Engineering Characteristics of Red Soil: A Case from Western Addis Ababa, Ethiopia

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A Thesis Submitted to School of Earth Science

Presented in partial fulfillment of the requirements for the degree of Master of Science

(Engineering Geology)

Addis Ababa University,

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Engineering Characteristics of Red Soil: A Case from Western Addis Ababa, Ethiopia

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Advisor

Dr. Zemenu Geremew

D E C L A R A T I O N

I hereby declare that this thesis is my original work that has been carried out under the supervision of Dr. Zemenu Geremew, School of Earth Sciences, Addis Ababa University during the year 2017 as part of the Degree of Master of Science Program in Engineering Geology in accordance with the rule and regulation of the institute. I further declare that this work hasn't been submitted to any other University or Institution for the award of any degree or diploma and all sources of materials used for the thesis have been duly acknowledged.

Medhanit Akalu

Signature____________________________

Place and date of submission:

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Contents

LIST OF SYMBOL AND ABBREVIATIONS

Symbols	Designation
A	Activity
AACRA	Addis Ababa City Road Authority
AASHTO	American Association of state Highway and transport Officials
ASTM	American Society for Testing Material
BS	British Standard
C	Cohesion
CBR	California Bearing Ratio
Cc	Coefficient of Compression
CL	Inorganic Silts of Low to Medium Plasticity
Cv	Coefficient of Variation
e	Void ratio
EBCS	Ethiopian Building code standards
ERA	Ethiopian Roads Authority
FS	Free Swell
Gs	Specific Gravity
LL	Liquid Limit
MDD	Maximum Dry Density
Ml	Inorganic Silts of Low Plasticity
MH	Inorganic silts of high plasticity
NMC	Natural Moisture Content
NMSA	National Meteorological Services Agency
OMC	Optimum Moisture Content
Pc	Pre consolidation pressure
PI	Plastic Index
PL	Plastic Limit
qu	Undrained Cohesion
SL	Shrinkage Limit
STD	Standard Deviation
UCS	Unconfined compressive strength
USCS	Unified Soil Classification
XRF	X-ray fluorescence

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BS 1377 –2(1990) Determination of the moisture content

BS 1377-3 (1990) Sulphate and Chloride content

ABSTRACT

Engineering Characteristics of Red soil a case from Western Addis Ababa, Ethiopia.

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Addis Ababa University, 2017

The main objective of this research work was to study the engineering characteristics of red soil in the western Addis Ababa.The engineering behavior of residual soils in the area, derived from the in-situ weathering and decomposition of parent rock, is determined by certain physical characteristics designated as engineering properties. For this work both Primary and secondary data from organizations were in use.

In this research work, some peculiar geotechnical and physio-chemical characteristics have been investigated on red soils from western Addis Ababa area. Laboratory test results indicate that the reddish brown materials are grouped under silty clayey and clayey soils. The silica to sesquoxide ratio values for two samples of 0.99 and 1.29 indicate that they are true-lateritic soils.The average values of the specific gravity, liquid limit, plasticity index and activity of clay are 2.56, 63%, 18% and 0.37 respectively. They are soils of medium to High plasticity. Free swell result gives an average value of free swell is 52; this indicates medium potential of expansiveness.

The direct shear strength test result gives an average value of Cohesion and angle of Friction respectively as 21KN/m^2 and 23^0. Maximum dry density and optimum moisture content values fall between 1.25 to 1.64 g/cm^{3}and 19 to 34% respectively. From the results of UCS average undrained shear strength gives 140Kpa.From Drilled BH data the soil thickness cross section has been produced which clearly shows that the soil thickness in the study area goes up to a maximum depth of 15m.Generally, the soils are classified as A-7-6 to A-7-5 subgroups of the AASHTO classification and according to Unified soil Classification system classify the soil as MH and CL. Finally, based on the general findings of the study, suitable recommendations have been forwarded.

Key words: residual soils, physio-chemical characteristics, index tests, mechanical tests and chemical tests.

CHAPTER 1 INTRODUCTION

These days infrastructures in and around Addis Ababa have been constructed in areas covered with soil. However the engineering properties of such soils have not been studied systematically. Residual red soils are formed by weathering and decomposition of rocks. They are rich in sesquioxides (Fe_2O_3 or Al_2O_3) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Due to the presence of iron oxides these soils are red in color ranging from light through bright to brown shades (Blight,1997).

Red soils occur mostly in tropical and sub-tropical regions with hot, humid climatic conditions. It has been suggested that a mean annual temperature of around 25°C is required for their formation, and in seasonal situations there should be a coincidence of the warm and wet periods. (Ciara, 1995).

Red soil is a widely available material in Ethiopia as mentioned by Ethiopian Roads Authority design manual (ERA, 2001). Roads constructed on such soils face a lack of construction materials to be used. To use this soil as construction materials its detailed engineering properties should be well studied and known.

This research aims at investigating the engineering characteristics of Red soil in and around Western Addis Ababa. For this to be achieved, different laboratory soil tests has been carried out and secondary data from private and governmental organizations was collected, processed and analyzed during the course of this research.

1.1 Background

The capital of Ethiopia, Addis Ababa, is expanding in all direction new commercial buildings, residential houses and roads infrastructures are under construction. Such rapid development needs engineering geological information for planning and design.

The geotechnical properties of residual soils are controlled by their mineralogical composition. It seems logical that the first level of any classification system should take account of the factors giving rise to their development. This entails the identification of the environmental factors (climate, parent rock, drainage conditions, etc) and the geological processes that lead to the formation of particular soil types. At the same time, the geotechnical properties of the soils must be determined.

The heterogeneity nature of soil makes it very difficult to conclude on the behavior of soil without some fundamental geotechnical investigation. Observations show variations in properties from point to point on the ground because of inherent differences in composition and consistency during formation.

There are few research works related to red soil engineering property in Addis Ababa; Hailemariam, (1992), Merihun, (2010) and Yodit, (2012), which focuses on Addis Ababa red clay soil mechanical behavior regarding red soil's deformation, permeability, strength and stress-strain behavior, correlation between critical state soil parameters, index properties of remolded red clay soils of Addis Ababa and the stress-strain behavior of undisturbed red clay soil and the shear strength characteristics has been studied previously.

1.2 Problem Statement

Despite the large coverage and use of the residually formed soils in Ethiopia, there has been few systematic research, standardization in testing, classification or description of these materials. Studying the engineering characteristics of soils and evaluating their behavior are very important. Ethiopia is one of the developing countries which are under the pressure of economic development. In order to satisfy the need, the country is on the move of huge expenditure on construction of high-rise buildings, bridges, water supply pipes, and other infrastructure throughout the country especially in around Addis Ababa.

