36	0.013362	0.0071	85.88	83.88
60	1.0290	0.002763333	1.0262	8.63	0.013362	0.0051	82.72	80.80
120	1.0280	0.002763333	1.0252	8.89	0.013362	0.0036	79.57	77.72
240	1.0270	0.002763333	1.0242	9.16	0.013362	0.0026	76.42	74.64
480	1.0260	0.002763333	1.0232	9.42	0.013362	0.0019	73.26	71.56
1440	1.0250	0.002763333	1.0222	9.69	0.013362	0.0011	70.11	68.48

% Gravel= 0.01%

% Sand= 2.31%

% Silt= 17.02%

% Clay= 80.66%

GRAIN SIZE ANLYSIS

Date of Tested:-10/09/2014, Wednesday @2:38AM

Pit no:- 7

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

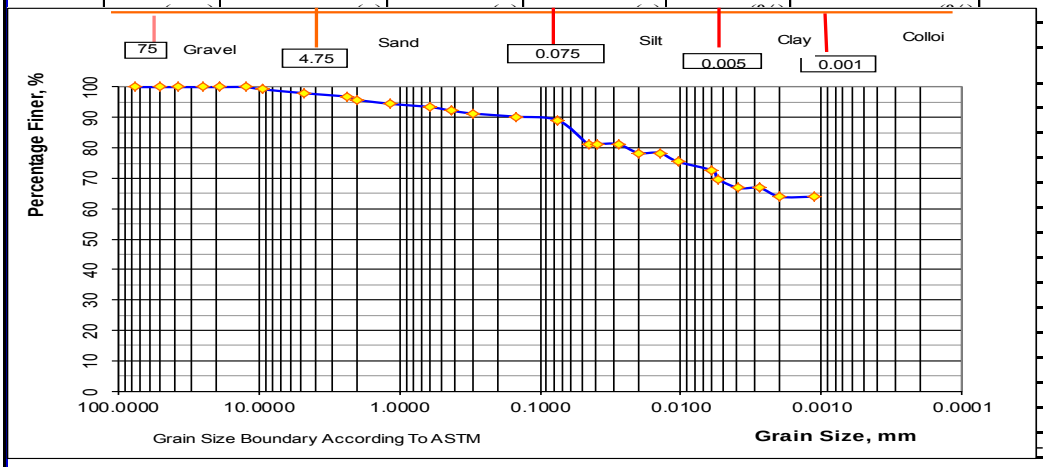
Color of sample:- Black

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.27
							97.99
							96.83
							95.80
							94.53
							93.40
							92.21
							91.30
							90.29
							89.09



Hydrometer Analysis

Specific Gravity of sc 2.62 — Test Temperature, deg.c 19.42

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0310	0.002816667	1.0282	8.10	0.013866	0.0456	91.19	81.23
1	1.0310	0.002816667	1.0282	8.10	0.013866	0.0395	91.19	81.23
2	1.0310	0.002816667	1.0282	8.10	0.013866	0.0279	91.19	81.23
4	1.0300	0.002816667	1.0272	8.36	0.013866	0.0201	87.95	78.35
8	1.0300	0.002816667	1.0272	8.36	0.013866	0.0142	87.95	78.35
15	1.0290	0.002816667	1.0262	8.63	0.013866	0.0105	84.72	75.47
30	1.0280	0.002816667	1.0252	8.89	0.013866	0.0075	81.48	72.59
60	1.0270	0.002816667	1.0242	9.16	0.013866	0.0054	78.24	69.71
120	1.0260	0.002816667	1.0232	9.42	0.013866	0.0039	75.01	66.82
240	1.0260	0.002816667	1.0232	9.42	0.013866	0.0027	75.01	66.82
480	1.0250	0.002816667	1.0222	9.69	0.013866	0.0020	71.77	63.94
1440	1.0250	0.002816667	1.0222	9.69	0.013866	0.0011	71.77	63.94

% Gravel= 2.01%

% Sand= 8.90%

% Silt= 20.17%

% Clay= 68.92%

GRAIN SIZE ANLYSIS

Date of Tested:-10/09/2014, Wednesday @2:47AM

Pit no:- 7

Depth:- @3.0m

Sample discription:- Ambo Expansive Soil

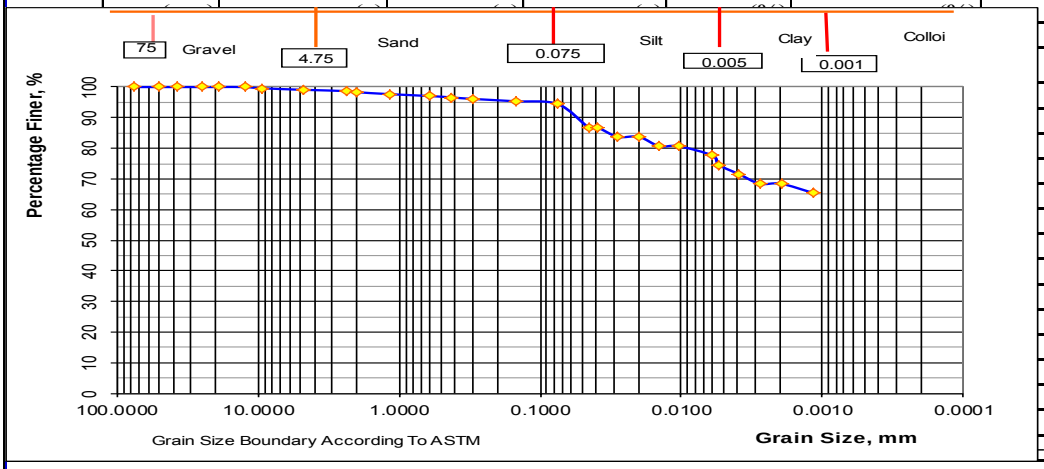
Color of sample:- Dark Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.61
							99.09
							98.68
							98.32
							97.69
							97.05
							96.61
							96.11
							95.36
							94.43



Hydrometer Analysis

Specific Gravity of sc 2.61 — Test Temperature, deg.c 20.15

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0310	0.00267	1.0283	8.10	0.01381	0.0454	91.94	86.83
1	1.0310	0.00267	1.0283	8.10	0.01381	0.0393	91.94	86.83
2	1.0300	0.00267	1.0273	8.36	0.01381	0.0282	88.70	83.76
4	1.0300	0.00267	1.0273	8.36	0.01381	0.0200	88.70	83.76
8	1.0290	0.00267	1.0263	8.63	0.01381	0.0143	85.45	80.70
15	1.0290	0.00267	1.0263	8.63	0.01381	0.0105	85.45	80.70
30	1.0280	0.00267	1.0253	8.89	0.01381	0.0075	82.21	77.63
60	1.0270	0.00267	1.0243	9.16	0.01381	0.0054	78.96	74.57
120	1.0260	0.00267	1.0233	9.42	0.01381	0.0039	75.72	71.50
240	1.0250	0.00267	1.0223	9.69	0.01381	0.0028	72.47	68.44
480	1.0250	0.00267	1.0223	9.69	0.01381	0.0020	72.47	68.44
1440	1.0240	0.00267	1.0213	9.95	0.01381	0.0011	69.23	65.37

% Gravel= 0.91%

% Sand= 4.66%

% Silt= 20.66%

% Clay= 73.77%

GRAIN SIZE ANLYSIS

Date of Tested:-15/09/2014, Monday @2:27AM

Pit no:- 8

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

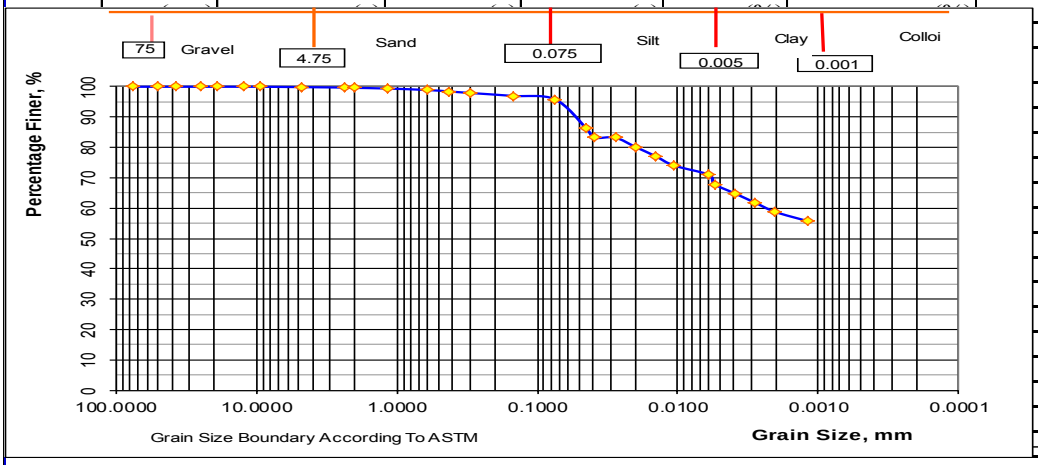
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.87
							99.73
							99.63
							99.41
							98.92
							98.44
							97.94
							96.99
							95.87



Hydrometer Analysis

Specific Gravity of sc 2.68 — Test Temperature, deg.c 19.42

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0310	0.002816667	1.0282	8.10	0.013643	0.0448	90.01	86.30
1	1.0300	0.002816667	1.0272	8.36	0.013643	0.0395	86.82	83.23
2	1.0300	0.002816667	1.0272	8.36	0.013643	0.0279	86.82	83.23
4	1.0290	0.002816667	1.0262	8.63	0.013643	0.0200	83.63	80.17
8	1.0280	0.002816667	1.0252	8.89	0.013643	0.0144	80.43	77.11
15	1.0270	0.002816667	1.0242	9.16	0.013643	0.0107	77.24	74.05
30	1.0260	0.002816667	1.0232	9.42	0.013643	0.0076	74.04	70.99
60	1.0250	0.002816667	1.0222	9.69	0.013643	0.0055	70.85	67.92
120	1.0240	0.002816667	1.0212	9.95	0.013643	0.0039	67.66	64.86
240	1.0230	0.002816667	1.0202	10.22	0.013643	0.0028	64.46	61.80
480	1.0220	0.002816667	1.0192	10.48	0.013643	0.0020	61.27	58.74
1440	1.0210	0.002816667	1.0182	10.75	0.013643	0.0012	58.08	55.68

% Gravel= 0.13%

% Sand= 4.00%

% Silt= 28.90%

% Clay= 66.97%

GRAIN SIZE ANLYSIS

Date of Tested:-15/09/2014, Monday @2:36AM

Pit no:- 8

Depth:- @2.8m

Sample discription:- Ambo Expansive Soil

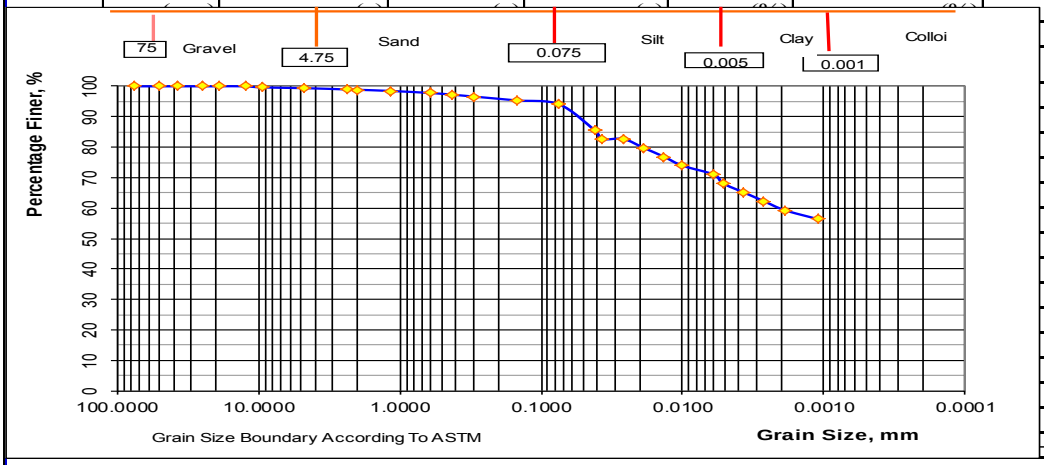
Color of sample:- Dark Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.63
							99.39
							98.96
							98.86
							98.48
							97.79
							97.23
							96.63
							95.37
							94.10



Hydrometer Analysis

Specific Gravity of sc 2.81 — Test Temperature, deg.c 20.13

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0320	0.002675	1.0293	7.84	0.012998	0.0420	90.97	85.61
1	1.0310	0.002675	1.0283	8.10	0.012998	0.0370	87.87	82.69
2	1.0310	0.002675	1.0283	8.10	0.012998	0.0262	87.87	82.69
4	1.0300	0.002675	1.0273	8.36	0.012998	0.0188	84.77	79.77
8	1.0290	0.002675	1.0263	8.63	0.012998	0.0135	81.67	76.85
15	1.0280	0.002675	1.0253	8.89	0.012998	0.0100	78.56	73.93
30	1.0270	0.002675	1.0243	9.16	0.012998	0.0072	75.46	71.01
60	1.0260	0.002675	1.0233	9.42	0.012998	0.0052	72.36	68.09
120	1.0250	0.002675	1.0223	9.69	0.012998	0.0037	69.26	65.17
240	1.0240	0.002675	1.0213	9.95	0.012998	0.0026	66.15	62.25
480	1.0230	0.002675	1.0203	10.22	0.012998	0.0019	63.05	59.33
1440	1.0220	0.002675	1.0193	10.48	0.012998	0.0011	59.95	56.42

% Gravel= 0.61%

% Sand= 5.29%

% Silt= 26.31%

% Clay= 67.79%

GRAIN SIZE ANLYSIS

Date of Tested:-16/09/2014, Tuesday @2:30AM

Pit no:- 9

Depth:- @1.5m

Sample discription:- Ambo Expansive Soil

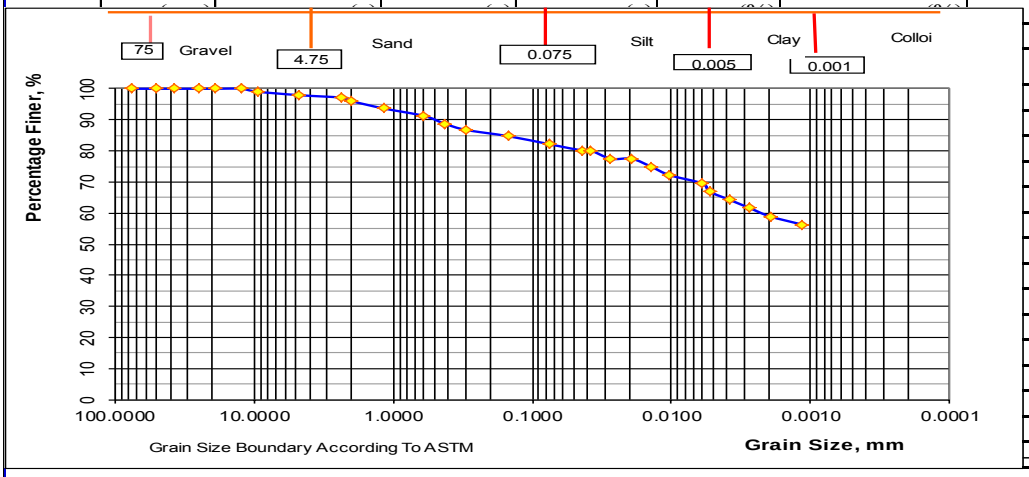
Color of sample:- Black

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.05
							97.94
							97.13
							96.03
							93.69
							91.25
							88.73
							86.76
							84.77
							82.14



