ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

INVESTIGATION ON SOME OF THE ENGINEERING PROPERTIES OF SOILS FOUND IN WOLENCHITY TOWN, ETHIOPIA

"A thesis submitted to the school of graduate studies of Adama Science and Technology University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Geotechnical Engineering)"

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APRIL, 2018

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DECLARATION

I, the undersigned, declare that the work in the project entitled “Investigation on Some of the Engineering Properties of Soils Found in Wolenchity Town” has been performed by me in the Department of Civil Engineering, under the supervision of my research advisor Dr Yadeta Chimdessa. The information derived from literature has been duly acknowledged in the text and list of references provided. No part of this project was previously presented for another degree at any university.

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Adama

Submission Date: April, 2018

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SYMBOLS AND ABBREVIATIONS

AASHTO - American Association of State Highway and Transportation Officials;

ASTM - American Society for Testing Materials standard;

ASTU – Adama Science and Technology University;

a_v – Coefficient of compressibility;

C – Cohesion;

Cc – Compression Index;

CL - Lean Clay;

C_v – Coefficient of Consolidation;

GF – Gravel Fraction;

GI- Group Index;

G_s – Specific gravity;

LL - Liquid Limit;

k – Coefficient of permeability;

MDD - Maximum Dry Density;

MH - Inorganic Elastic silt;

ML - Inorganic Silt (sandy silt);

NMC - Natural Moisture Content;

OMC - Optimum Moisture Content;

P_c – Pre-consolidation pressure;

P_o – Over-burden Pressure;

PI - Plastic Index;

PL - Plastic Limit;

SM – Silty sand;

SP - Poorly graded sandy with gravel;

SW – Well graded sand;

USCS - Unified Soil Classification System;

ϕ – Angle of internal friction.

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ABSTRACT

Investigation of soil properties at site is a basic prerequisite to economical design of the sub-structural elements and provides sufficient information for feasibility and economic studies of proposed structures. The causes of failure of engineering structures built on soils are mostly related to misunderstanding of the engineering properties of soil prior to construction. The objective of this research is to investigate the engineering property of soil found in Wolenchity town in order to understand clearly the nature of soils by collecting samples from eight test pits at different parts of the town and laboratory tests were done on the collected samples. The natural moisture content and specific gravity of the studied soils are ranging from 11.72 – 33.58% and 2.60 to 2.70 respectively. The grain size analysis test result showed that the dominant proportion of soil of the research area is sandy and silty soil, which has a fraction of clay 0.92 – 18.54%, silt 3.08 – 59.14%, sand 31.4 – 78.9% and gravel 0.3 – 28.8%. The LL: 25 – 49%, PL: NP – 34.85% and PI: NP –15%. The studied soils are non-swelling soil with free swell with 0 – 25%. According to USCS, four soil types were identified in the study area: ML, SM, SW and SP. The AASHTO Classification System shows that soils of the town are A-2-4, A-3, A-4, A-6, A-7-5 and A-7-6. The maximum dry density and optimum moisture content ranges from 1.3 to 1.7 g/cm^3 and 17.5 to 31% respectively. The values of shear strength parameters, cohesion (C) and internal friction angle (ϕ) ranges from 1.41 - 15.95kPa and 21.5 - 30.7º, respectively. Finally one-dimensional consolidation test showed that; the soil under investigation is over consolidated in its natural state, have compression index ranging from 0.17 - 0.22, coefficient of consolidation ranging from 0.023 to 0.132 cm^2/min and coefficient of permeability ranging from 0.15x10^{-8} to 18.16x10^{-8} cm/sec.

Key Word: Atterberg limit, Maximum dry density, Optimum moisture content, Cohesion, Angle of internal friction, Compression index, over consolidation, Coefficient of consolidation, Soils.

Chapter One

Introduction

1.1 Background of the Problem

Investigation of soil properties at site is a basic prerequisite to economical design of the sub-structural elements. It provides sufficient information for feasibility and economic studies of proposed structures (Arora, 2004). In recent times, the alarming rate at which the lives are being lost due to collapsed building, bridges, dams, roads, etc calls for critical solutions. Soils, depending on its mineralogical composition, can cause significant damage to engineering infrastructures unless proper design and construction measures are taken. The better solutions in reducing loss of life and collapse of structure are critical geotechnical investigation of soils in advance (Das 2007).

At present day there is dramatic increase in urbanization in Ethiopia associated with increased population and transformation policy of development i.e. from agriculture to industrial transformations. This increase in urban population has been accompanied by an equally strong growth in the number of high-rise buildings, roads, bridges, water supply pipes, and other infrastructure constructions.

In country like Ethiopia which is actively participating in construction industry now a day's needs many construction works or projects in the future, geotechnical investigation on the engineering properties of soils are very essential. Because these data are very important for all civil engineering design such as foundation, bridge abutments, pavements, retaining structures, etc. for future construction projects in the country. So many researchers have been done on characterizing and indentifying the behavior of soils found in different part of the country. However, the behavior of soils are varies from place to place depending upon the type of parent material, climate and topography (Murthy, 2010). In addition, the type and amount of clay minerals in the soil determine the shrinkage and swelling potential of the soil, which is also, depends upon climate and degree of weathering of parent rock (Bowles, 1996). Therefore, it is important to make localized study for the different regions.

The engineering geological soil and material investigations are important components in urban planning and designing of every engineering structure. The causes of failure of engineering structures built on soils are mostly related to the expansive nature of the soils. The problems are either due to misunderstanding of the behavior of the soil or lack of information on engineering properties of soil prior to proposed construction. This also causes a great economical loss for maintaining the distracted structure. Thus a detailed investigation should be carried out on the soil, particularly on clay rich soils, before using as a construction material or constructing structure on or in it.

Wolenchity is one of the fast growing towns of Boset Wereda in Ethiopia. The growth of trade and commerce is ongoing in the town. Investors are attracted to construct different projects in the town due to its location (Addis-Djibouti busy roads and railway) and near distance from Adama and Addis Ababa. Due to this so many buildings are under construction and planned to be constructed in the future and also the town is located in industry park expansion plan by governments. This effort should be accompanied by strict and professionally ethical quality assurance and supervision of construction. One of the important activities is proper investigation of soil behavior and design of structure which considers the actual ground condition. This research is therefore directed to the study of basic engineering properties of soil (i.e. index properties, shear strength, one-dimensional consolidation as well as swelling characteristics) of Wolenchity town.

1.2 Objectives of the Study

1.2.1 General Objective

The overall objective of this study was to assess and evaluate the engineering geological and geotechnical conditions of the soils found in Wolenchity town.

1.2.2 Specific Objective

- ✓ To determine moisture content, specific gravity, grain size, Atterberg limit and swelling characteristics of the soils.
- ✓ To determine shear strength parameters of the soils.

- ✓ To determine maximum dry density and optimum moisture content of the soils.
- ✓ To classify the soils according to USCS and AASHTO.
- ✓ To determine one-dimensional consolidation

1.3 Scope of the Study

Sixteen samples from eight representative pits were being collected in the town from different areas. The scope of this study is limited to investigating the index properties, shear strength, swelling properties one-dimensional consolidation and compaction characteristics of the soil in the Wolenchity town. The depth of the investigations in this research is limited to maximum depth of 3m.

1.4 Methodology of the Study

To achieve the above mentioned objectives eight sampling areas were selected which represent different types of soils found in the town. To select the sampling areas and to take representative samples, discussion was made on topographic map of the town with explanation from concerned municipality staffs for possible variation on soil types, visual site investigation and information from resident, and construction firms were also collected to consider the different soil types and to take the sample evenly in the whole town. From the selected sampling areas, test pits were excavated to a depth of around three meters for a visual observation of the sub-surface condition and to take representative samples. Only disturbed samples were taken because of the silty nature of the soil which makes recovering of undisturbed sample difficult. Since it was difficult to bring undisturbed samples to the laboratory, natural moisture content test was done at the field by taking balance and moisture can at field. Then after, the natural moisture content was immediately determined.

The specific gravity of each type of soil was determined according to ASTM D-854-00(Standard Test Method for Specific Gravity of Soils) for the soil finer than 2mm. The precision and bias of each pair of tests were investigated and all are within the ASTM accepted range.

Grain Size Analysis was conducted according to ASTM D 422-63- Standard Test Method for Particle-Size Analysis of Soils. The grain size distribution for soil particles finer than 0.075mm was determined using 152H Hydrometer (Standard Test Method for Amount of Material in the Soil Finer than the No. 200 Sieve).

Atterberg Limits tests were conducted on fine grained soils. Then liquid limit, plastic limit, and plasticity index for each type of soil was determined according to ASTM D-4318-98 (Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils). The standard four-point method for determining the liquid limit was used for all tests.

The compaction test and the direct shear test were conducted from the dry sample in laboratory using standard proctor compaction test and direct shear box, respectively.
Finally one-dimensional consolidation test is conducted by using consolidometer to determine consolidation parameters for higher percentage fraction of fine soils.

1.5 Organization of the Thesis

This thesis work is divided in to five chapters, each covering a specific topic of the research work. In chapter one the background of the problem, objective, methodology and scope of the thesis work and organization of the thesis are presented. Literature review is briefly revised in chapter two. In chapter three the general description of the study area in which this research is done is presented. The fourth chapter deals with in-situ properties with sample description and laboratory results obtained. Comparison with previously done researches is also revised in this chapter. Chapter five is the conclusions and recommendations drawn from the research. Finally, raw data, analysis and results of the index properties test, compaction test, direct shear test and one-dimensional consolidation for selected test pits are included in appendix.

Chapter Two

Literature Review

2.1 General

Soils, in the geotechnical engineering sense, can be regarded as engineering materials widely used as construction materials, foundation materials and as a support for different engineering structures that is formed by weathering of rock. The properties of soils are complex and widely variable from place to place laterally or vertically. Like other construction materials, soil also possesses mechanical and engineering properties related to strength, compressibility, and permeability. It is more important to quantify these properties to predict and determine how soil will behave under different natural and artificial field loading for the safe and economic design of soil structures (e.g. embankments, dams, waste contaminant liners, highway base courses, etc.), as well as other structures that will overlay the soil. Every civil engineering work involves the determination of soil type and its associated engineering application; certain properties are more significant than others. The common problems faced by civil engineers are related to bearing capacity and compressibility of soil and seepage through the soil. These problems are solved by detail investigation, determination of the physical and index properties of the soil (Craig, 2004).

Their physical characteristics can be determined by experiment, and the application of methods of analysis enables these properties to be used to predict their likely behavior under defined working conditions. But unlike other engineering materials such as metals and concrete, over which control can be exercised during manufacture, soils are naturally occurring materials, which more often than not have to be used in their natural condition (Dagnachew, 2011).

Soil index properties are used extensively by engineers to distinguish between the different kinds of soil within a broad category, e.g. clay will exhibit a wide range of engineering properties depending upon its composition. Classification tests determined by index properties will provide the engineer with valuable information when the results are compared against empirical data relative to the index properties determined (Adem, 2014).

The type and characteristics of soil depends on its origin. The engineering properties namely permeability, consolidation, compaction and shear strength are governed by the mode of formation, stress history, groundwater conditions and physicochemical characteristics of the surface deposits derived from parent material (Craig, 2004).

2.2 Soil Formation and Soil Deposits

Soils are formed as a result of weathering processes of physical disintegration, chemical and biological decomposition of parent rocks involved in complex interaction with the parent material, topography, climate, and living organisms. The soil forming factors are parent material, climate, relief or topography, organisms and time/exposure (Aysen, 2002).

The properties of soil formed by physical weathering are the same with the parent materials as the process involves reduction of size without any change in the original composition of the parent rock. The main agent responsible for this processes are temperature changes, wedging action of tree roots, erosion, freezing and thawing. Chemical weathering causes both reduction in size and chemical alteration of the original parent rock. The main agents responsible for chemical weathering are hydration, carbonation, leaching and oxidation. Chemical weathering is much more important than physical weathering in soil formation. Soils at a particular site can be residual (that is weathered in place of their original parent materials) or transported (moved by water, wind, glacier, etc.) and the geologic history of a particular deposit significantly affects its engineering behavior (Venkatramaiah, 2006).

Chemical decomposition of rocks results in the formation of clay minerals. These clay minerals impart plastic properties to soils. Clayey soils are formed by chemical decomposition (Venkatramaiah, 2006).

2.2.1 Parent Material

Parent materials are the material underlying the soil from which, in most cases, the soil develops by the disintegration and decomposition of rock. There are two main variables in parent materials that affect soils: grain size and composition. Grain size is the main determinant of soil texture. Texture influences the soil structure, consistency, cation exchange capacity, profile drainage, moisture retaining capacity and organic content (Dagnachew, 2011).

2.2.2 Relief or Topography and Drainage

Topography refers to the slope characteristics of a soil that has a major influence on drainage characteristics which in turn is known to have major effect on soil mineralogy. It control over soil properties particularly strong in tropical environment reflecting the importance of lateral movement of water and soil materials (Adem, 2014).

It includes the degree or steepness, length, shape and direction of a slope. These factors influence the amount of rainwater runoff, the amount of rain that enters the soil and the amount that collects in small depressions on the soil surface. Soils on steep slopes have higher amounts of runoff and erosion than those on level topography. The amount of moisture in the soil during its development affects the rate of weathering and the development of subsoil colors. Soils in depressions and on nearly level topography are likely to have poor or very poor natural drainage. Soils on moderately sloping to steep topography are usually well drained.

2.2.3 Time

The length of time affects mechanical and chemical weathering of parent materials and the other soil forming factors. A typical soil's age must be measured in thousands of years. It may actually take hundreds of years for these factors to form one inch of soil from parent material.

2.2.4 Climate

Climate refers to temperature, rainfall, freezing, thawing, wind and sunlight. It is the principal factor governing the rate and type of soil formation. Especially the amount and distribution of precipitation, and temperature are the two important components of climate that influence the formation and properties of soils.

The temperature variable is adequately represented by mean annual temperature, which doesn't differ greatly from the nearly constant temperature in the lower part of the regolith. According to

Van’s Hoff’s principle the velocity of a chemical reaction increases by a factor of 2 or 3 for every 10 ^{o}c rise of temperature.

The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system (Dagnachew, 2011).

2.3 General Types of Soils

Depend on their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75 to 76.2 mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75 mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eyes is about 0.075 mm. Soil grains ranging from 0.075 to 0.002 mm are termed as silt and those that are finer than 0.002 mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials (Murthy, 2010).

2.4 Soil Particle Size and Shape

The size of particles may range from gravel to the finest size possible. Their characteristics vary with the size. Soil particles coarser than 0.075 mm are visible to the naked eye or may be examined by means of a hand lens. The coarser fractions of soils consist of gravel and sand. The individual particles of gravel, which are fragments of rock, are composed of one or more minerals, whereas sand grains contain mostly one mineral which is usually quartz. The individual grains of gravel and sand may be angular, sub angular, sub-rounded, rounded or well-rounded. Gravel may contain grains which may be flat. Some sands contain a fairly high percentage of mica flakes that give them the property of elasticity.

Silt and clay constitute the finer fractions of the soil. Any grain of this fraction generally consists of only one mineral. The particles may be angular, flake-shaped or sometimes needle-like (Dagnachew, 2011).

2.5 Soil Mineralogical Composition

Mineral particles can be inorganic particles derived from rock materials and minerals. They are extremely variable in size and composition. Primary minerals: present in original rock from which soil is formed. These occur predominantly in sand and silt fractions, and are weathering resistant (quartz, feldspars). Secondary minerals: formed by decomposition of primary minerals, and their subsequent weathering and decomposition into new ones (clay minerals).Humus or organic matter: decomposed organic materials (Aysen, 2002).

2.6 Soil Texture

Common descriptive terms such as gravels, sands, silts and clays are used to identify specific texture in soils. Texture refers to the appearance or feel of a soil. Sands and gravels are grouped together as coarse grained soil. Clays and silts are fine grained soils. Coarse grained soils feel gritty and hard. Fine grained soils feel smooth (Budhu, 2010).

2.7 Laboratory Test

A wide variety of laboratory tests can be performed on soils to measure a wide difference of soil properties. Some soil properties are intrinsic to the composition of the soil matrix and are not affected by sample disturbance, while other properties depend on the structure of the soil as well as its composition, and can only be effectively tested on relatively undisturbed samples. Some soil laboratory tests measure direct properties of the soil, while others measure "index properties" which provide useful information about the soil without directly measuring the property desired (Adem, 2014).

2.7.1 Natural Moisture Contents

Natural moisture content is amount of water contained in soils that characterize the performance of soil under the action of load and temperature. The calculation of water content is important in determining consistency limits of soil, soil compaction control, for the calculation of stability of all kinds of earth works and foundations and in expressing phase relationship of soil volume (ASTM, 2004).

2.7.2 Specific Gravity

Specific gravity is the ratio of the mass of a unit volume of a soil solid to the mass of the same volume of gas-free distilled water at stated temperature. The determination of specific gravity of soil is used in calculating phase relationships of soils (that is the relative volumes of solids to water and air in a given volume of soil). Most of the values fall within a range of 2.6 to 2.9. The specific gravity of solids of light-colored sand, which is mostly made of quartz, may be estimated to be about 2.65; for clayey and silty soils, it may vary from 2.6 to 2.9 (Das, 2007).
There are two methods for the determination specific gravity of soil solids. These are Method-A, procedures for moist specimen and Method-B, procedure for oven dry specimen. For organic soils; highly plastic, fine grained soils; tropical soils; and soils containing halloysite, procedure A shall be the preferred method. This procedure is the preferred method (ASTM, 2004).

2.7.3 Grain Size Distribution

Grain-size analysis is a method in which the relative proportion of material of each grain size present in a given soil mass is determined.

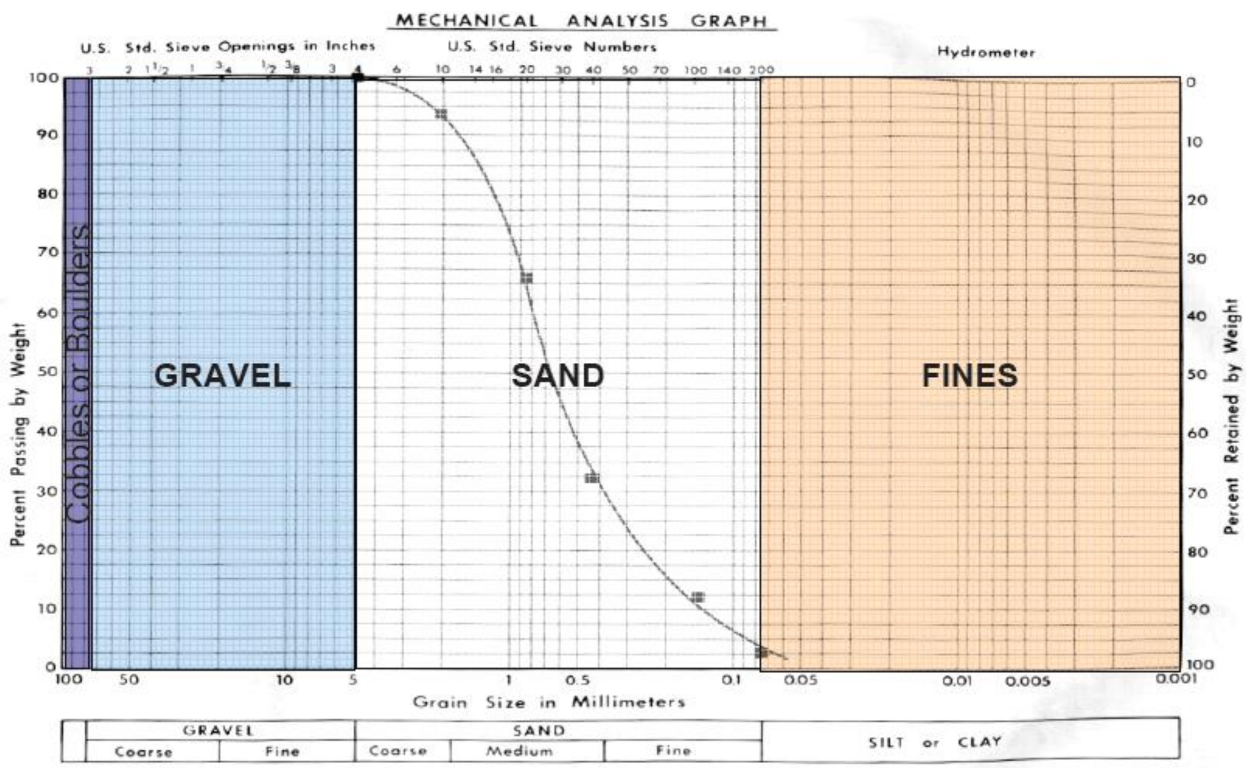


Fig.2.1 Grain Size Distribution Curves

Grain size analysis used to determine the percentage of different grain sizes contained within a soil, which is required in classifying the soil and determination of engineering properties of the soil.

Grain size distribution of soils is determined by using sieve analysis and hydrometer analysis. Sieve analysis is used for the determination of distribution of the particle size coarser than 0.075mm (retained on the sieve No. 200), while hydrometer analysis is used for the determination of fine grained soil i.e. finer than No. 200. The grain-size distribution of mixed soils is determined by combining sieve analysis and hydrometer analysis (Alemayehu, 1999).

2.7.4 Atterberg Limit

The term consistency is applied to fine grained soil and indicates an ability to be rolled and remolded without breaking apart. It depends on the type and amount of clay minerals in the soils. Atterberg limit is most important index properties of soil that is used for classification of fined grained soils and correlation with other engineering behavior (Das, 2010).

Consistency determines the properties of fine grained soil and denotes degree of firmness of the soil that is indicated by tests in the field as soft, firm, stiff or hard. As the plasticity of soil increases; the compressibility of soil increases, higher shrinkage-swell potential and its permeability is lowered (Gebremedhin, 2010).

Depending on the moisture content, the Swedish soil scientist Albert Atterberg classify the behavior of soil into four basic states:- solid, semisolid, plastic, and liquid.

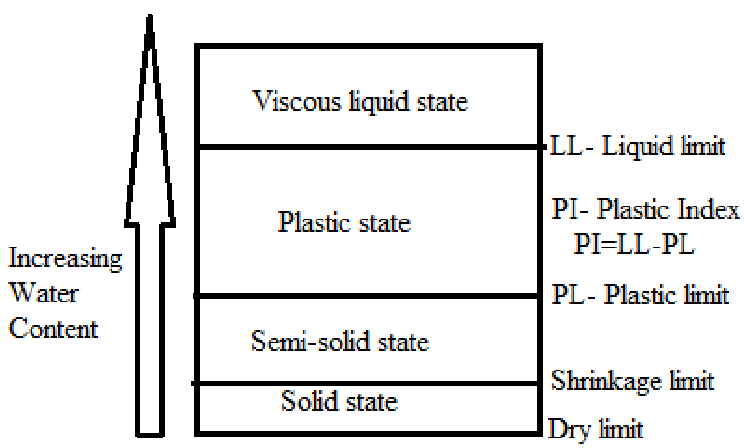


Fig. 2.2 Consistency States of Soils and Atterberg Limit

The difference between liquid limit and plastic limit is called plasticity index. Plasticity index is used for soil classification and describes the range of water contents over which the soil has a plastic consistency.

2.7.5 Free Swell

Free swell tests consists of placing 10ml oven dry soil which has passed 0.425mm (No. 40) sieve in 100ml water and determining the swelled volume after the material settles, without any surcharge, to the bottom of a graduated cylinder. Clay minerals, soil mineralogy and structures, fabric and several physic-chemical aspects of soil influence the magnitude of swelling pressure and amount of swelling. Among clay minerals montmorillonite influences the magnitude of swelling maximally than Illites and Kaolinites (Gebremedhin, 2010). After 24 hours free swell is determined as:-

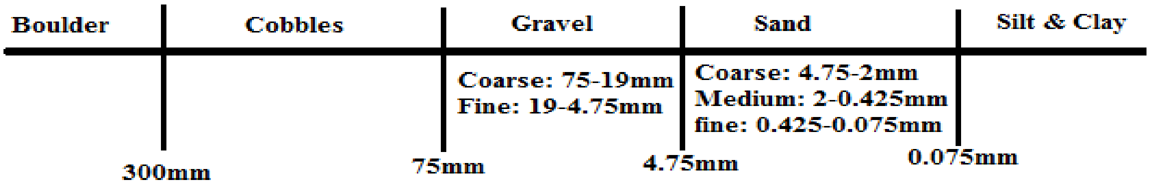
$$FreeSwell = \left(\frac{\text{Final volume} - \text{Initial volume}}{\text{Initial volume}}\right) * 100\% \ldots\ldots\ldots\ldots\ldots\ldots. 2.1$$

2.7.6 Classification of the Soils

A soil classification system provides a method of identifying and describing soils into a particular group that would likely exhibit similar properties. Soil classification is used to make possible estimation of characteristics of soil, specify a certain soil type that is best suitable for a given engineering application and help the engineer to rate the performance of a given soil either as construction materials. The ability to identify and classify the soils properly is a basic to all engineering problem analysis related with earth materials. Soils are grouped into various types on the basis of their grain size, origin and formation, structures of soils, texture of soils, plasticity, etc. (Arora, 2004).

Soil classifications systems of the study area were made based on the two most popular engineering soil classifications known as Unified Soil Classification System (USCS) and American Association of State Highway and Transport Officials (AASHTO). Soil components may be described as gravel, sand, silt, or clay based on different grain size distributions.

Average grain size classification according to ASTM, 2000



Average grain size classification according to AASHO (Teferra, 1999)

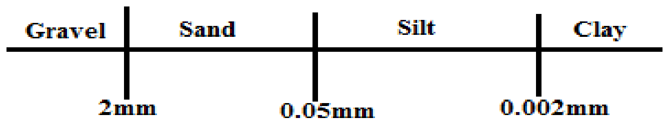


Fig. 2.3 Classification of Soil Based on Average Grain Size

I. Unified Soil Classification Systems (USCS)

Unified Soil Classification Systems is most widely used classification systems in all engineering problems related with the soils. The systems classify the soils based on grain size, gradation, compressibility and Atterberg limits. According to this classification systems soil is grouped into coarse grained, when more than half of the soil sample is larger than the No. 200 and fine grained; when more than half of the soil sample is finer than the No. 200 sieve (Murthy, 2010).