Adequate knowledge of the sub-surface geology and determining the engineering characteristics of the soil is therefore very crucial for the safety and serviceability of the engineering structures. There are few number of research findings on the evaluation of red soil engineering behavior. Therefore, It is believed that more researches on the red soil need to be conducted in order to satisfy the requirements for the unceasing construction work demands in the country and in and around Addis Ababa in particular.

1.3 Significance of the Study

It is obvious that areas which have a well-studied engineering geological evaluation demand very little cost to accomplish additional site specific studies. The findings of this research work will help the investment companies to have a general understanding of the engineering property of the red soils. Therefore, this may minimize the cost for detailed engineering studies on the ground. It is strongly believed that the study may contribute much through the present study. Furthermore, it is the significance of this research paper to add additional information on the engineering properties of red the soil thus to minimize the risk of any probable damage to the buildings or road constructions in the study areas.

It is also wise to understand that areas with plenty of prior engineering geological studies in the study areas will possibly attract more investment than areas with less similar studies. Therefore, this study work can be conspicuous as one of the resources on the engineering geological characteristics of red soil in western part of Addis Ababa so that it acts as background knowledge for future engineering studies in the area.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of the study is to assess the engineering characteristics of Red soils in the Western part of Addis Ababa, study area.

1.4.2 Specific Objectives

The study has the following specific objectives:

- To characterize the physio-chemical properties of red soil.
- To investigate the engineering properties of red soil.

- To assess the vertical and lateral variation of red soil.
- To provide recommendations on using red soils for construction purposes.

1.5 Methodology

To accomplish the above objectives of this research, desk study was applied which include literature review, understanding of existing site investigation reports, identification of potential red soil coverage area through topographical maps, gathering of engineering geological and topographic maps. Besides, collection of secondary data of drilled borehole logging and laboratory test results for selected red soil samples in the study area has been done. In addition, the researcher assessed information about the geology, hydrology, climate, and drainage conditions was also utilized.

The literature survey encompasses both published and unpublished reports of investigations, published textbooks and journals that are obtained from different sources for better understanding on the characteristics of the red soil in study area. Field work has been done to gather primary data on the geology, topography and soilformations of the study area. Beside five test Pits were excavated and representative disturbed and undisturbed red soil samples were collected for further analysis on physical, mechanical and chemical properties. Afterwards, post field activities such as data organization of Soil samples laboratory test result from secondary data and primary data for further analysis and discussion has been done.

Some of the index, chemical and mechanical laboratory soil test results which were used for the analysis include consistency limit tests, particle size determination, specific gravity, moisture content, odometer test, compaction test, direct shear test and chemical tests.After wards range of values for the laboratory test results were presented in the summary formBy means of all organized data and the interpretations made on it, the red soil's engineering property has been characterized. Microsoft excel were used to organize and give statistical figure of collected data. In addition ArcGis Software is used to present collected data and area coverage of the soil in a map form.

1.6 Scope of the study

This study particularly focuses on the engineeringcharacterization of thered soils in study area based on laboratory testing from primary collected samples and analyzing secondary data on the red soil from the study area.

1.7 Limitations

This research study has to undergo some limitations during the process of data collection. The secondary data sources were unable to provide the researcher crucial data for the study.And the secondary data lack well organized geo-database system. In addition to this,in many institutions, limitations of laboratory tools for mineralogy tests (XRD) equipment were observed.

1.8 Thesis Outline

Chapter 1: Gives a general introduction, includes background of the study, problem statement, objectives of the study, methodology, significance of the research, and scope of the study and outline of the thesis.

Chapter 2: Reviews wide and detail literatures regarding to red soils. This comprises a brief description about red soils and discusses previous works relevant to the present research.

Chapter 3: Provides an overview of the regional geology, description of the study area including geographical location, climate, geology, physiography and drainage conditions, hydrogeology and the Red soils distribution of Addis Ababa.

Chapter 4: Discusses mainly on the methodology of the current research, how both primary and secondary data were organized, analyzed and processed.

Chapter 5: Addresses data processing techniques, analysis and discussion of test results on major laboratory test methods. Beside a range of values for the engineering property, discussion on the classification, genesis and thickness of red soils in the study area. It also presents a detailed description of the engineering properties of Red soil.

Chapter 6: Focuses on the conclusions and recommendations forwarded through the present research work.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Soil can be described as residual or transported on the basis of the mode of formation. Residual soils are derived from weathering of parent rock at the original location. Whereas transported soils are those which are formed from the rock weathering at one location and transported by wind, water, ice, or gravity to the present site. (Brink, 2015)

Residual red soils are tropically weathered soils with a high concentration of sesquioxides of iron and alumina. They exist in wide range of chemical composition. Silica content varies from low to medium and exists usually as kaolinite, whenever it is found in substantial amounts.(Blight, 1997).

The engineering properties of residual soils vary considerably from the top layer to the bottom layer. Residual soils have a gradual transition from relatively fine material near the surface to large fragments of stones at greater depth. The properties of the bottom layer resembles to that of the parent rock in many aspects. Its thickness is generally limited to few meters (Blight, 1997).

2.2. Review on Tropical Red Soils

The chemical and mineralogical changes through weathering as well as the changes in physical characteristics of tropical soils endorse the unique characteristics that can be attributed to the compositions and micro structure of a material developed under hot and wet soil forming conditions. Geology, climate and topography are some of the major influencing factors in tropical soil formation and the subsequent properties of these materials (Brink, 2015, P.4).Similarly, Brink (2015) explained that the nature and properties of tropical residual soils are directly related to the weathering of rock masses in situ and are intimately associated with the mineralogy of the parent materials, the nature of the tropical climate and on drainage conditions.

With regard to the type of residual red soil formed over various types of parent rock under well-drained conditions, the sesquioxides of iron and aluminum can occur due to the weathering of practically all igneous rocks. Pyroclastic and other extrusive volcanic rocks can also produce allophane and Metahalloysites in addition to kaolinite, particularly under cooler climatic conditions encountered at higher altitudes.

According to Wesley (2009), in tropical red soil the predominant mineral is halloysite but may also contain kaolinite, with gibbsite and goethite. Halloysite particles are generally very small in size but are of low activity, and soils containing Halloysite as the predominant mineral generally have good engineering properties. Red clays generally form in well drained areas in a tropical climate having a wet and dry season.

When considering residual tropical red soils formed over various types of parent rock, the sesquioxides of iron and aluminum and kaolinite are formed through the weathering of basically all igneous rocks, with kaolinite clays representing the eventual end product of weathering (Northmore et al., 1992).

The red soils normally occur on sloping ground close to local high points where there is good drainage, with a vegetative cover of little organic matter and high temperature and rainfall. Water removes the more soluble bases and silica, leaving the soil rich in iron, in the form of iron oxide, and aluminum, as clay minerals of the kaolin group (Dumbleton, 1967).

Moreover, according to ERA (2013), these soils are present in the western part of Ethiopia, western and north-western highlands, southern lowlands and southern rift, most parts of the central highlands, and in pockets of well drained lands throughout the north-east and eastern highlands.