Hydrometer Analysis

Specific Gravity of sc 2.63 — Test Temperature, deg.c 19.73

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0330	0.002755	1.0302	7.57	0.013773	0.0438	97.56	80.14
1	1.0330	0.002755	1.0302	7.57	0.013773	0.0379	97.56	80.14
2	1.0320	0.002755	1.0292	7.84	0.013773	0.0273	94.33	77.49
4	1.0320	0.002755	1.0292	7.84	0.013773	0.0193	94.33	77.49
8	1.0310	0.002755	1.0282	8.10	0.013773	0.0139	91.11	74.84
15	1.0300	0.002755	1.0272	8.36	0.013773	0.0103	87.88	72.19
30	1.0290	0.002755	1.0262	8.63	0.013773	0.0074	84.66	69.54
60	1.0280	0.002755	1.0252	8.89	0.013773	0.0053	81.43	66.89
120	1.0270	0.002755	1.0242	9.16	0.013773	0.0038	78.21	64.24
240	1.0260	0.002755	1.0232	9.42	0.013773	0.0027	74.98	61.59
480	1.0250	0.002755	1.0222	9.69	0.013773	0.0020	71.75	58.94
1440	1.0240	0.002755	1.0212	9.95	0.013773	0.0011	68.53	56.29

% Gravel= 2.06%
% Sand= 15.80%
% Silt= 15.79%
% Clay= 66.35%

GRAIN SIZE ANLYSIS

Date of Tested:- 16/09/2014, Tuesday @2:53AM

Pit no:- 9

Depth:- @3.0m

Sample discription:- Ambo Expansive Soil

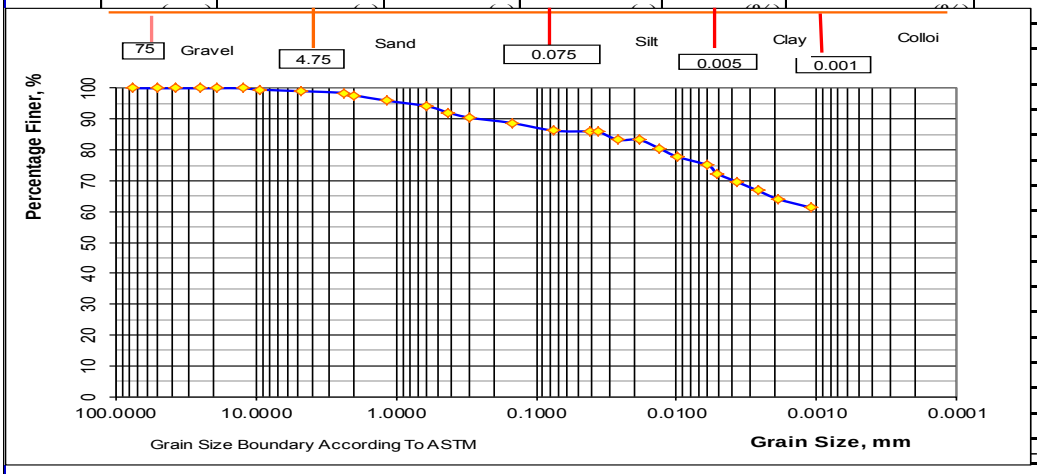
Color of sample:- Black

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.56
							99.05
							98.50
							97.73
							96.00
							94.16
							92.10
							90.47
							88.75
							86.25



Hydrometer Analysis

Specific Gravity of sc 2.69 — Test Temperature, deg.c 20.13

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0340	0.002675	1.0313	7.31	0.013468	0.0420	99.75	86.03
1	1.0340	0.002675	1.0313	7.31	0.013468	0.0364	99.75	86.03
2	1.0330	0.002675	1.0303	7.57	0.013468	0.0262	96.57	83.29
4	1.0330	0.002675	1.0303	7.57	0.013468	0.0185	96.57	83.29
8	1.0320	0.002675	1.0293	7.84	0.013468	0.0133	93.38	80.54
15	1.0310	0.002675	1.0283	8.10	0.013468	0.0099	90.20	77.79
30	1.0300	0.002675	1.0273	8.36	0.013468	0.0071	87.02	75.05
60	1.0290	0.002675	1.0263	8.63	0.013468	0.0051	83.83	72.30
120	1.0280	0.002675	1.0253	8.89	0.013468	0.0037	80.65	69.55
240	1.0270	0.002675	1.0243	9.16	0.013468	0.0026	77.46	66.81
480	1.0260	0.002675	1.0233	9.42	0.013468	0.0019	74.28	64.06
1440	1.0250	0.002675	1.0223	9.69	0.013468	0.0011	71.09	61.32

% Gravel= 0.95%

% Sand= 12.80%

% Silt= 14.15%

% Clay= 72.10%

GRAIN SIZE ANLYSIS

Date of Tested:- 16/09/2014, Tuesday @3:00AM

Pit no:- 10

Depth:- @1.2m

Sample discription:- Ambo Expansive Soil

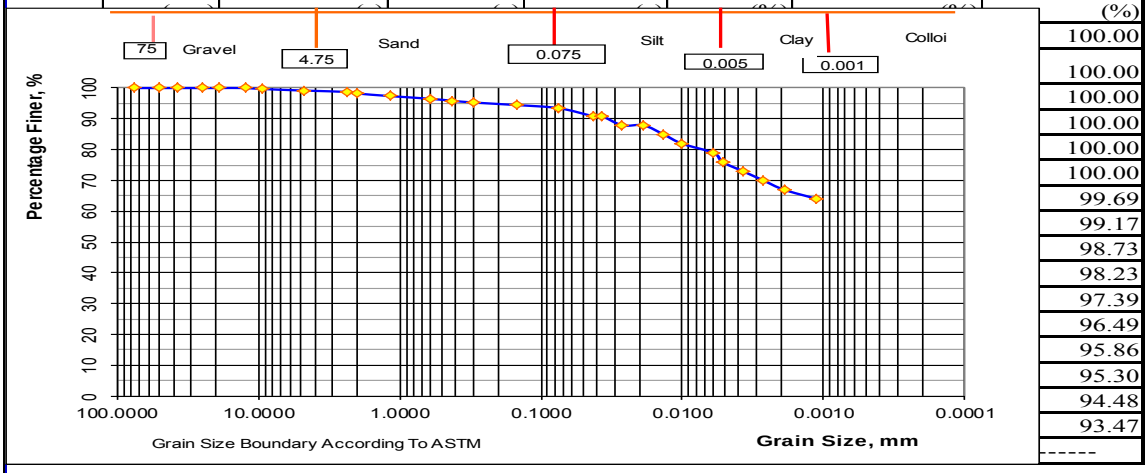
Color of sample:- Black

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.69
							99.17
							98.73
							98.23
							97.39
							96.49
							95.86
							95.30
							94.48
							93.47



Hydrometer Analysis

Specific Gravity of sc 2.68 — Test Temperature, deg.c 20.71

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0330	0.002558333	1.0304	7.57	0.013427	0.0427	97.23	90.87
1	1.0330	0.002558333	1.0304	7.57	0.013427	0.0369	97.23	90.87
2	1.0320	0.002558333	1.0294	7.84	0.013427	0.0266	94.03	87.89
4	1.0320	0.002558333	1.0294	7.84	0.013427	0.0188	94.03	87.89
8	1.0310	0.002558333	1.0284	8.10	0.013427	0.0135	90.84	84.90
15	1.0300	0.002558333	1.0274	8.36	0.013427	0.0100	87.65	81.92
30	1.0290	0.002558333	1.0264	8.63	0.013427	0.0072	84.45	78.93
60	1.0280	0.002558333	1.0254	8.89	0.013427	0.0052	81.26	75.95
120	1.0270	0.002558333	1.0244	9.16	0.013427	0.0037	78.06	72.96
240	1.0260	0.002558333	1.0234	9.42	0.013427	0.0027	74.87	69.98
480	1.0250	0.002558333	1.0224	9.69	0.013427	0.0019	71.68	66.99
1440	1.0240	0.002558333	1.0214	9.95	0.013427	0.0011	68.48	64.01

% Gravel= 0.83%

% Sand= 5.71%

% Silt= 17.86%

% Clay= 75.60%

GRAIN SIZE ANLYSIS

Date of Tested:- 16/09/2014, Tuesday @3:00AM

Pit no:- 10

Depth:- @2.5m

Sample discription:- Ambo Expansive Soil

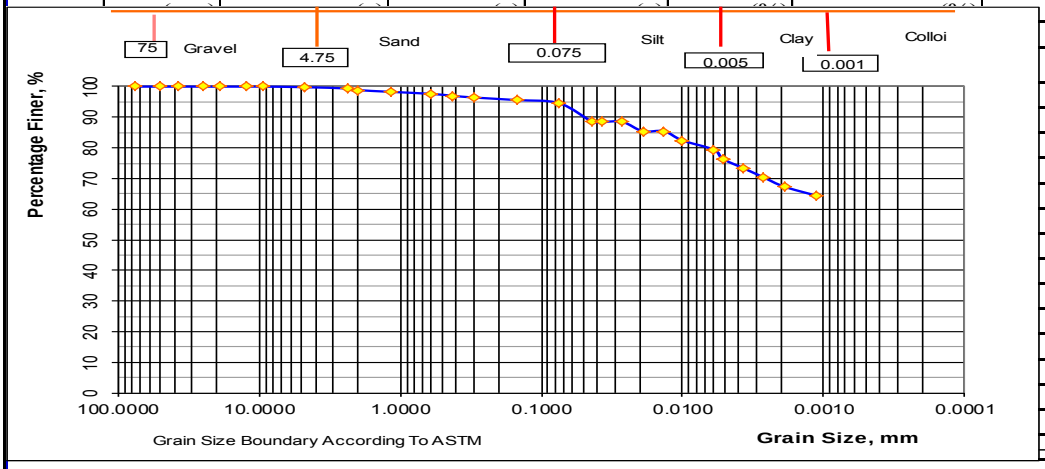
Color of sample:- Grey

Standard Reference: ASTM D 422 - Standard Test Method for Particle-Size

Analysis of Soils

Sieve Analysis — Total mass of sample, 1500

Sieve No	Sieve Opening	Mass of Sieve	Mass of sieve + Retained soil	Mass of Retained soil	Percentage Retained	Cum. Percentage Retained	Perc. Passing (%)
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							100.00
							99.81
							99.37
							98.87
							98.30
							97.63
							96.99
							96.43
							95.62
							94.60



Hydrometer Analysis

Specific Gravity of sc 2.69 — Test Temperature, deg.c 20.32

Elapsed Time (min)	Actual ydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	rc. Finer ombined (%)
0.75	1.0320	0.002636667	1.0294	7.84	0.013437	0.0434	93.51	88.46
1	1.0320	0.002636667	1.0294	7.84	0.013437	0.0376	93.51	88.46
2	1.0320	0.002636667	1.0294	7.84	0.013437	0.0266	93.51	88.46
4	1.0310	0.002636667	1.0284	8.10	0.013437	0.0191	90.32	85.45
8	1.0310	0.002636667	1.0284	8.10	0.013437	0.0135	90.32	85.45
15	1.0300	0.002636667	1.0274	8.36	0.013437	0.0100	87.14	82.43
30	1.0290	0.002636667	1.0264	8.63	0.013437	0.0072	83.95	79.42
60	1.0280	0.002636667	1.0254	8.89	0.013437	0.0052	80.77	76.41
120	1.0270	0.002636667	1.0244	9.16	0.013437	0.0037	77.58	73.40
240	1.0260	0.002636667	1.0234	9.42	0.013437	0.0027	74.40	70.38
480	1.0250	0.002636667	1.0224	9.69	0.013437	0.0019	71.22	67.37
1440	1.0240	0.002636667	1.0214	9.95	0.013437	0.0011	68.03	64.36

% Gravel= 0.19%

% Sand= 5.21%

% Silt= 18.55%

% Clay= 76.05%

APPENDIX2: Analysis of Swelling Characteristics Test Results

FREE SWELL TEST

Date of Tested:- 21/08/2014, Thursday @5:50AM

Pit no:- 1

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*200.0*	*195.0*	*197.5*	*97.5*

FREE SWELL TEST

Date of Tested:- 21/08/2014, Thursday @6:10PM

Pit no:- 1

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*245.0*	*240.0*	*242.5*	*142.5*

FREE SWELL TEST

Date of Tested:- 21/08/2014, Thursday @6:30PM

Pit no:- 2

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*240.0*	*260.0*	*250.0*	*150.0*

FREE SWELL TEST

Date of Tested:- 21/08/2014, Thursday @6:55PM

Pit no:- 2

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*215.0*	*220.0*	*217.5*	*117.5*

FREE SWELL TEST

Date of Tested:- 21/08/2014, Thursday @7:00PM

Pit no:- 3

Depth:- @1.4m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*240.0*	*250.0*	*245.0*	*145.0*

FREE SWELL TEST

Date of Tested:- 23/08/2014, Saturday @4:50AM

Pit no:- 3

Depth:- @2.5 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*250.0*	*260.0*	*255.0*	*155.0*

FREE SWELL TEST

Date of Tested:- 23/08/2014, Saturday @5:00AM

Pit no:- 4

Depth:- @1.3m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*255.0*	*250.0*	*252.5*	*152.5*

FREE SWELL TEST

Date of Tested:- 23/08/2014, Saturday @5:10AM

Pit no:- 4

Depth:- @2.8m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*250.0*	*250.0*	*250.0*	*150.0*

FREE SWELL TEST

Date of Tested:- 23/08/2014, Saturday @5:20AM

Pit no:- 5

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*210.0*	*210.0*	*210.0*	*110.0*

FREE SWELL TEST

Date of Tested:- 23/08/2014, Saturday @5:50AM

Pit no:- 5

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*210.0*	*210.0*	*210.0*	*110.0*

FREE SWELL TEST

Date of Tested:- 25/08/2014, Monday @10:30PM

Pit no:- 6

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*260.0*	*265.0*	*262.5*	*162.5*

FREE SWELL TEST

Date of Tested:- 25/08/2014, Monday @10:40PM

Pit no:- 6

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*250.0*	*255.0*	*252.5*	*152.5*

FREE SWELL TEST

Date of Tested:- 25/08/2014, Monday @10:50PM

Pit no:- 7

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Referance:- Gibbs and Holtz, 1969

Initial	*Final Volume*		*Average*	*Free*
Volume	*Sample No.1*	*Sample No.2*	*Final Volume*	*Swell*
(cc)	*(cc)*	*(cc)*	*(cc)*	*(%)*
100.0	*230.0*	*230.0*	*230.0*	*130.0*

FREE SWELL TEST

Date of Tested:- 25/08/2014, Monday @10:55PM

Pit no:- 7

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Referance:- Gibbs and Holtz, 1969

Initial	*Final Volume*		*Average*	*Free*
Volume	*Sample No.1*	*Sample No.2*	*Final Volume*	*Swell*
(cc)	*(cc)*	*(cc)*	*(cc)*	*(%)*
100.0	*240.0*	*240.0*	*240.0*	*140.0*

FREE SWELL TEST

Date of Tested:- 25/08/2014, Monday @11:05PM

Pit no:- 8

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*230.0*	*240.0*	*235.0*	*135.0*

FREE SWELL TEST

Date of Tested:- 25/08/2014, Monday @11:30PM

Pit no:- 8

Depth:- @2.8 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*240.0*	*220.0*	*230.0*	*130.0*

FREE SWELL TEST

Date of Tested:- 27/08/2014, Wednesday @10:30PM

Pit no:- 9

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*240.0*	*250.0*	*245.0*	*145.0*

FREE SWELL TEST

Date of Tested:- 27/08/2014, Wednesday @10:40PM

Pit no:- 9

Depth:- @3.0 m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*245.0*	*240.0*	*242.5*	*142.5*

FREE SWELL TEST

Date of Tested:- 27/08/2014, Wednesday @7:30PM

Pit no:- 10

Depth:- @1.2m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*230.0*	*215.0*	*222.5*	*122.5*