Plasticity chart is used for classification of fined grained soils by using liquid limit and plasticity index results. As the percentage of plasticity index increases the amount of clays is high in the soil. The important feature of this chart is the empirical A-line that is given by the equation PI = 0.73(LL - 20), which separate the inorganic clays from the inorganic silts. Inorganic clay values lie above the A-line, but inorganic silts lie below the A-line. Organic silts plot in the same region below the A-line and with LL ranging from 30 to 50 as the inorganic silts of medium compressibility. Organic clays plot in the same region as inorganic silts of high compressibility but below the A-line and LL greater than 50. A line called the U-line lies above the A-line. The U-line is approximately the upper limit of the relationship of the plasticity index to the liquid limit for any currently known soil. The equation for the U-line can be given as PI = 0.91(LL - 8) (Wubshet, 2015).

II. American Association of State Highway and Transport Officials (AASHTO) Classification System

The AASHTO system enables classification of soils based on sieve analysis, liquid limit and plastic limit. Soil is grouped into granular materials (35% or less total sample passing No. 200) and silty-clay materials (more than 35% of total sample passing No. 200). The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7.It uses similar techniques as that of USCS but the dividing line has an equation of the form PI= LL-30 (Murthy, 2010).

Group index (GI) is calculated to evaluate the quality of a soil as a highway subgrade material, with the groups and subgroups of the soil. As the of group increase the quality of soil as subgrade material is reduced. A group index of zero indicates a good subgrade, whereas index of 20 or greater shows a very poor subgrade (Das, 2010).

Group Index of A-1-a, A-1-b, A-2-4, A-2-5 and A-3 are zero.

Group Index of A-2, A-4, A-5, A-6 and A-7 are:-

$$GI = (F200 - 35)*[0.2 + 0.005*(LL - 40)] + 0.01*(F200 - 15)*(PI - 10) \quad \ldots\ldots 2.2$$

Group Index of A-2-6 and A-2-7 is:-

$$GI = 0.01 * (F200 - 15) * (PI - 10) \quad \ldots\ldots 2.3$$

2.7.7 Compaction of the Soils

Compaction is the densification of soil by reducing the void spaces covered by air between soil particles through mechanical means. Compaction of soils is used to improve their engineering properties by increasing strength characteristics and reducing amount of undesirable settlement of structures. Geotechnical engineers assure that compacted fills are meeting the prescribed design specifications by determining density (as a percentage of the “maximum” density measured in a standard laboratory test), and the water content. The degree of compaction of a soil is depending on its dry unit weight and water added to the soil during compaction which is used as a softening agent on the soil particles. A particular amount of water content, at which the maximum dry unit weight is obtained, is generally known as the optimum moisture content (Das, 2010).

The optimum moisture content and maximum dry density of soil under investigation is determined by laboratory standard proctor compaction test according to ASTM D698. The soil is compacted by a 24.4N hammer falling a distance of 0.305meters (1 foot) into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer (Krishna, 2002).

2.7.8 Shear Strength of Soil

The stability and safety of any geotechnical structure is dependent on the strength of the soil. When the soil fails; a structure founded on and in it can collapse, endangering lives and causing economic damages. However, the problems related with bearing capacity, lateral pressure against retaining walls, slope stability, etc., are all influenced by the shear strength of the soil. The shear strength of soils is, therefore, is important engineering properties to geotechnical engineers. All soils engineering problems are related to the shear strength of the soil in one way or the others (Robert, 2009).

The shear strength of a soil mass is the internal frictional resistance of a soil to resist failure and sliding along any plane inside it. It is required to make estimates of the load-bearing capacity of soils and the stability of geotechnical structures, and in analyzing the stress–strain characteristics of soils (Arora, 2004).

The most common laboratory methods employed to obtain shear strength parameters are direct shear test, triaxial compression test and unconfined compression test. For this thesis direct shear test are used.

2.7.9 One Dimensional Consolidation

Consolidation is a process in which the saturated soil is compressed under steady static pressure. It happen due to expulsion of water from the void space in soil, then the volume of soil is reduced as shifting of position of particles takes place which result in the settlement of the structure. The compression of the soil mass takes place due to the imposed stresses (may be almost immediate or time dependent) depending upon the soil's permeability characteristics.

Cohesionless soils are compressed relatively in a short period of time as compared to cohesive soils which are less permeable (Arora, 2004).

The compressibility characteristics of a soil mass might be happen due to any or a combination of the following factors:

- ✓ Compression of solid particle and water in void space,
- ✓ Compression and expulsion of air in void space and
- ✓ Expulsion of water in void space.

A study of the compressibility of soils is extremely necessary for forecast the magnitude and time of settlement of structures on different type of soils. If the settlement is not kept to allowable limit, the desired use of the structure may be afflicted and the design life of the structure may be shortened (Murthy, 2010).

Generally total consolidation of saturated clay strata under excess effective pressure can be divided into three stages:-

- ✓ Initial consolidation
- ✓ Primary consolidation
- ✓ Secondary consolidation

2.8 Review of the Previous Studies

Investigation of soils properties is very essential in providing sufficient data or information and to come up with reliable results that can be used in designing and constructing civil engineering structures. Many investigations are done on soils of Ethiopia.

Dagnachew (2011) has studied about investigation on some of engineering characteristics of soils found in Adama. Based on experimental results of index property test soil under investigation are expansive and expansive and significant variations in the investigated depths as well as in different pits were found. The suitability of soils as construction material is that much not good.

Genet (2013) has studied about investigation into shear strength characteristics of soils in Adama town. Based on experimental results the shear strength parameters of expansive soils ranges from 7.01-7.61kPa in cohesion and 23.16-23.83º in angle of internal friction and non-expansive soils cohesion ranges from 6.65-18.25kPa and angle of internal friction 25.01-32.26º.

Ayenew (2004) has studied about investigation into shear strength characteristics of expansive soil of Ethiopia. Based on experimental results the shear strength of expansive soil ranges from 30-150kPa in cohesion and 3-25 degree in angle of internal frication in UU test on unsaturated soil. For saturated soil sample in UU test the cohesion ranges from 55-94kPa. There is a decrease in strength in saturated samples, which shows that the degree of saturation and the suction pressure can have major influence on the shear strength of expansive soil.

Bezza (2015) has studied about investigation into some of engineering properties of soils found in Ziway town. Based on experimental results the soil under investigation is classified as ML and SM according to USCS. The quality of soils as construction material is fair and good. Direct shear test showed that cohesion ranges from 2.9 to 20.2kPa and angle of internal friction ranges from 24.9 to 28.4º.

Samuel (1989) has studied about investigation in to some of engineering properties of Addis Ababa red clay soils. Based on experimental results from 13 samples around Kolfe, Rufael and Semen Gebeya areas he found out the depth of red clay soil in Addis Ababa ranges from few centimeters to about 10 meters. In the area covered by the study, however, the thickness of the soil is found to be one and half meter in Semen Gebeya and Rufael areas and more than 3m in Kolfe area and finally index property test result indicates the soil is not potentially expansive.

The soils of Ambo town are highly plastic. Black and gray soils have higher plasticity index than reddish brown and brown soils. Grain size analysis shows that the predominant proportion of the soils is clay size fraction. According to AASHTO soil classification system soils of Ambo town are grouped in A-7-5. This indicates that they have poor quality and unsuitable for using as a sub grade material. The consistency of Ambo soils in dry season is found to be stiff to hard as the UCS ranges from 112kPa -545kPa (Behaylu, 2014).

Chapter Three

General Description of the Study Area

3.1 General

Wolenchity (also transliterated Wolenchite and Aulancheti) is town in east-central Ethiopia and the principal town in Boset Woreda of Oromia located in the Rift Valley and along the busy Addis Ababa-Djibouti road (fig. 3.1). The old and newly reconstructed railway was also passing through the town. This town has a longitude 39º 26′E (39.433E), latitude of 8º 40′N (8.66ºN) and elevation of 1435 meters above mean sea level. It is around 25 km and 125 km from Adama and Addis Ababa, respectively. The town also holds Saturday livestock market.

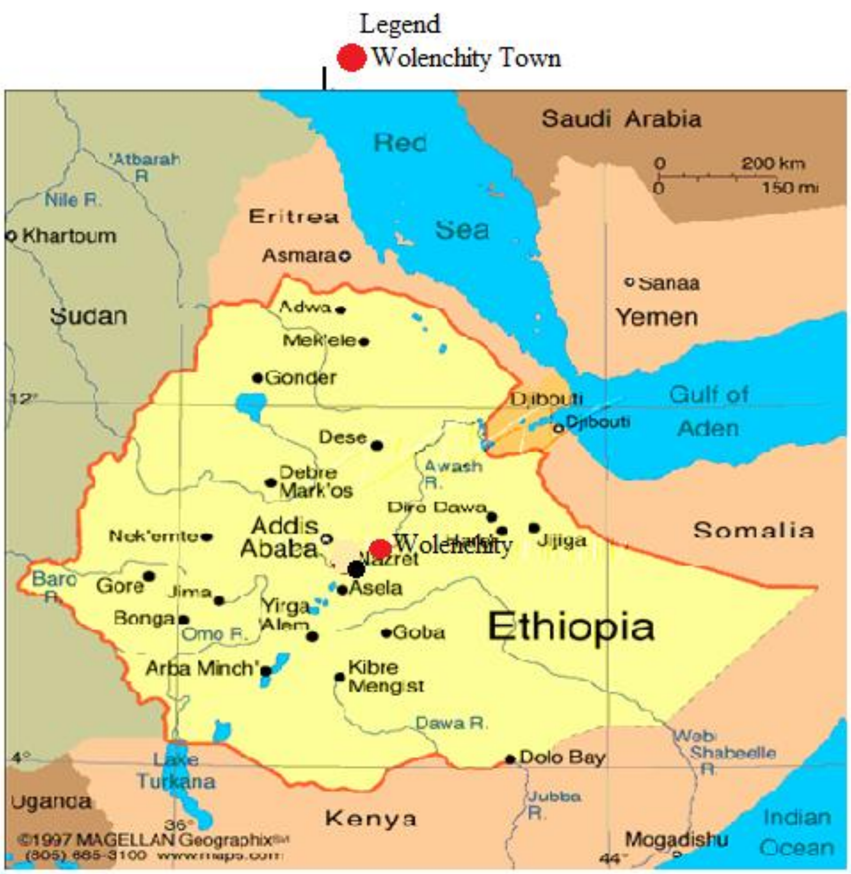


Fig. 3.1 Map and Location of the Study Area

Wolenchity is home to one of 66 congregation of the Emmanuel church, a network of former Ethiopian Orthodox believers who have left the church due to unresolved questions or issues over traditional practices, which has received support of Meserete Kristos College.

The Woreda has an estimated urban population of 37,142 (fraction of CSA population projections to July 2014). The town has two kebeles (named 01 and 02).

Urban livelihoods are diverse with around a third (36%) still dependent on farming, informal or formal business and trade sustaining a further third (34%) and day laboring and formal employment also significant. According to the baseline survey the average annual household income is 10,885 Birr.

3.2 Geology and Geomorphology of the Study Area

The Ethiopian rift system which is part of the East African Rift System may be subdivided into three main sections. There are: the south western rift zone, the main Ethiopian rift, and Afar. The Wolenchity area is an extensive flat plain in the north Main Ethiopian Rift bounded by Western highland escarpment to the north and volcanic mountains to the south. It is situated between 39^0 14’ 57” to 39^0 33’ 16” East and 8^o27’ 37” to 8^0 48’ 18.85” North covering a total area of 780 km^2.

The study area is affected with tectonic structures. Normal faults, fracture zones, volcanic domes and flows are dominantly found. In the study area there are three major faults. One strike NNE-SSW to the west and east of the area and sub-parallel faults west of Wolenchity confines the lacustrine sediment in both sides striking NNW-SSE direction. The lacustrine sediments are also bounded to the north by minor faults striking NE-SW direction across the major NNW-SSE faults. The graven covered with lacustrine sediments is dissected by several NNE-SSW striking faults in to blocks between 100 and 700m in width. The throws of the faults range up to about 50m.

3.3 Topography and Drainage Conditions

The altitude of Wolenchity town varies from about 500m to 1500m above mean sea level. The only perennial river in the vicinity of Wolenchity is Awash River into which all the streams in the town join.

3.4 Climate

3.4.1. Rainfall

The records of National Meteorological Agency from Eastern and Central Oromia Metrological Service Center show that the mean annual rainfall for eleven years i.e. from 2007 to 2016 is 819.009mm. As shown in Fig 3.2, the rainy season is only in months of July and August.

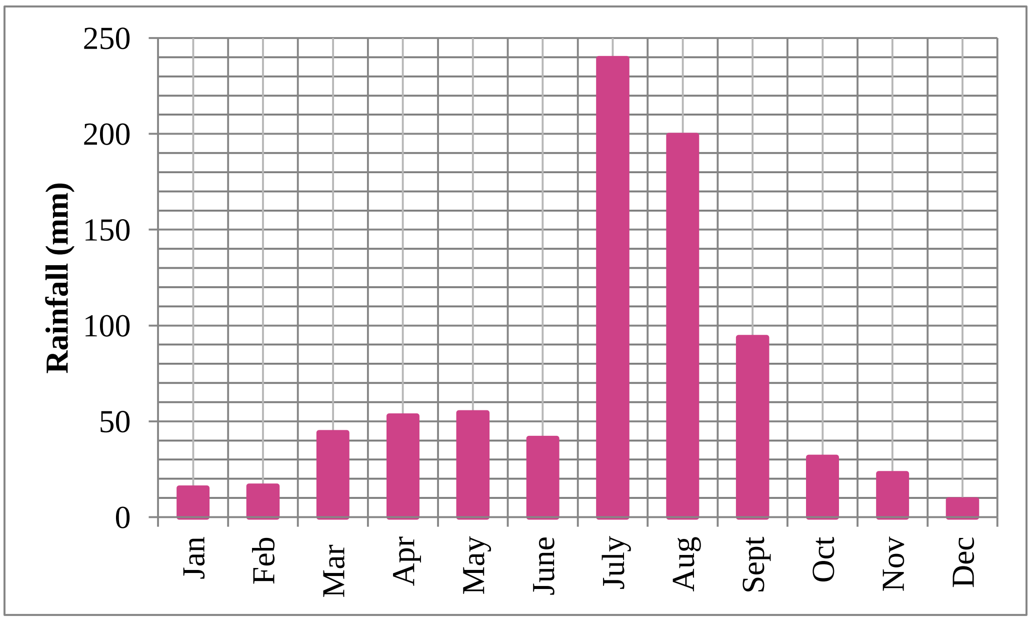


Fig. 3.2 Mean Monthly Rainfall of Wolenchity Town for 11 Years

3.4.2. Temperature

In a mountainous tropical country like Ethiopia distribution of both temperature and rainfall is affected and controlled by altitude.

Generally, regions between 1500-2300 meters a.m.s.l. categorized as ('woina dega' or sub tropical climate) have temperatures that range between 15 - 20^{o}C, areas between 500-1500 meters a.m.s.l. categorized as ('kola' or tropical climate) have 20-30^{o}C temperature and areas below 500 meters a.m.s.l. categorized as ('bereha' or desert climate) have a temperature of 30^{o}C and above (Dagnachew, 2011).

The town of Wolenchity is categorized as kola or tropical climate to woina-dega or subtropical climate, with an altitude ranging from 500-1500meters a.m.s.l., has a mean minimum, mean maximum and mean average monthly temperatures of 12.48°C, 24.44°C and 18.37°C respectively. From Fig.3.3 the highest temperatures are during months of April, May, September, October and November where as January, February, March and December have low temperature. From Fig.3.4 the mean monthly average temperature ranges from 11.83°C to 24.91°C.

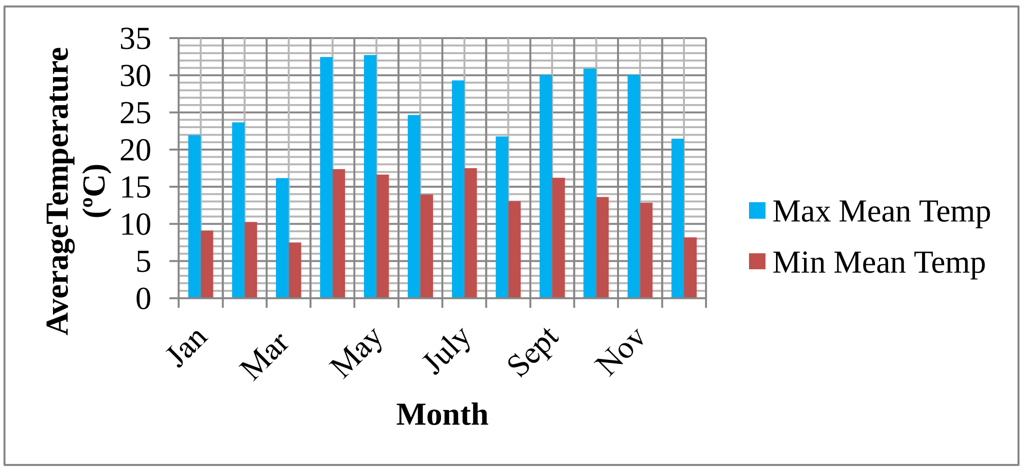


Fig. 3.3 Average Monthly Maximum and Minimum Temperature of Wolenchity Town for 4 Years

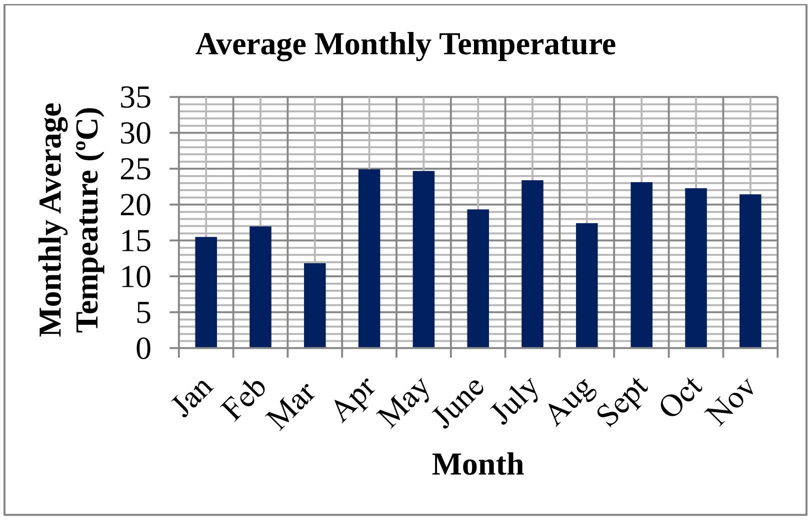


Fig. 3.4 Monthly Average Temperature of Wolenchity Town for 4 Years

Chapter Four

In-situ Properties and Laboratory Test Results and Discussions

4.1 General Identification of the Soil in the Study Area

The representative soil samples for this thesis work were collected from Wolenchity town. To select the sampling areas and collecting representative samples, discussion was made on topographic map of the town with explanation from concerned municipality staffs for possible variation on soil types, visual site investigation and information from resident, and construction firms were also collected to consider the different soil types and to take sample evenly in the whole town. Accordingly, sixteen samples from eight representative sampling areas (fig. 4.1) were selected from various locations of the town as site investigation around the town confirmed. The representative samples from selected eight sampling areas were considered enough for the town to investigate its index and engineering properties. Pits were excavated to the maximum depth of three meters. The global coordinates of sampling location of the town is determined and presented in the following table.

Table 4.1: Global Coordinates of Sampling Areas

TP	Location	Northing (m)	Easting (m)	Elevation (m)
TP-1	Genet Sefer Around Hewariyat Church	957653	547910	1445
TP-2	Harar Beri Around Sifan Hotel	958196	548826	1468
TP-3	Wolenchity City Administration	957363	547460	1456
TP-4	Digelu Gebere Mehber	957189	546887	1404
TP-5	Kehadid Belay Around Hamecha	957709	547327	1458
TP-6	Addisu Sefer Around Hospital	957936	548228	1449
TP-7	Shawa Beri Around World Vision	956670	546766	1415
TP-8	Ethio-Telecom Area Around Turufat Hotel	957269	547407	1468

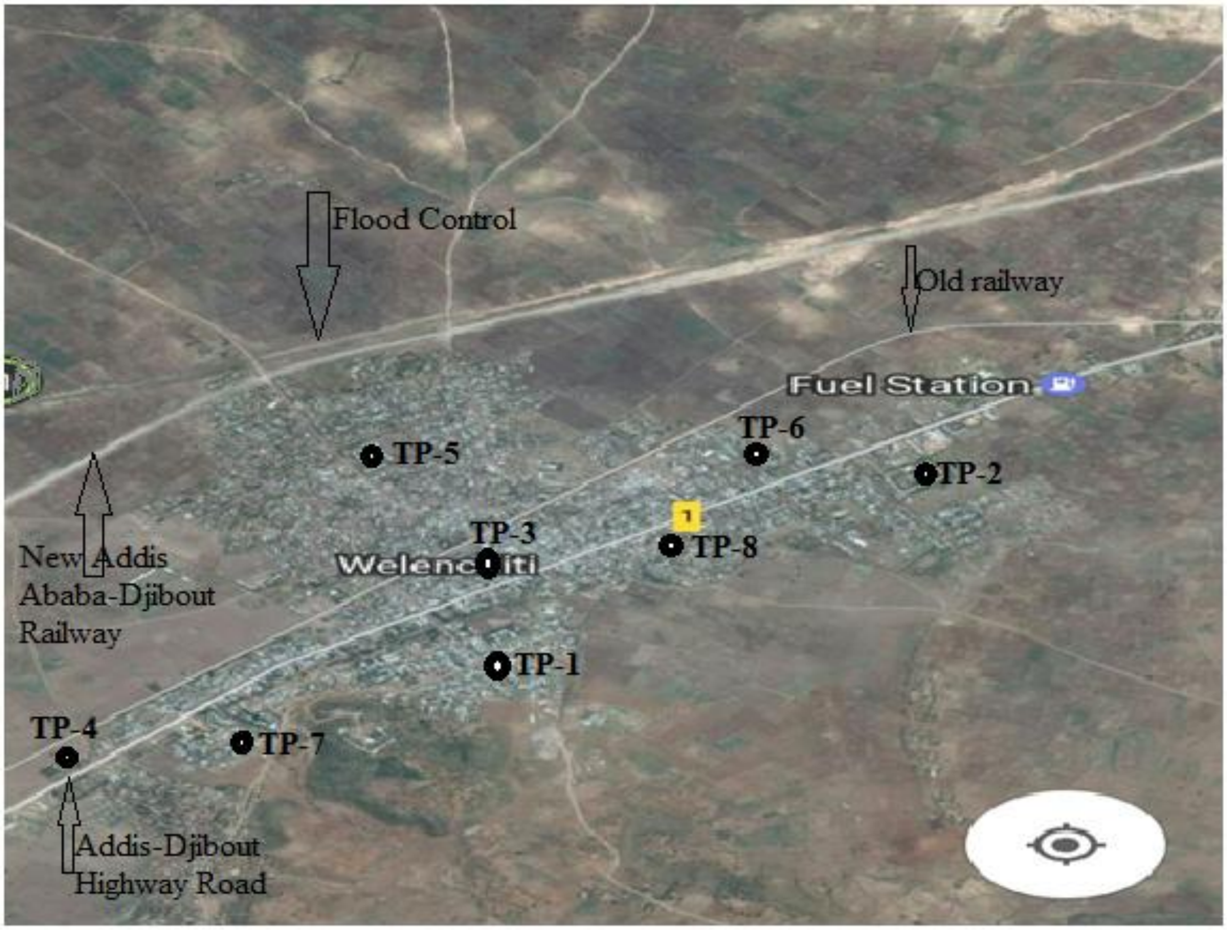


Fig. 4.1 Sampling Area Location Shown on the Map of Wolenchity Town

4.2 Index Properties

Index Properties are the properties of soil which help engineers to indicate the engineering characteristics of a soil and which assist in determining its classification accurately. It provides sufficient information about properties of soil for a proper evaluation of the suitability of soil for use as; support for structure constructed on and in it or construction material (Venkatramaiah, 2006).

Basic soil properties and parameters can be grouped into three categories. These are physical, index, and engineering properties. Physical soil properties include particle size and distribution, specific gravity, and water content. Index parameters of cohesive soils include liquid limit, plastic limit, shrinkage limit, and activity. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties (Adem, 2014).

4.2.1 Natural Moisture Content

The natural moisture contents of the soil in the study area were determined by following ASTM D2216-98 procedures. Since it was difficult to bring undisturbed samples to the laboratory, this test was done at the field by taking a balance to the field. Then after sample were collected and the natural moisture content was immediately determined (Dagnachew, 2011).

The natural moisture content of the soil of the study area is presented in the table 4.2. It ranges from 11.72 - 33.58%. The result shows that; the natural moisture content varies from 20 – 30% for sandy silt; 21 – 34% for low plastic silts and is 12% for well and poorly graded sand.

Table 4.2: Natural Moisture Content Results of the Study Area

Test Pit	Depth (m)	Natural Water Content (%)
1	1.5	30.21
	3	12.43
2	1.5	24.43
	3	28.18
3	1.5	33.58
	3	30.12
4	1.5	29.26
	3	28.65
5	1.5	21.28
	3	22.34
6	1.5	25.59
	3	20.45
7	1.5	26.18
	3	11.72
8	1.5	32.41
	3	23.71

4.2.2 Specific Gravity

The specific gravity of soil solids are determined by following ASTM D 854-02 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer (ASTM, 2004).

The specific gravity of the studied soils is summarized in the following table 4.3. The specific gravity of the soil under study area is 2.60 to 2.70. The result (table 4.3) shows that the well and poorly graded sandy soils have 2.64 – 2.67, low plastic silts have 2.60 – 2.69 and sandy silt have 2.64 – 2.68.

Table 4.3: Specific Gravity Test Result for the Study Area

Test Pit	Depth (m)	Specific Gravity	Water Used For Testing
1	1.5	2.70	Tap Water
	3	2.67	"
2	1.5	2.64	"
	3	2.68	"
3	1.5	2.66	"
	3	2.67	"
4	1.5	2.60	"
	3	2.65	"
5	1.5	2.67	"
	3	2.66	"
6	1.5	2.69	"
	3	2.68	"
7	1.5	2.69	"
	3	2.64	"
8	1.5	2.61	"
	3	2.67	"

4.2.3 Grain Size Analysis

Two methods were used to determine the particle-size distribution of the soil samples: sieve analysis, for particle sizes larger than 0.075 mm (No. 200) in diameter; and hydrometer analysis for particle-sizes smaller than 0.075 mm in diameter. During hydrometer analysis sodium hexametaphosphate (NaPO3) or Calgon was used as a dispersion agent, and all analysis was determined based on ASTM (D 421 & 422) procedure. The diameter range is adopted from ASTM as follows: >4.75 mm gravel; 4.75 – 0.075 mm sand; 0.075 – 0.002 mm silt and < 0.002 mm clay (ASTM, 2004).