2.3 Origin and Formation of Residual Soils

Particles of residual soil often consist of aggregates or crystals of weathered mineral matters that breakdown and become progressively finer if the soil is manipulated (Blight, 1997). Residual soils are usually originated and formed through the effect of weathering process, climate, and topography.

2.3.1 Weathering Process

As stated by Blight (1997), residual soils are formed by the in situ weathering of rocks, through physical, chemical and biological processes. Most commonly, residual soils are formed from igneous or metamorphic parent rocks. However, residual soils formed from sedimentary rocks are also common. Chemical processes tend to predominate in the weathering of igneous rocks.

Physical weathering, which is the outcome of mechanical development, generates end products consisting of angular blocks, cobbles, gravel, sand, silt and even clay sized rock flour. These end products have mineral compositions which are exactly like those of the original rock. On the other hand, chemical weathering produces the decomposition of rock and the formation of new minerals. Intemperate or semi- tropical zones, the chemical changes in primary minerals tend to produce end products consisting of clay minerals that prevail Kaolinite and occasionally by Halloysite and by hydrated or dehydrous-oxides of Iron and Aluminum (Blight, 1997).

On volcanic rock or ash deposits which have undergone a relatively short period of weathering, or at altitudes where cooler climatic conditions prevail, amorphous allophane and amorphous or crystalline halloysite clay minerals may be dominant. Smectites (montmorillonites) may also develop during the early weathering stages of volcanic materials. Ultimately, with prolonged weathering under appropriate conditions, kaolinite and gibbsite may form (Northmore et al, .1992).

2.3.2 Climate

As mentioned by Fredlundand (1993), climate exerts a considerable influence on the rate of weathering. Physical weathering is more predominant in dry climates while the extent and rate of chemical weathering is largely controlled by the availability of moisture and by the temperature. He asserts that climate has further effect on the properties of tropical residual soils. In sub humid tropical and subtropical areas water tables are often deeper than 5 to 10 m and the effects of un-saturation, desiccation and seasonal or longer term rewetting have to be taken into account in geotechnical design. There are many accounts of the effect of un-saturation on the behavior of soils (Fredlundand, 1993).

2.3.3 Topography

Topography determines the amount of available water for each zone of weathering. The accumulation of soils in valleys and hollows is the effect of precipitation. On hillsides, the depth of weathering increases down the slope, whereas, Kaolinite/Halloysite is the predominant clay minerals at the top of the slope and Smectite at the bottom of the slope (Blight, 1997). Moreover, Van Schuylenborgh (1971), pointed out that on slopes, a relative decrease in silica content may be achieved at lower elevations by the deposition of sesquioxides transported down the slope by groundwater. Although kaolinite is the dominant clay mineral formed as a result of prolonged tropical weathering.

2.4. Engineering Characteristics of Soils

A soil mass, as explained by Blight (1997), is always subjected to changing environment, depending upon the chemical and physical properties of the soil, the necessary actions for construction purposes will be taken. Soil properties need to be studied to improve the workability of the soil, therefore studying soil properties inside out is very important. Soil properties can broadly be divided into two categories depending upon their properties achieved during soil formation process; physical properties and chemical properties of soil. One of the physical properties of soils is color. Its reddish color is mainly associated with the weathering condition, drainage and wetness. According to Gilloth (1962), greenish, bluish, and grayish colors in the soil indicate wetness, whereas, bright colors (reds and yellows), on the other hand, indicate well-drained soils. Dark colors in the soil usually indicate organic matter. They may also indicate wetness for wetter soils can accumulate more organic matter.

As explained by Mitchell and Sitar (1982), tropical red soils are highly sensitive to changes in the natural moisture content of the material, with such changes typically resulting in irreversible changes in the physical properties of the material.Similarly, they are highly sensitive to structural breakdown and treatment. (Brink, 2015).

The tests required for determination of engineering properties of soils are generally elaborated and time consuming. Sometimes the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests. This is possible if index properties are determined. The properties of soils which are not of primary interest to the geotechnical engineer but which are indicative of the engineering properties are called index properties. The most widely used are the particle size distribution and the soil consistency tests. Moisture and density relationships are also commonly used as index properties both in evaluating foundations and to control compaction, even though their determination is required in connection with other test results(Arora, 2004).

Determination of the moisture content is required as a guide to classification of soils and to evaluate the behavior of soils during construction. This is determined by using the oven drying method. The moisture content relates only to the water which is removable by oven drying at 105-110°C (Das, 2005).

Soil laboratory test analysis is an examination by which the quality of soil is determined. The process of examining a soil under known conditions in order to determine quality, identify its constituents. The physical properties of material are tested in order to determine their ability to satisfy particular requirements.(Arora, 2004)
Free swell characteristics to estimate swell potential of a soil were classified accordingly by (Holtz and Gibbs, 1956). Those soils with free swell of less than 50% are considered to have low degree of expansion.(Table 2.1)

Table 2.1 Free Swell Classification (Holtz and Gibbs, 1956)

Free Swell Value	Free swell characteristics	Potential Expansiveness
<50	Low	Low
50-100	Medium	Medium
100-200	High	High
>200	Very High	Very High

Depending on the initial moisture content of the soil, the material may exist in four possible states: solid, semi-solid, plastic and liquid. In each state the consistency and behavior of the soil is different, these influence the engineering properties of the soil. The boundary between each state signifies a change in the soil's characteristics and behavior at that specific moisture content, and these are known as the Atterberg Limits(Das, 2005).

Activity of a soil is used as an index for identifying the swelling potential of clay soil. According to Skempton (1953) the plasticity index of a soil increases linearly with the percentage of clay-size fraction (% finer than 2μm by weight) present. Activity is the slope of the line correlating PI and % finer than 2μm. Depending upon activity the soil can be classified as inactive, normal and active The soil containing clay mineral Montmorillonite have very high activity (A>4). The mineral Kaolinite are least active (<1), whereas the soil containing the mineral Illite are more active (A=1 to 2). Inactive clays: A<0.75, Normal clays: 0.75<A<1.40 and Active clays: A> 1.40. (Arora, 2004).

Table 2.2 Qualitative classification of plasticity index (Burmister, 1949)

Plasticity Index,%	Description
0	Non plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
Above 40	Very high plasticity

The shear strength of soil is an important aspect in many foundation-engineering problems related to stability such as the bearing capacity of shallow foundations and deep foundation.

Different authors used different classification techniques to classify residual tropical soils on the basses of the mineralogical composition alone. As stated in (Lyon, 1971), the AASHTO classification system is convenient as the bases for classifying residual soils in addition to the Unified soil classification method.

2.5 Red Soil Distribution in Ethiopia

Ethiopia is one of the countries in the tropical zone. Consequently, the various soil forming factors in the tropical areas influences the red soil distribution in Ethiopia. Some of the factors are climate, regional landform, local topography and the underlying parent materials. Drainage is an important factor in the formation of some soils.