FREE SWELL TEST

Date of Tested:- 27/08/2014, Wednesday @7:50PM

Pit no:- 10

Depth:- @2.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Referance:- Gibbs and Holtz, 1969

Initial Volume (cc)	*Final Volume*		*Average Final Volume (cc)*	*Free Swell (%)*
	Sample No.1 (cc)	*Sample No.2 (cc)*		
100.0	*200.0*	*210.0*	*205.0*	*105.0*

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 12/08/2014, Tuesday @5:30AM

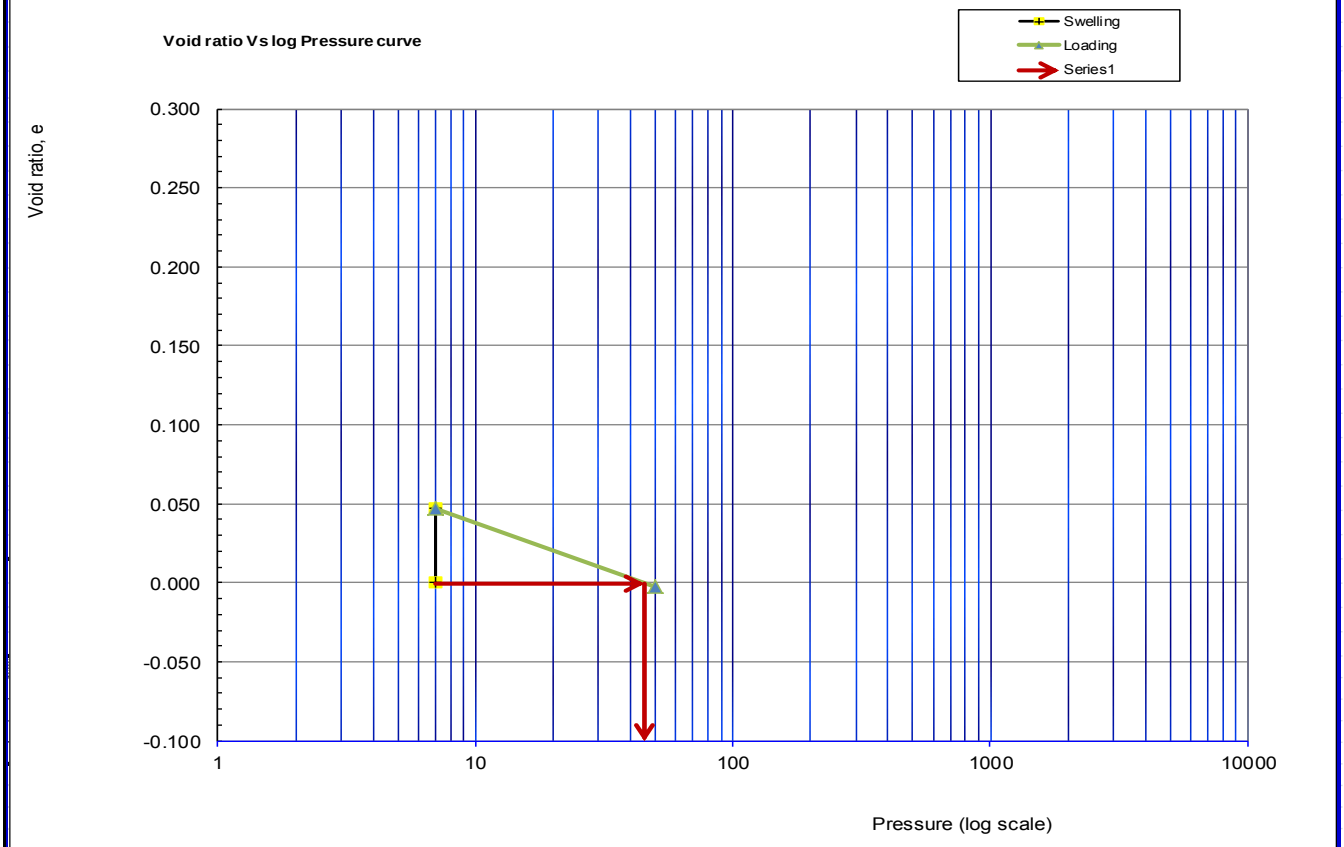
Pit no:- 1

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**44.85 Kpa**
Swelling Potential=	**1.80%**
Initial Reading=	2.2+0.08+0d=2.64mm
Final Reading=	2.6+0.04+0d=2.28mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 28/08/2014, Thursday @5:00AM

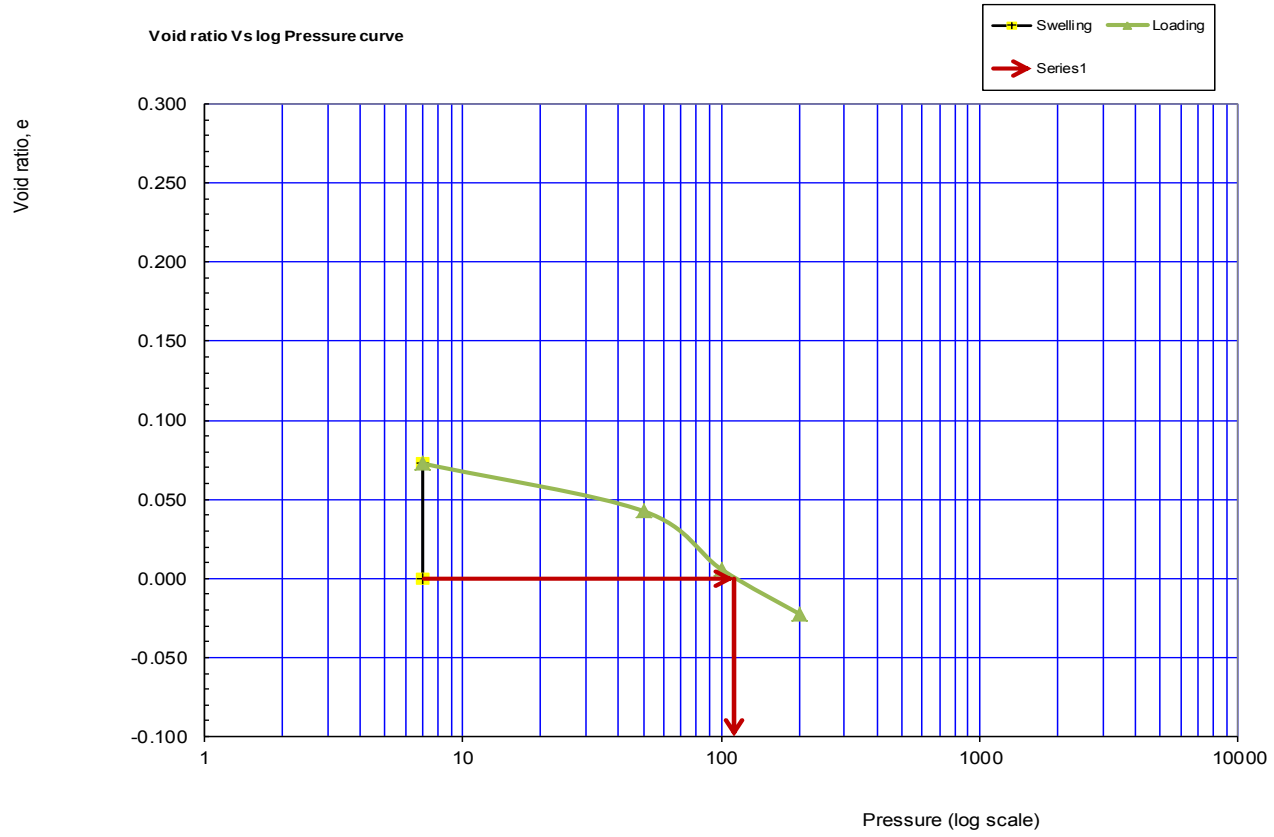
Pit no:- 1

Depth:- @3.0m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**110.80 Kpa**
Swelling Potential=	**3.26%**
Initial Reading=	4.4+0.04+1d=4.442mm
Final Reading=	5.0+0.08+7d=5.094mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 16/08/2014, Saturday @3:40AM

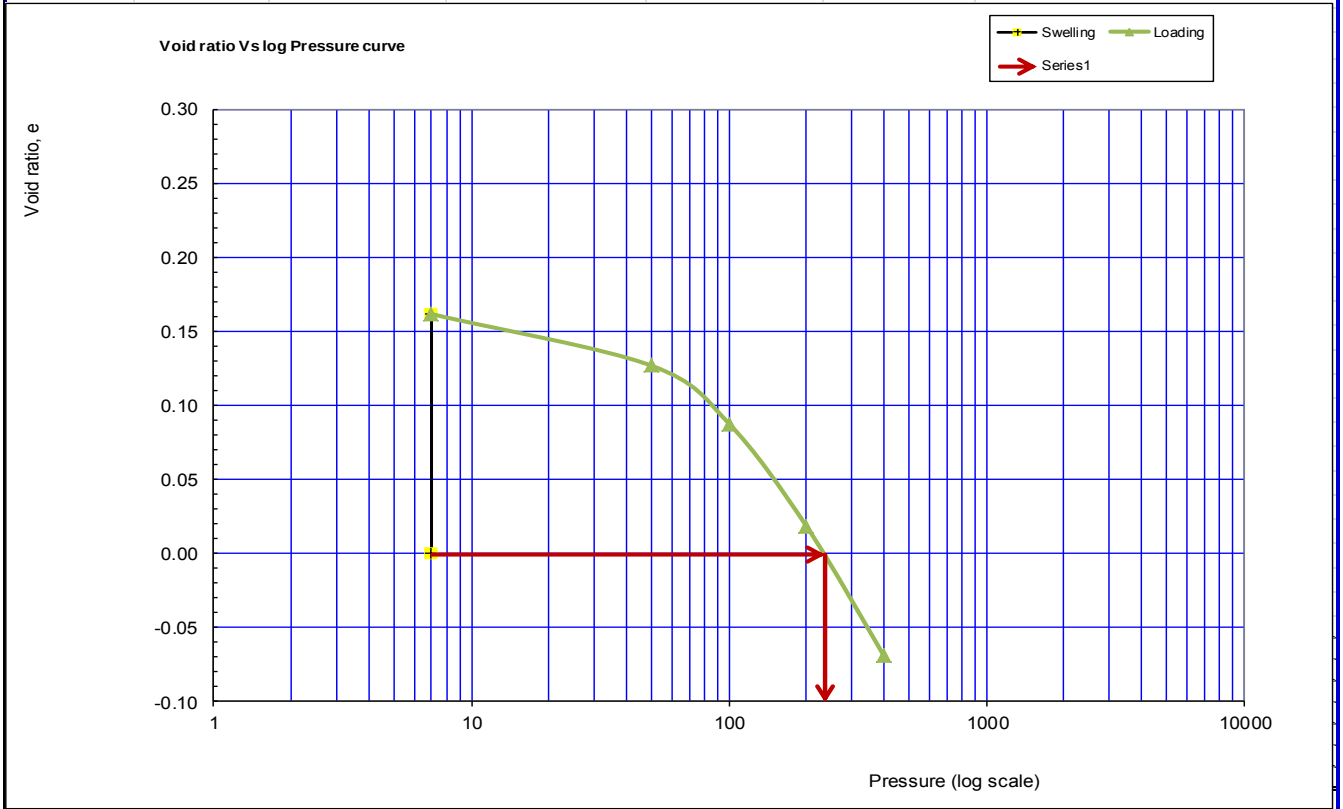
Pit no:- 2

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**233.55 Kpa**
Swelling Potential=	**7.98%**
Initial Reading=	2.4+0.00+4d=2.408mm
Final Reading=	4.0+0.00+2d=4.004mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 16/08/2014, Saturday @5:30AM

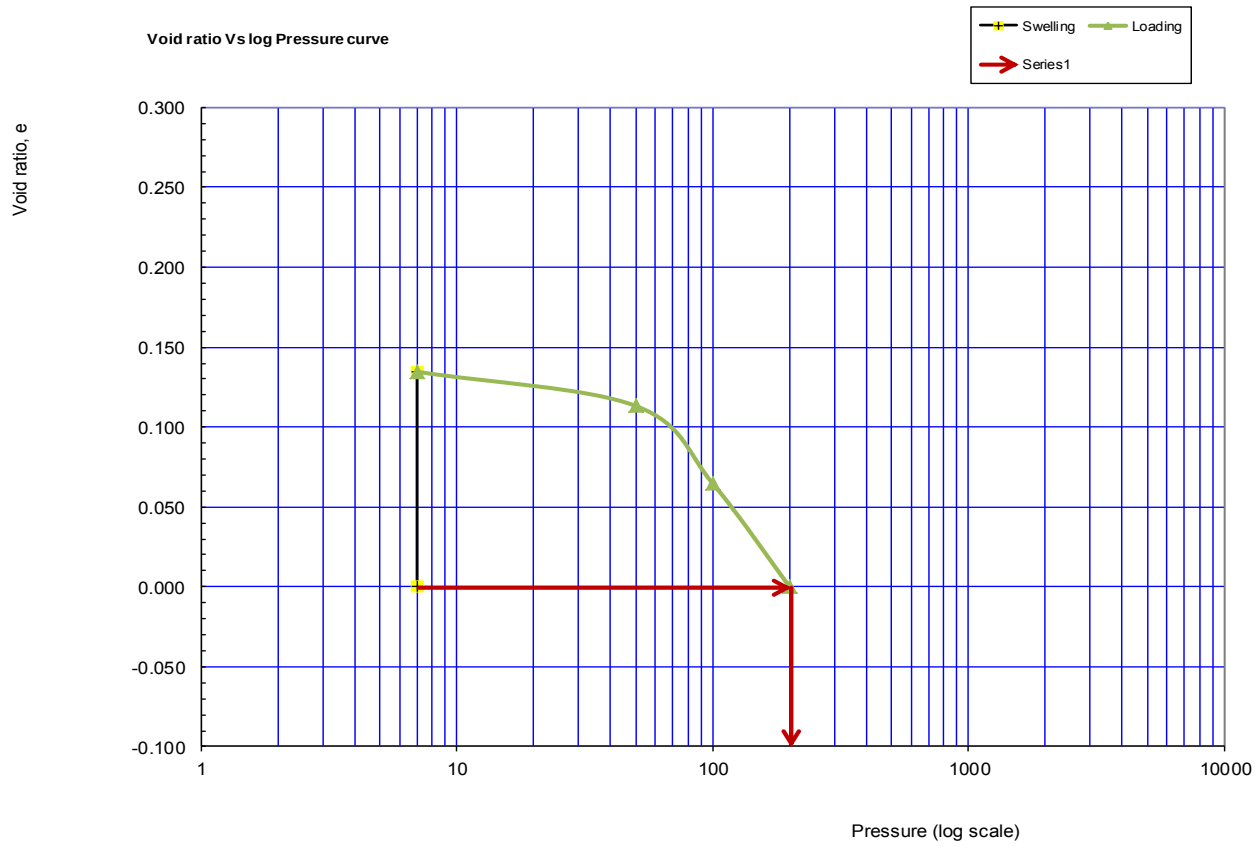
Pit no:- 2

Depth:- @2.8m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**200.00 Kpa**
Swelling Potential=	**6.62%**
Initial Reading=	1.0+0.14+8d=1.156mm
Final Reading=	2.4+0.08+0d=2.480mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 25/08/2014, Monday @6:30PM