The grain size analysis is summarized in the table 4.4 and figure 4.2 and 4.3. The result shows that study area have clay content ranges from 0.92 to 18.58%, silt fraction ranging from 3.08 to 59.14%, sand fraction ranging from 31.4 to 78.9% and gravel fraction ranging from 0.3 to 28.8%. The dominant proportions of the soils of the study area are sandy soil for eight samples and two samples at depth of 3m and 1.5m respectively and silty soil for six samples at depth of 1.5m.

Table 4.4: Grain Size Analysis of the Study Area

Test Pit	Depth (m)	Percent amount of particle size			
		Gravel (%)	Sand (%)	Silty (%)	Clay (%)
1	1.5	1.2	78.9	12.61	7.29
	3	24.3	70.8	3.63	1.27
2	1.5	0.8	32.7	53.11	13.39
	3	1	56.8	32.93	9.27
3	1.5	2	32.3	59.14	6.56
	3	7.1	62.4	27.07	3.43
4	1.5	0.5	32.1	48.82	18.58
	3	2.5	52.7	28.67	16.13
5	1.5	3.1	36.2	43.17	17.53
	3	7.3	61.4	23.51	7.79
6	1.5	0.7	40.8	43.41	15.09
	3	5.4	49.1	41.87	3.63
7	1.5	15.4	49.2	28.03	7.37
	3	28.8	67.2	3.08	0.92
8	1.5	0.3	31.4	56.60	11.70
	3	6.3	49.1	38.83	5.77

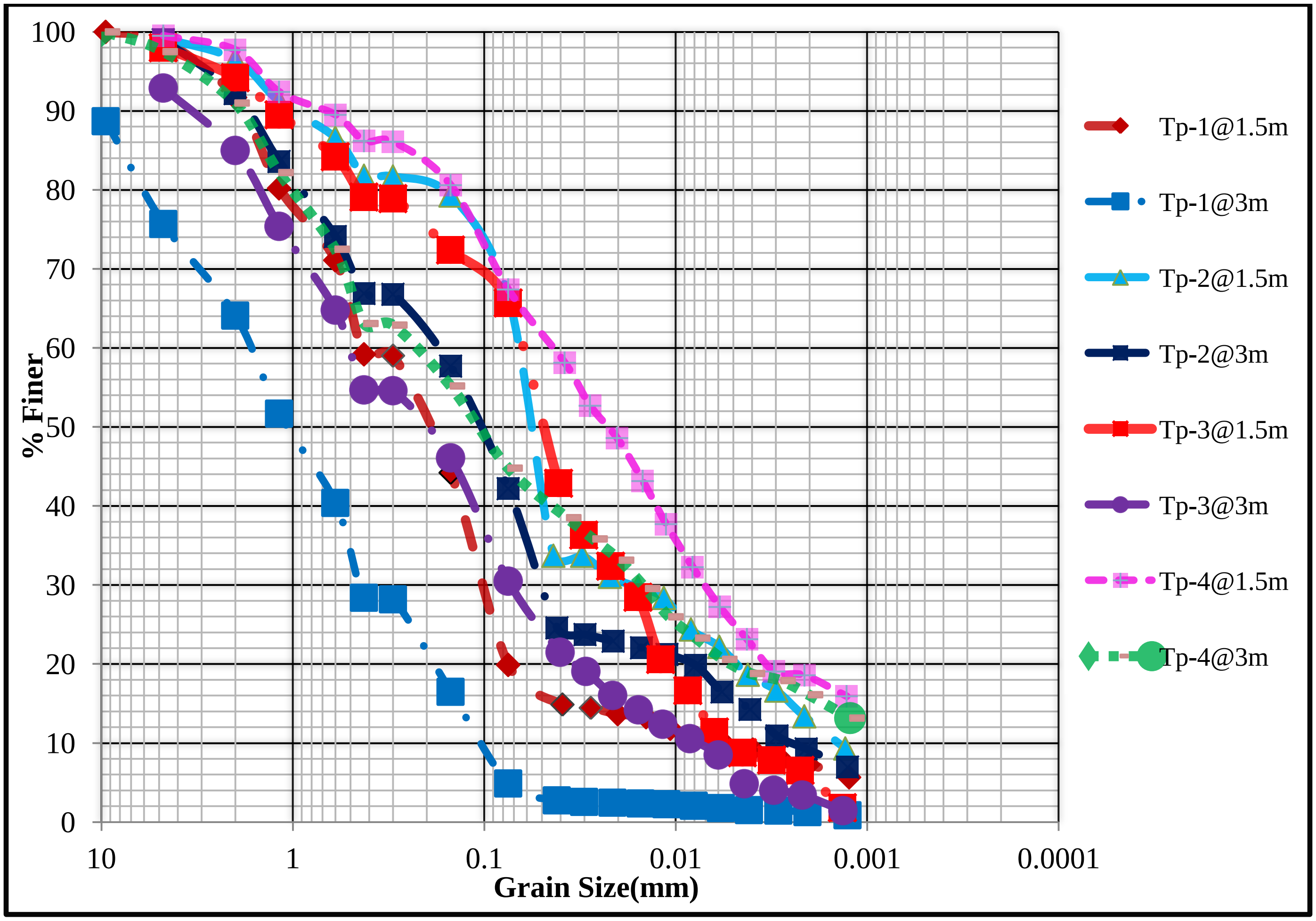


Fig. 4.2 Combined Grain Size Analysis of the Study Area for TP-1 to TP-4

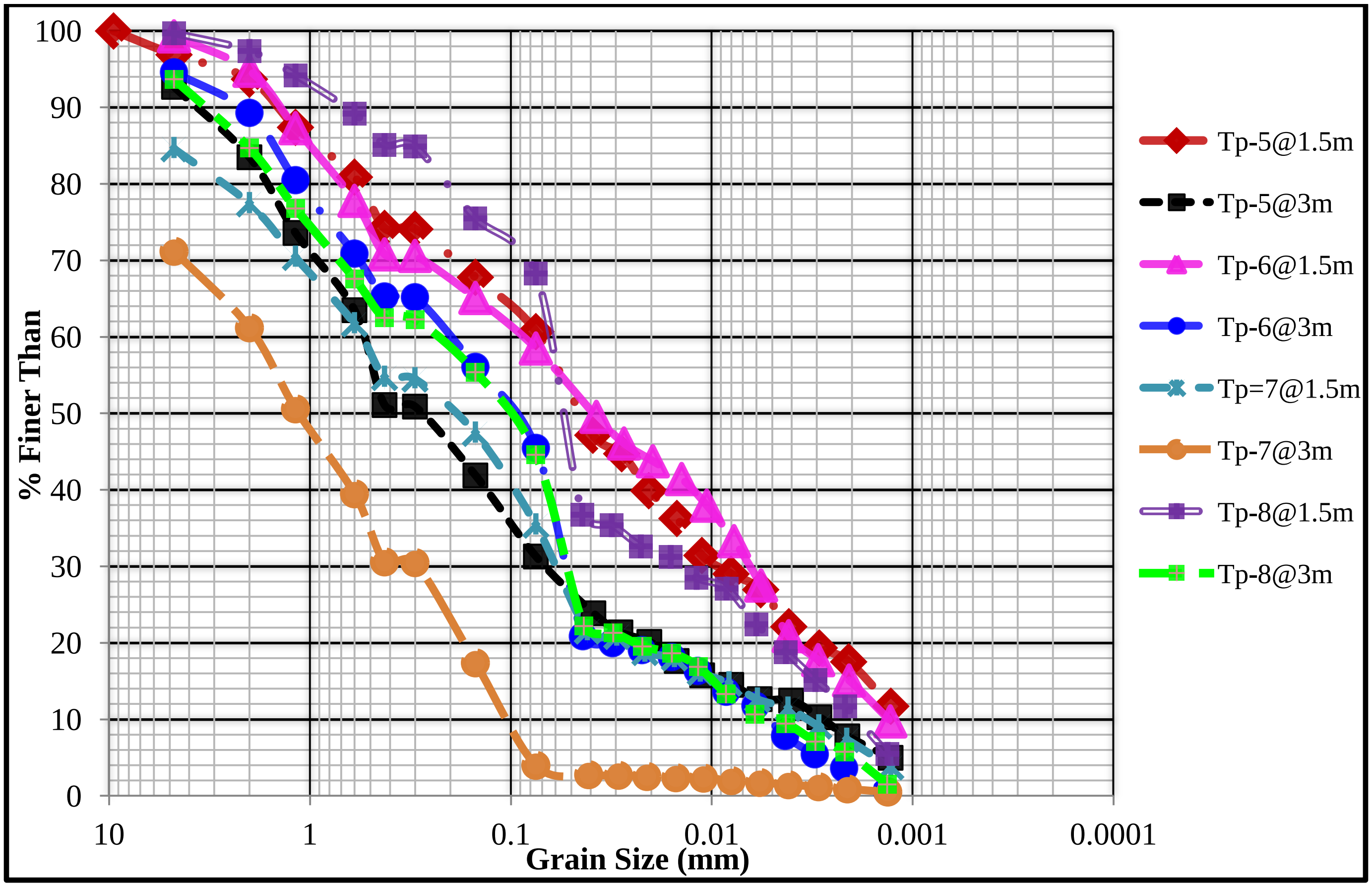


Fig. 4.3 Combined Grain Size Analysis of the Study Area for TP-5 to TP-8

4.2.4 Atterberg Limit

The Atterberg limit of soil samples was determined in the laboratory based on ASTM D 4318-98 (Table 4.5). The well and poorly graded sandy soil is non-plastic, low plastic silts have LL: 35 to 49%, and silty sand soil LL: 25 to 33%. The PL ranges from 26.11 to 34.85%, 22.56 to 28.28% and NP for low plastic silt, sandy silt, and well and poorly graded sand respectively. Most of the soils of the study area fall in intermediate plasticity type, except some of the silty sand soils which fall in soils of low plasticity type. The PI of silty sand ranges from 3.15 to 8.89%, low plastic silt 8.83 to 15% and NP for well and poorly graded sand. In general, most of the plasticity values of the soils of the town fall in the low plastic range (3.15-15%).

Table 4.5**:** Atterberg Limit of the Study Area

Test Pit	Depth(m)	LL (%)	PL (%)	PI (%)
1	1.5	26	22.56	3.44
	3	NP	NP	NP
2	1.5	35	26.11	8.89
	3	31	25	6
3	1.5	49	34.85	14.15
	3	30.5	24.01	6.49
4	1.5	45	30	15
	3	25	21.85	3.15
5	1.5	37	26.11	10.89
	3	33	25.15	7.85
6	1.5	38	29.17	8.83
	3	34	28.28	5.72
7	1.5	30	26.67	3.33
	3	NP	NP	NP
8	1.5	43	29.05	13.95
	3	28	23.61	4.39

4.2.5 Free Swell

Free swell results the studied soils are summarized in the table 4.6 below. From the table free swell of the soils of the Wolenchity town ranges from 0 to 25%. Those soils having a free swell less than 50% are considered as non-expansive, soils having a free swell between 50% and 100% are marginal and those having more than 100% are expansive soils. Therefore a soil under the study area is non-expansive due to less amount of clay contents and don't pose significant damage on light weight engineering structures.

Table 4.6: Free Swell Test Results of the Study Area

Test Pit	Depth (m)	Free Swell (%)	Water Used for Testing
1	1.5	8	Tap Water
	3	0	Tap Water
2	1.5	14	Tap Water
	3	12	"
3	1.5	7	"
	3	4	"
4	1.5	25	"
	3	21	"
5	1.5	23	"
	3	10	"
6	1.5	18	"
	3	4	"
7	1.5	8	"
	3	0	"
8	1.5	14	"
	3	7	"

4.3 Classification of the Soils under Study Area

4.3.1 Unified Soil Classification Systems (USCS)

According to unified soil classification system as shown in table 4.7 below four soil types were identified in the study area: SM (Sandy silt), ML (Low plastic silt), SW (well-graded sand) and SP (poorly graded sand). For TP-1 and TP-7 at 3m to determine whether the soil is well graded or poorly graded soil; the coefficient of uniformity (Cu) and coefficient of gradation (Cc) is determined from grain size distribution curve. If $C_u \geq 6$, $1 \leq C_c \leq 3$, $F_{200} < 5\%$ and $GF < 15$ the soil is well graded sand (SW). If $Cu < 6$ and/or $1 > Cc > 3$, $F_{200} < 5\%$ and $GF \geq 15$ the soil is poorly graded sand with Gravel (SP). From the plot of plasticity chart in figure 4.4 the soils found in Wolenchity town lies below is A-line; which categorized as low plastic silt and silty sand.

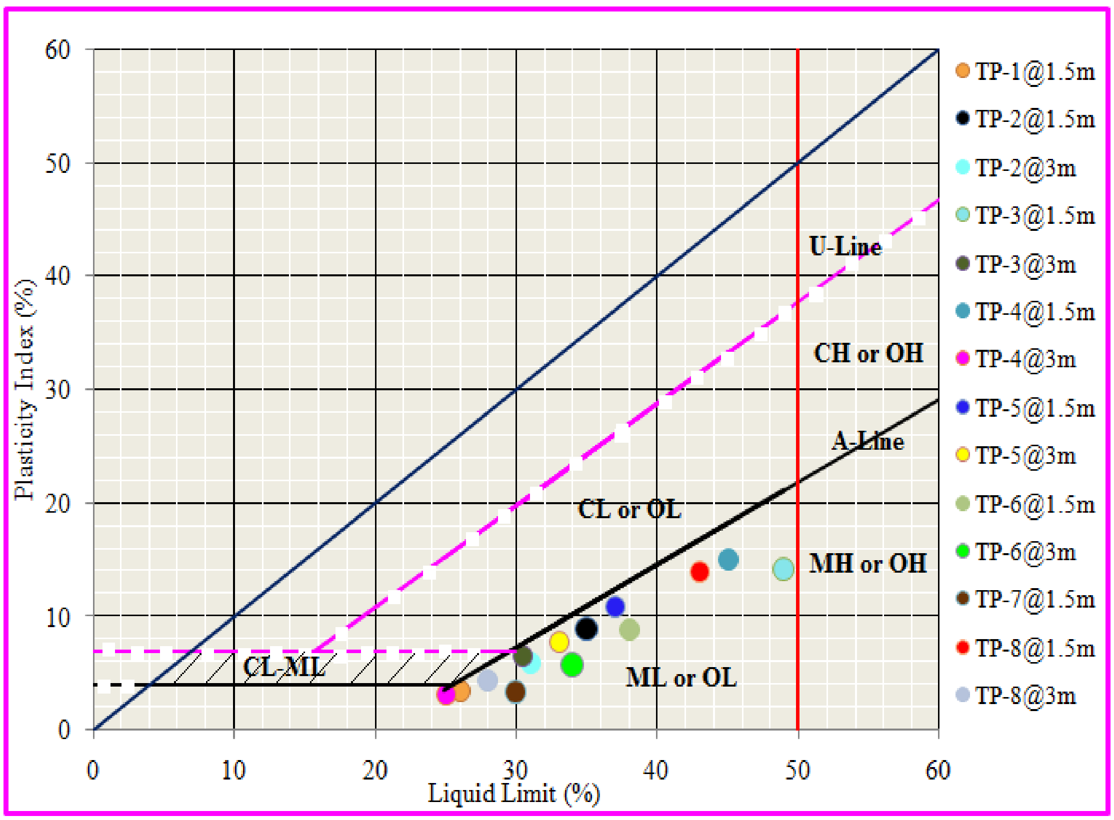


Fig. 4.4 Plasticity Chart of the Study Area According to Unified Soil Classification System

Table 4.7: USCS Classification of the Soil in the Study Area

Test Pit	Depth (m)	Gravel (%)	Sand (%)	Silty (%)	Clay (%)	LL (%)	PL (%)	PI (%)	Soil Type
1	1.5	1.2	78.9	12.61	7.29	26	22.56	3.44	SM
	3	24.3	70.8	3.63	1.27	NP	NP	NP	SW
2	1.5	0.8	32.7	53.11	13.39	35	26.11	8.89	ML
	3	1	56.8	32.93	9.27	31	25	6	SM
3	1.5	2	32.3	59.14	6.56	49	34.85	14.15	ML
	3	7.1	62.4	27.07	3.43	30.5	24.01	6.49	SM
4	1.5	0.5	32.1	48.82	18.58	45	30	15	ML
	3	2.5	52.7	28.67	16.13	25	21.85	3.15	SM
5	1.5	3.1	36.2	43.17	17.53	37	26.11	10.89	ML
	3	7.3	61.4	23.51	7.79	33	25.15	7.85	SM
6	1.5	0.7	40.8	43.41	15.09	38	29.17	8.83	ML
	3	5.4	49.1	41.87	3.63	34	28.28	5.72	SM
7	1.5	15.4	49.2	28.03	7.37	30	26.67	3.33	SM
	3	28.8	67.2	3.08	0.92	NP	NP	NP	SP
8	1.5	0.3	31.4	56.60	11.70	43	29.05	13.95	ML
	3	6.3	49.1	38.83	5.77	28	23.61	4.39	SM

TP	Depth (m)	C_u	C_c	F_{200}	GF	Soil Type
1	3	15.45	1.08	4.9	11	SW
7	3	20	0.8	4	18	SP

4.3.2 American Association of State Highway and Transport Officials (AASHTO) Classification System

According to AASHTO soil classification system table 4.8 and fig. 4.5, the soil of the study area is classified as A-2-4, A-3, A-4, A-6, A-7-5 and A-7-6. The quality of materials rated from fair to poor (for A-4, A-6, A-7-5 and A-7-6) and excellent to good (for A-2-4 and A-3) as sub grade material. The LL of A-6, A-7-5 and A-7-6 soil is 37%, 45-49% and 43% respectively. This shows the soil is medium compressible i.e. LL values fall in a range of 30-50% which medium compressible soil. The plasticity index of this soil is greater than 10%; so the plasticity of soil shows the fall in medium plastic i.e. the property of clay soil. Generally A-6, A-7-5 and A-7-6 soil is grouped as clayey soil according to AASHTO classification system based on its percent finer than No.200 and Atterberg limit (LL and PI) values.

Table 4.8: AASHTO Classification of the Soil of the Study Area

TP	Depth (m)	Percent Passing			LL (%)	PI (%)	GI	Group Classification	Subgrade Rating
		#10	#40	#200					
1	1.5	91.7	59.2	20	26	3.44	0	A-2-4	Excellent to Good
	3	64.1	28.4	5	NP	NP	0	A-3	Excellent to Good
2	1.5	96.5	81.8	67	35	8.89	5	A-4	Fair to Poor
	3	92.2	66.9	42	31	6	0	A-4	Fair to Poor
3	1.5	94.2	79.1	66	49	14.15	10	A-7-5	Fair to Poor
	3	85	54.7	31	30.5	6.49	0	A-2-4	Excellent to Good
4	1.5	97.7	86.2	67	45	15	10	A-7-5	Fair to Poor
	3	91	63.1	45	25	3.15	0	A-4	Fair to Poor
5	1.5	93.7	74.2	61	37	10.89	5	A-6	Fair to Poor
	3	83.5	51.1	31	33	7.85	0	A-2-4	Excellent to Good
6	1.5	94.8	70.8	59	38	8.83	4	A-4	Fair to Poor
	3	89.3	65.3	46	34	5.72	0	A-4	Fair to Poor
7	1.5	77.4	54.7	35	30	3.33	0	A-2-4	Excellent to Good
	3	61.2	30.6	4	NP	NP	0	A-3	Excellent to Good
8	1.5	97.4	85.1	68	43	13.95	9	A-7-6	Fair to Poor
	3	84.7	62.5	45	28	4.39	0	A-4	Fair to Poor

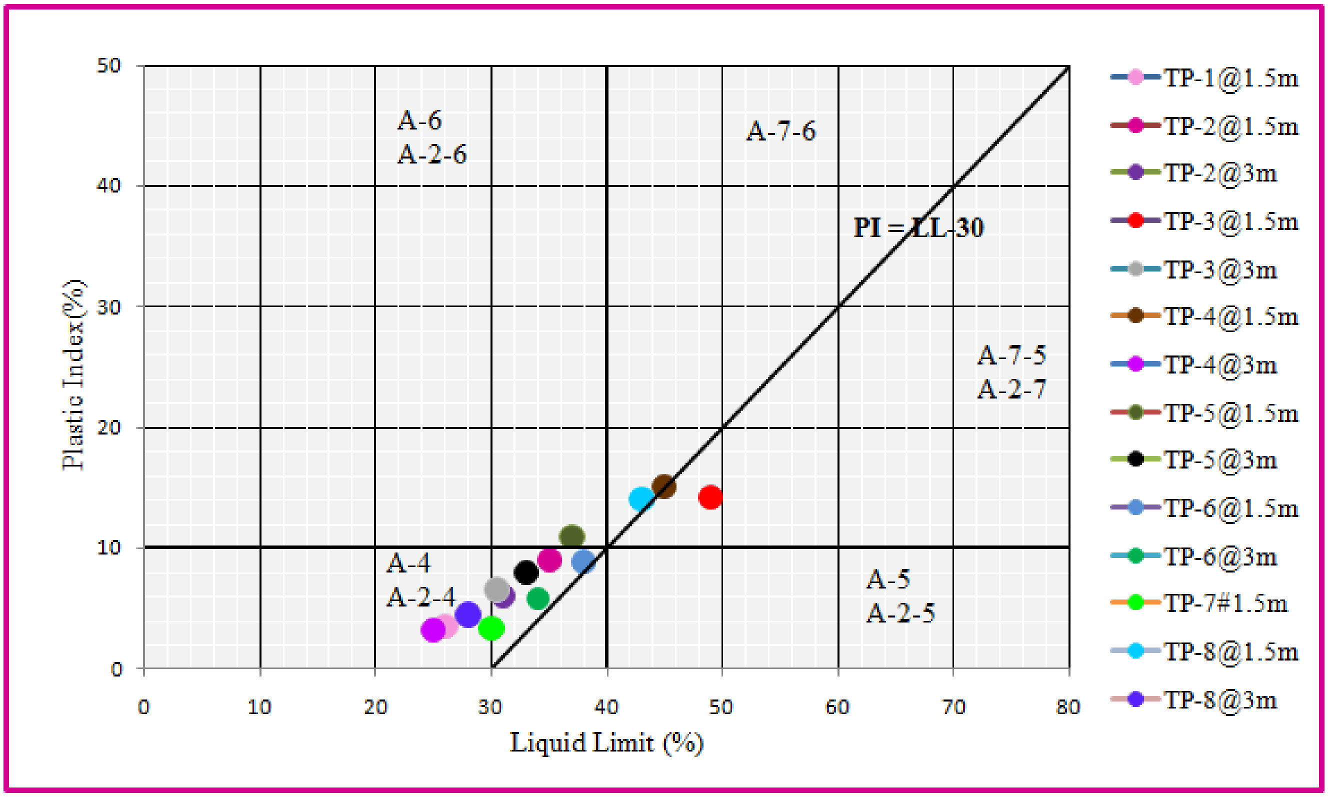


Fig. 4.5: Plasticity Chart of the Study Area According to AASHTO Classification System

4.4 Compaction of the Soils

4.4.1 General

The optimum moisture content and maximum dry density of soil under investigation is determined by laboratory standard proctor compaction test according to ASTM D698. The soil is compacted by a 24.4N hammer falling a distance of 0.305meters (1 foot) into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer (Krishna, 2002).

The values of optimum moisture contents and maximum dry density of the studied soils have been summarized in table 4.9.From the test results the maximum dry density (MDD) of soils of Wolenchity town ranges from 1.3 to 1.6g/cm^3 and the optimum moisture (OMC) content ranges from 17.5 to 31%. Therefore soil rich in fine fraction (ML and SM) shows poor compaction characteristics compared to well and poorly graded sand.

Table 4.9: Compaction Test Results of the Study Area

Test Pit	**Depth (m)**	**OMC (%)**	**MDD (g/cm^3)**
1	1.5	17.6	1.54
	3	17.5	1.6
2	1.5	31	1.35
	3	17.8	1.58
3	1.5	21.5	1.42
	3	17.5	1.53
4	1.5	23	1.3
	3	19	1.46
5	1.5	26	1.35
	3	20	1.49
6	1.5	22	1.39
	3	18.5	1.53
7	1.5	21.5	1.56
	3	18	1.57
8	1.5	27	1.33
	3	18	1.51

4.5 Shear Strength of Soil

Direct shear test of soil under study area in laboratory is performed according to ASTM D 3080. The results of the shear strength parameters of the study area is summarized in table 4.10.The results of the direct shear test showed that cohesion ranges from 1.41 to 15.95kPa and angle of internal friction ranges from 21.5 to 30.7 degree. The result show that; the latter is a function of fine fraction (clay content), while the former is relatively higher for sandy soils. The soil of the study area has lower cohesion and binding force due to less amount of clay content, so that the soil is vulnerable to erosion. But the soil withstands the heavy stress from the structures.

Table 4.10: Shear Strength Parameters Results of Soil of the Study Area

Test Pit	**Depth (m)**	**C (kPa)**	**ϕ (^{0})**
1	3	3.08	28.7
2	3	15.95	25.3
3	3	14.92	30.7
4	3	8.63	26.98
5	3	11.95	26.9
6	3	10.1	27.2
7	3	1.41	28.6
8	3	15.71	21.5

4.6 One Dimensional Consolidation

4.6.1 Preconsolidation Pressure (P_c)

A soil at the field may have been pre-consolidated during the geologic past by tectonic force, or desiccation of clay deposit, or the weight of an ice which has melted away, or by other geologic overburden and or building loads which no longer exist. The practical significance of the pre-consolidation load appears in calculating settlements of structures.

Several methods have been proposed for determining the value of the maximum consolidation pressure. These are field method which are based on geological evidence and graphical methods for determining the pre-consolidation pressure based on laboratory test data. The earliest and the most widely used method was the one proposed by Casagrande (1936). The method involves locating the point of maximum curvature, B, on the laboratory e-log *p* curve of an undisturbed sample as shown in Fig. 4.6. From *B*, a tangent is drawn to the curve and a horizontal line is also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure P_c (Murthy, 2010).