According to ERA,(2013) Red soils can be formed from many kinds of rocks if the weathering conditions, climate and drainage are suitable. In Ethiopia, they have developed mainly on volcanic (basalts, ryholites, etc.) and pyroclastic rocks. In the western part of the country they have also been seen on granitic terrains. The iron oxide in these soils, which accounts for their dark red color, occurs in a hydrated (goethite) and an unhydrated form (hematite). Goethite and hydrated halloysite predominate under wetter conditions. The clay mineral is usually kaolin of the halloysite type, which occurs as hydrated and meta-halloysite. Hydrated halloysite is readily converted to meta-halloysite on drying. Kaolin in the form of halloysite has a disordered structure, which gives rise to a soil of higher potential plasticity than well-ordered kaolinites.

Red soil deposits are present in the western and north-western highlands, southern lowlands and southern rift, most part of the central highlands, and in pockets of well drained lands throughout the north-east and eastern highlands of Ethiopia. The southern and western parts of Ethiopia are characterized by residually formed laterites that are widely used as construction materials and have been found satisfactory for many earthworks applications (Teklay, et.al, 2015).

2.5.1 Red Soil Distribution in Addis Ababa

Geotechnical drilling data and engineering geological map of Addis Ababa, reveal that red clays in Addis Ababa are dominantly underlain by basalts; basic (dark colored) igneous rock rich in iron and magnesium(Kebede Tsehayu et al.,1990).

Geotechnical data from 1996 to 2014 shows red clays in Addis Ababa are extensively distributed around Gulele sub-city, Burayu and part of Kolfe Keraniyo specifically around Atanatera. Some part of Addis Ketema and Arada sub-cities are also covered with red clays. (Lamesgin Melesse, 2014).

Similarly, a study by the GSE (2009) , showed that the red clay deposit that occurs in Burayu area is the product of alteration of trachaitic Basalt rocks. Geotechnical drilling data revealed that red clays in Addis Ababa are dominantly underlain by basalts. Besides, from the engineering geological map of Addis Ababa (Kebede Tsehayu et al., 1990), localities where red clays are found are underlain by dominantly of basalts although there are places in Gulele where red clays are underlain by rhyolite.

Other regions with red soil include parts of localities such as Kokebe-Tsebah and British Embassy through Kotebe College of Teachers Education are underlain by rhyolites. From these observations, it can be roughly generalized that red clays of Addis Ababa are dominantly derived from basalts and rhyolites(Lamesgin Melesse, 2014).

2.6 Review on Engineering Property of Red Soil in Ethiopia

The first systematic study of tropical weathered residual soils in Ethiopia was carried by Morin and Parry (1971). They stated that the Ethiopian red soils have formed as residual from basaltic volcanic rocks in places with plenty of rainfall and good drainage. The principal clay minerals that constitute the Ethiopian red soil are kaolinite and halloysite. Montmorillonite is also found in the Ethiopian red soil in lesser amount. The red color of the Ethiopian soils indicates the presence of iron.

Table 2.3 Review on Properties of Ethiopian red clay soils (Morin and Parry, 1971)

Properties	**Values/Results**
Parent rock	Olivine Basalt,Basalt,Trachyte.
Rain fall,cm/Yr	122-234
Temprature,^{0}F	57-68
Drainage	Fair- good
Principal clay minerals	Kaolinite,Hallysite,Montmorillonite
PH-Value	5.1-6.8
Principal Cations	Calcium,Magnesium,Potassium
Cation Exchange Capacity,m.e/100g	30-77
Clay(2),µ%	34-76
Liquide Limit,%	44-66
Plasticity Index,%	14-30
Shrinkage Limit,%	10-30
Specific Gravity	2.61-2.91
Organic Content,%	1-4

Max Density G/cc OMC,%	1.18-1.69 38-29
CBR Test Value	6 - 9
Unconfined compressive Strength,Kpa	147-251
Expansion Pressure, Kpa	21-958

Moreover, the Ethiopian red clay is found to be acidic, which is similar to that of other tropical soils. The cation exchange capacity is from 30 to 77 milli-equivalents per 100g. The Ethiopian red clay soils do not show wide range in index properties as compared to other tropical soils. They have also generally lower clay contents, liquid limits and plasticity indices. The shrinkage limit of the red clay varies from 10% to 30%. (Table 2.3) The volume change tendency of the Ethiopian red clay soil is also significant at the lower moisture content. However, red clay soils are less expensive than the Ethiopian black clay soils because of high amount of kaolinite and halloysite relative to Montmorillonite. The unconfined compressive strength of the red clay soil varies from 147 to 251kpa and has even more strength. The Ethiopian red clay soils have similar densities, however, lower dry density than other tropical soils when compacted according to AASHTO standard. The red clay soil shows less plasticity but some are near to the dividing line between low plasticity and high plasticity groups (Morin and Parry,1971).

Research work by Merihun Lukas (2010), titled with the Effect of remolding on mechanical behavior of Addis Ababa red clay, was observed the effect of soil remolding on the mechanical behavior of red clay of Addis Ababa. He tried to identify the effect of remolding by conducting a series of laboratory tests such as triaxial compression and consolidation tests on the undisturbed and remolded soil samples. The soil was remolded by compacting at optimum moisture content and conduct basic tests to see the engineering properties of the soils. The one dimensional consolidation tests were done on samples of diameters of 50mm and 70mm and height of 18mm with the effective consolidation stresses of 50 kpa to 1600 kpa. A total of eight one-dimensional consolidation tests were done. Triaxial test done on soil samples collected from Kolfe areas were conducted on Automatic triaxial testing machines and samples collected from Addisu-gebeya. A total of twenty-four triaxial CU tests were run out of which twelve were undisturbed and twelve were remolded. The results of triaxial tests were used to examine the stress-strain and strength behavior.

Table 2.4 Summary of test results from Merihun Lukas (2010)

No	**Station**	**LL**	**PL**	**PI**	**SL**	**Free swell**	**Moisture content**	**Specific Gravity**	**Bulk Density**
1	**Kolfe**	61	27	34	12	20	22	2.72	1.92
2	**Addisu-gebeya**	72	33	39	20	32	28	2.71	1.9

The test results shows when the heavily over-consolidated red clays collected from Kolfe and Addisu-gebeya remolded at OMC and tested under: the oedometer undergo large deformation, 1.87mm to 3.51mm, because of remolding resulted in larger initial void ratios, 0.769 to 0.917, than undisturbed samples due to low preloading stresses/ compacting effort, 100kPa to 220kPa, that the soil has ever experienced, oedometer shown smaller coefficient of consolidation, 37.15m2/yr. to 8.38m2/yr., and result in reduced permeability, 0.119m/yr. to 0.003m/yr. This could be because of short time for the soil grains of remolded samples to be arranged in the favorable condition, triaxial compression result in low deviator stresses in general, because of low pre-shearing stresses that the remolded samples had ever experienced (Merihun Lukas, 2010).