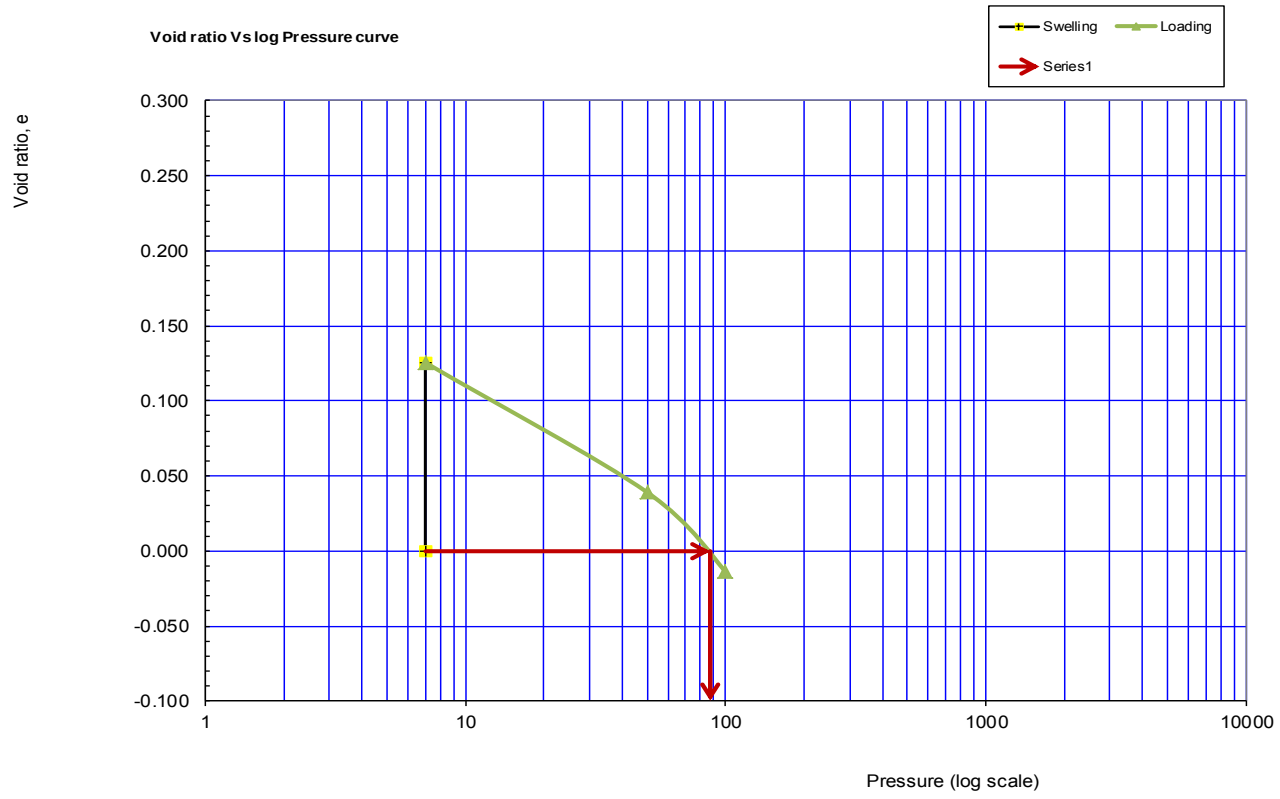
Pit no:- 3

Depth:- @1.4m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**86.55 Kpa**
Swelling Potential=	**4.99%**
Initial Reading=	3.6+0.00+0d=3.600mm
Final Reading=	4.4+0.18+9d=4.598mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 01/09/2014, Monday @10:00PM

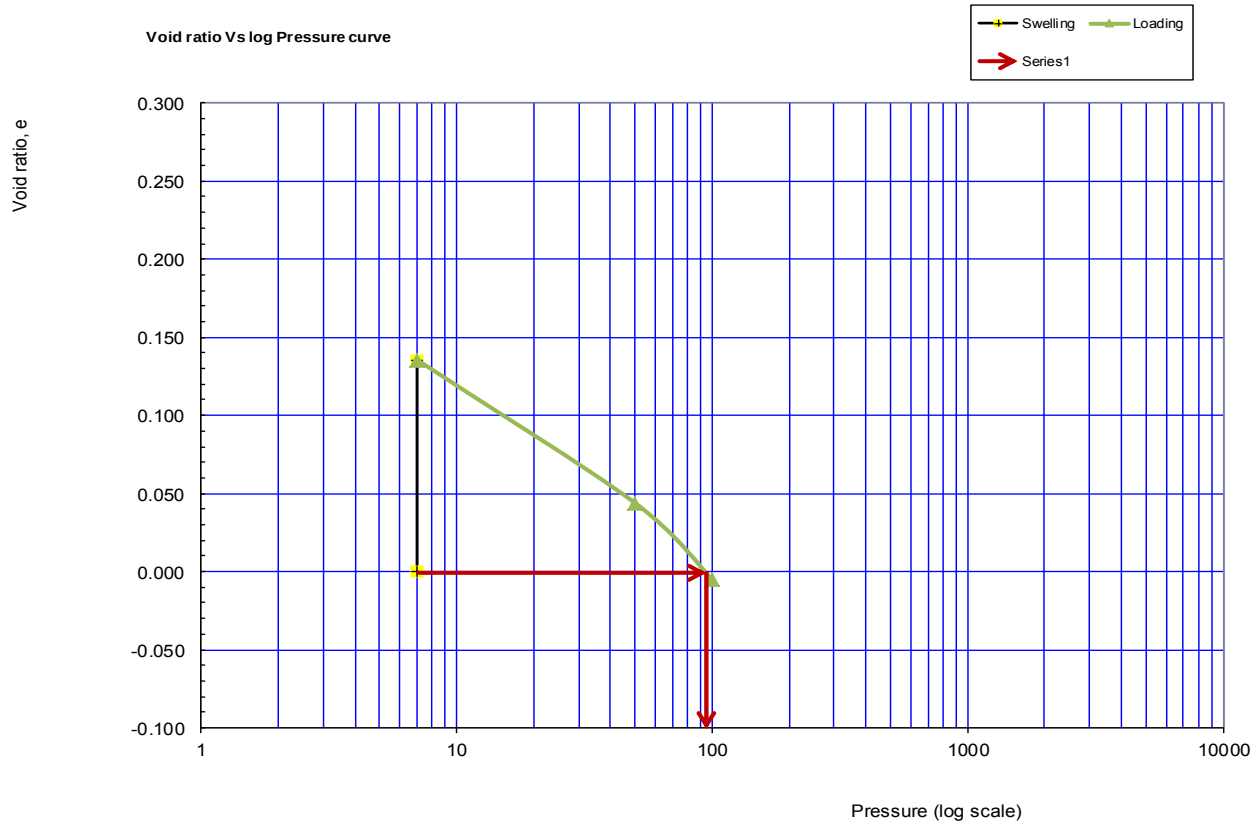
Pit no:- 3

Depth:- @2.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**94.25 Kpa**
Swelling Potential=	**6.37%**
Initial Reading=	3.6+0.00+0d=3.600mm
Final Reading=	4.8+0.06+7d=4.874mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 20/08/2014, Wednesday @6:40PM

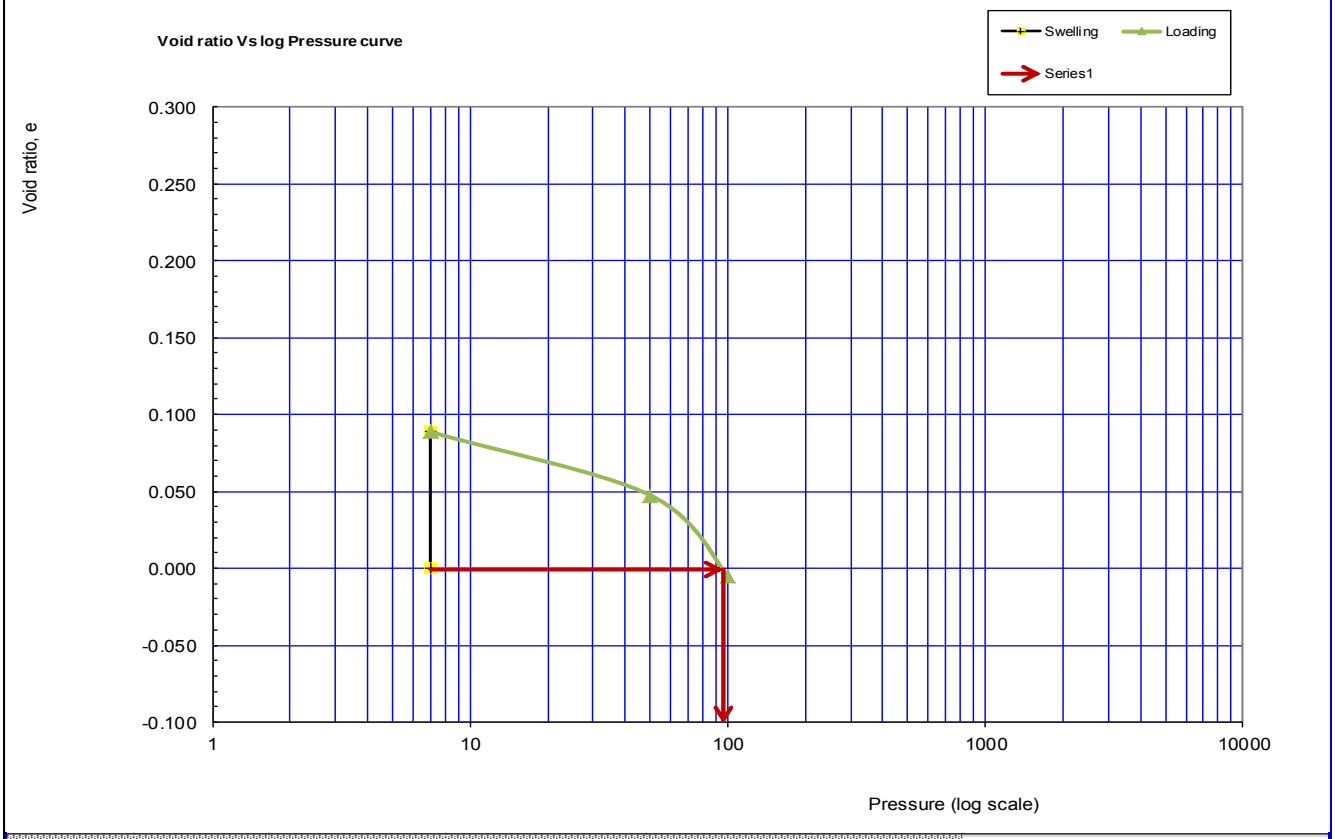
Pit no:- 4

Depth:- @1.3m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**95.45 Kpa**
Swelling Potential=	**3.96%**
Initial Reading=	3.4+0.10+0d=3.500mm
Final Reading=	4.2+0.08+6d=4.292mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 25/08/2014, Monday @6:30PM

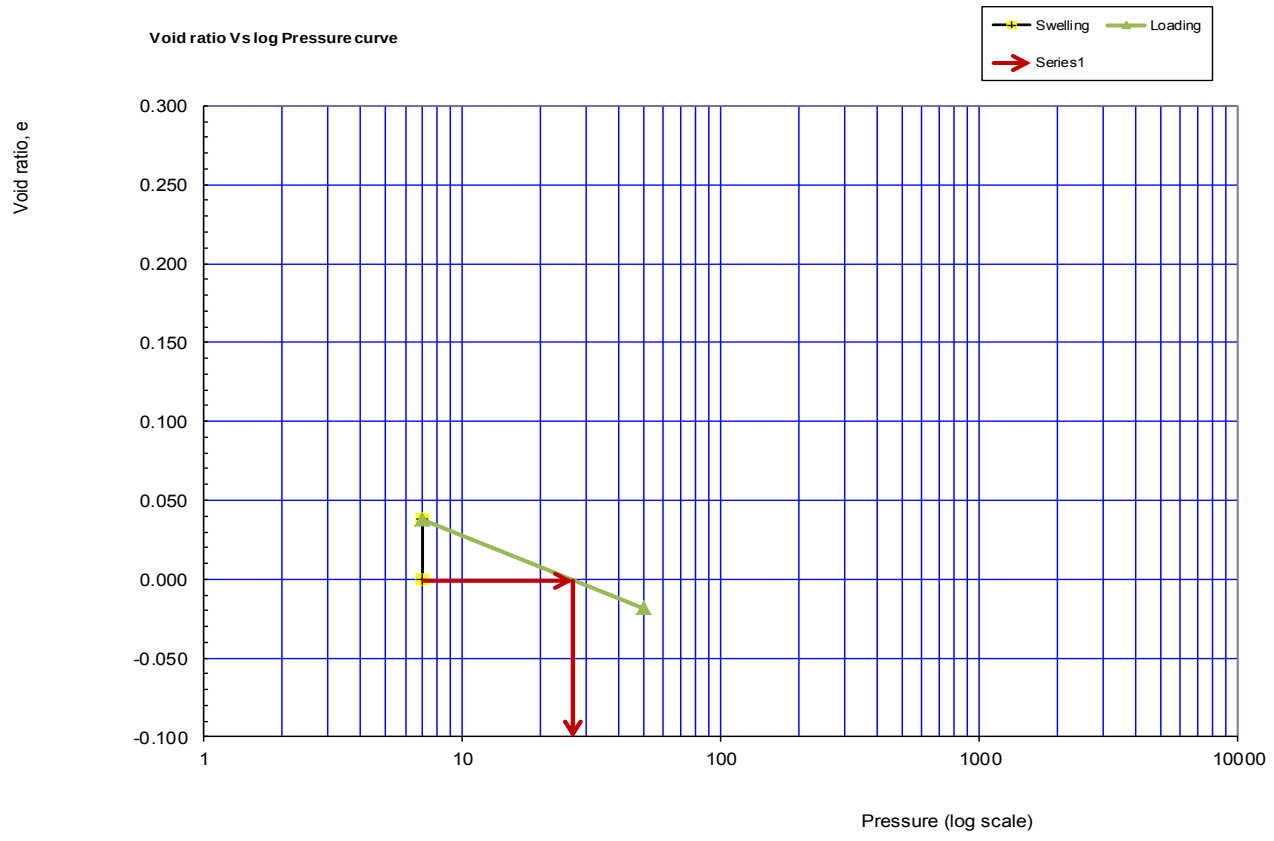
Pit no:- 4

Depth:- @2.8m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**26.45 Kpa**
Swelling Potential=	**1.78%**
Initial Reading=	4.2+0.00+0d=4.200mm
Final Reading=	4.4+0.14+8d=4.556mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 28/08/2014, Thursday @6:00PM