The soil under investigation has pre-consolidation (Pc) ranging from 65 to 100kPa which is greater than present effective over-burden pressure (Po) that ranging from 26.75 to 35.62kPa. The ratio of pre-consolidation pressure to present effective over-burden pressure ranges from 2.07 to 2.81. The result of ratio of pre-consolidation pressure to present effective over-burden pressure shows that; the soil of study area is over-consolidated soil. And also the void space between soil decreases with increasing applied pressure, rate of consolidation is quickly happened.

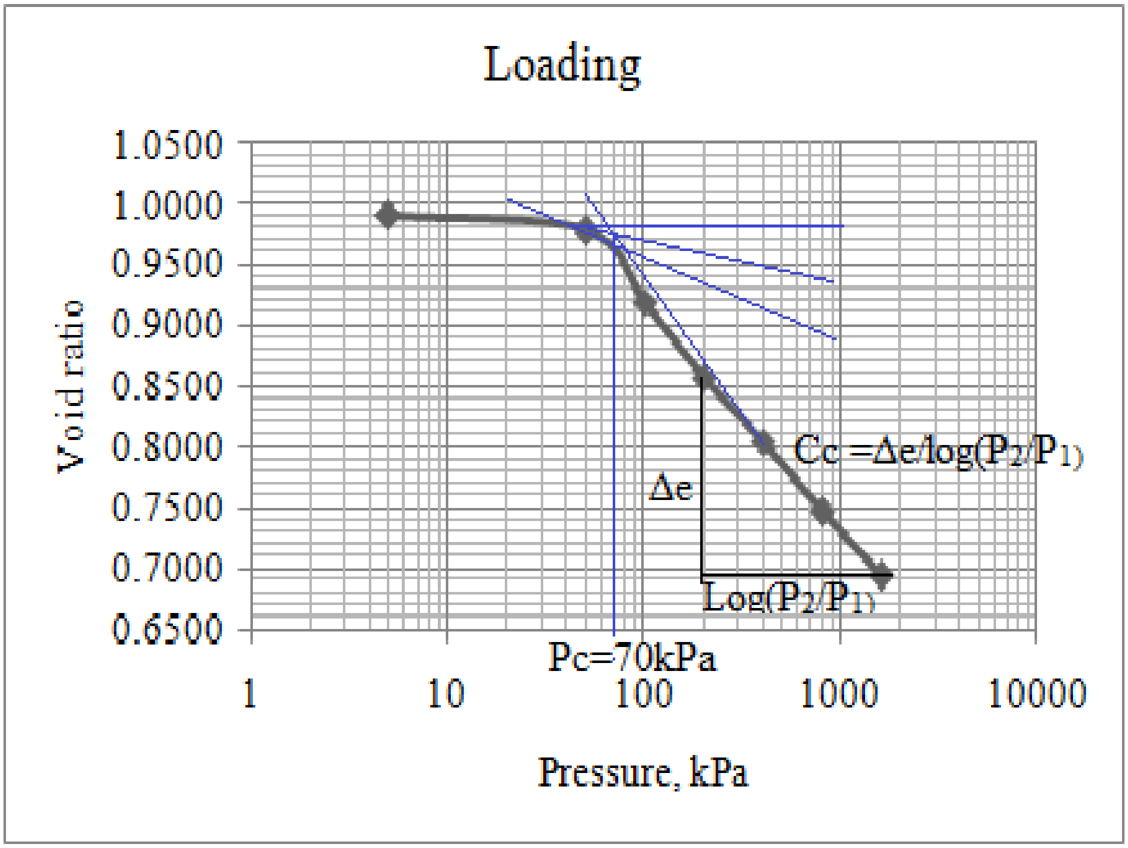


Fig. 4.6 Typical Void-ratio Vs Pressure (log-scale) Curve to Determine Pc and C_c for TP-4

Table 4.11: Pre-consolidation Pressure Results of the Study Area

TP	Depth, m	Pressure, kPa	Void Ratio	Compression Index (C_c)	Preconsolidation Pressure (P_c), kPa	Over-burden Pressure (P_o), kPa	OCR
4	1.5	5	0.9893	0.18	70	33.78	2.07
		50	0.9774				
		100	0.9185				
		200	0.8576				
		400	0.8042				
		800	0.7458				
		1600	0.6940				
5	1.5	5	0.8181	0.22	100	35.62	2.81
		50	0.7523				
		100	0.7011				
		200	0.6484				
		400	0.5960				
		800	0.5325				
		1600	0.4744				
6	1.5	5	0.8173	0.17	65	26.75	2.43
		50	0.7437				
		100	0.6779				
		200	0.6157				
		400	0.5610				
		800	0.5135				
		1600	0.4640				

4.6.2 Coefficient of consolidation (Cv)

The Coefficient of Consolidation is a parameter used to describe the rate at which saturated clay or other soil undergoes consolidation when subjected to an increase in pressure.

There are two alternative methods that are in common use for the determination of C_v. They are: Casagrande logarithm of time fitting method and Taylor square root of time fitting method. Taylor square root of time fitting method is more convenient for general case. The fitting method consists of first drawing the straight line which best fits the early portion of the laboratory curve. Next a straight line is drawn which at all points has abscissa 1.15 times as great as those of the first line. The intersection of this line and the laboratory curve is taken as 90% consolidation point. Its value (Fig 7.6) may be read and is designated as t_{90}.

$$\mathrm{Cv} = \frac{0.848\mathrm{Hd}r^2}{\mathrm{t}90} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

Where H_{dr}^2- drainage path determined from $H_{av}/2 = (H_o+H_f)/4$

The C_v of soils of the study area is ranging from 0.023 to 0.132cm/min as summarized in table 4.12. The result shows Cv is increasing and decreasing with increasing applied due to unknown clay minerals. It increases with consolidation pressure for kaolinites but decreases with consolidation pressure for montmorillonite (bentonite).

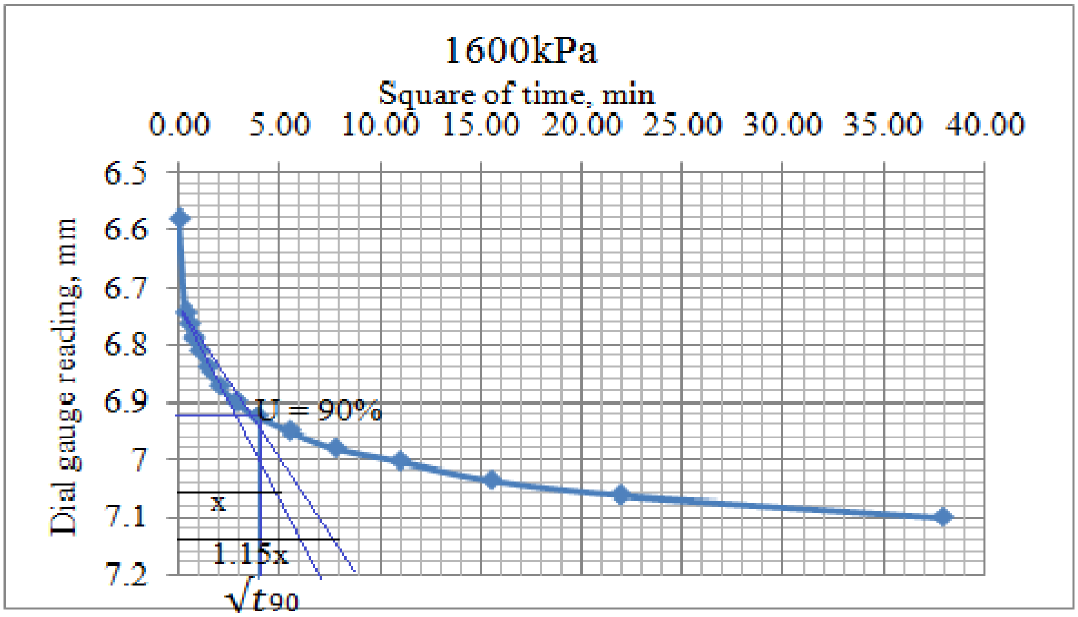


Fig. 4.7 Dial gauge reading Vs Square Root of Time Curve to Determine Cv for TP-4

Table 4.12: Coefficient of Consolidation Results of the Study Area

TP	Depth, m	Pressure, kPa	Void ratio	Coefficient of consolidation (C_v), (cm^2/min)
4	1.5	50	0.9774	0.132
		100	0.9185	0.057
		200	0.8576	0.044
		400	0.8042	0.027
		800	0.7458	0.031
		1600	0.6940	0.023
5	1.5	50	0.7523	0.045
		100	0.7011	0.054
		200	0.6484	0.031
		400	0.5960	0.046
		800	0.5325	0.042
		1600	0.4744	0.038
6	1.5	50	0.7437	0.129
		100	0.6779	0.114
		200	0.6157	0.104
		400	0.5610	0.040
		800	0.5135	0.028
		1600	0.4640	0.029

4.6.3 Coefficient of Permeability

The coefficient of permeability can be measured using field tests, or tests conducted in the laboratory. Permeability is sometimes also estimated from one dimensional consolidation test. The coefficient of permeability can be obtained from the following equation:-

$$k = \frac{Cv * av * \gamma w}{1 + e} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4.2$$

Where: - C_v – coefficient of consolidation, a_v – coefficient of compressibility, e – void ratio and γ_w – unit weight of water. Using equation 4.5 above, the coefficient of permeability as a function of coefficient of consolidation, coefficient of consolidation, unit weight of water and void ratio was calculated for each load increment and shown in Table 4.13 below. It is noted that coefficient of compressibility (a_v) is the ratio of change in void ratio to change in pressure. According to Terzaghi and Peck (1967), the classification of soil according to hydraulic conductivity *k* is as follows:

High degree of permeability, *k* is over 0.1 cm/s, medium degree of permeability, *k* is between 0.1 and 0.001 cm/s, low permeability, *k* is between 0.001 and 1×10^{-5} cm/s, very low permeability, *k* is between 1×10^{-5} and 1×10^{-7} cm/s, Practically impermeable, *k* is less than 1×10^{-7} cm/s. As shown in Table 4.13, the range of coefficient of permeability values of the study area ranging from 0.15×10^{-8} to 18.16×10^{-8} cm/sec, which indicates that the soils are practically impervious or have low permeability due to higher fraction of fine grained soil (Wubshet, 2015). This shows the soil under investigation require long period of time for consolidation due to poor drain of water from the soil of low permeability. And also both coefficient of permeability (k) and coefficient of compressibility (a_v) decreases with increasing consolidation pressure.

Table 4.13: Coefficient of Permeability of the Study Area

Depth, m	Pressure, kPa	Void ratio	Coefficient of compressibility (a_v), 10^{-4} (m^2/kN)	Coefficient of consolidation (C_v), (cm^2/min)	Coefficient of Permeability (k), 10^{-8} (cm/s)
1.5	50	0.9774	-	0.132	-
	100	0.9185	11.80	0.057	5.84
	200	0.8576	6.00	0.044	2.34
	400	0.8042	2.67	0.027	0.67
	800	0.7458	1.46	0.031	0.43
	1600	0.6940	0.65	0.023	0.15
1.5	50	0.7523	-	0.0455	-
	100	0.7011	10.25	0.0544	5.46
	200	0.6484	5.26	0.0308	1.64
	400	0.5960	2.62	0.0462	1.27
	800	0.5325	1.59	0.0417	0.72
	1600	0.4744	0.73	0.0377	0.31
1.5	50	0.7437	-	0.129	-
	100	0.6779	16.00	0.114	18.16
	200	0.6157	6.22	0.104	6.64
	400	0.5610	2.73	0.040	1.17
	800	0.5135	1.19	0.028	0.36
	1600	0.4640	0.62	0.029	0.20

4.7 Comparison with Previously Done Researches

For the soil of study area under investigation; Index property were studied and a comparison was made with others thesis done in different parts of the country. Results of the current research are summarized and compared to with range of values of soils found in Adama, Worabe and Ziway.

A comparison of soil of the study area with other researches done in parts of the country is summarized in the table 4.14 below.

Table 4.14: Index Property Test Results in Different Parts of the Country

	Previous Thesis (Abu, 2007)	Previous Thesis (Dagnachew,2011)	Previous Thesis (Bezza,2015)	Previous Thesis (Abdulfetah,2015)	Current Thesis
Soil Type	Silt and silty sand	Silt &silty sand	Silt, silty sand, silty clay, sand-silt-clay mixtures	Black expansive soils	Silt, silty sand and Sandy
Location	Adama	Adama	Ziway	Worabe	Wolenchity
Clay (%)	14-58	5.4-40.5	0.66-10.93	34.3 – 72.7	0.92-18.54
Silt (%)	14-61	17.6-60.7	17.15-73.03	17.3-54.2	3.08-59.14
Sand (%)	25-56	14.5-54.6	15.16-81.3	4.3-66.7	31.4-78.9
LL (%)	39-49.4	29-73	27-37	49.5 -131	25-49
PL (%)	26-37.4	24-39	23-29	15-49.3	21.85-34.85
PI (%)	10-15.0	5-34.0	4-8.0	15-90	3.15-15
NMC (%)	25-30.5	17.5-36.5	22.6-35.83	22.56-57.51	11.72-33.58
Sp. Gravity	2.61-2.7	2.4-2.7	2.4-2.62	2.65- 2.85	2.60-2.70
Free Swell, %	-	18-50	-	30-145	0-25
MDD (g/cm^3)	1.33-1.53	1.27-1.62	1.22-1.55	-	1.30-1.60
USCS from plasticity chart	ML & SM	SM, ML & MH	SM & ML	MH, CH, CL,SM & SL	ML, SM, SW & SP

Chapter Five

Conclusion and Recommendation

5.1. Conclusion

- ✓ The grain size analysis indicate that the dominant proportion of soil particle in the study area is sand and silt, which has gravel content from 0.3 – 28.8%., sand fraction 31.4 – 78.9%, silt fraction 3.08 – 59.14% and clay content ranging from 0.92 – 18.54%.Four soil types were identified in the study area according to USCS soil classification system: SM (Sandy silt), ML (Low plastic silt), SW (well-graded sand) and SP (poorly graded sand). The natural moisture content varies from 20 – 30% for sandy silt; 21 – 34% for low plastic silts and is 12% for well and poorly graded sand.
- ✓ The liquid limit of the soil varies from 25 – 34% for sandy silt; 35 – 49% for low plastic silt and non-plastic for well and poorly-graded sand. Similarly the plasticity of the soil varies from 3 – 8%; 9 – 15% for low plastic silt and non-plastic both for well and poorly-graded sand. Hence the studied soils are generally non-plastic to low plastic soils. The free swell of the soil of the study area varies from 0 – 25%, indicating that the studied soils are non-expansive and don’t pose significant damage on light weight engineering structures.
- ✓ According to AASHTO soil classification system, the soils of the study area rated as fair to poor (A-4, A-6, A-7-5 and A-7-6) and excellent to good (A-2-4 and A-3) for sub grade material.
- ✓ The optimum moisture content (OMC) and maximum dry density (MDD) of the studied soil ranges from 17.5 – 31% and 1.30 to 1.60 g/cm^3, respectively. The soil rich in fine fraction (ML and SM) shows poor compaction characteristics compared to well and poorly graded sand.
- ✓ The shear strength parameters i.e. cohesion and angle of internal friction vary from 1.4 to 15.95kPa and 21.5 to 30.7° respectively. The latter is a function of fine fraction (clay content), while the former is relatively higher for sandy soils.

- ✓ Finally one-dimensional consolidation shows that the area under investigation is over consolidated in its natural state, have compression index ranging from 0.17 to 0.22, coefficient of consolidation ranging from 0.023 to 0.132 cm^2/min and coefficient of permeability ranging from $0.15x10^{-8}$ to $18.16x10^{-8}$ cm/sec.
- ✓ Generally, the result of the study area indicates that; the soils possess desirable engineering characteristics i.e. low compressibility, good shear strength, low plasticity and less susceptible to shrinkage and swelling with variation of moisture content.

5.2. Recommendation

- ✓ In this research samples of soil were collected only from eight test pits; so the numbers of test pits are not good enough to determine all engineering properties of the town. However, by increasing the number of sampling area in-depth investigation more detail results are obtained.
- ✓ As the area of the study found in earth-quake zone; the dynamic properties of soils with relation to respond of soil to earthquake motion should be studied in future.
- ✓ The Correlation of the index properties of the study area with shear strength parameters may also be done.

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Appendix-A: Index Properties Test Results

Appendix-A.1: Specific Gravity

Location:- Genet Sefer					
Sample Number:TP-1@1.50 & 3.0m		T=21°C		T=19°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer Bottle no.	1A	1B	1C	1D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	62	62	62
4	Weight of Pycnometer + dry soil + water, g	165.62	164.9	165.17	165.34
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	2.96	2.44	2.61	2.73
7	Av. Sp. Gravity at stated temperature	2.70		2.67	
8	Temperature Coefficient (K)	0.99979		1.00020	
9	Specific gravity (Gs) @ 20°C	2.70		2.67	

Location:-Harar Beri					
Sample Number:TP-2@1.50 & 3.0m		T=22°C		T=21°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer Bottle no.	2A	2B	2C	2D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	62	62	62
4	Weight of Pycnometer + dry soil + water, g	165.86	164.22	165	165.5
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	3.18	2.09	2.50	2.86
7	Av. Sp. Gravity at stated temperature	2.64		2.68	
8	Temperature Coefficient (K)	0.99957		0.99979	
9	Specific gravity (Gs) @ 20°C	2.64		2.68	

Location:-Wolenchity City Administration					
Sample Number:TP-3@1.50 & 3.0m		T=19°C		T=21°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer Bottle no.	3A	3B	3C	3D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	62	62	62
4	Weight of Pycnometer + dry soil + water, g	165.51	164.93	165.27	165.23
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	2.87	2.46	2.68	2.65
7	Av. Sp. Gravity at stated temperature	2.66		2.67	
8	Temperature Coefficient (K)	1.00020		0.99979	
9	Specific gravity (Gs) @ 20°C	2.66		2.67	

Location:-Digeleu Gebere Mehber					
	Sample Number:TP-4@1.50 & 3.0m	T=22°C		T=21°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer Bottle no.	1A	1B	1C	1D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	63	62	62
4	Weight of Pycnometer + dry soil + water, g	165.3	165	165.25	165.2
5	Weight of Pycnometer + water, g	159	159	159	159
6	Specific gravity (Gs)	2.70	2.50	2.67	2.63
7	Av. Sp. Gravity at stated temperature	2.60		2.65	
8	Temperature Coefficient (K)	0.99957		0.99979	
9	Specific gravity (Gs) @ 20°C	2.60		2.65	

Location:- Kehadid Belay					
Sample Number:TP-5@1.50 & 3.0m		T=19°C		T=22°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer bottle no.	1A	1B	1C	1D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	62	62	62
4	Weight of Pycnometer + dry soil + water, g	166	164	165.14	165.33
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	3.33	2.00	2.59	2.72
7	Av. Sp. Gravity at stated temperature	2.67		2.66	
8	Temperature Coefficient (K)	1.00020		0.99957	
9	Specific gravity (Gs) @ 20°C	2.67		2.66	

Location:- Addisu Sefer Around Hospital					
Sample Number:TP-6@1.50 & 3.0m		T=21°C		T=21°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer bottle no.	2A	2B	2C	2D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	62	62	62
4	Weight of Pycnometer + dry soil + water, g	164.13	166	165	165.51
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	2.05	3.33	2.50	2.87
7	Av. Sp. Gravity	2.69		2.68	
8	Temperature Coefficient (K)	0.99979		0.99979	
9	Specific gravity (Gs) @ 20°C	2.69		2.68	

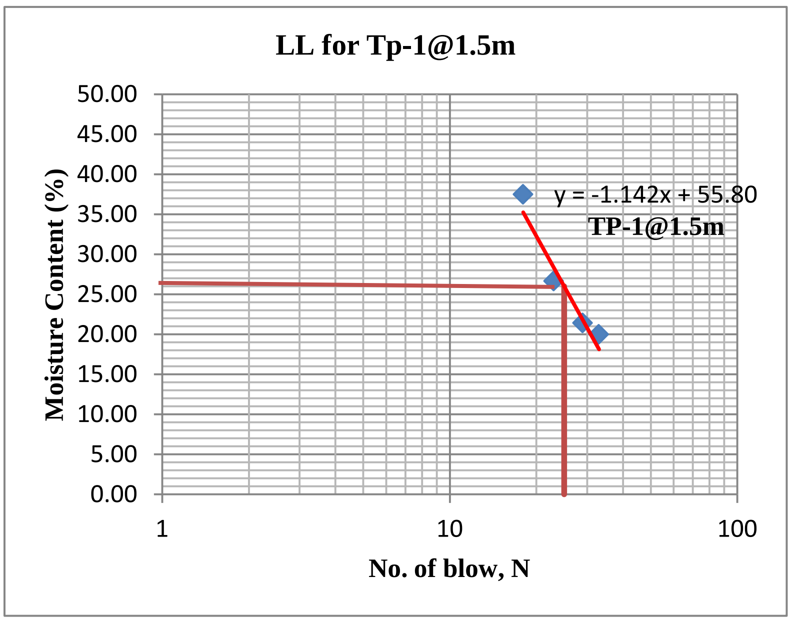
Location:-Shawa Beri Around World Vision					
Sample Number:TP-7@1.50 & 3.0m		T=21°C		T=22°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer bottle no.	7A	7B	7C	7D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	62	62	62
4	Weight of Pycnometer + dry soil + water, g	165.35	165.2	165.32	165.1
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	2.74	2.63	2.72	2.56
7	Av. Sp. Gravity	2.69		2.64	
8	Temperature Coefficient (K)	0.99979		0.99957	
9	Specific gravity (Gs) @ 20°C	2.69		2.64	

Location:-Ethio-Telecom Around Turufat Hotel					
Sample Number:TP-8@1.50 & 3.0m		T=22°C		T=22°C	
No.	**Item**	**1.5m**		**3m**	
1	Pycnometer bottle no.	8A	8B	8C	8D
2	Weight of Pycnometer	52	52	52	52
3	Weight of Pycnometer + dry soil, g	62	63	62	62
4	Weight of Pycnometer + dry soil + water, g	165	165.33	165.1	165.4
5	Weight of Pycnometer + water, g	159	159	159	159
6	Spefic gravity (Gs)	2.50	2.72	2.56	2.78
7	Av. Sp. Gravity	2.61		2.67	
8	Temperature Coefficient (K)	0.99957		0.99957	
9	Specific gravity (Gs) @ 20°C	2.61		2.67	

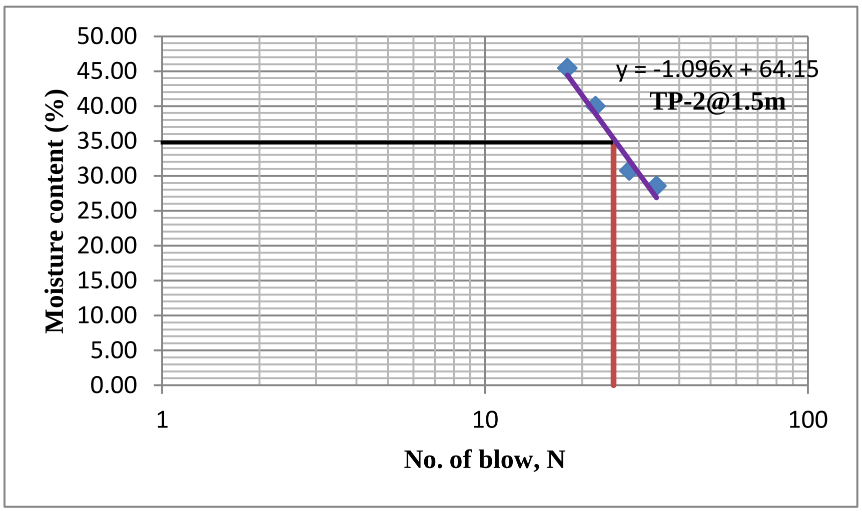
Appendix-A.2: Atterberg Limit

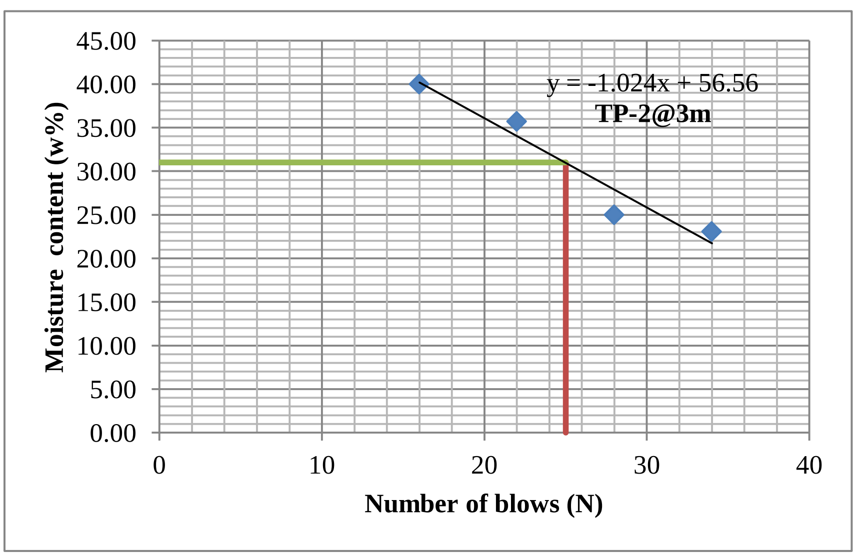
1. Liquid Limit

Location:- Genet Sefer					
Sample Number:Tp-1@1.50m					
No.	**Item**	**1.50m**			
1	Sample number	1A	1B	1C	1D
2	Mass of can (g)	60	59	61	61
3	Mass of can + moist Soil (g)	78	76	80	83
4	Mass of can + dry Soil (g)	75	73	76	77
5	Mass of solid soils (g)	15	14	15	16
6	Mass of pore water	3	3	4	5
7	Water content (w %)	20.00	21.43	26.67	37.5
8	Number of blows (N)	33	29	23	18
		LL=26%			