CHAPTER 3 THE STUDY AREA

3.1 Introduction

This chapter deals with the description about the study area which includes the location of study area, geologic, topographical, climatic and hydro geologic conditions which possibly have influenced the formation of Red soil. This section also addresses the distribution of red soil in the study area and its surrounding. In addition, meteorological data which gives information about temperature and rainfall conditions in Addis Ababa is also included.
Red soils have various industrial application in many parts of the country but the most widespread application is in the construction industry. According to study from GSE(2001) around the study area specifically in Gulele and Burayu there are local brick manufacturing factory that uses the red soil.

3.2 Location of the Study Area

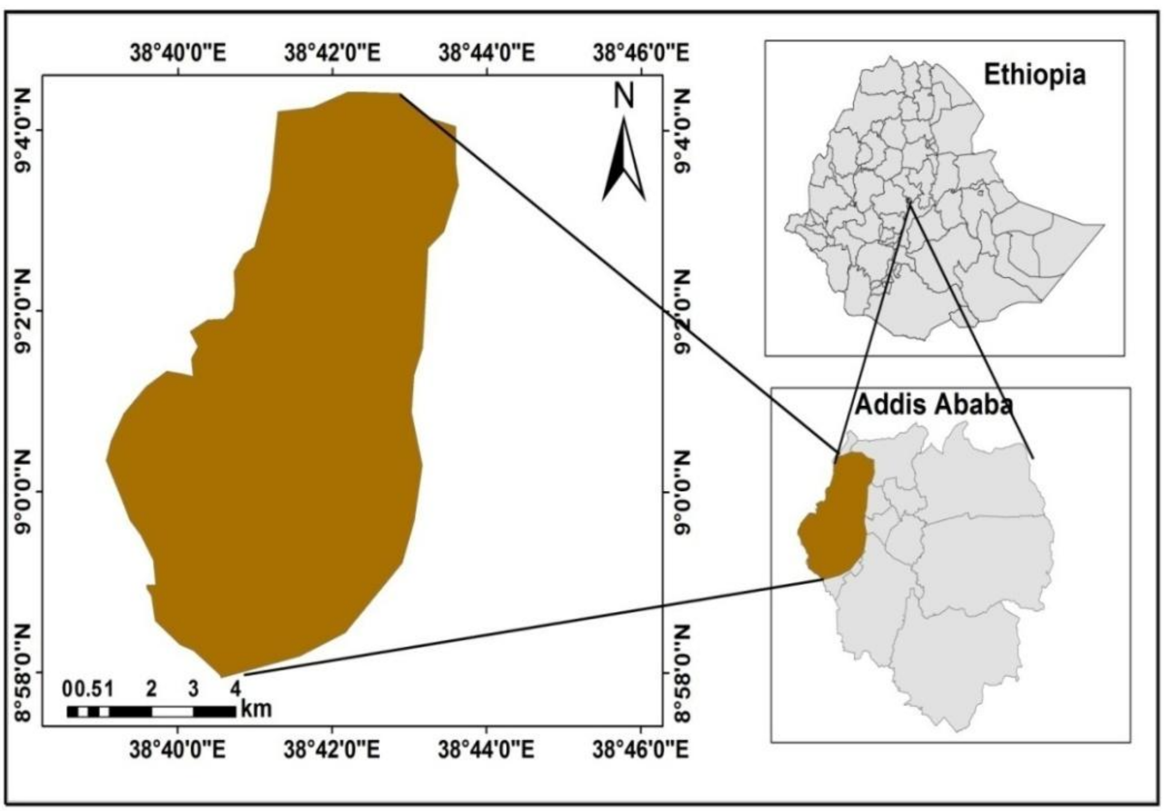

Fig 3.1 Location Map of the Study Area

The Study area is located in western side of Addis Ababa bounded approximately by the coordinate’s longitude: 8^{0}58'80"N, 9^{0}4'00"N and latitude: 38^{0}39'00"E, 38^{0}44'00"E. The area coverage for the current study is approximately 176.32 sq km,which includes the localitiesof Kolfe Keraniyo, Addis Ketema and parts of Gulele and Arada.(Fig 3.1)

3.3 Regional Geology of Addis Ababa

Addis Ababa is located in the western margin of the Main Ethiopian Rift Valley. The marginshows Mio-Pliocene volcanic and is characterized by normal faults down thrown towards the rift. The upper (outer) boundary of the margin is marked by the large fault running approximately east-west immediately north of the Addis Ababa-Ambo road.The lower boundary run northeast to southwest parallel to the principal systems of fissures of the rift-floor from Nazareth to awash Station (Zanettin and Justin, 1974).

Various researchers systematically proposed the geology and volcanic stratigraphic sequences of Addis Ababa area. Haile Selassie Girmay and Getaneh Assefa (1989) proposed the stratigraphy of Addis Ababa area based on K/Ar absolute age determination taken from different literature and field work.The suggested Miocene-Pleistocene volcanic succession from bottom to top is Alaji Basalts, Intoto Silicics, Addis Ababa Basalts, Nazareth Group and Bofa Basalts.

3.3.1 Alaji Basalts

This unit is composed of basalts, which show variation in texture from highly porphyric to aphanitic. The unit is intercalated with gray and glassy welded tuff. The outcrops of Alaji basalts are situated in the North and Northeastern part of Addis Ababa. They form high topography and Rhyolites have more area extent than trachytes. Trachytes and rhyolites are contemporaneous in age. The Alaji basalt is underlain by tuffs and ignimbrites and is overlain by the Entoto Trachyites (Haileselassie Girmay and Getaneh Assefa, 1989)

3.3.2 Entoto Silicic

The unit is unconformably overlain by Addis Ababa basalt on the foothills of Entoto hills andis composed of rhyolites and trachytes with minor amount of welded tuff and obsidian (Hailesellase Girmay and Getaneh Asefa, 1989). The rhyolitic lava flows outcrop on the top and the foothills of the Entoto ridge, predominantly in the western side. It also outcrops in the eastern part of the town around Kokebe Tsebah School. The thickness is quite variable as it frequently forms dome structure. The thickness becomes maximum on the top of Entoto ridge and thin both towards the plateau and the plain east of Addis Ababa.The rhyolites are overlain by porphyritic trachytes and underlain by a sequence of tuffs and Ignimbrites. Tuffs and Ignimbrites are welded and characterized by columnar jointing. The trachytic lava flows outcrop on the top of Entoto Ridge and its foothills. The trachyte and the alaji aphanitic basalts are separated by paleosoil indicating time gap.