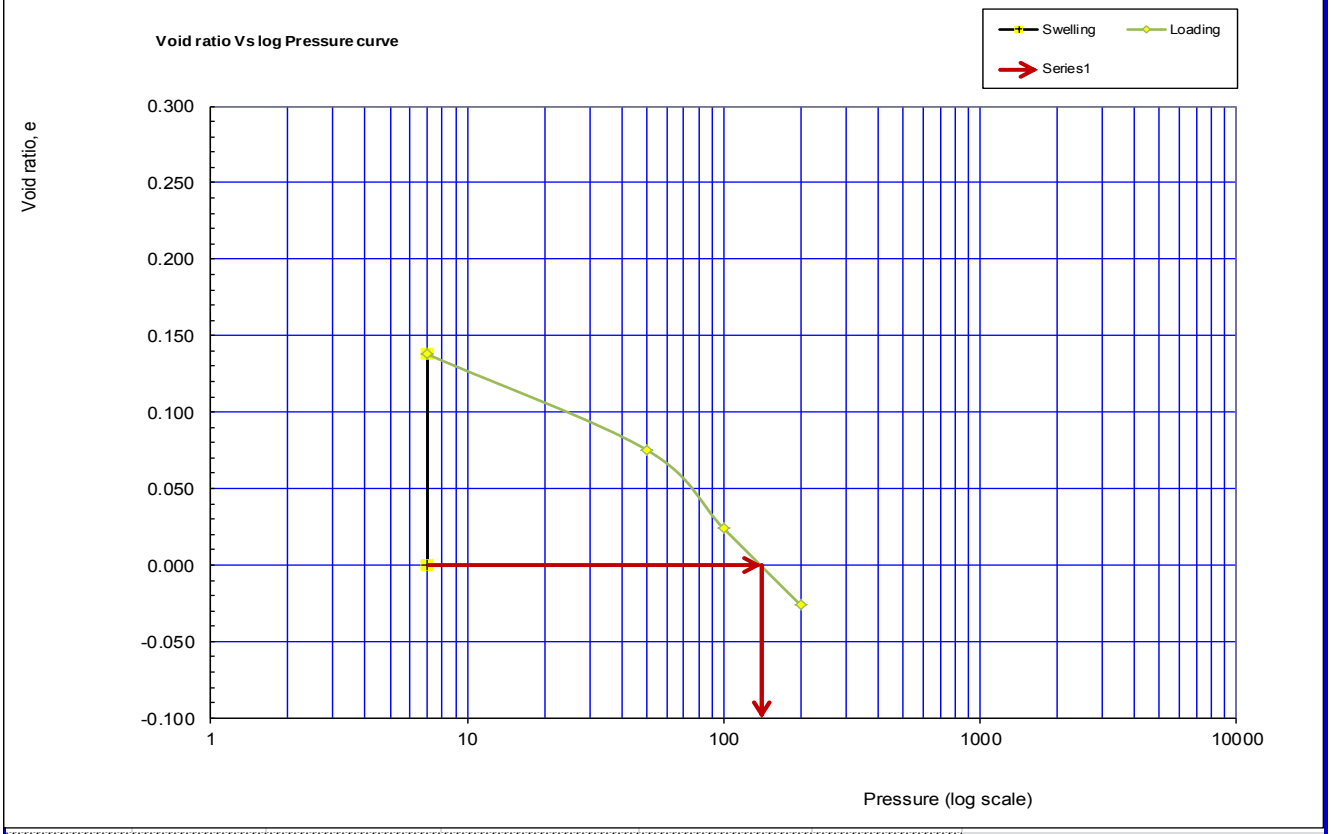
Pit no:- 5

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**140.05 Kpa**
Swelling Potential=	**6.78%**
Initial Reading=	3.2+0.00+0d=3.200mm
Final Reading=	4.4+0.14+8d=4.556mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 04/09/2014, Thursday @8:00PM

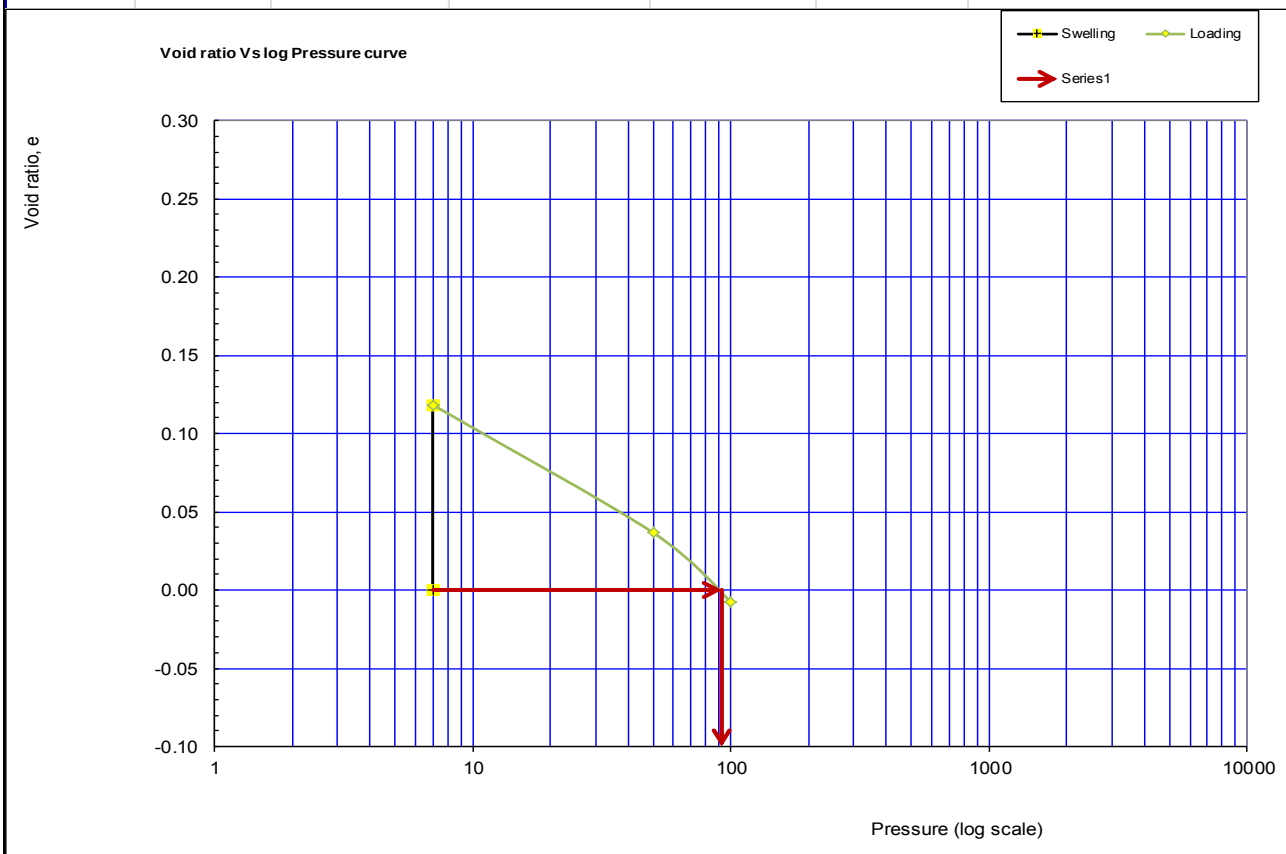
Pit no:- 5

Depth:- @3.0m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**90.75 Kpa**
Swelling Potential=	**5.20%**
Initial Reading=	5.4+0.00+0d=5.400mm
Final Reading=	6.4+0.04+0d=6.440mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 04/09/2014, Thursday @8:30PM

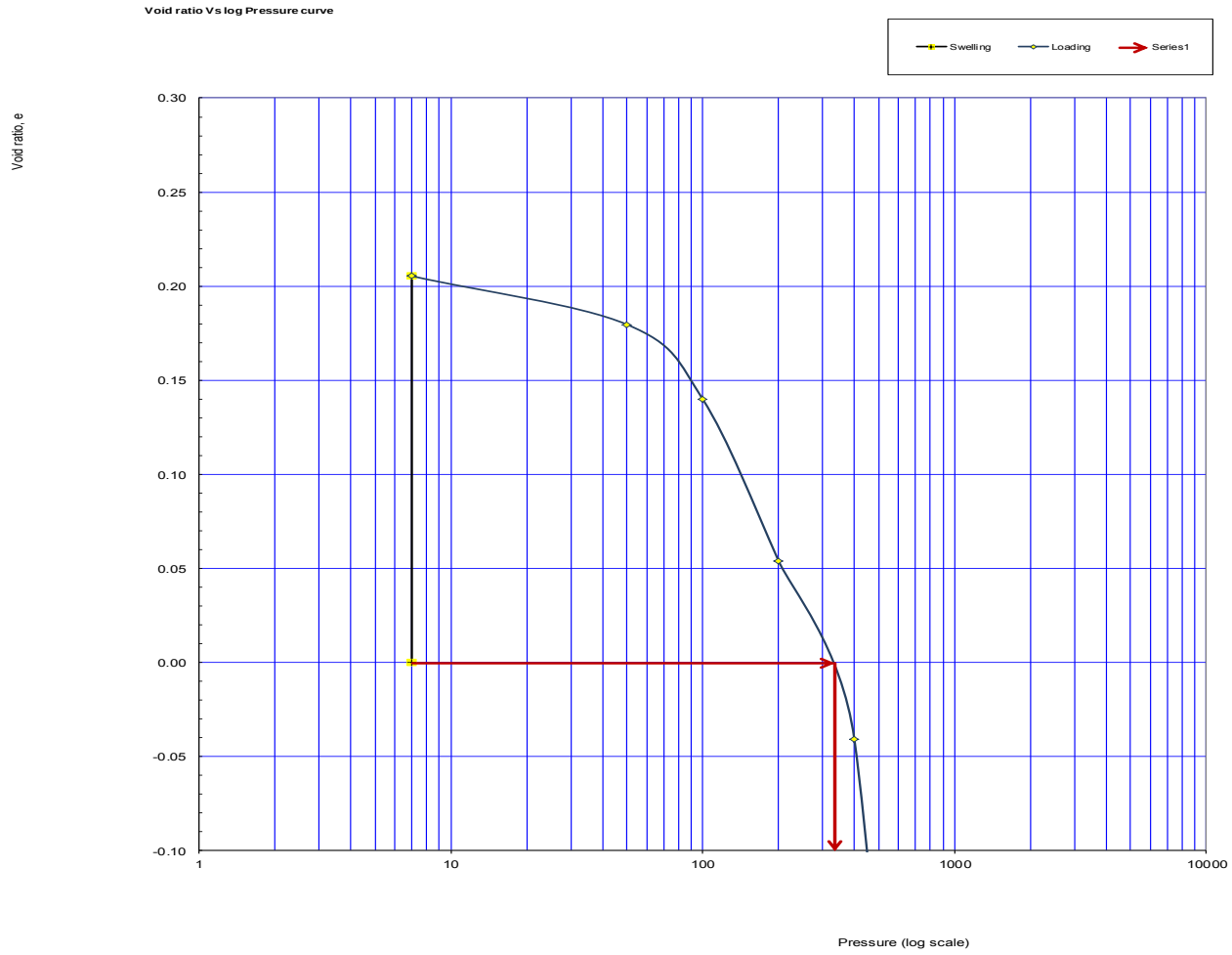
Pit no:- 6

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**334.23 Kpa**	
Swelling Potential=	**9.73%**	
Initial Reading=	**5.0+0.00+0d=**	**5.000mm**
Final Reading=	**6.8++0.14+3d=**	**6.946mm**

SWELLING PRESSURE TEST WITH ONE CONSOI

Date of Tested:- 06/09/2014, Saturday @5:20AM

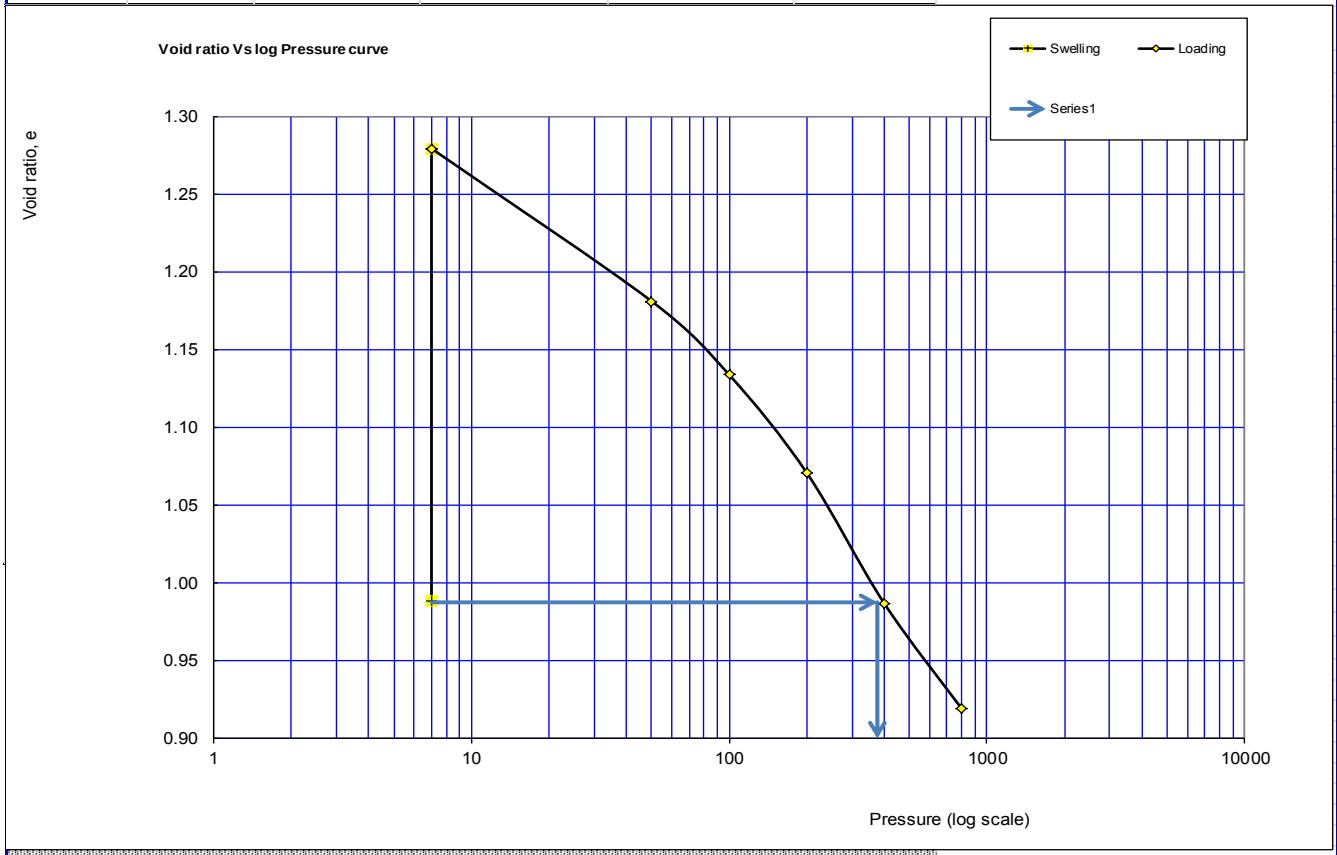
Pit no:- 6

Depth:- @3.0m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**374.25 Kpa**
Swelling Potential=	**9.840%**
Initial Reading=	**4.4+0.00+0d=4.400mm**
Final Reading=	**7.4+0.12+6d=7.532mm**

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 13/09/2014, Satursday @5:00AM

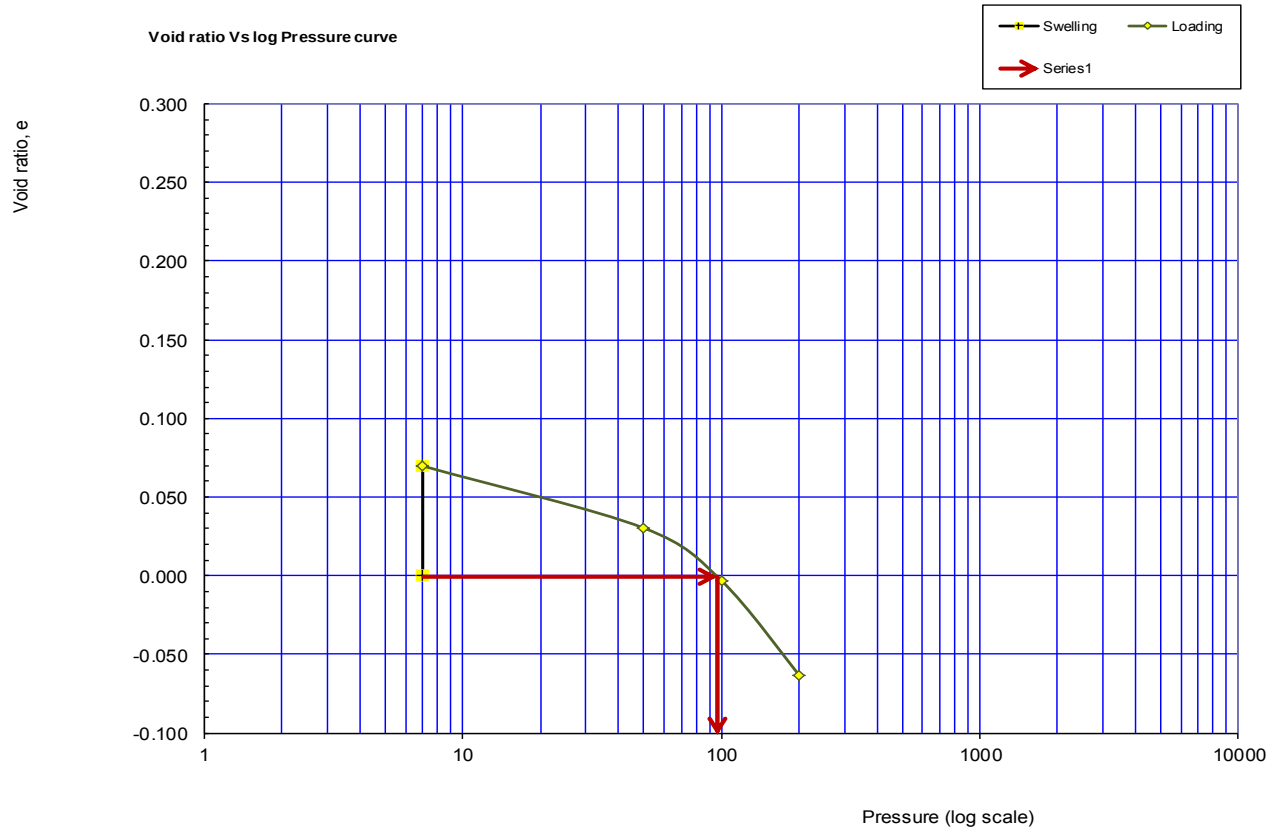
Pit no:- 7

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**95.65 Kpa**
Swelling Potential=	**3.19%**
Initial Reading=	4.0+0.00+0d=4.000mm
Final Reading=	4.6+0.03+4d=4.638mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 18/09/2014, Thursday @5:00AM