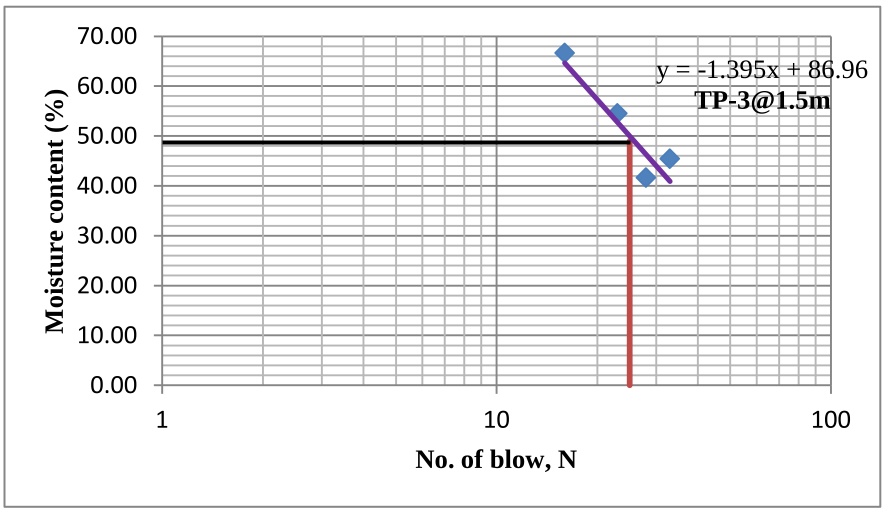


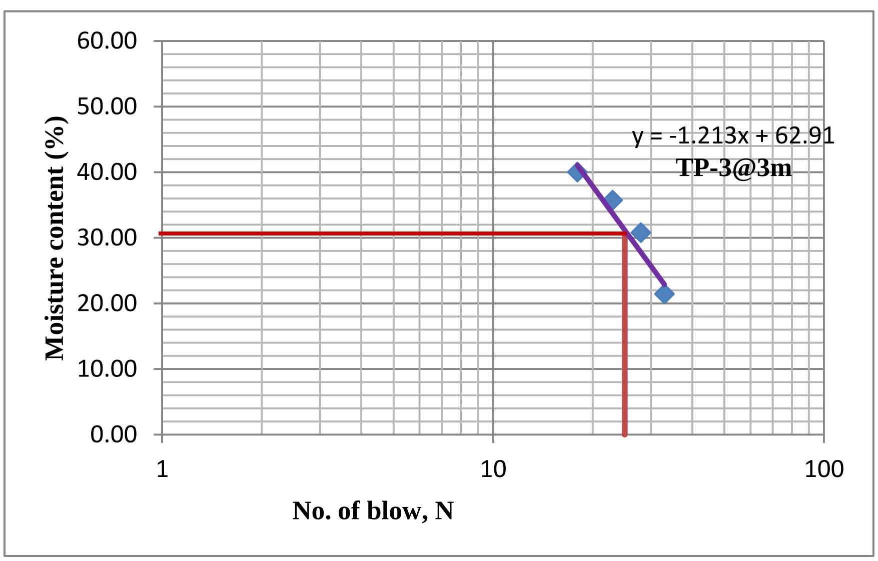
Location:- Harar Beri									
Sample Number:Tp-2@1.50 & 3.0m									
No.	**Item**	**1.50m**				**3.0m**			
1	Sample number	1A	1B	1C	1D	2A	2B	2C	2D
2	Mass of can (g)	6	6	8	6	61	61	61	59
3	Mass of can + moist Soil (g)	22	27	25	24	82	80	81	75
4	Mass of can + dry Soil (g)	17	21	21	20	76	75	77	72
5	Mass of solid soils (g)	11	15	13	14	15	14	16	13
6	Mass of pore water	5	6	4	4	6	5	4	3
7	Water content (w %)	45.45	40.00	30.77	28.57	40.00	35.71	25.00	23.08
8	Number of blows (N)	18	22	28	34	16	22	28	34
		LL=35%				**LL=31%**			



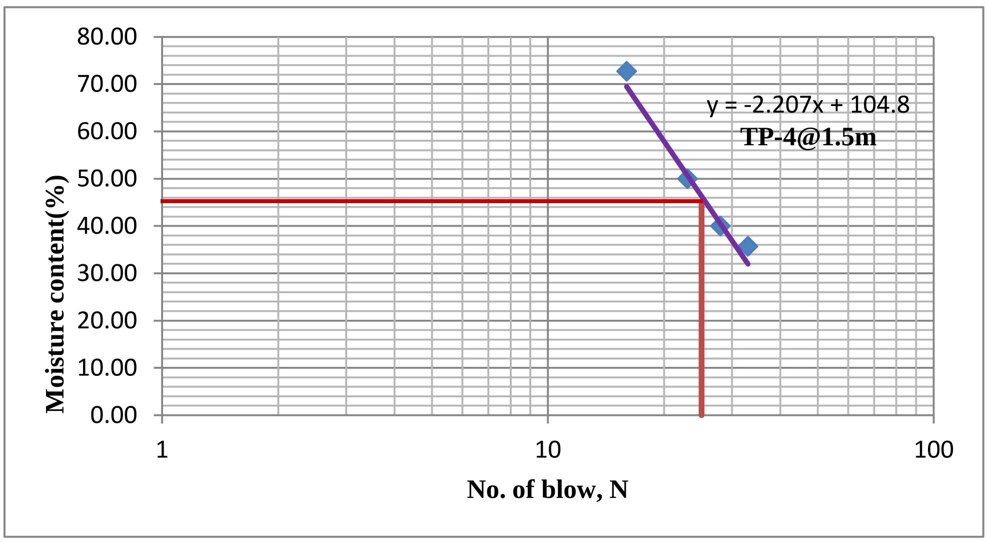


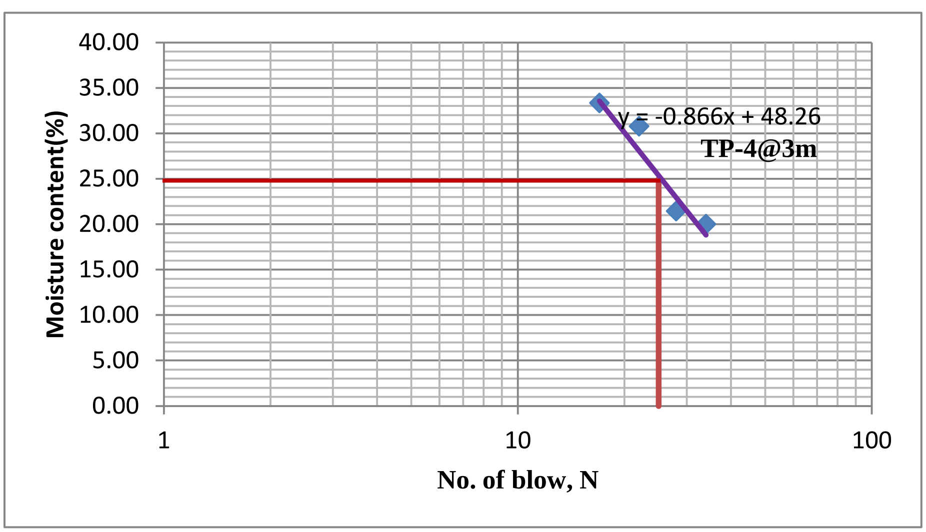
No.	Item	1.50m				3.0m			
	Location:- Wolenchity City Administration								
	Sample Number:Tp-3@1.50 & 3.0m								
1	Sample number	1A	1B	1C	1D	2A	2B	2C	2D
2	Mass of can (g)	60	60	61	60	8	8	8	8
3	Mass of can + moist Soil (g)	80	77	78	76	22	27	25	25
4	Mass of can + dry Soil (g)	72	71	73	71	18	22	21	22
5	Mass of solid soils (g)	12	11	12	11	10	14	13	14
6	Mass of pore water	8	6	5	5	4	5	4	3
7	Water content (w%)	66.67	54.55	41.67	45.45	40.00	35.71	30.77	21.43
8	Number of blows (N)	16	23	28	33	18	23	28	33
		LL=49%				LL=30.5%			



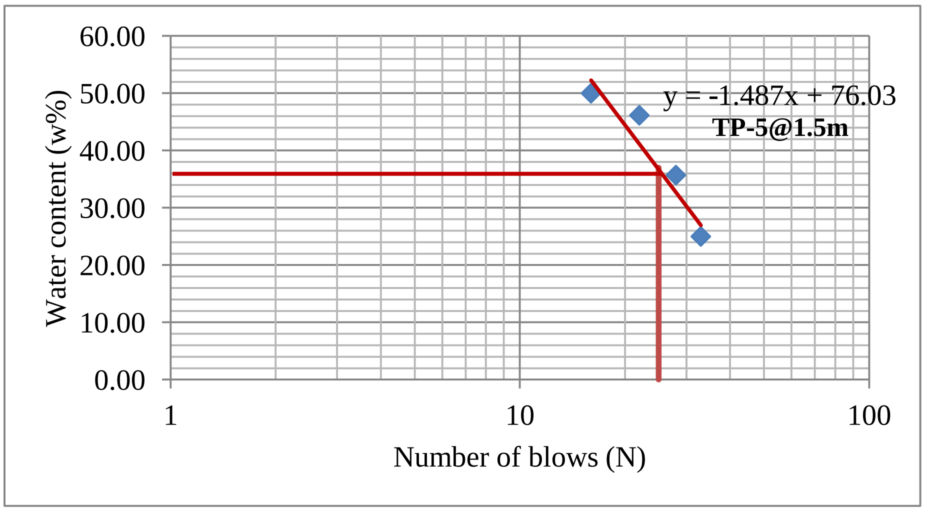


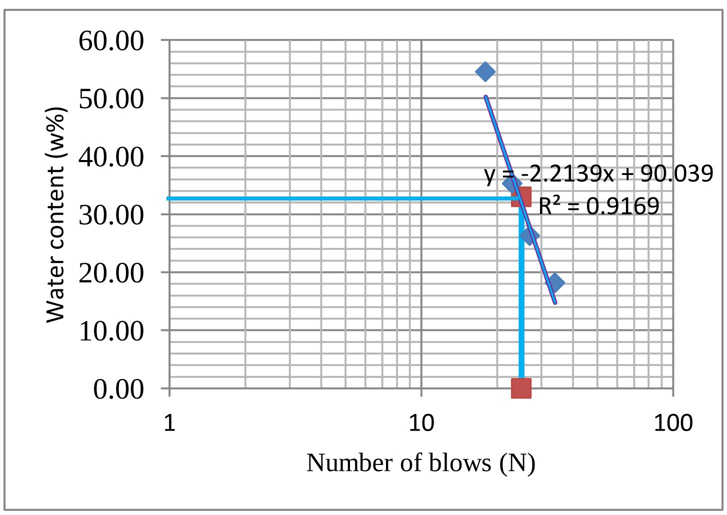
Location:- Digelu Gebere Mehber									
Sample Number:Tp-4@1.50 & 3.0m									
No.	**Item**	**1.50m**				**3.0m**			
1	Sample number	1A	1B	1C	1D	2A	2B	2C	2D
2	Mass of can (g)	8	8	8	8	8	8	8	8
3	Mass of can + moist Soil (g)	27	23	22	27	28	25	25	26
4	Mass of can + dry Soil (g)	19	18	18	22	23	21	22	23
5	Mass of solid soils (g)	11	10	10	14	15	13	14	15
6	Mass of pore water	8	5	4	5	5	4	3	3
7	Water content (w%)	72.73	50.00	40.00	35.71	33.33	30.77	21.43	20.00
8	Number of blows (N)	16	23	28	33	17	22	28	34
		LL=45%				**LL=25%**			



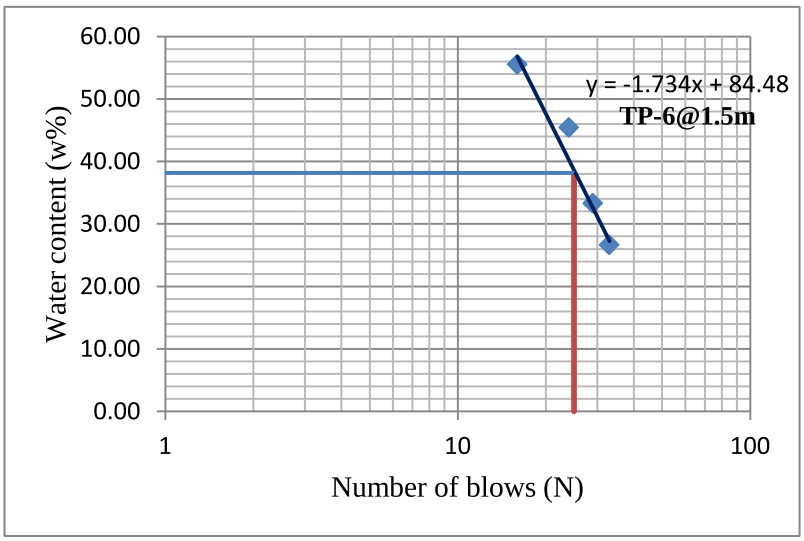


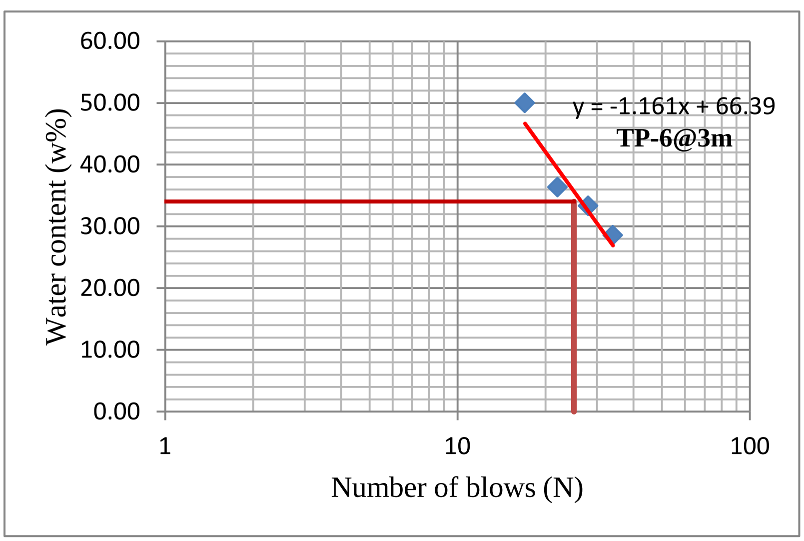
Location:- Kehadid Belay									
Sample Number:Tp-5@1.50 & 3.0m									
No.	**Item**	**1.50m**				**3.0m**			
1	Sample number	5A	5B	5C	5D	1A	2B	2C	2D
2	Mass of can (g)	60	60	60	60	60	60	60	60
3	Mass of can + moist Soil (g)	75	79	79	80	77	83	84	86
4	Mass of can + dry Soil (g)	70	73	74	76	71	77	79	82
5	Mass of solid soils (g)	10	13	14	16	11	17	19	22
6	Mass of pore water	5	6	5	4	6	6	5	4
7	Water content (w %)	50.00	46.15	35.71	25.00	54.55	35.29	26.32	18.18
8	Number of blows (N)	16	22	28	33	18	23	27	34
		LL=37%				**LL=33%**			



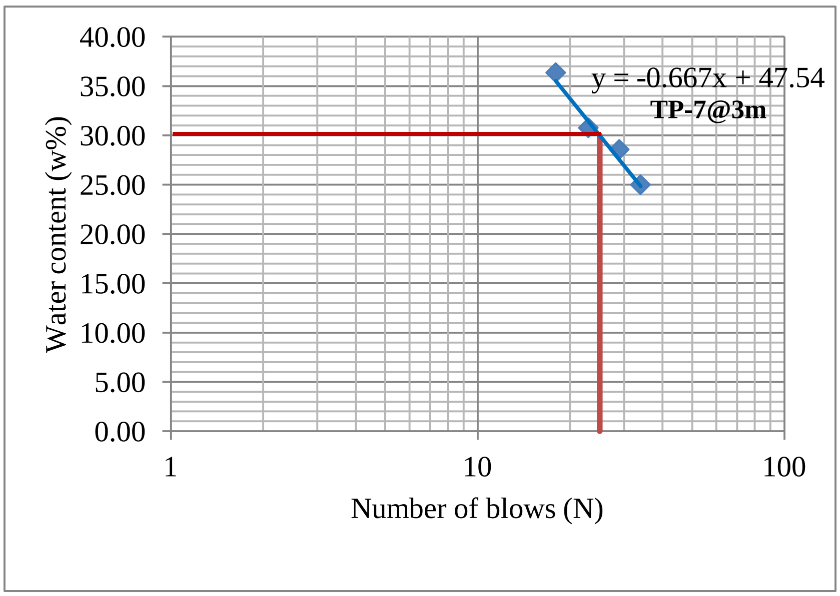


Location:- Addisu Sefer									
Sample Number:Tp-6@1.50 & 3.0m									
No.	**Item**	**1.50m**				**3.0m**			
1	Sample number	1A	1B	1C	1D	2A	2B	2C	2D
2	Mass of can (g)	9	9	9	9	9	9	9	9
3	Mass of can + moist Soil (g)	23	25	25	28	24	24	25	27
4	Mass of can + dry Soil (g)	18	20	21	24	19	20	21	23
5	Mass of solid soils (g)	9	11	12	15	10	11	12	14
6	Mass of pore water	5	5	4	4	5	4	4	4
7	Water content (w %)	55.56	45.45	33.33	26.67	50.00	36.36	33.33	28.57
8	Number of blows (N)	16	24	29	33	17	22	28	34
		LL=38%				**LL=34%**			

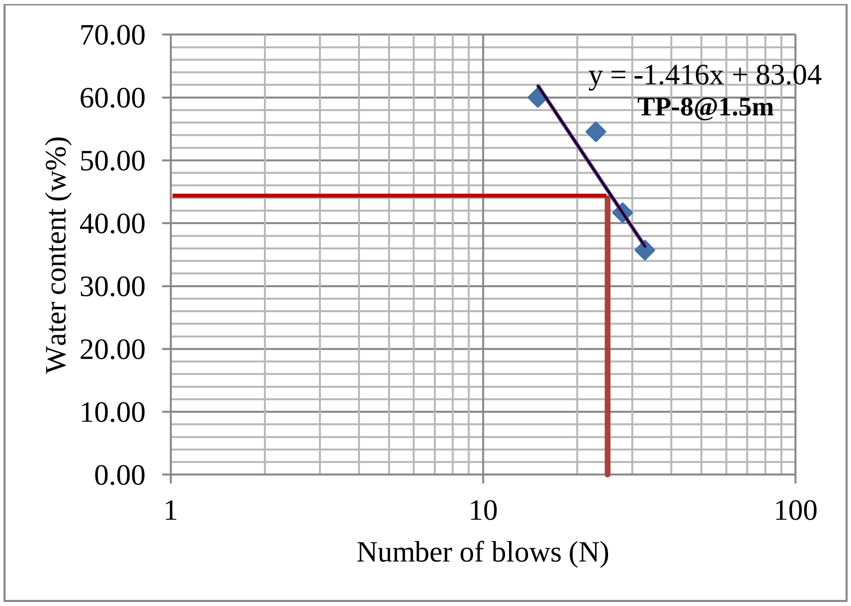


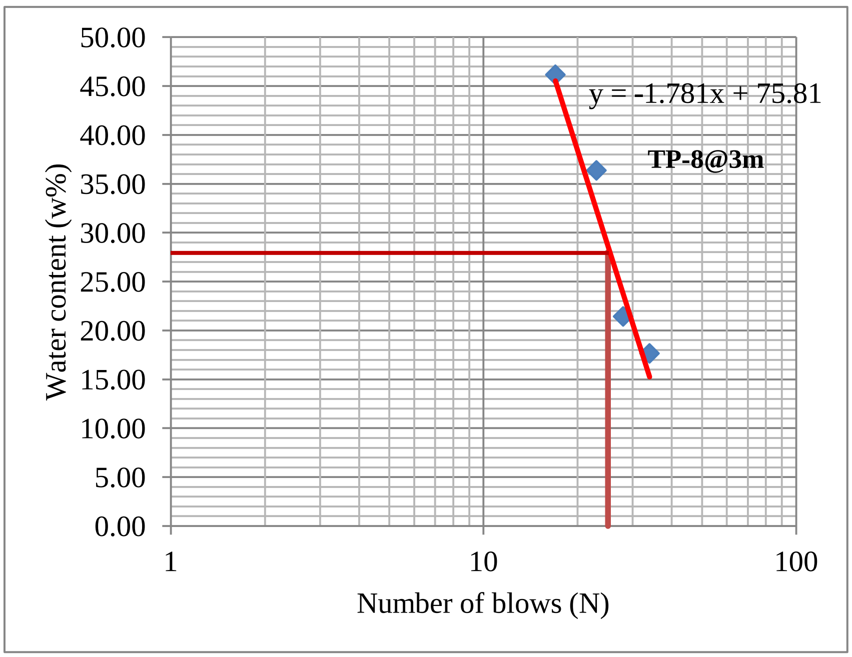


Location:- Shawa Beri					
Sample Number:Tp-7@1.50m					
No.	**Item**	**1.50m**			
1	Sample number	1A	1B	1C	1D
2	Mass of can (g)	9	9	9	9
3	Mass of can + moist Soil (g)	24	26	27	29
4	Mass of can + dry Soil (g)	20	22	23	25
5	Mass of solid soils (g)	11	13	14	16
6	Mass of pore water	4	4	4	4
7	Water content (w%)	36.36	30.77	28.57	25.00
8	Number of blows (N)	18	23	29	34
		LL=30%			



Location:- Ethio Telecom									
Sample Number:Tp-8@1.50 & 3.0m									
No.	**Item**	**1.50m**				**3.0m**			
1	Sample number	1A	1B	1C	1D	2A	2B	2C	2D
2	Mass of can (g)	60	61	61	60	60	60	60	60
3	Mass of can + moist Soil (g)	84	78	78	79	79	75	77	80
4	Mass of can + dry Soil (g)	75	72	73	74	73	71	74	77
5	Mass of solid soils (g)	15	11	12	14	13	11	14	17
6	Mass of pore water	7	6	5	5	6	4	3	3
7	Water content (w %)	60.00	54.55	41.67	35.71	46.15	36.36	21.43	17.65
8	Number of blows (N)	15	23	28	33	17	23	28	34
		LL=43%				**LL=28%**			


70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Water content (w%)
1
10
100
Number of blows (N)
y = -1.416x + 83.04
TP-8@1.5m


50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Water content (w%)
1
10
100
Number of blows (N)
y = -1.781x + 75.81
TP-8@3m

2. Plastic Limit

Location:- Genet Sefer			
Sample Number:Tp-1@1.50m			
No.	**Item**	**1.5m**	
1	Moisture can no.	1A	1B
2	Mass of can	60	60
3	Mass of can + moist soil, g	72	72
4	Mass of can + dry soil,g	69.7	69.9
5	Mass of dry soil,g	9.7	9.9
6	Mass of water,g	2.3	2.1
7	Water content,%	23.71	21.21
	PL (%)	**22.56**	
	Pl(%)	**3.44**	

Location: Harar Beri					
Sample Number:Tp-2@1.50 & 3.0m					
No.	**Item**	**1.5m**		**3m**	
1	Moisture can no.	1A	1B	1C	1D
2	Mass of can	8	8	60	61
3	Mass of can + moist soil, g	29	25	78	78
4	Mass of can + dry soil,g	24.6	21.55	74.5	74.5
5	Mass of dry soil,g	16.6	13.55	14.5	13.5
6	Mass of water,g	4.4	3.45	3.5	3.5
7	Water content,%	26.5	25.5	24.14	25.93
	PL (%)	**26.11**		**25.00**	
	PI (%)	**8.89**		**6.00**	

Location:-Wolenchity City Administration					
Sample Number:Tp-3@1.50 & 3.0m					
No.	**Item**	**1.5m**		**3m**	
1	Moisture can no.	1A	1B	1C	1D
2	Mass of can	60	60	95	92
3	Mass of can + moist soil, g	75	72	112	109
4	Mass of can + dry soil,g	71.11	68.97	104.6	105.82
5	Mass of dry soil,g	11.11	8.97	9.6	13.82
6	Mass of water,g	3.89	3.03	7.4	3.18
7	Water content,%	**35**	**33.85**	**25**	**23.01**
	PL (%)	**34.85**		**24.01**	
	PI (%)	**14.15**		**6.39**	

Location:- Digelu Gebere Mehber					
Sample Number:Tp-4@1.50 & 3.0m					
No.	**Item**	**1.5m**		**3m**	
1	Moisture can no.	1A	1B	1C	1D
2	Mass of can	8	8	8	8
3	Mass of can + moist soil, g	27	28	28	28
4	Mass of can + dry soil,g	22.64	23.36	24.39	24.44
5	Mass of dry soil,g	14.64	15.36	16.39	16.44
6	Mass of water,g	4.36	4.64	3.61	3.56
7	Water content,%	29.75	30.25	22	21.68
	PL (%)	**30.00**		**21.85**	
	PI (%)	**15.00**		**3.15**	

Location:- Kehadid Belay					
Sample Number:Tp-5@1.50 & 3.0m					
No.	**Item**	**1.5m**		**3m**	
1	Moisture can no.	1A	1B	1C	1D
2	Mass of can	60	60	60	60
3	Mass of can + moist soil, g	73	71	69	70
4	Mass of can + dry soil,g	70.29	68.74	67.18	68.01
5	Mass of dry soil,g	10.29	8.74	7.18	8.01
6	Mass of water,g	2.71	2.26	1.82	1.99
7	Water content,%	26.35	25.87	25.4	24.89
	PL (%)	**26.11**		**25.15**	
	Pl (%)	**10.89**		**7.85**	

Location:-Addisu Sefer					
Sample Number:Tp-6@1.50 & 3.0m					
No.	**Item**	**1.5m**		**3m**	
1	Moisture can no.	1A	1B	1C	1D
2	Mass of can	60	61	60	60
3	Mass of can + moist soil, g	72	71	70	68
4	Mass of can + dry soil,g	69.29	68.74	67.83	66.22
5	Mass of dry soil,g	9.29	7.74	7.83	6.22
6	Mass of water,g	2.71	2.26	2.17	1.78
7	Water content,%	29.17	29.17	27.8	28.75
	PL (%)	**29.17**		**28.28**	
	PI (%)	**8.83**		**5.72**	

Location:-Shawa Beri			
Sample Number:Tp-7@1.50m			
No.	**Item**	**1.5m**	
1	Moisture can no.	1A	1B
2	Mass of can	60	60
3	Mass of can + moist soil, g	72	68
4	Mass of can + dry soil,g	69.5	66.3
5	Mass of dry soil,g	9.5	6.3
6	Mass of water,g	2.5	1.7
7	Water content,%	**26.33**	**27**
	PL (%)	**26.67**	
	PI (%)	**3.33**	