3.3.3 Addis Ababa Basalts

Stratigraphically, this unit is underlain by the Entoto silicics and overlain by lower welded tuff of the Nazareth group. It is porphyritic in texture and mainly present in the central part of the city (Hailesellase Girmay and Getaneh Asefa, 1989). Olivine porphyritic basalts outcrop around Merkato, Teklehamanote and sidest Kilo. The Lower Welded tuff overlies both types of basalt nearby the building college, the kolfe Police School, the Kokebe Tseba School and Yeka Mariam church. On the other hand, only in the gorge of the Ketchene stream the olivine porphyritic basalt is overlain by the plagioclase porphyritic basalt.

3.3.4 Nazareth Group

The units identified in this group are lower welded tuff, aphanitic basalt and upper welded tuff. Welded tuffs have been related to Wachecha and Yerer Volcanisms. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly south of Filwoha fault and extended towards Nazareth (Hailesellase Girmay and GetanehAsefa, 1989). The units in this group are Lower Welded Tuff,Aphanitic Basalt and Upper Welded Tuff

3.3.4.1 Lower Welded Tuff

It outcrops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta. Generally it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase porphyritic basalt. The age of this unit overlaps with the period of the activity of wechecha trachyte volcanoes.

3.3.4.2 Aphanitic Basalt

It covers the southern part of the city, especially the area of Bole International Airport and Lideta Old Airfield. The rock body shows vertical curved columnar jointing together with sub-horizonal sheet jointing. Along the course of Akaki River large amygdales of calcite occur in this basalt. Kaolinite lenses are present at the contact with the younger ignimbrite.

3.3.4.3 Upper Welded Tuff

It outcrops all over the southern part of the city including Bole, Nefas Silk and Railway Station; nevertheless it is also present in the central and northern part of the city. It is gray colored, vertically and horizontally jointed and composed of sanidine, anortoclase, rebekite, quartz, pumice and unidentified volcanic fragments (Hailesellasie Girmay and Getaneh Assefa, 1989). The welded tuff is underlain by aphanitic basalt and overlain by young olivine basalts.

3.3.5 Bofa Basalts

Bofa Basalts outcrop southward from Akaki River where they appear in the form of boulders reaching a thickness of 10 meters. They are restricted and dominated in the southeastern part of the city. This rock is characterized by big vesicles that are filled by calcite. This basalt is underlain by the tuffs which cover the welded tuff.

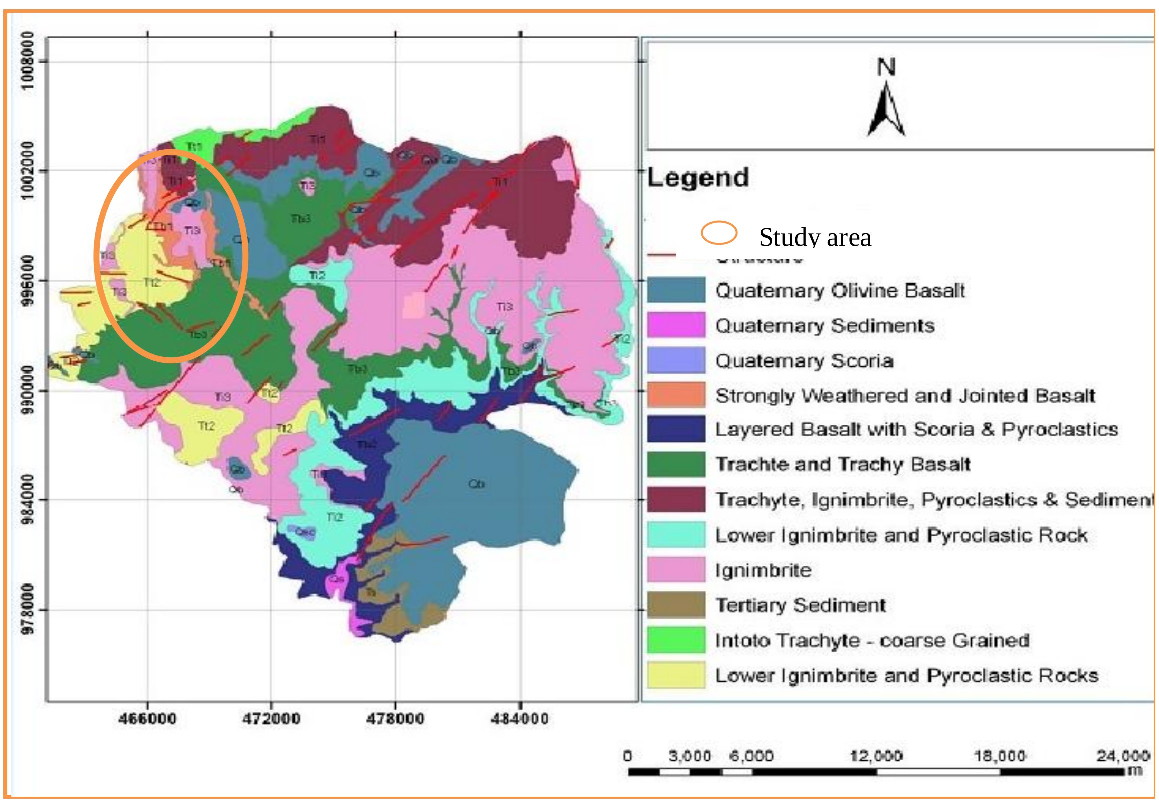

Fig.3.2 Geological map of Addis Ababa area (modified from Asegid Getahun, 2007)

3.4 Local Geology of Study Area

The geological history of the study area is an integral part of the evolution and development of the Ethiopian Plateau and the Rift system. The area is covered by different volcanic rocks with both acidic and basic compositions and overlain by residual soils varying in thickness from a few cm to about several meters.(Morton, 1979).

According to geological map of Addis Ababa(Fig 3.2) Trachy-basalts, Ignimbrites and Basalts are the major outcrops in the western parts of Addis Ababa.The trachy-basalts cover places around General Wingate School. They are slightly weathered and intersected by fractures. The red soil, which is formed on ignimbrite rock, as observed around Asko Condominium site to a shallower depth of up to 2m during sampling has two layers based on colour variations: the lower light red soil and the upper dark red soil. The change in colour between the two layers is not sharp but gradual.

The geology in the study area cover with Addis Ababa basalt mainly alkaline and olivene basalt and Addis Ababa Ignimbrite covers part of Gulele, Addis Ketema and Arada subcity. central volcanics of wechecha, Entoto, pyroclastic trachytic lava flows covers most of Kolfe keraniyo subcity. Moreover, the degree of weathering, fracturing and morphology of the area plays a great role in controlling the development and thickness of soil horizon above the aphanitic basalts. The physical disintegration and chemical decomposition become more pronounced along the surface of the joint sets.

Borehole logs produced prior to the construction of the condominium houses in the study area shows that the thickness of the residual red soil layer in the area is about 0.5-15m thick. Furthermore, the ignimbrite rock is found below a depth of 2m from the ground surface around Asko,Addis sefer Area.