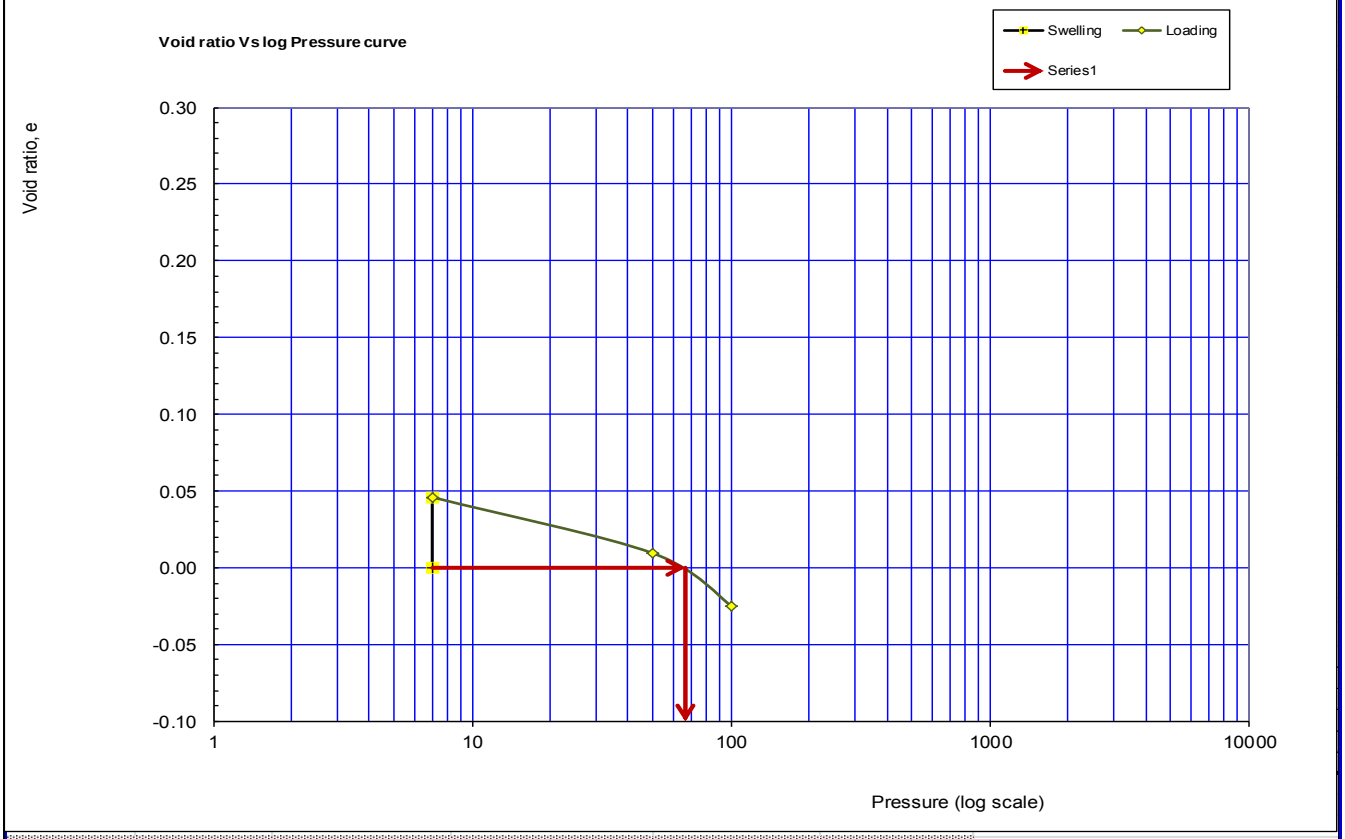
Pit no:- 7

Depth:- @3.0m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**66.15 Kpa**
Swelling Potential=	**2.06%**
Initial Reading=	4.2+0.00+0d=4.200mm
Final Reading=	4.6+0.00+6d=4.612mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 18/09/2014, Thursday @5:00AM

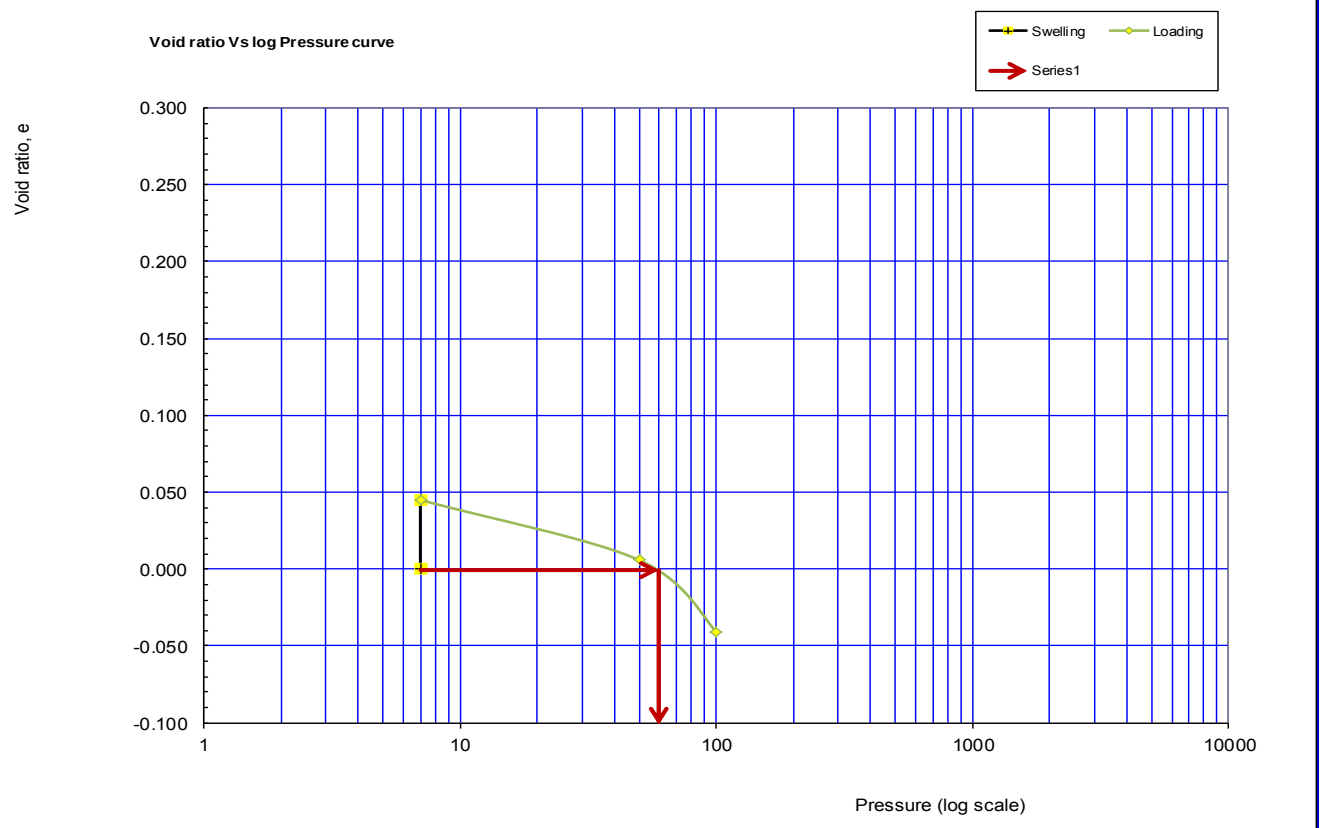
Pit no:- 8

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**58.90 Kpa**
Swelling Potential=	**2.06%**
Initial Reading=	4.0+0.00+0d=4.000mm
Final Reading=	4.4+0.00+6d=4.412mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 18/09/2014, Thursday @5:00AM

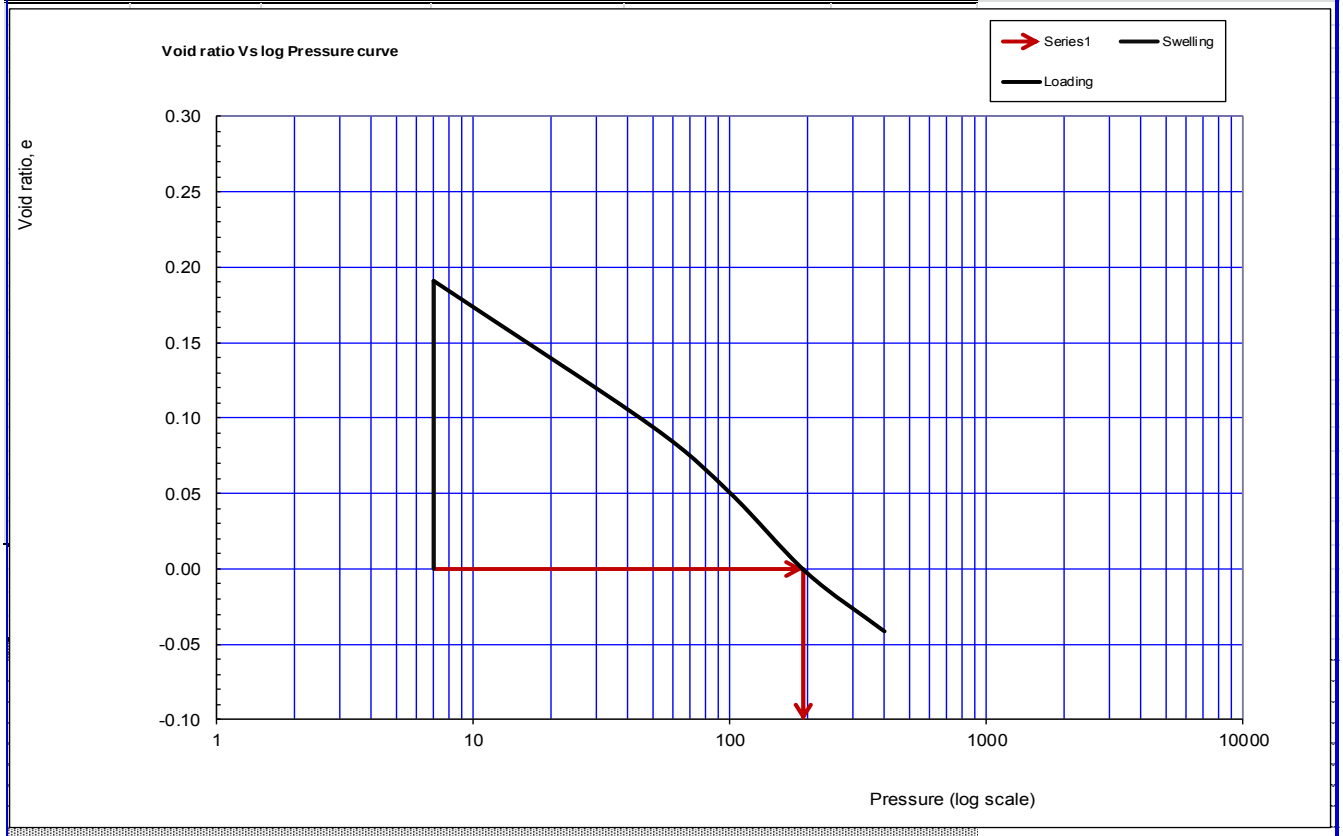
Pit no:- 8

Depth:- @2.8m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Dark Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**191.15 Kpa**
Swelling Potential=	**7.38%**
Initial Reading=	**5.0+0.00+0d=5.000mm**
Final Reading=	**6.4+0.06+8d=6.476mm**

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 24/09/2014, Wednesday @5:30AM

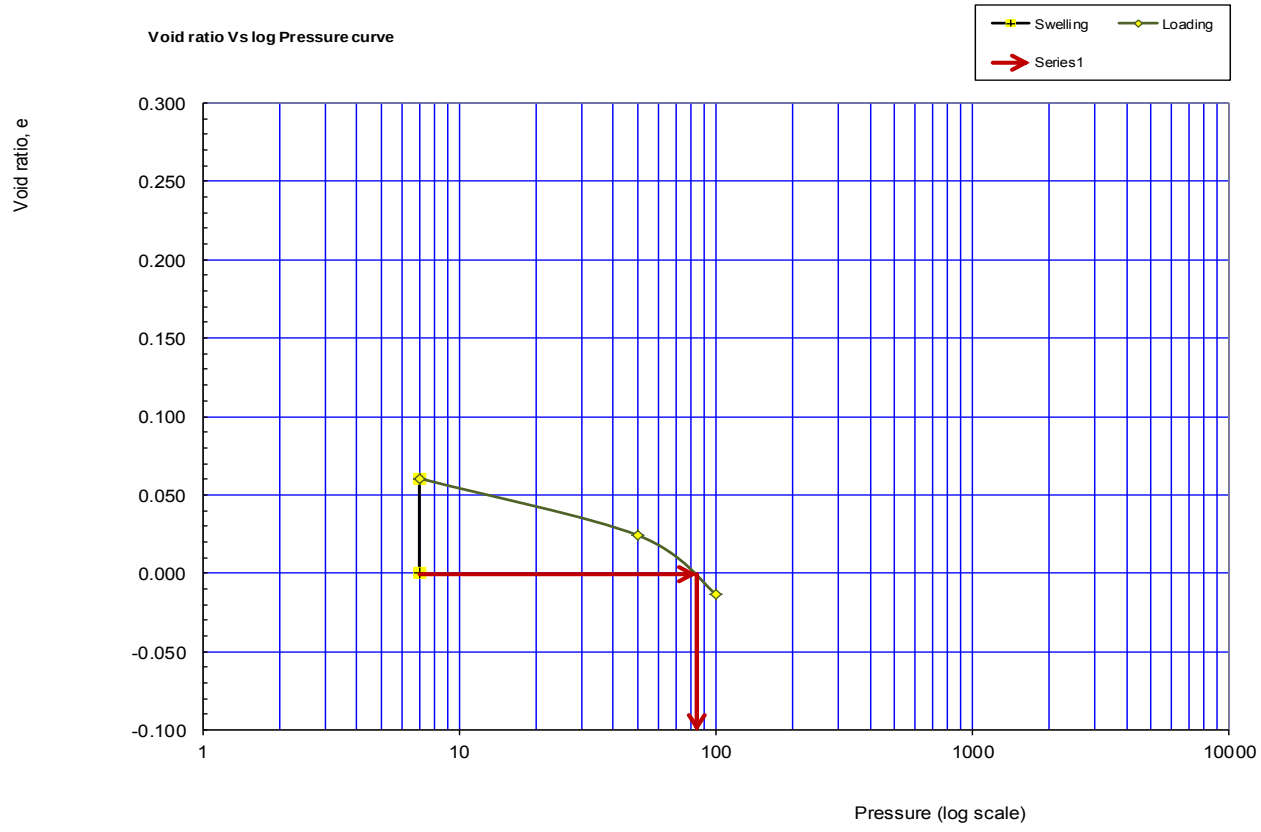
Pit no:- 9

Depth:- @1.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**82.00 Kpa**
Swelling Potential=	**2.80%**
Initial Reading=	4.4+0.00+0d=4.400mm
Initial Reading=	4.8+0.16+0d=4.960mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 24/09/2014, Wednesday @5:30AM