Location:- Ethio-Telecom					
Sample Number:Tp-8@1.50 & 3.0m					
No.	**Item**	**1.5m**		**3m**	
1	Moisture can no.	1A	1B	1C	1D
2	Mass of can	60	60	60	60
3	Mass of can + moist soil, g	75	74	70	71
4	Mass of can + dry soil,g	71.61	70.87	68.07	68.93
5	Mass of dry soil,g	11.61	10.87	8.07	8.93
6	Mass of water,g	3.39	3.13	1.93	2.07
7	Water content,%	29.25	28.85	24	23.22
	PL (%)	**29.05**		**23.61**	
	PI (%)	**13.95**		**4.39**	

Appendix-B: Compaction Test

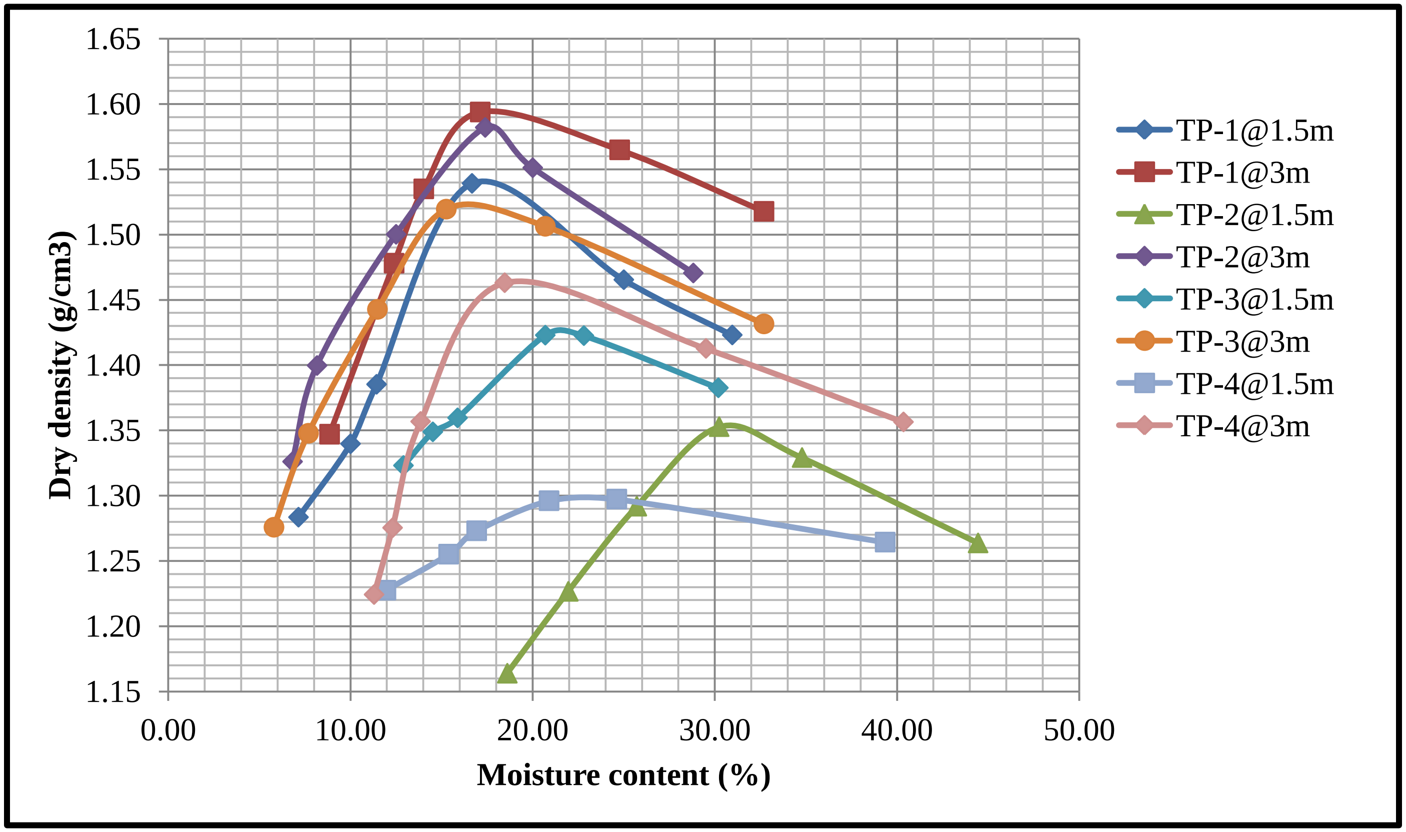
Location:- Genet Sefer	TP-1 at 1.5m depth						TP-1 at 3m depth					
Trial No.	1	2	3	4	5	6	1	2	3	4	5	6
Mold weight +sample (gm)	5702	5795	5861	6099	6133	6163	5788	5972	6056	6166	6247	6305
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1298	1391	1457	1695	1729	1759	1384	1568	1652	1762	1843	1901
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.38	1.47	1.54	1.80	1.83	1.86	1.47	1.66	1.75	1.87	1.95	2.01
Wet weight +can	53	52	47	51	52	63	131	135	130	139	143	146
Dry weight + can	50	48	43	45	43	50	121	121	115	120	116	112
weight of can	8	8	8	9	7	8	8	8	8	9	7	8
weight of moisture	3	4	4	6	9	13	10	14	15	19	27	34
Weight of dry soil	42	40	35	36	36	42	113	113	107	111	109	104
Moisture content (%)	7.14	10.00	11.43	16.67	25.00	30.95	8.85	12.39	14.02	17.12	24.77	32.69
Dry density (g/cm3)	1.28	1.34	1.39	1.54	1.47	1.42	1.35	1.48	1.53	1.59	1.56	1.52
Location:- Harar Beri	TP-2 at 1.5m depth						TP-2 at 3.0m depth					
Mold weight +sample (gm)	5707	5816	5937	6067	6095	6127	5741	5833	5997	6157	6161	6192
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1303	1412	1533	1663	1691	1723	1337	1429	1593	1753	1757	1788
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.38	1.50	1.62	1.76	1.79	1.83	1.42	1.51	1.69	1.86	1.86	1.89
Wet weight +can	59	58	52	65	69	73	56	62	63	63	81	85
Dry weight + can	51	49	43	52	53	53	53	58	57	55	69	68

weight of can	8	8	8	9	7	8	9	9	9	9	9	9
weight of moisture	8	9	9	13	16	20	3	4	6	8	12	17
Weight of dry soil	43	41	35	43	46	45	44	49	48	46	60	59
Moisture content (%)	18.60	21.95	25.71	30.23	34.78	44.44	6.82	8.16	12.50	17.39	20.00	28.81
Dry density (g/cm3)	1.16	1.23	1.29	1.35	1.33	1.26	1.33	1.40	1.50	1.58	1.55	1.47
Location: - Wol. City Adm.	TP-3 at 1.5m depth						TP-3 at 3.0m depth					
Mold weight +sample (gm)	5814	5862	5891	6025	6053	6103	5678	5774	5922	6057	6120	6197
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1410	1458	1487	1621	1649	1699	1274	1370	1518	1653	1716	1793
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.49	1.54	1.58	1.72	1.75	1.80	1.35	1.45	1.61	1.75	1.82	1.90
Wet weight +can	130	131	134	131	130	129	133	130	128	130	130	129
Dry weight + can	122	122	124	119	117	113	129	125	121	121	118	112
weight of can	60	60	61	61	60	60	60	60	60	62	60	60
weight of moisture	8	9	10	12	13	16	4	5	7	9	12	17
Weight of dry soil	62	62	63	58	57	53	69	65	61	59	58	52
Moisture content (%)	12.90	14.52	15.87	20.69	22.81	30.19	5.80	7.69	11.48	15.25	20.69	32.69
Dry density (g/cm3)	1.32	1.35	1.36	1.42	1.42	1.38	1.28	1.35	1.44	1.52	1.51	1.43
Location: - Dig. Gebere Mehber	TP-4 at 1.5m depth						TP-4 at 3.0m depth					
Mold weight +sample (gm)	5701	5771	5809	5883	5930	6067	5690	5756	5862	6040	6131	6201
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1297	1367	1405	1479	1526	1663	1286	1352	1458	1636	1727	1797
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.37	1.45	1.49	1.57	1.62	1.76	1.36	1.43	1.54	1.73	1.83	1.90
Wet weight +can	135	135	137	140	141	145	129	133	134	137	139	140
Dry weight + can	127	125	126	126	125	121	122	125	125	125	121	117

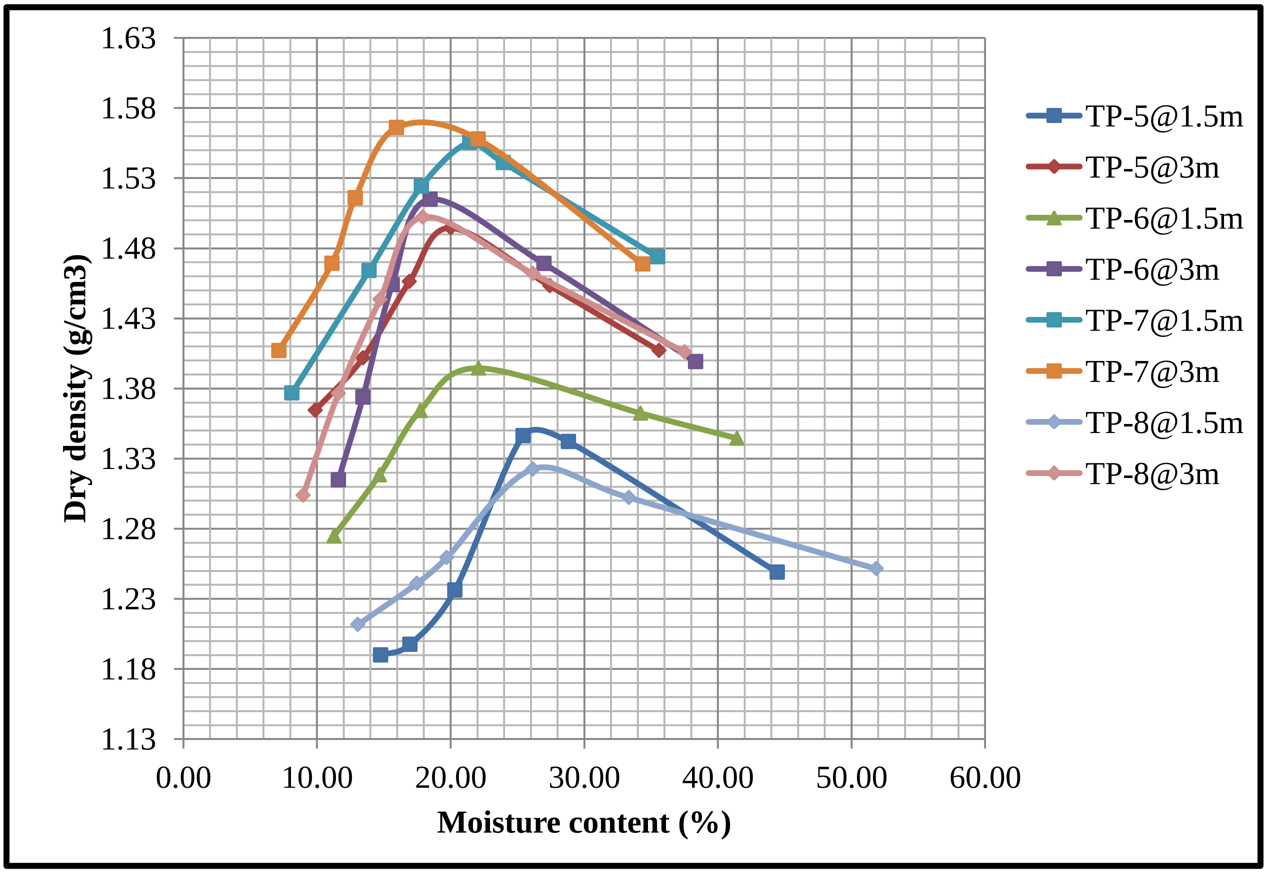
weight of can	60	60	61	59	60	60	60	60	60	60	60	60
weight of moisture	8	10	11	14	16	24	7	8	9	12	18	23
Weight of dry soil	67	65	65	67	65	61	62	65	65	65	61	57
Moisture content (%)	11.94	15.38	16.92	20.90	24.62	39.34	11.29	12.31	13.85	18.46	29.51	40.35
Dry density (g/cm3)	1.23	1.26	1.27	1.30	1.30	1.26	1.22	1.28	1.36	1.46	1.41	1.36
Location:- Kehadid Belay	TP-5 at 1.5m depth						TP-5 at 3.0m depth					
Mold wet +sample (gm)	5693	5726	5808	5998	6036	6107	5819	5905	6011	6097	6152	6205
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1289	1322	1404	1594	1632	1703	1415	1501	1607	1693	1748	1801
Mold volume (cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.37	1.40	1.49	1.69	1.73	1.80	1.50	1.59	1.70	1.79	1.85	1.91
Wet weight +can	130	129	137	134	136	138	138	136	143	144	139	140
Dry weight + can	121	119	124	119	119	114	131	127	131	130	122	119
weight of can	60	60	60	60	60	60	60	60	60	60	60	60
weight of moisture	9	10	13	15	17	24	7	9	12	14	17	21
Weight of dry soil	61	59	64	59	59	54	71	67	71	70	62	59
Moisture content (%)	14.75	16.95	20.31	25.42	28.81	44.44	9.86	13.43	16.90	20.00	27.42	35.59
Dry density (g/cm3)	1.19	1.20	1.24	1.35	1.34	1.25	1.36	1.40	1.46	1.49	1.45	1.41
Location:- Addisu Sefer	TP-6 at 1.5m depth						TP-6 at 3.0m depth					
Mold wt +sample (gm)	5743	5831	5920	6011	6130	6199	5789	5875	5991	6098	6165	6231
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1339	1427	1516	1607	1726	1795	1385	1471	1587	1694	1761	1827
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.42	1.51	1.61	1.70	1.83	1.90	1.47	1.56	1.68	1.79	1.87	1.94
Wet weight +can	139	146	154	155	162	160	137	136	134	137	140	143
Dry weight + can	131	135	140	138	136	131	129	127	124	125	123	120
weight of can	60	60	61	61	60	61	60	60	60	60	60	60

weight of moisture	8	11	14	17	26	29	8	9	10	12	17	23
Weight of dry soil	71	75	79	77	76	70	69	67	64	65	63	60
Moisture content (%)	11.27	14.67	17.72	22.08	34.21	41.43	11.59	13.43	15.63	18.46	26.98	38.33
Dry density (g/cm3)	1.27	1.32	1.36	1.39	1.36	1.34	1.31	1.37	1.45	1.51	1.47	1.40
Location:- Shawa Beri	TP-7 at 1.5m depth						TP-7 at 3.0m depth					
Mold wt +sample (gm)	5809	5978	6099	6187	6207	6289	5827	5945	6019	6118	6199	6267
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1405	1574	1695	1783	1803	1885	1423	1541	1615	1714	1795	1863
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.49	1.67	1.80	1.89	1.91	2.00	1.51	1.63	1.71	1.82	1.90	1.97
Wet weight +can	140	142	147	146	148	145	135	140	139	142	143	146
Dry weight + can	134	132	134	131	131	123	130	132	130	131	128	124
weight of can	60	60	61	61	60	61	60	60	60	62	60	60
weight of moisture	6	10	13	15	17	22	5	8	9	11	15	22
Weight of dry soil	74	72	73	70	71	62	70	72	70	69	68	64
Moisture content (%)	8.11	13.89	17.81	21.43	23.94	35.48	7.14	11.11	12.86	15.94	22.06	34.38
Dry density (g/cm3)	1.38	1.46	1.52	1.56	1.54	1.47	1.41	1.47	1.52	1.57	1.56	1.47
Location:- Ethio-Telecom	TP-8 at 1.5m depth						TP-8 at 3.0m depth					
Mold wt +sample (gm)	5697	5780	5827	5979	6043	6198	5745	5854	5967	6076	6145	6229
Mold weight (gm)	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404	4404
Sample weight (gm)	1293	1376	1423	1575	1639	1794	1341	1450	1563	1672	1741	1825
Mold volume (Cm3)	944	944	944	944	944	944	944	944	944	944	944	944
Bulk density(g/cm3)	1.37	1.46	1.51	1.67	1.74	1.90	1.42	1.54	1.66	1.77	1.84	1.93
Wet weight +can	138	135	140	142	140	143	133	137	138	139	142	138
Dry weight + can	129	124	127	125	120	115	127	129	128	127	125	117
weight of can	60	61	61	60	60	61	60	60	60	60	60	61
weight of moisture	9	11	13	17	20	28	6	8	10	12	17	21

Weight of dry soil	69	63	66	65	60	54	67	69	68	67	65	56
Moisture content (%)	13.04	17.46	19.70	26.15	33.33	51.85	8.96	11.59	14.71	17.91	26.15	37.50
Dry density (g/cm3)	1.21	1.24	1.26	1.32	1.30	1.25	1.30	1.38	1.44	1.50	1.46	1.41



MDD vs OMC Test Results for TP-1 to TP-4

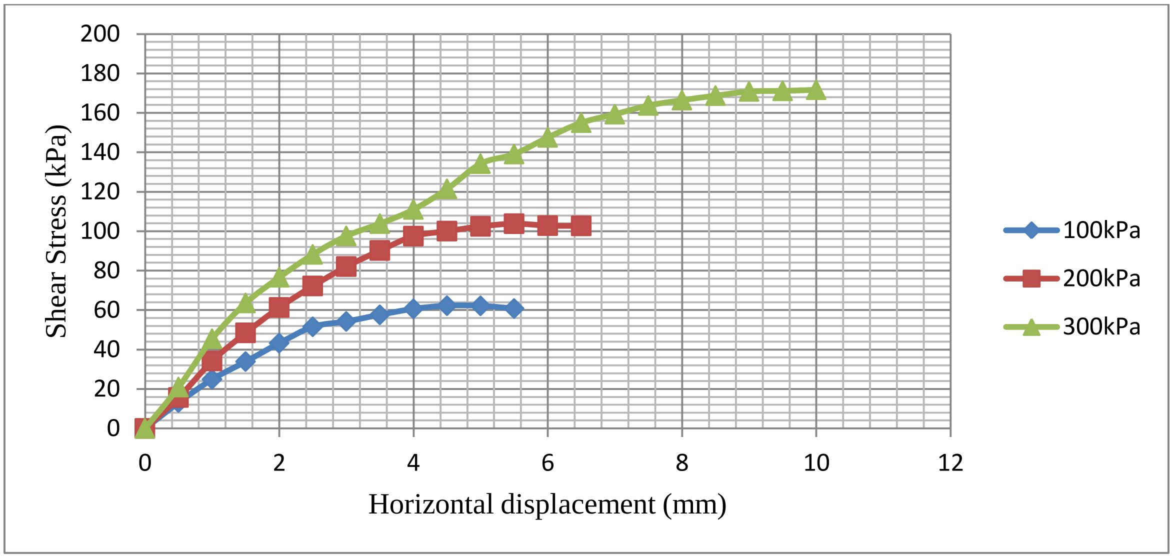


MDD vs OMC Test Results for TP-5 to TP-8

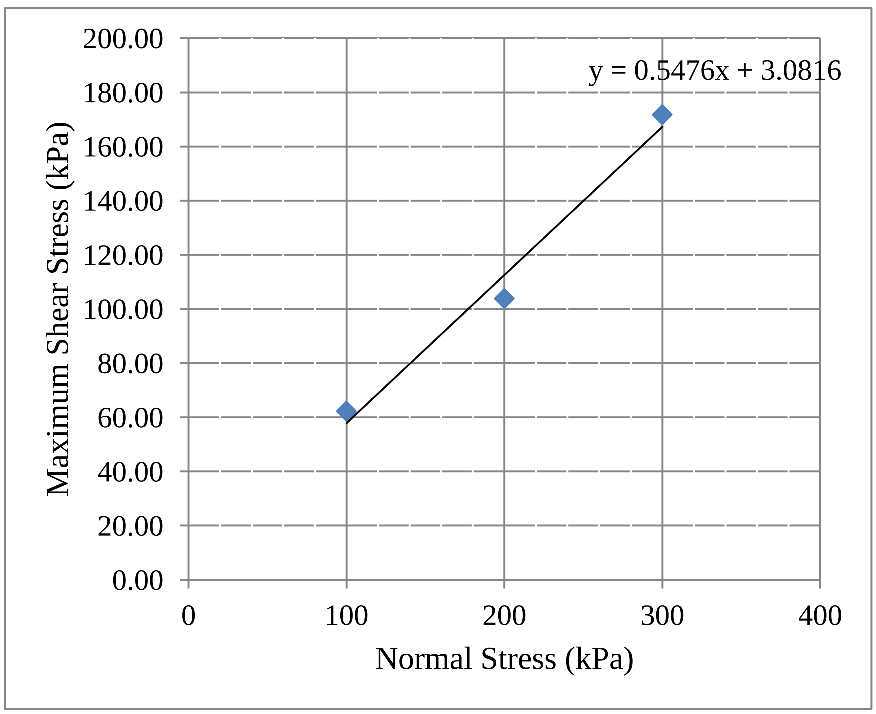
Appendix-C: Direct Shear Test

Location: Genet Sefer		TP-1	Depth (m)	3	Shear test Type :	CD
Moisture Content = 12.43%		Length of sample (mm)		60	Proving Ring Cal., kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displacement (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	67	0.05	13.14	80	0.06	15.69	107	0.07	20.98
1	0.00354	126	0.09	24.92	173	0.12	34.21	230	0.16	45.48
1.5	0.00351	170	0.12	33.90	243	0.17	48.46	319	0.22	63.62
2	0.00348	215	0.15	43.25	305	0.21	61.35	381	0.27	76.64
2.5	0.00345	254	0.18	51.54	356	0.25	72.23	435	0.30	88.26
3	0.00342	265	0.19	54.24	401	0.28	82.08	477	0.33	97.63
3.5	0.00339	279	0.20	57.61	437	0.31	90.24	503	0.35	103.86
4	0.00336	291	0.20	60.63	468	0.33	97.50	533	0.37	111.04
4.5	0.00333	296	0.21	62.22	476	0.33	100.06	578	0.40	121.50
5	0.0033	293	0.21	62.15	483	0.34	102.45	633	0.44	134.27
5.5	0.00327	284	0.20	60.80	485	0.34	103.82	650	0.46	139.14
6	0.00324				476	0.33	102.84	683	0.48	147.56
6.5	0.00321				471	0.33	102.71	711	0.50	155.05
7	0.00318							724	0.51	159.37
7.5	0.00315							737	0.52	163.78
8	0.00312							742	0.52	166.47
8.5	0.00309							745	0.52	168.77
9	0.00306							747	0.52	170.88
9.5	0.00303							741	0.52	171.19
10	0.003							736	0.52	171.73



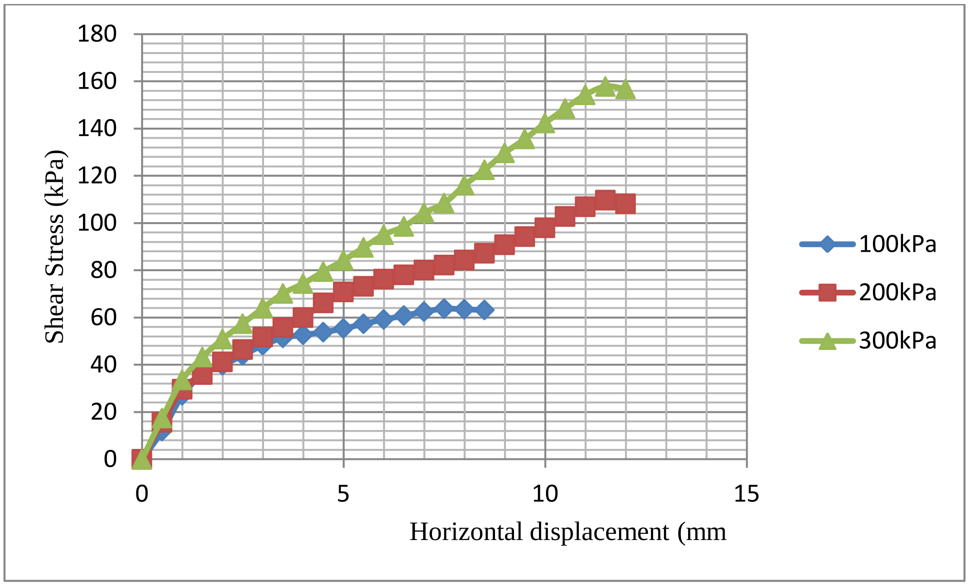
Normal Stress (kPa)		100	200	300
Maximum Shear Stress (kPa)		62.22	103.82	171.73