3.5 Soil Distribution in Addis Ababa

The soil development in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks, the weathering products are either remaining in places and fromed residual soils or transported and deposited in low lying flat lands and depressions(Tamiru Alemayehu et al., 2006).

The detrital materials derived from elevated areas around the city from Entoto, Wechecha, Furi and Yerer are transported and deposited in the piedmont and along the stream courses of Addis Ababa. The black soil covers most parts of Mekanisa, Ayertena, Akaki, Kality, Lideta and Bole. Old basic and acidic rocks that control in the central, western and south western parts of Addis Ababa are weathered and form thick soil profile. In places where young basaltand welded tuffs occur, the thickness of soil cover is reduced (Tamiru Alemayehu et al.,2006).

The engineering geological soil units in Addis Ababa area are grouped into their genetic soil units as alluvial, alluvial Fan, colluvial, lacustrine and Residual soils. Alluvial soils which includes channels and terrace deposits seen in some places along Akaki river and in the south western parts of Addis Ababa and along Kebena River. These soils consist of stratified deposits of Gravel and clay transported by streams. (Kebede Tsehayu et al., 1990)

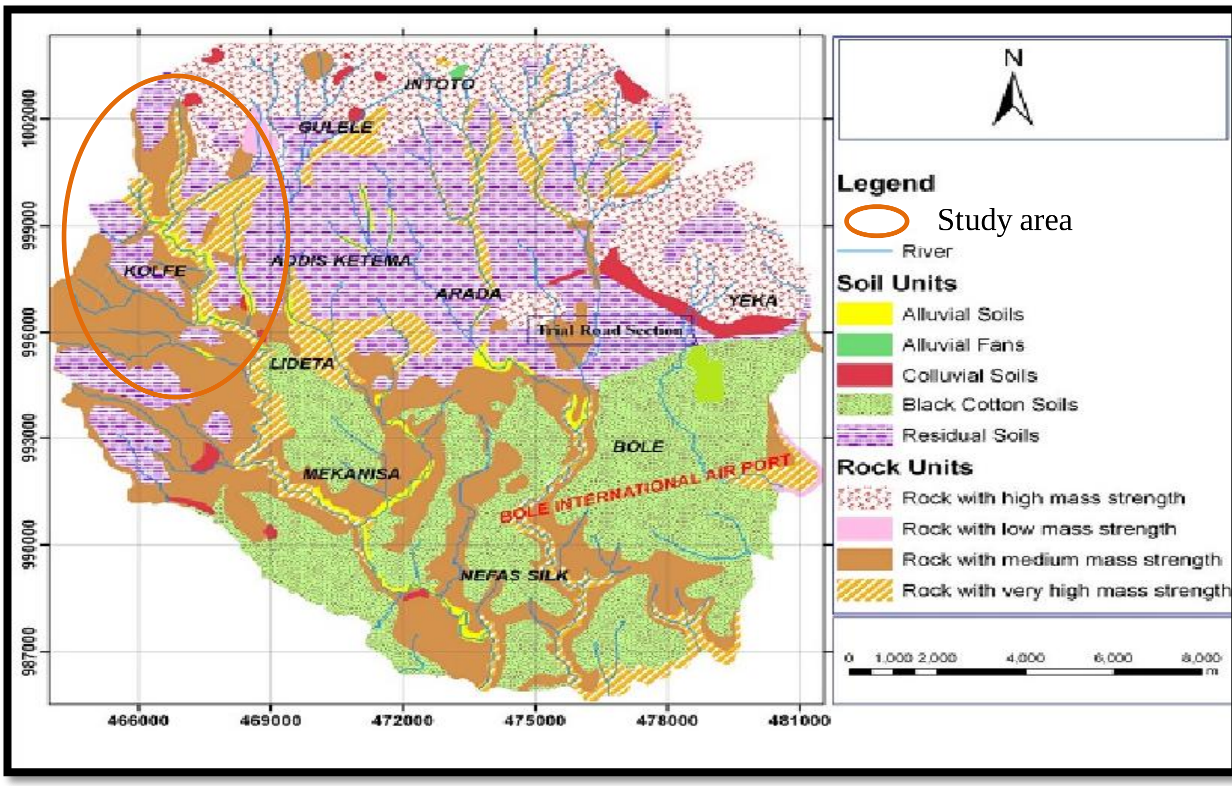

Fig 3.3 Engineering Geological Map of Addis Ababa (Kebede Tsehayu and Tadese Hailemariam,1990)

The alluvial soils consist of more or less stratified deposits of gravel and clay transported by streams. Alluvial fan is deposited where there is a decrease in gradient from a hill to a plain along a river section. It is coarser near the mouth of the river and become finer outwards and found in the Intoto region dissected by deep gullies (Kebede Tsehayu and Tadese Hailemariam, 1990).

Lacustrine soils, alternatively named as Black cotton soil found around Lideta Bole Mekanisa areas. These areas are flat and relatively low lying.

Residual Red soils in Addis Ababa are widely distributed next to Black soil as seen from the engineering geological map of Addis Ababa. Red soil is widely distributed in Western, North western, in the central some parts in the eastern parts of the city.Residual soils mainly located in Gulele and Kolfe area from Sample tested provide grain size of 62% clay, 33% silt and 5% sand. In some localities reddish brown soil with a thickness of more than 10 meter is commonly seen.

Colluvial soils are found in areas where there is a great contrast in the topography. These areloose and incoherent deposits, consisting of fine to coarse grain particles. Colluvial soils aremainly located at the foot slopes of northeastern part of Entoto silicics and other few places(Kebede Tsehayu and Tadese Hailemariam, 1990).

The low lying flat areas around Addis Ababa are dominated by black cotton soils. These soils have extremely high plasticity and very high degree of swelling as compared to the other identified soil types found in Addis Ababa. The thickness of this soil varies at places from 2 to 10m. The highest thickness is found in Bole area and in Beklo Bet area it is about 5m thick (Kebede Tsehayu and Tadese Hailemariam, 1990).

3.6 Physiography

The topography, accompanied with the drainage condition of the study area played a major role on the color and distribution of the soils. In relatively gentle and steep slopes of the northern, northeastern, and northwestern parts of the city, light brown to yellowish brown soils are common. These areas are well-drained in favor of the topography. In low lying areas of the city (southern, central, southeastern and western parts), where surface drainage is poor and often water logged, dark colored (dark grey) soils are dominant.