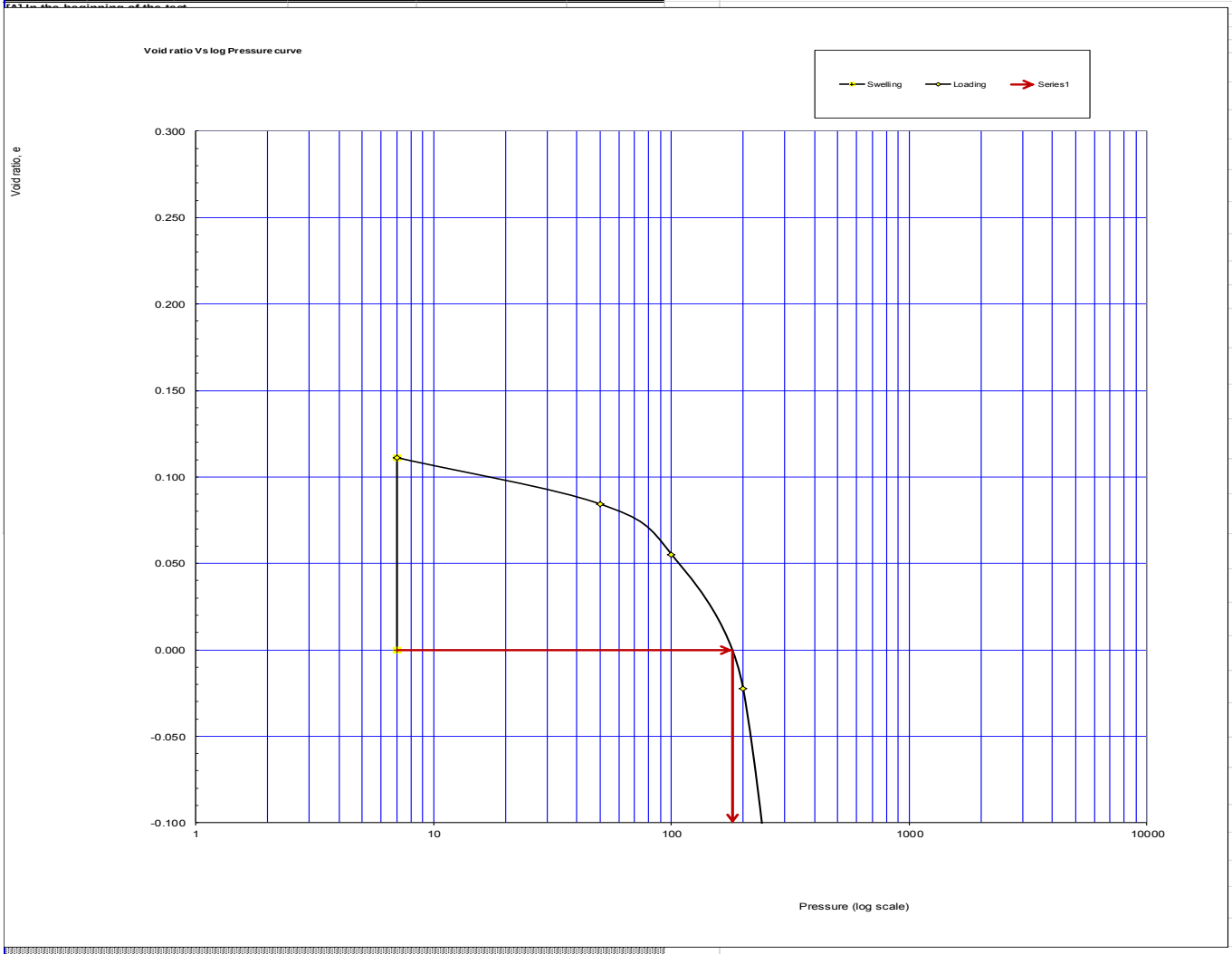
Pit no:- 9

Depth:- @3.0m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Black

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**179.98 Kpa**
Swelling Potential=	**5.60%**
Initial Reading=	**4.0+0.00+0d=4.000mm**
Final Reading=	**5.0+0.12+0d=5.120mm**

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 01/10/2014, Wednesday @3:00AM

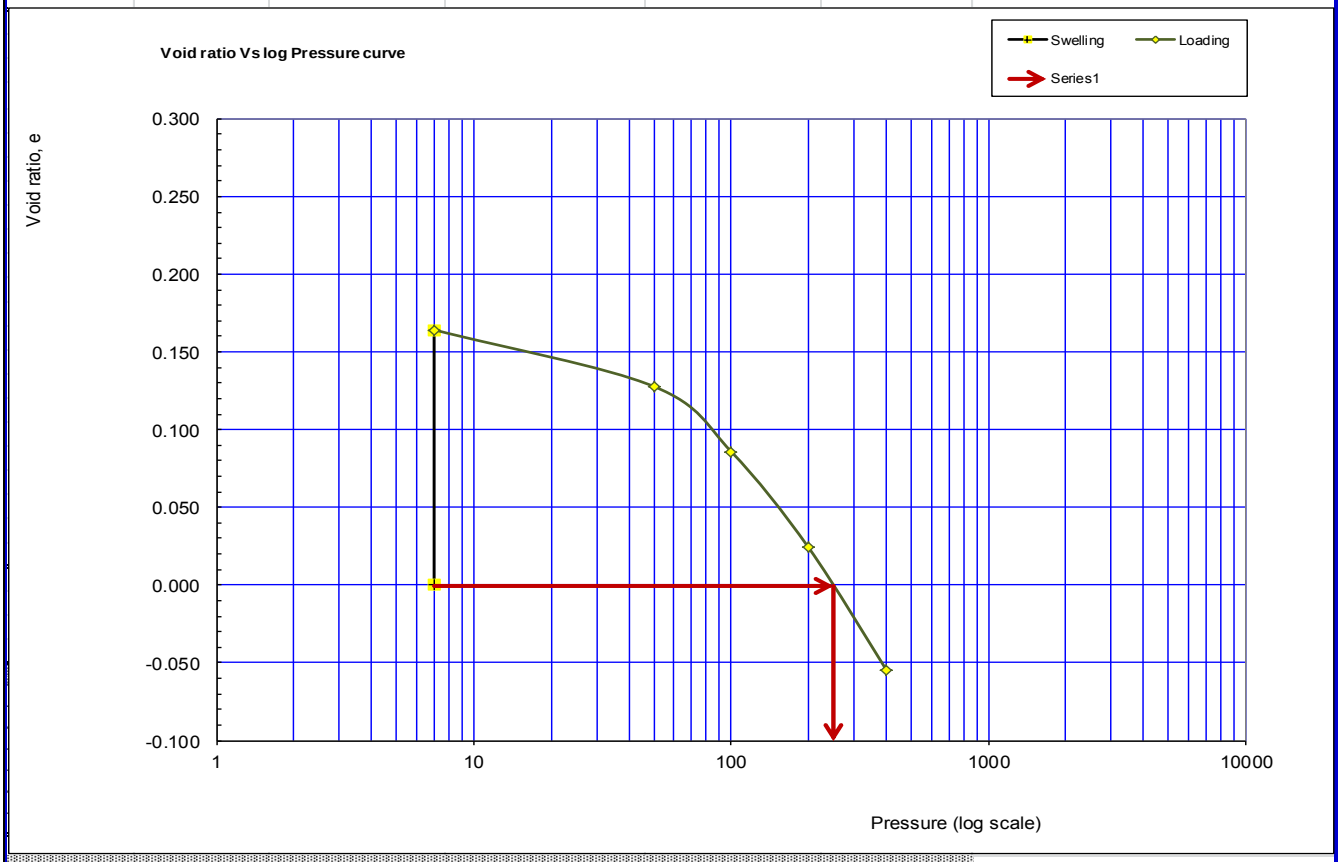
Pit no:- 10

Depth:- @1.2m

Sample discription:- Ambo Expanssive Soil

Color of sample:- Black

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**250.45 Kpa**
Swelling Potential=	**8.61%**
Initial Reading=	4.0+0.00+0d=4.000mm
Fina Reading=	5.6+0.12+1d=5.722mm

SWELLING PRESSURE TEST WITH ONE CONSOLLIDATION

Date of Tested:- 01/10/2014, Wednesday @3:30AM

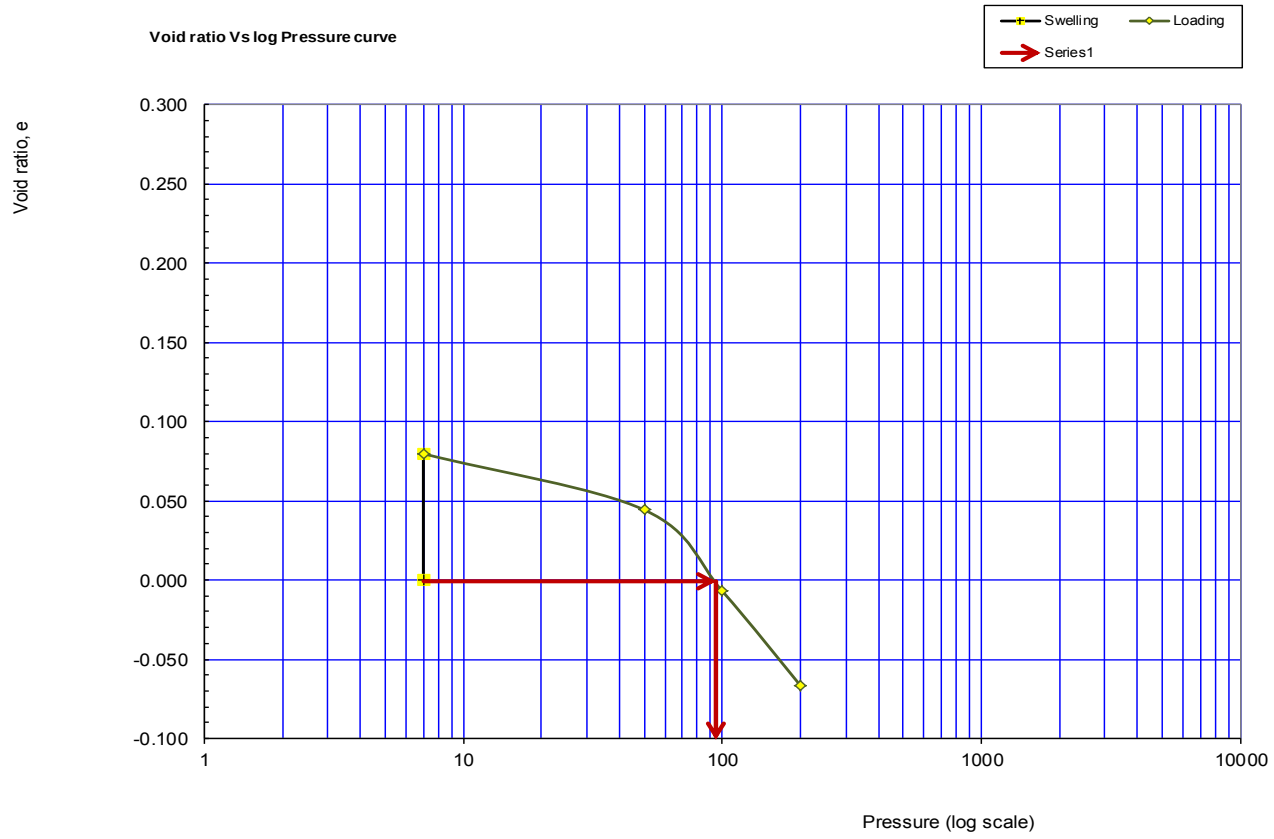
Pit no:- 10

Depth:- @2.5m

Sample discription:- Ambo Expanssive Soil

Color of sample:-Grey

Standard Referance:-ASTM D 4546 – Standard Test Method for One Dimensional Swell or Settlement Potential of Cohesive Soil



Swelling Pressure=	**93.25 Kpa**
Swelling Potential=	**4.05%**
Initial Reading=	3.6+0.00+0d=3.600mm
Final Reading=	4.4+0.00+5d=4.410mm

APPENDIXC: Meteorological Data of Ambo Town

Temperature Condition of Ambo town

Year	Monthly Temperature (In Degree Celsius)												Mean Annual Temp
	J	F	M	A	M	J	J	A	S	O	N	D	
1999	19.55	20.20	20.10	20.80	19.35	18.00	16.70	16.65	16.95	17.45	15.35	17.80	18.24
2000	19.10	20.25	20.85	20.10	19.00	17.55	17.10	16.95	17.45	17.80	17.75	19.90	18.73
2001	18.50	20.15	19.75	20.75	19.60	17.50	17.40	18.45	17.05	18.20	18.05	18.80	18.68
2002	118.80	19.80	19.75	20.60	20.75	18.65	18.50	17.05	18.35	18.60	19.25	19.60	19.11
2003	16.75	20.30	20.85	20.20	19.85	18.30	17.55	17.60	17.05	17.60	18.75	18.25	18.59
2004	20.20	20.20	20.50	20.45	20.15	18.85	17.20	17.30	17.35	17.90	18.55	20.90	19.21
2005	19.00	21.35	20.95	21.20	19.80	18.30	17.05	17.40	17.90	17.60	17.85	17.85	18.85
2006	19.90	20.85	20.05	19.80	18.70	18.10	17.60	17.50	17.65	18.70	18.90	18.20	18.83
2007	19.95	17.15	20.95	20.70	20.20	18.30	17.85	17.20	17.80	18.65	18.80	18.35	18.83
2008	22.00	23.40	21.90	23.25	19.65	18.35	17.30	16.95	17.70	18.05	18.10	19.00	19.64
Mean Monthly Average Temp	19.38	20.37	20.77	20.79	19.71	18.19	17.39	17.31	17.23	18.06	18.14	18.87	18.87

Rainfall Condition of Ambo town

Year	Monthly Rainfall (mm)												Mean Annual RF
	J	F	M	A	M	J	J	A	S	O	N	D	
1999	8.40	0.30	39.50	12.50	69.20	59.80	173.90	129.90	95.90	119.20	1.30	1.00	59.24
2000	0	0	9.30	51.50	93.70	121.20	186.40	191.60	135.40	84.10	20.70	14.80	75.73
2001	5.60	12.50	60.50	70.40	186.10	148.50	219.80	243.10	110.5	41.80	5.40	11.00	92.93
2002	78.70	16.90	55.60	56.30	51.90	177.60	162.50	130.20	40.30	3.00	0	17.80	65.90
2003	32.90	99.30	55	179.10	9.40	209.50	134.20	142.70	78.40	9.30	1.20	16.40	80.62
2004	38.70	16.00	30.20	108.70	26.80	137.10	203.60	110.70	134.90	19.00	0	9.60	77.94
2005	25.20	0	86.90	47.50	67.70	166.30	158.00	187.20	98.40	19.00	12.40	0	72.38
2006	0	16.70	150.70	65.10	157.70	109.90	196.80	298.60	76.50	17.90	18.80	0	92.39
2007	49.30	36.80	40.20	38.90	130.90	275.20	232.00	310.10	187.50	11.00	0	0	109.33
2008	0	0	1.00	18.70	157.30	161.80	308.00	260.20	84.00	64.80	101.80	2.70	96.69
Monthly Average RF	23.88	19.35	52.89	64.87	95.07	156.69	197.52	210.43	104.18	38.91	16.16	7.33	82.32