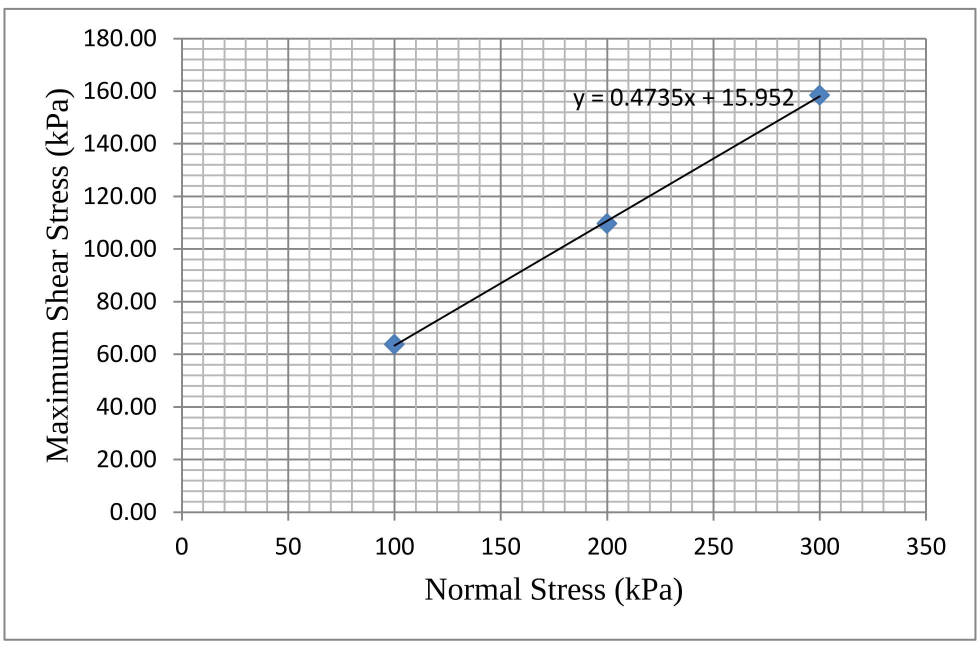
C (kPa)	ϕ (°)
3.081	28.7

Location: Harar Beri		TP-2	Depth (m)	3	Shear test Type :	CD
Moisture Content = 28.18%		Length of sample (mm)		60	Proving Ring Cal., kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displace ment (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	61	0.04	11.96	80	0.06	15.69	89	0.06	17.45
1	0.00354	137	0.10	27.09	150	0.11	29.66	170	0.12	33.62
1.5	0.00351	180	0.13	35.90	180	0.13	35.90	217	0.15	43.28
2	0.00348	198	0.14	39.83	205	0.14	41.24	253	0.18	50.89
2.5	0.00345	217	0.15	44.03	229	0.16	46.46	283	0.20	57.42
3	0.00342	236	0.17	48.30	253	0.18	51.78	313	0.22	64.06
3.5	0.00339	249	0.17	51.42	270	0.19	55.75	340	0.24	70.21
4	0.00336	253	0.18	52.71	288	0.20	60.00	357	0.25	74.38
4.5	0.00333	256	0.18	53.81	315	0.22	66.22	378	0.26	79.46
5	0.0033	261	0.18	55.36	334	0.23	70.85	397	0.28	84.21
5.5	0.00327	268	0.19	57.37	342	0.24	73.21	419	0.29	89.69
6	0.00324	274	0.19	59.20	353	0.25	76.27	440	0.31	95.06
6.5	0.00321	279	0.20	60.84	358	0.25	78.07	452	0.32	98.57
7	0.00318	284	0.20	62.52	364	0.25	80.13	474	0.33	104.34
7.5	0.00315	287	0.20	63.78	370	0.26	82.22	488	0.34	108.44
8	0.00312	283	0.20	63.49	376	0.26	84.36	517	0.36	115.99
8.5	0.00309	280	0.20	63.43	385	0.27	87.22	541	0.38	122.56
9	0.00306				397	0.28	90.82	567	0.40	129.71
9.5	0.00303				408	0.29	94.26	587	0.41	135.61
10	0.003				420	0.29	98.00	610	0.43	142.33
10.5	0.00297				436	0.31	102.76	630	0.44	148.48
11	0.00294				449	0.31	106.90	648	0.45	154.29
11.5	0.00291				456	0.32	109.69	656	0.46	157.80
12	0.00288				451	0.32	109.62	652	0.46	158.47



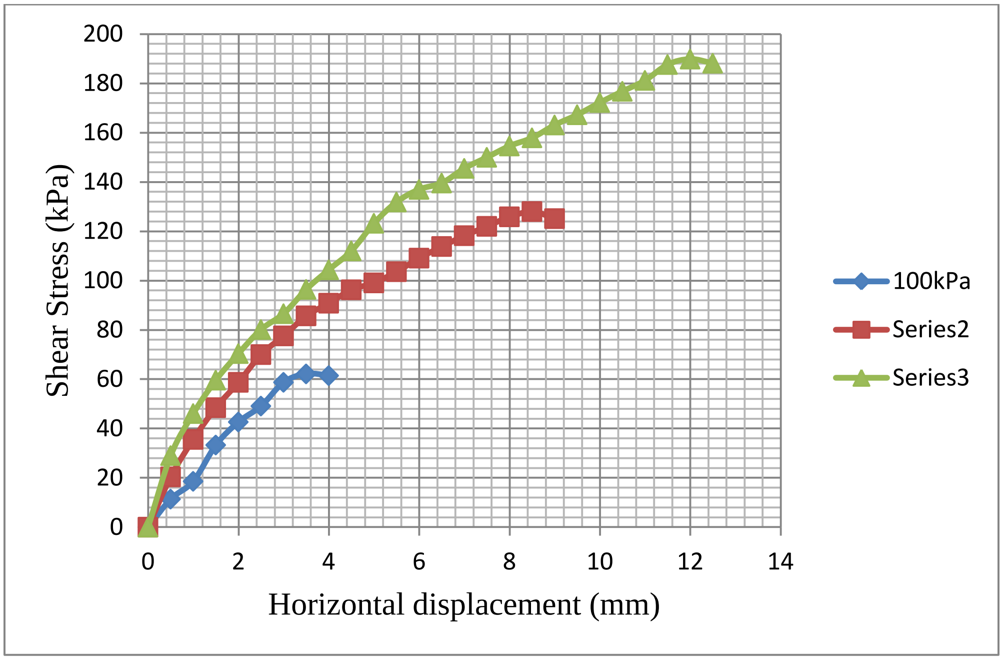
Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	63.78	109.69	158.47



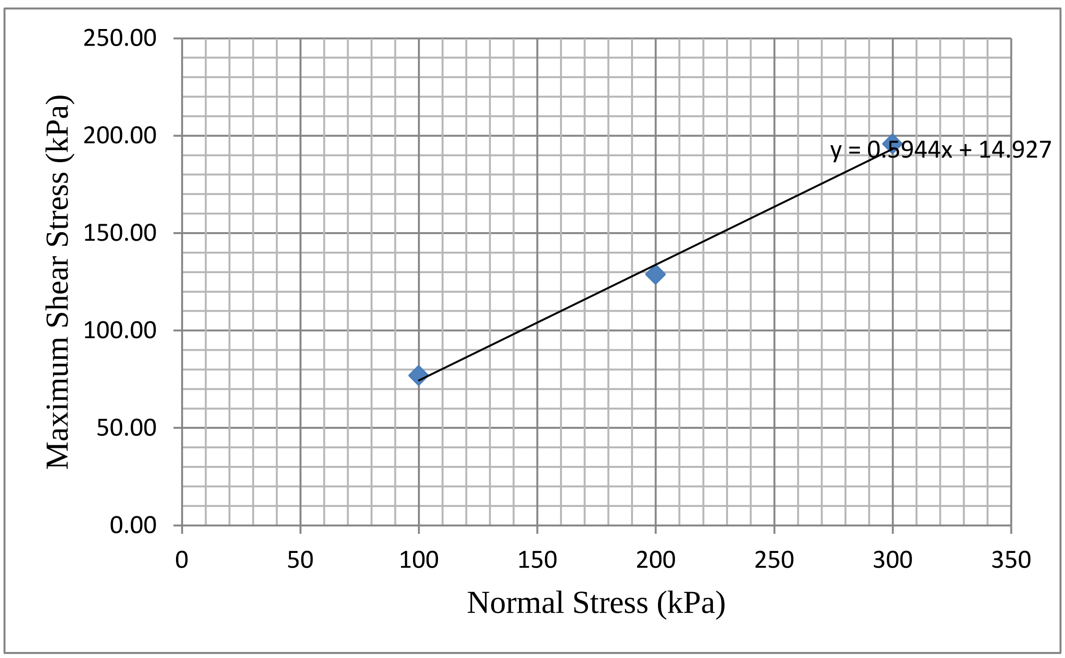
C (kPa)	ϕ (°)
15.95	25.3

Location: Wol. City Adm.		TP-3	Depth (m)	3	Shear test Type :	CD
Moisture Content = 30.12%		Length of sample (mm)		60	Proving Ring Cal., kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displace ment (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	58	0.04	11.37	104	0.07	20.39	148	0.10	29.02
1	0.00354	94	0.07	18.59	180	0.13	35.59	233	0.16	46.07
1.5	0.00351	167	0.12	33.30	243	0.17	48.46	299	0.21	59.63
2	0.00348	212	0.15	42.64	292	0.20	58.74	350	0.25	70.40
2.5	0.00345	242	0.17	49.10	345	0.24	70.00	395	0.28	80.14
3	0.00342	287	0.20	58.74	379	0.27	77.57	423	0.30	86.58
3.5	0.00339	301	0.21	62.15	415	0.29	85.69	467	0.33	96.43
4	0.00336	369	0.26	76.88	436	0.31	90.83	501	0.35	104.38
4.5	0.00333				458	0.32	96.28	533	0.37	112.04
5	0.0033				467	0.33	99.06	581	0.41	123.24
5.5	0.00327				484	0.34	103.61	616	0.43	131.87
6	0.00324				505	0.35	109.10	634	0.44	136.98
6.5	0.00321				522	0.37	113.83	640	0.45	139.56
7	0.00318				537	0.3759	118.208	661	0.46	145.50
7.5	0.00315				549	0.3843	122	675	0.47	150.00
8	0.00312				561	0.3927	125.865	689	0.48	154.58
8.5	0.00309				568	0.3976	128.673	697	0.49	157.90
9	0.00306				563	0.3941	128.791	713	0.50	163.10
9.5	0.00303							724	0.51	167.26
10	0.003							738	0.52	172.20
10.5	0.00297							750	0.53	176.77
11	0.00294							761	0.53	181.19
11.5	0.00291							780	0.55	187.63
12	0.00288							801	0.56	194.69
12.5	0.00285							797	0.56	195.75



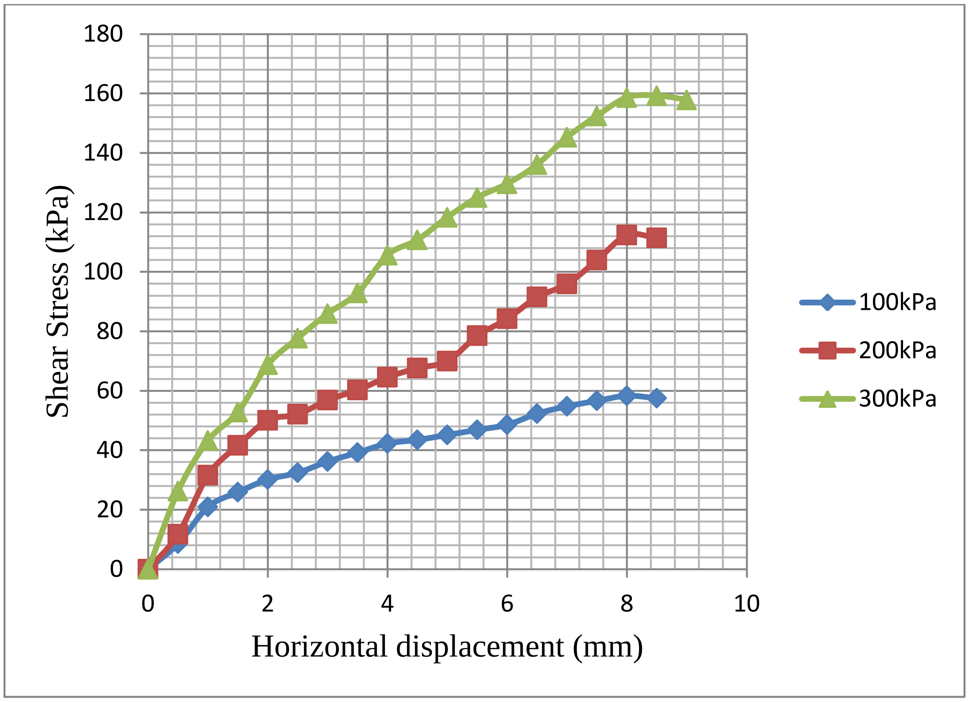
Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	76.88	128.79	195.75



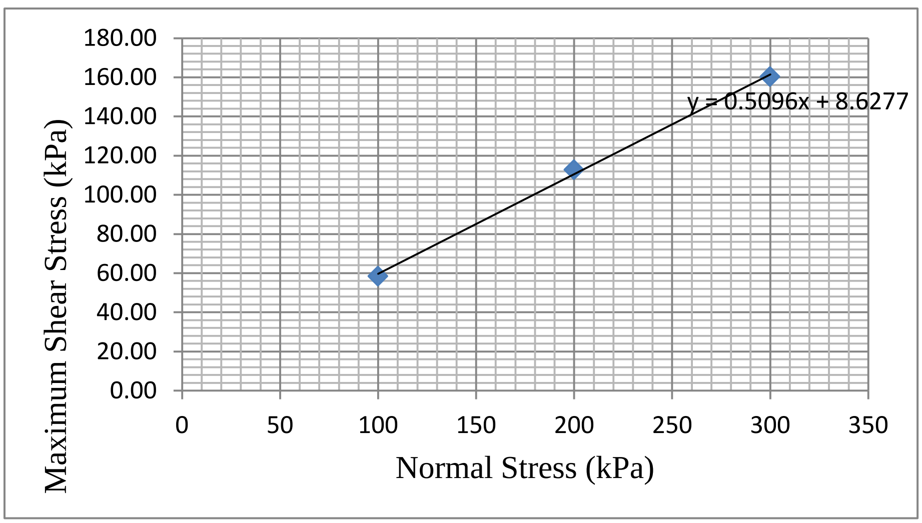
C (kPa)	ϕ (°)
14.92	30.7

Location: Digelu Gebere Mehber		TP-4	Depth (m)	3	Shear test Type :	CD
Moisture Content = 28.65%		Length of sample (mm)		60	Proving Ring Cal., kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displace ment (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	44	0.03	8.63	60	0.04	11.76	134	0.09	26.27
1	0.00354	106	0.07	20.96	160	0.11	31.64	219	0.15	43.31
1.5	0.00351	130	0.09	25.93	209	0.15	41.68	265	0.19	52.85
2	0.00348	150	0.11	30.17	249	0.17	50.09	342	0.24	68.79
2.5	0.00345	160	0.11	32.46	257	0.18	52.14	383	0.27	77.71
3	0.00342	177	0.12	36.23	278	0.19	56.90	420	0.29	85.96
3.5	0.00339	190	0.13	39.23	292	0.20	60.29	450	0.32	92.92
4	0.00336	203	0.14	42.29	310	0.22	64.58	507	0.35	105.63
4.5	0.00333	207	0.14	43.51	322	0.23	67.69	527	0.37	110.78
5	0.0033	213	0.15	45.18	330	0.23	70.00	558	0.39	118.36
5.5	0.00327	219	0.15	46.88	367	0.26	78.56	584	0.41	125.02
6	0.00324	225	0.16	48.61	390	0.27	84.26	600	0.42	129.63
6.5	0.00321	240	0.17	52.34	420	0.29	91.59	624	0.44	136.07
7	0.00318	249	0.17	54.81	436	0.31	95.97	660	0.46	145.28
7.5	0.00315	255	0.18	56.67	468	0.33	104.00	686	0.48	152.44
8	0.00312	260	0.18	58.33	501	0.35	112.40	707	0.49	158.62
8.5	0.00309	258	0.18	58.45	498	0.35	112.82	703	0.49	159.26
9	0.00306							701	0.49	160.36



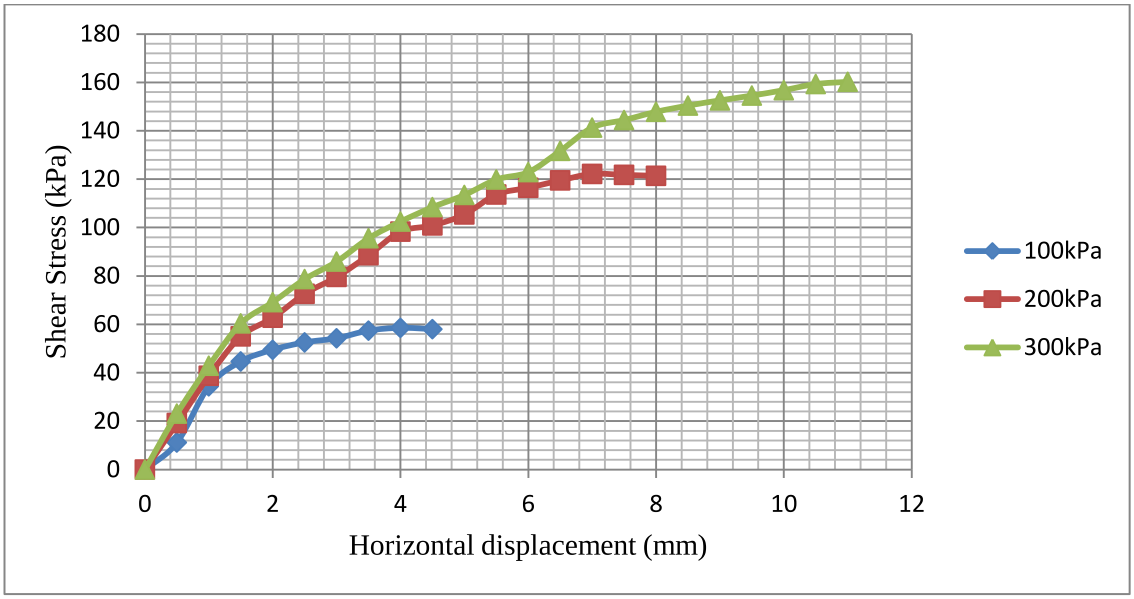
Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	58.45	112.82	160.36



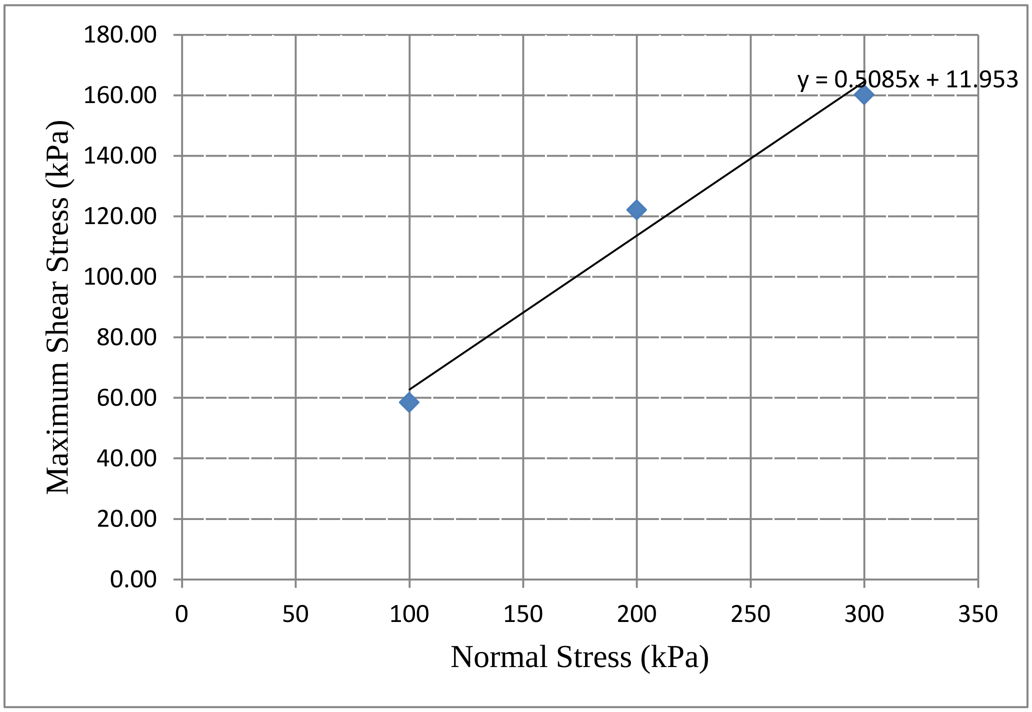
C (kPa)	ϕ (°)
8.627	26.98

Location: Kehadid Belay					TP-5	Depth (m)	3	Shear test Type :		CD
Moisture Content = 22.34%					Length of sample (mm)		60	Proving Ring Cal., kN/Div		0.0007
Area of the sample (m2)		0.0036			Width of sample (mm)		60	Hor. dial reading correction		0.01
					Depth of sample (mm)		25	Rate of Strain, mm/min		1.6

Hor. displacement (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	57	0.04	11.18	98	0.07	19.22	118	0.08	23.14
1	0.00354	174	0.12	34.41	196	0.14	38.76	217	0.15	42.91
1.5	0.00351	224	0.16	44.67	276	0.19	55.04	303	0.21	60.43
2	0.00348	246	0.17	49.48	312	0.22	62.76	344	0.24	69.20
2.5	0.00345	259	0.18	52.55	358	0.25	72.64	388	0.27	78.72
3	0.00342	265	0.19	54.24	389	0.27	79.62	420	0.29	85.96
3.5	0.00339	278	0.19	57.40	429	0.30	88.58	463	0.32	95.60
4	0.00336	281	0.20	58.54	472	0.33	98.33	492	0.34	102.50
4.5	0.00333	276	0.19	58.02	480	0.34	100.90	516	0.36	108.47
5	0.0033				497	0.35	105.42	535	0.37	113.48
5.5	0.00327				531	0.37	113.67	560	0.39	119.88
6	0.00324				539	0.38	116.45	569	0.40	122.93
6.5	0.00321				548	0.38	119.50	604	0.42	131.71
7	0.00318				555	0.39	122.17	642	0.45	141.32
7.5	0.00315				548	0.38	121.78	650	0.46	144.44
8	0.00312				541	0.38	121.38	659	0.46	147.85
8.5	0.00309							664	0.46	150.42
9	0.00306							667	0.47	152.58
9.5	0.00303							669	0.47	154.55
10	0.003							672	0.47	156.80
10.5	0.00297							676	0.47	159.33
11	0.00294							673	0.47	160.24



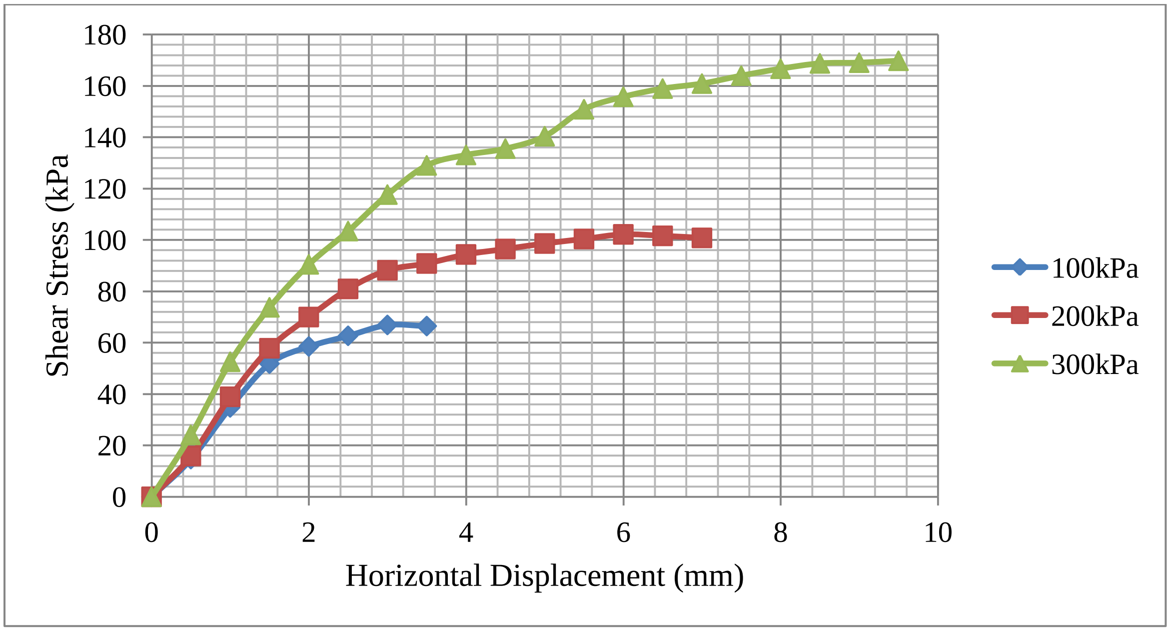
Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	58.54	122.17	160.24



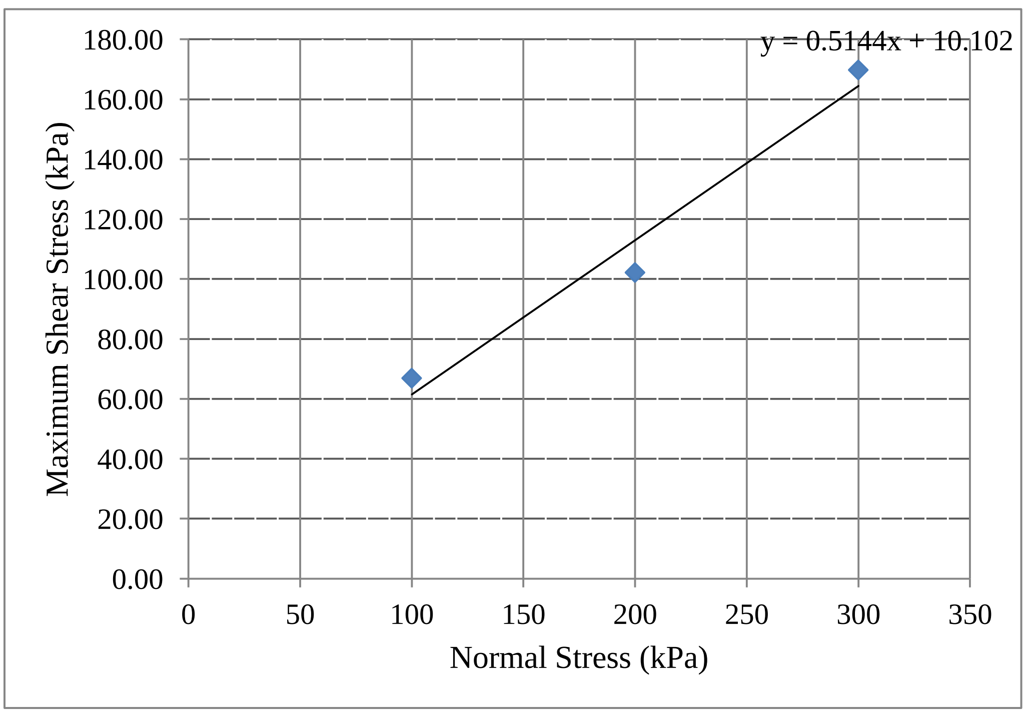
C (kPa)	ϕ (°)
11.95	26.9

Location: Addisu Sefer		TP-6	Depth (m)	3	Shear test Type :	CD
Moisture Content = 20.45%		Length of sample (mm)		60	Proving Ring Cali. kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displace ment (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	75	0.05	14.71	81	0.06	15.88	123	0.09	24.12
1	0.00354	176	0.12	34.80	197	0.14	38.95	266	0.19	52.60
1.5	0.00351	260	0.18	51.85	290	0.20	57.83	370	0.26	73.79
2	0.00348	291	0.20	58.53	348	0.24	70.00	450	0.32	90.52
2.5	0.00345	309	0.22	62.70	399	0.28	80.96	510	0.36	103.48
3	0.00342	327	0.23	66.93	431	0.30	88.22	575	0.40	117.69
3.5	0.00339	322	0.23	66.49	440	0.31	90.86	625	0.44	129.06
4	0.00336				453	0.32	94.38	639	0.45	133.13
4.5	0.00333				459	0.32	96.49	645	0.45	135.59
5	0.0033				465	0.33	98.64	662	0.46	140.42
5.5	0.00327				469	0.33	100.40	705	0.49	150.92
6	0.00324				473	0.33	102.19	721	0.50	155.77
6.5	0.00321				466	0.33	101.62	729	0.51	158.97
7	0.00318				458	0.32	100.82	731	0.51	160.91
7.5	0.00315							738	0.52	164.00
8	0.00312							743	0.52	166.70
8.5	0.00309							745	0.52	168.77
9	0.00306							739	0.52	169.05
9.5	0.00303							735	0.51	169.80



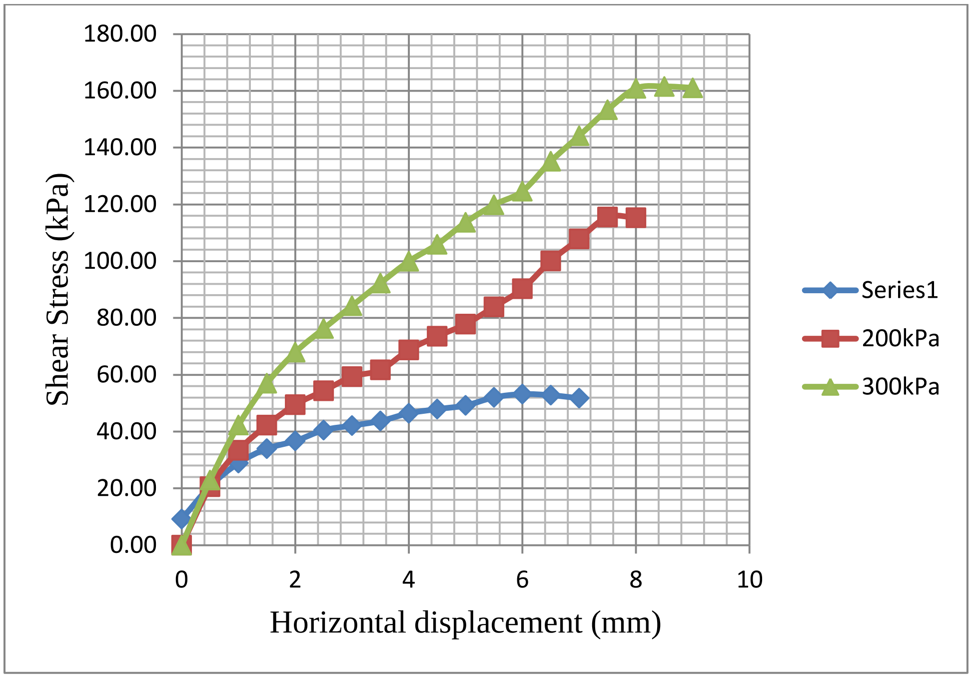
Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	66.93	102.19	169.80



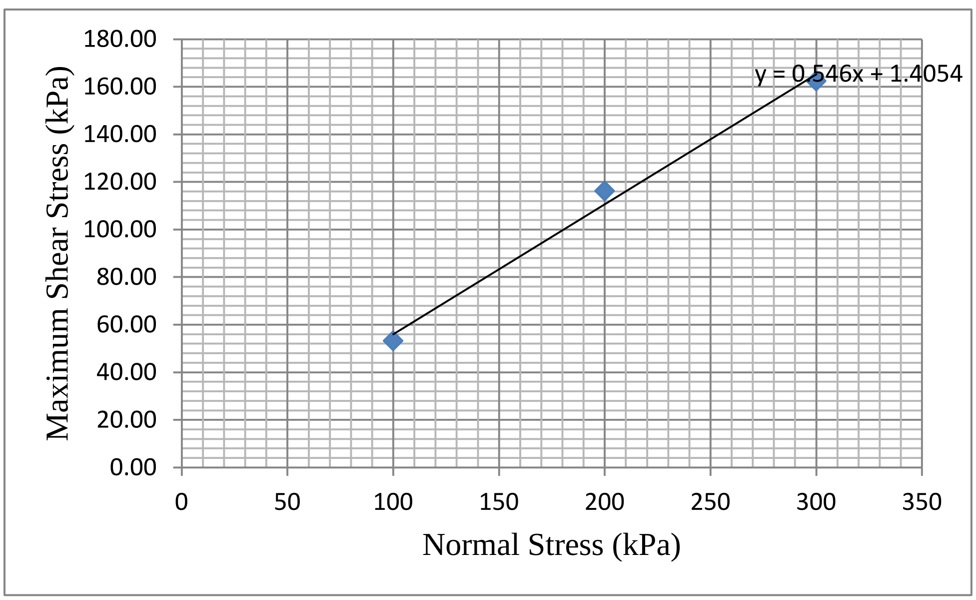
C (kPa)	ϕ (°)
10.1	27.2

Location: Shawa Beri		TP-7	Depth (m)	3	Shear test Type :	CD
Moisture Content = 11.72%		Length of sample (mm)		60	Proving Ring Cal., kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displace ment (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	47	0.03	9.22	105	0.07	20.59	117	0.08	22.94
1	0.00354	105	0.07	20.76	169	0.12	33.42	214	0.15	42.32
1.5	0.00351	145	0.10	28.92	212	0.15	42.28	286	0.20	57.04
2	0.00348	169	0.12	33.99	246	0.17	49.48	338	0.24	67.99
2.5	0.00345	181	0.13	36.72	268	0.19	54.38	376	0.26	76.29
3	0.00342	198	0.14	40.53	290	0.20	59.36	412	0.29	84.33
3.5	0.00339	204	0.14	42.12	299	0.21	61.74	447	0.31	92.30
4	0.00336	210	0.15	43.75	330	0.23	68.75	480	0.34	100.00
4.5	0.00333	221	0.15	46.46	350	0.25	73.57	504	0.35	105.95
5	0.0033	226	0.16	47.94	367	0.26	77.85	536	0.38	113.70
5.5	0.00327	230	0.16	49.24	392	0.27	83.91	560	0.39	119.88
6	0.00324	241	0.17	52.07	418	0.29	90.31	577	0.40	124.66
6.5	0.00321	244	0.17	53.21	459	0.32	100.09	620	0.43	135.20
7	0.00318	240	0.17	52.83	490	0.34	107.86	655	0.46	144.18
7.5	0.00315	237	0.17	52.67	520	0.36	115.56	690	0.48	153.33
8	0.00312				518	0.36	116.22	717	0.50	160.87
8.5	0.00309							713	0.50	161.52
9	0.00306							710	0.50	162.42



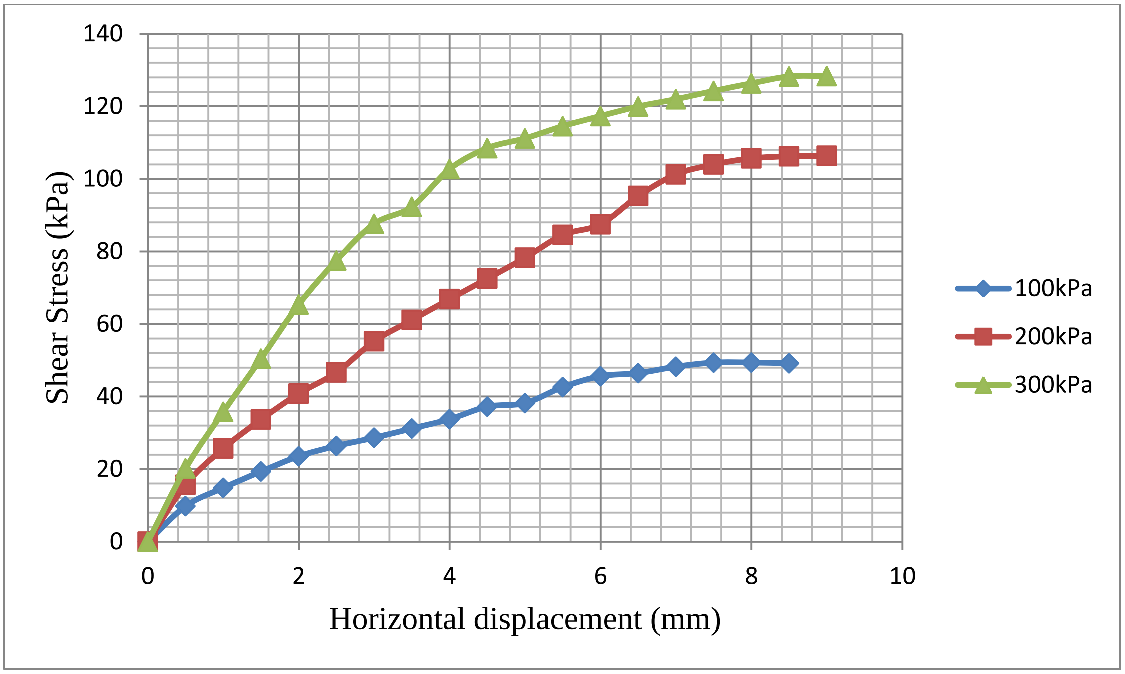
Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	53.21	116.22	162.42



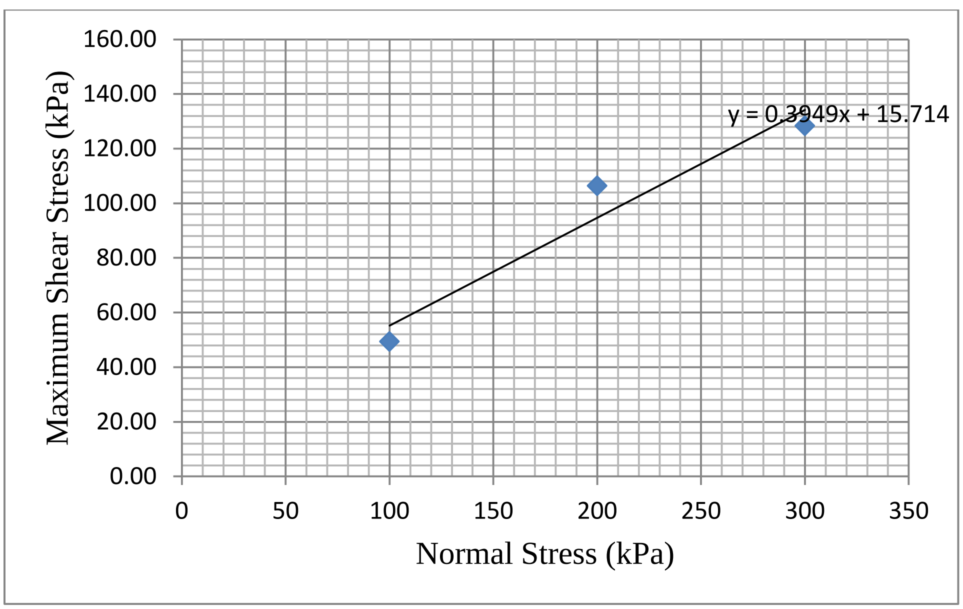
C (kPa)	ϕ (°)
1.405	28.6

Location: Ethio Telecom		TP-8	Depth (m)	3	Shear test Type :	CD
Moisture Content = 23.71%		Length of sample (mm)		60	Proving Ring Cal., kN/Div	0.0007
Area of the sample (m2)	0.0036	Width of sample (mm)		60	Hor. dial reading correction	0.01
		Depth of sample (mm)		25	Rate of Strain, mm/min	1.6

Hor. displacement (mm)	Corrected Area (m2)	For 100kPa			200kPa			300kPa		
		Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)	Proving ring factor Div	Shear Force (kN)	Shear Stress (kPa)
0	0.0036	0	0	0	0	0	0	0	0.00	0.00
0.5	0.00357	50	0.04	9.80	80	0.06	15.69	103	0.07	20.20
1	0.00354	75	0.05	14.83	130	0.09	25.71	181	0.13	35.79
1.5	0.00351	97	0.07	19.34	169	0.12	33.70	253	0.18	50.46
2	0.00348	117	0.08	23.53	203	0.14	40.83	325	0.23	65.37
2.5	0.00345	130	0.09	26.38	230	0.16	46.67	382	0.27	77.51
3	0.00342	140	0.10	28.65	270	0.19	55.26	428	0.30	87.60
3.5	0.00339	151	0.11	31.18	296	0.21	61.12	447	0.31	92.30
4	0.00336	162	0.11	33.75	321	0.22	66.88	493	0.35	102.71
4.5	0.00333	177	0.12	37.21	345	0.24	72.52	516	0.36	108.47
5	0.0033	180	0.13	38.18	369	0.26	78.27	524	0.37	111.15
5.5	0.00327	199	0.14	42.60	395	0.28	84.56	535	0.37	114.53
6	0.00324	211	0.15	45.59	405	0.28	87.50	543	0.38	117.31
6.5	0.00321	213	0.15	46.45	437	0.31	95.30	550	0.39	119.94
7	0.00318	219	0.15	48.21	460	0.32	101.26	554	0.39	121.95
7.5	0.00315	222	0.16	49.33	468	0.33	104.00	559	0.39	124.22
8	0.00312	220	0.15	49.36	471	0.33	105.67	563	0.39	126.31
8.5	0.00309	217	0.15	49.16	469	0.33	106.25	566	0.40	128.22
9	0.00306				465	0.33	106.37	561	0.39	128.33



Normal Stress (kPa)	100	200	300
Maximum Shear Stress (kPa)	49.36	106.37	128.33



C (kPa)	ф (º)
15.71	21.5

Appendix-D: One-dimensional Consolidation Test Results

Location: Digelu Gebere Mehber		Specimen type: Remolded
TP-4	Sample Depth: 1.5m	Test: Consolidation

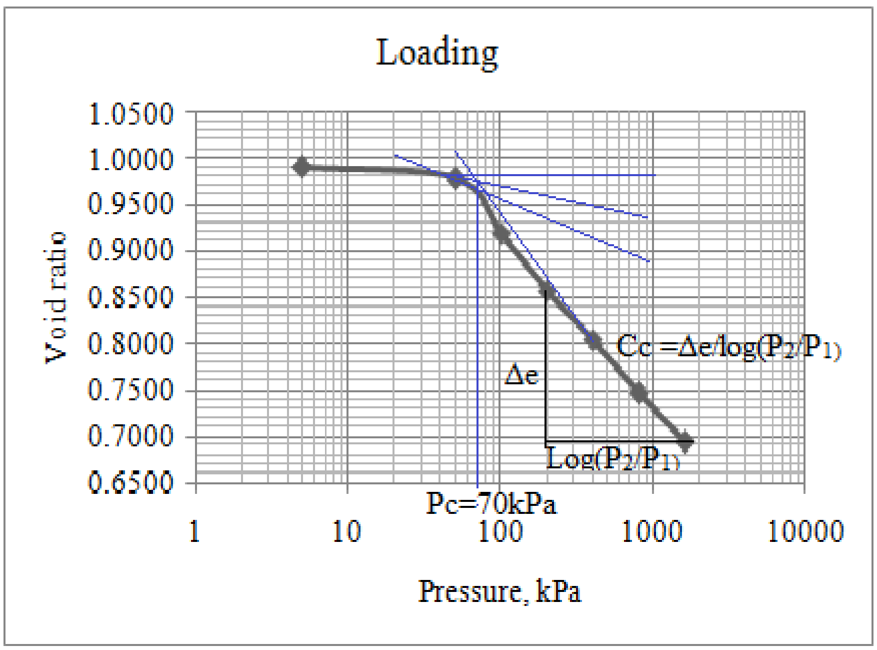
Data Before Test		Data After Test	
Natural Moisture Content (w_o), %	29.26	Mass of Ring + wet soil (M_{R+ws}), g	137.3
Specific Gravity (G_s)	2.6	Mass of Ring + dry soil (M_{R+ds}), g	121.8
Internal dia of the ring (D), mm	50	Mass of dry soil (M_{ds}), g	51.3
The height of the ring (H_o), mm	20	Mass of water (M_{wf}), g	15.45
Area of specimen ($A=\pi D^2/4$), cm^2	19.625	Water content ($w_f=M_{wf}/M_{ds}$), %	30.12
Volume of Specimen ($V=A*H_o$), cm^3	39.25	height of solids ($H_s= M_{ds}/(A*G_s*\rho_w)$), mm	10.05
Mass of Ring (M_R), g	70.5	height of Voids ($H_v= H_o-H_s$), mm	9.95
Mass of Ring + wet soil (M_{R+ws}), g	136.8	Initial void ratio ($e_o=Hv/H_s$)	0.99
Mass of wet soil (M_{ws}), g	66.3	Density of water (ρ_w), g/cm^3	1
		Bulk density ($\rho_b=M_{ws}/V$), g/cm^3	1.69
		Dry density ($\rho_d=\rho_b/(1+w_o)$), g/cm^3	1.39

Time, min	5kPa	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
0	4.13	4.132	4.251	4.844	5.456	5.993	6.58
0.10	4.13	4.21	4.45	5.037	5.638	6.264	6.743
0.25	4.13	4.212	4.481	5.069	5.66	6.285	6.764
0.50	4.13	4.214	4.502	5.092	5.692	6.302	6.788
1	4.13	4.216	4.534	5.13	5.724	6.33	6.81
2	4.13	4.219	4.57	5.167	5.748	6.334	6.84
4	4.13	4.223	4.596	5.194	5.783	6.368	6.872
8	4.13	4.226	4.622	5.216	5.81	6.392	6.899
15	4.13	4.229	4.645	5.248	5.836	6.418	6.924
30	4.13	4.233	4.678	5.273	5.867	6.44	6.95
60	4.13	4.238	4.721	5.32	5.89	6.471	6.98
120	4.13	4.24	4.744	5.344	5.914	6.498	7.003
240	4.13	4.243	4.773	5.37	5.946	6.522	7.036
480	4.1315	4.245	4.799	5.42	5.969	6.549	7.062
1440	4.132	4.251	4.844	5.456	5.993	6.58	7.101

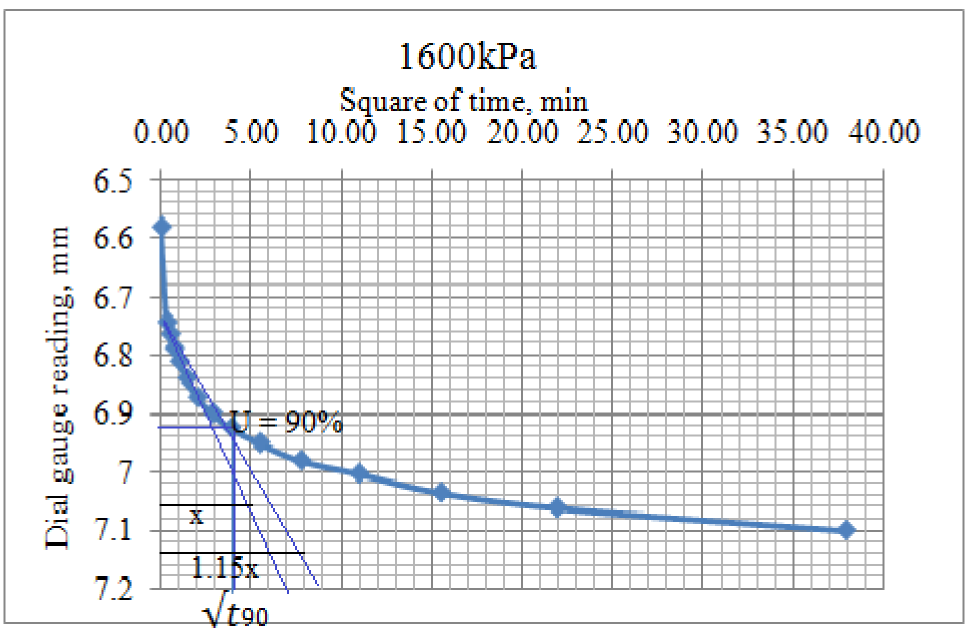
Cumulative dials gauge reading at the end of each consecutive unloading						
Dial gauge reading in mm						
1600kPa	800kPa	400kPa	200kPa	100kPa	50kPa	5kPa
7.101	7.035	6.962	6.914	6.855	6.798	6.721

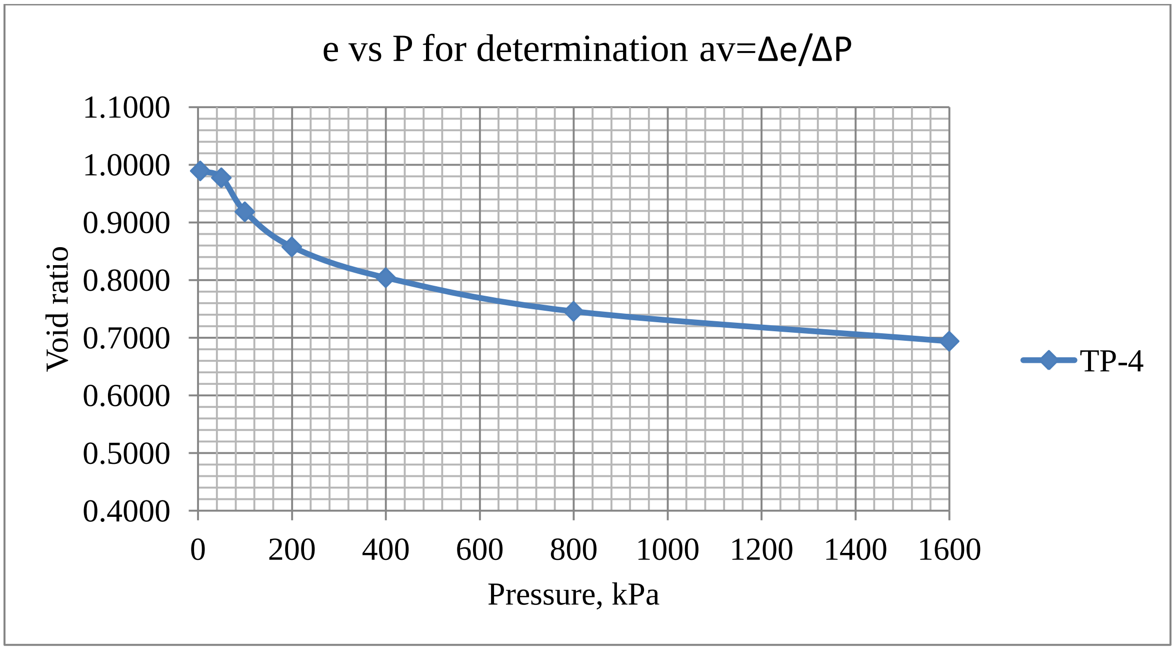
Loading											
Applied Pressure	Final Dial gauge Reading, mm	Change in specimen height (ΔHs), mm	Change in Void ratio ($\Delta e = \Delta Hs/H_s$)	Final specimen height (H_f), mm	Void height (H_v), mm	Void ratio $e = e_i - \Delta e_{i+1}$	Cv cm^2/min	Cc	P_c, kPa	P_o, kPa	OCR
5kPa	4.132	0	0	20	9.95	0.99	0	0.18	70	33.78	2.07
50kPa	4.251	0.119	0.0118	19.88	9.83	0.9774	0.132				
100kPa	4.844	0.593	0.0590	19.29	9.23	0.9185	0.057				
200kPa	5.456	0.612	0.0609	18.68	8.62	0.8576	0.044				
400kPa	5.993	0.537	0.0534	18.14	8.09	0.8042	0.027				
800kPa	6.58	0.587	0.0584	17.55	7.50	0.7458	0.031				
1600kPa	7.101	0.521	0.0518	17.03	6.98	0.6940	0.023				

P (kPa)	5	50	100	200	400	800	1600
e	0.9893	0.9774	0.9185	0.8576	0.8042	0.7458	0.6940



Dial gauge reading in mm								
Time, min	**5kPa**	**50kPa**	**100kPa**	**200kPa**	**400kPa**	**800kPa**	**1600kPa**	**SQRT(t)**
0	4.13	4.132	4.251	4.844	5.456	5.993	6.58	0.00
0.10	4.13	4.21	4.45	5.037	5.638	6.264	6.743	0.32
0.25	4.13	4.212	4.481	5.069	5.66	6.285	6.764	0.50
0.50	4.13	4.214	4.502	5.092	5.692	6.302	6.788	0.71
1	4.13	4.216	4.534	5.13	5.724	6.33	6.81	1.00
2	4.13	4.219	4.57	5.167	5.748	6.334	6.84	1.41
4	4.13	4.223	4.596	5.194	5.783	6.368	6.872	2.00
8	4.13	4.226	4.622	5.216	5.81	6.392	6.899	2.83
15	4.13	4.229	4.645	5.248	5.836	6.418	6.924	3.87
30	4.13	4.233	4.678	5.273	5.867	6.44	6.95	5.48
60	4.13	4.238	4.721	5.32	5.89	6.471	6.98	7.75
120	4.13	4.24	4.744	5.344	5.914	6.498	7.003	10.95
240	4.13	4.243	4.773	5.37	5.946	6.522	7.036	15.49
480	4.1315	4.245	4.799	5.42	5.969	6.549	7.062	21.91
1440	4.132	4.251	4.844	5.456	5.993	6.58	7.101	37.95





TP	Depth, m	Pressure, kPa	Void Ratio	Coefficient of consolidation (C_v), (cm^2/min)	Coefficient of compressibility (a_v), 10^{-4} (m^2/kN)	Coefficient of Permeability (k), 10^{-8} (cm/s)	Volume of Compressibility (m_v), 10^{-4} (m^2/kN)
4	1.5	5	0.9893	-	-	-	-
		50	0.9774	0.132	-	-	-
		100	0.9185	0.057	11.80	5.84	5.93
		200	0.8576	0.044	6.00	2.34	3.02
		400	0.8042	0.027	2.67	0.67	1.34
		800	0.7458	0.031	1.46	0.43	0.73
		1600	0.6940	0.023	0.65	0.15	0.33