APPENDIXD: Scatter Plot of Swelling Potential with Index Properties

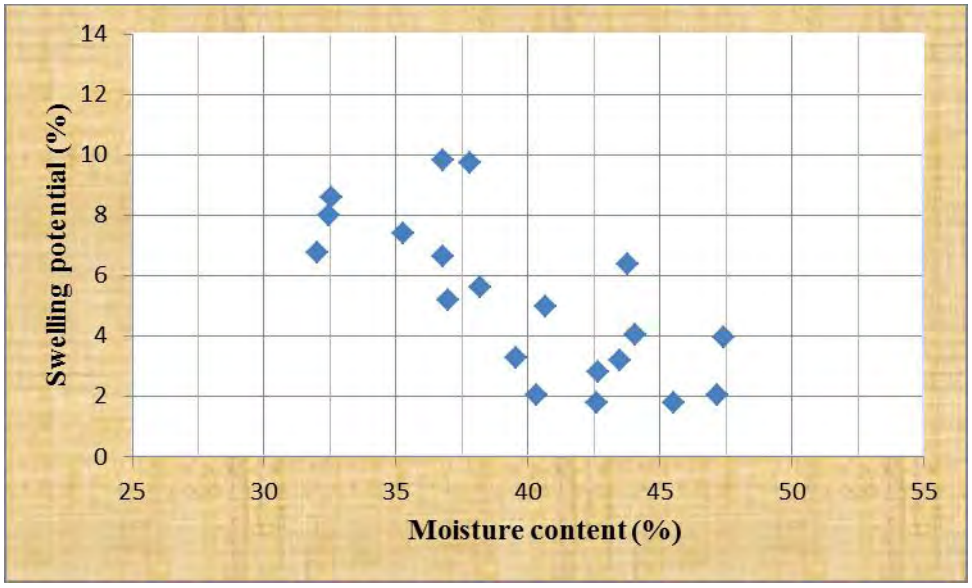


Figure: Scatter plots of SPO vs. Moisture content

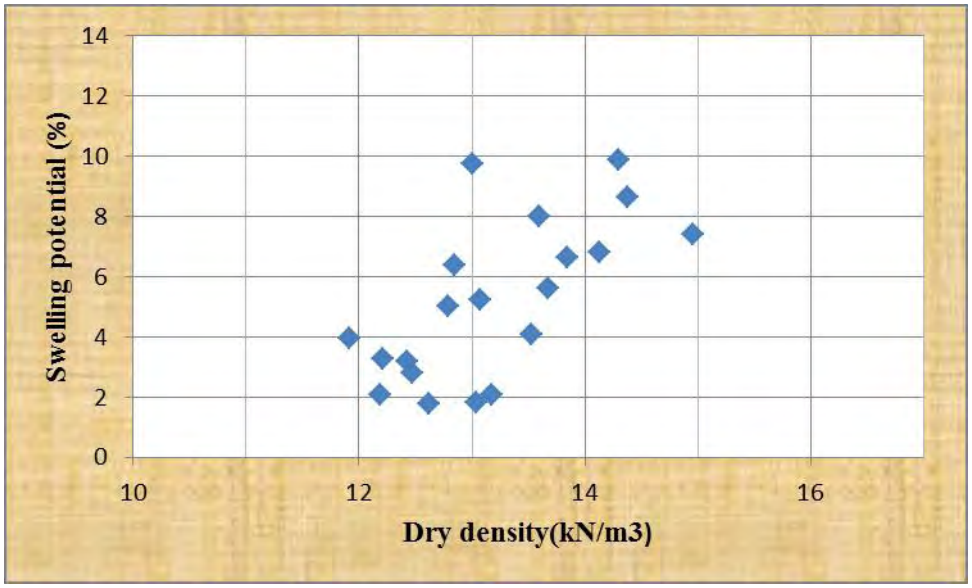


Figure: Scatter plots of SPO vs. Dry density

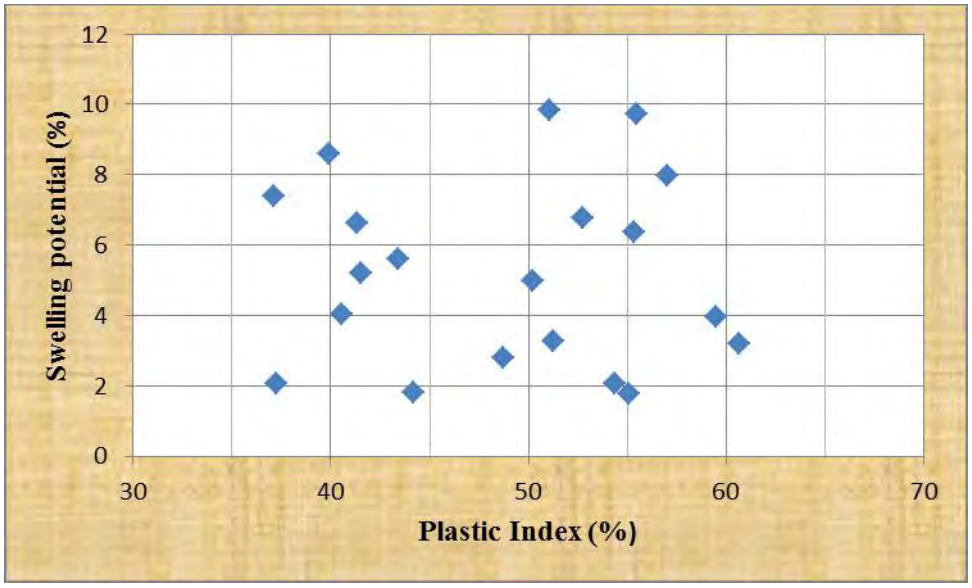


Figure: Scatter plots of SPO vs. Plastic Index

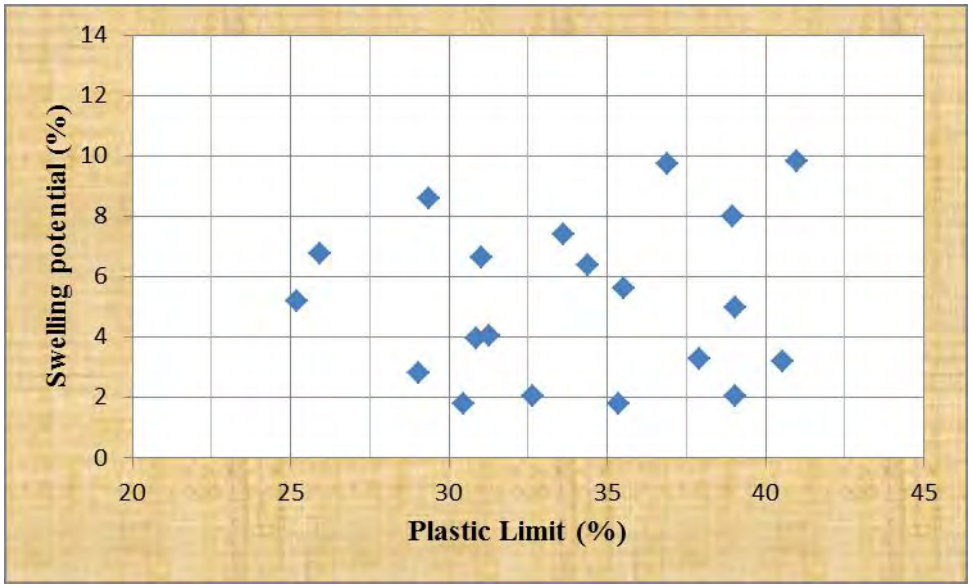


Figure: Scatter plots of SPO vs. Plastic Limit

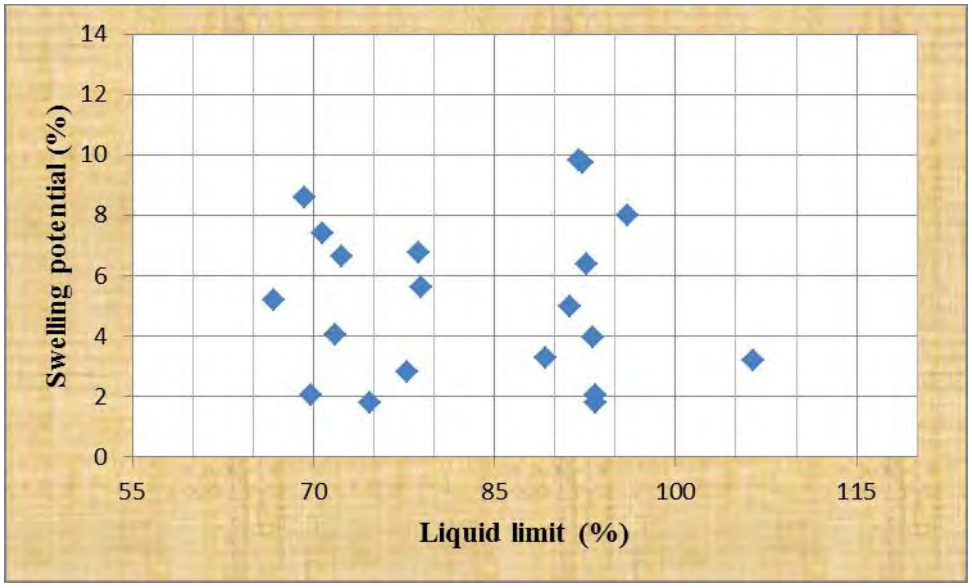


Figure: Scatter plots of SPO vs. Liquid Limit

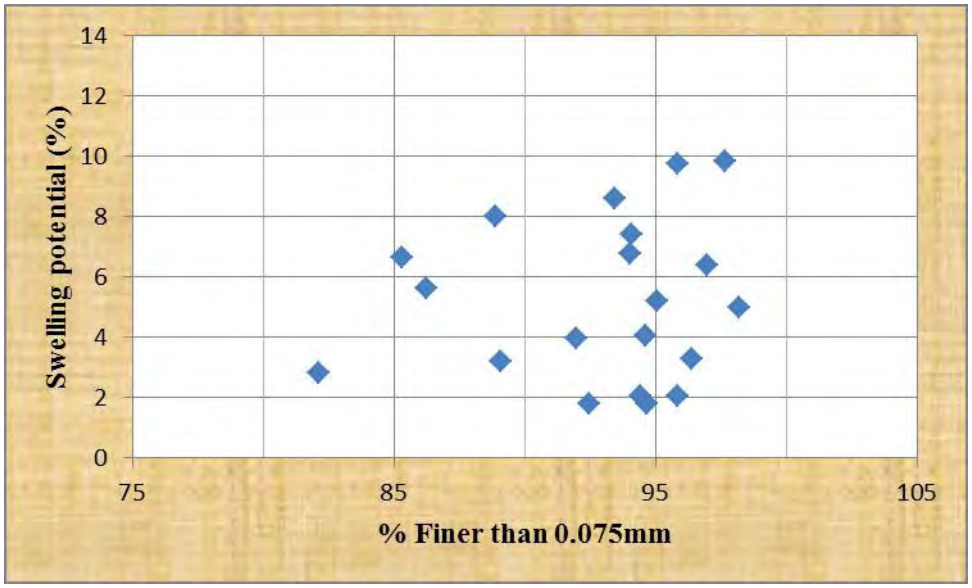


Figure: Scatter plots of SPO vs. % Finer than 0.075mm (% P200)

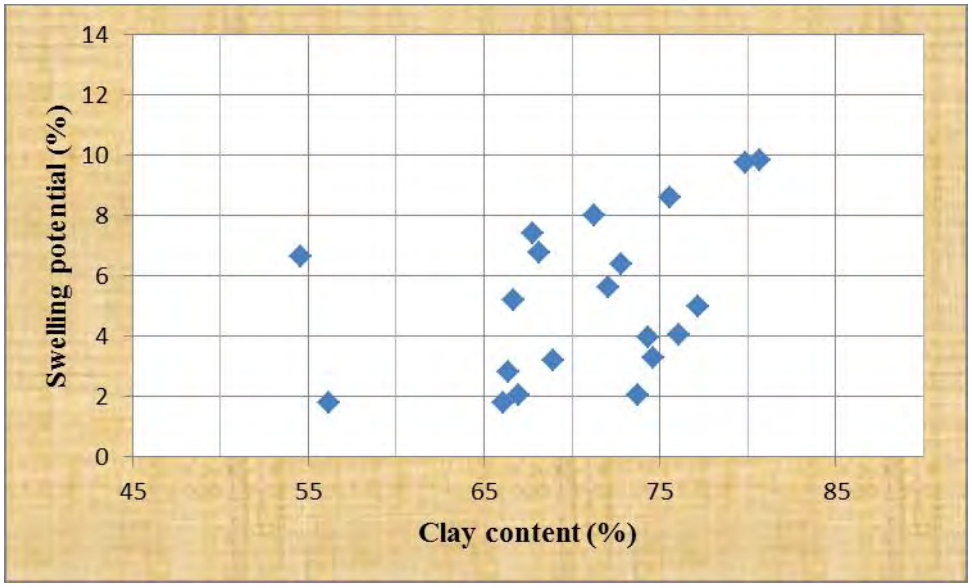


Figure: Scatter plots of SPO vs. Clay content

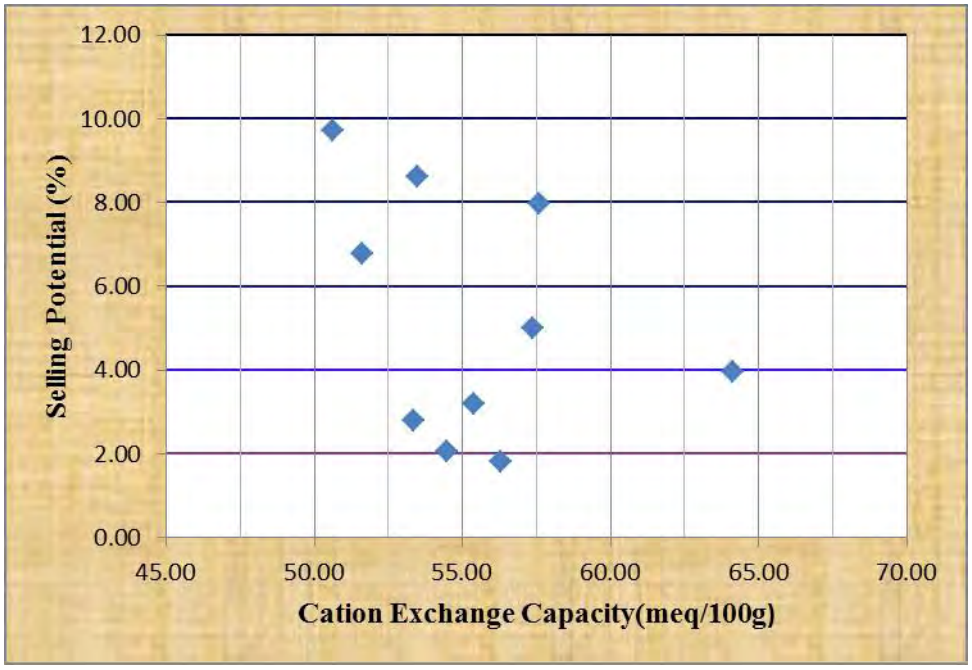


Figure: Scatter plots of SPO vs. CEC