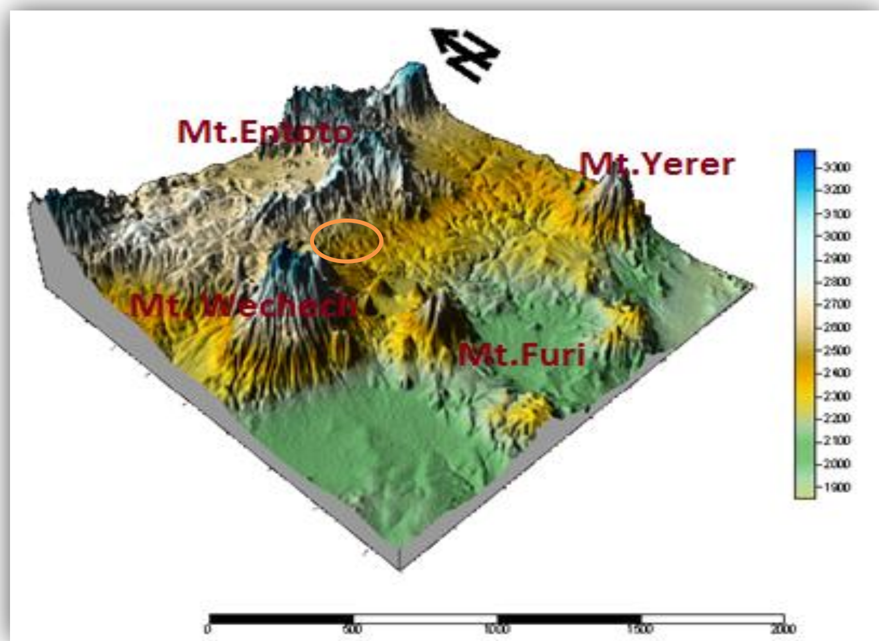

Fig 3.4 D map of Addis Ababa

Prominent volcanic features surrounding the city are Mt. Wechecha in the west (3385m a.s.l.), Mt. Furi (2839m a.s.l.) in the southwest and Mt. Yerer (3100 a.s.l.) in the southeast.

They are characterized by rugged landscapes and steeper slopes. The general inclination of the slope becomes lower towards the southern part of the city (Tamiru Alemayehu. et al., 2006).

3.7 Climate

The Ethiopian climate is mainly controlled by theseasonal migration of the Inter TropicalConvergence Zone (ITCZ) and the associatedatmospheric circulations of air as well as by thecomplex topography of the country. The altitude of the study area is generally above 1600m and occasionally above 2000m. The climate in these areas is favorable for the formation of Tropical red soils (Addiszemen Teklay, 2015).

Climate is the principal factor governing the rate and type of soil formation. The two most important components of climate are the amount and distribution of precipitation, and temperature. (Gilloth (1962).

Ethiopia is classified into five climatic zones; These include "Kur" (Alpine), above 3000m mean sea level; "Dega" (Temperate), 2300m to about 3000m; "Weina Dega" (Sub tropical), 1500m to about 2300m; "Kolla" (Tropical), 800m to about 1500m and "Bereha" (Desert), less than 800m. Most parts of Addis Ababa fall under the Weina Dega (Sub tropical) category.(EMA,1981 as cited in Habtamu Solomon,2011).

3.7.1 Rainfall

From engineering geological point of view, variations in rainfall brings fluctuations of the groundwater table, there by producing variations in the moisture content or degree of saturation of the underlying earth materials. The moisture content variation has a greater impact on the engineering properties of earth materials as strength of foundation materials decreases with increase in moisture content. Hence, prior knowledge of rainfall variation of an area helps to understand its impact on ground water table fluctuations and to pass the right decision on the design and long term safety of engineering structure.

In Addis Ababa, rainfall intensity variation is attributed to differences in Topography. The high elevated areas such as the Entoto receive relatively greater precipitation than lowland areas around Bole and Akaki.

The mean monthly and annual mean rainfall of National Meteorological Services Agency (NMSA) stations in Addis Ababa located at Addis Ababa Ayertena (2006 to 2016), Addis Ababa Observatory (Teklehaymanote) and Entoto Stations were used.

According to National Meteorological Services Agency data from the mean monthly rainfall the months from May to September receives highest rainfall.(Table 3.1)

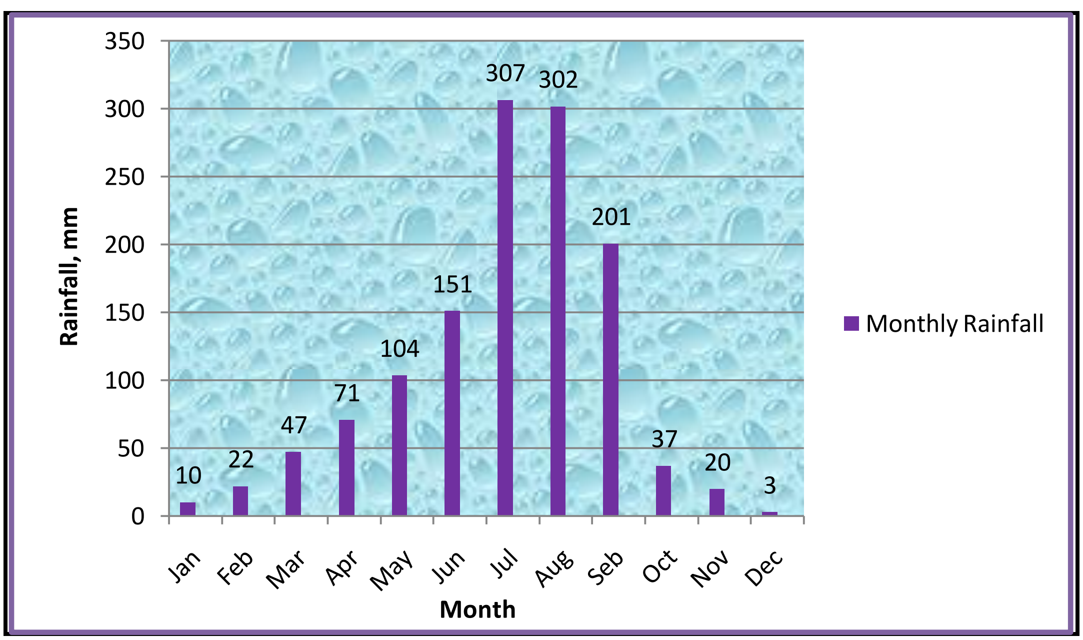

Fig. 3.5 Mean Monthly rainfall

The annual rainfall for the year is about 1275mm.In addition the years 2016, 2013and 2010 received highest rainfall as compared to the rest of years. (Table 3.2)

Table.3.1 Mean Monthly Rainfall (Source: National Meteorological Services Agency)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Seb	Oct	Nov	Dec
Mean Monthly Rainfall,mm	10	22	47	71	104	151	307	302	201	37	20	3

Table 3.2 Mean Annual Rainfall (Source: National Meteorological Services Agency)

Year	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
Mean Annual Rainfall,mm	141.6	92.0	94.3	125.7	104.6	81.9	117.9	106.3	103.5	102.1	112.4

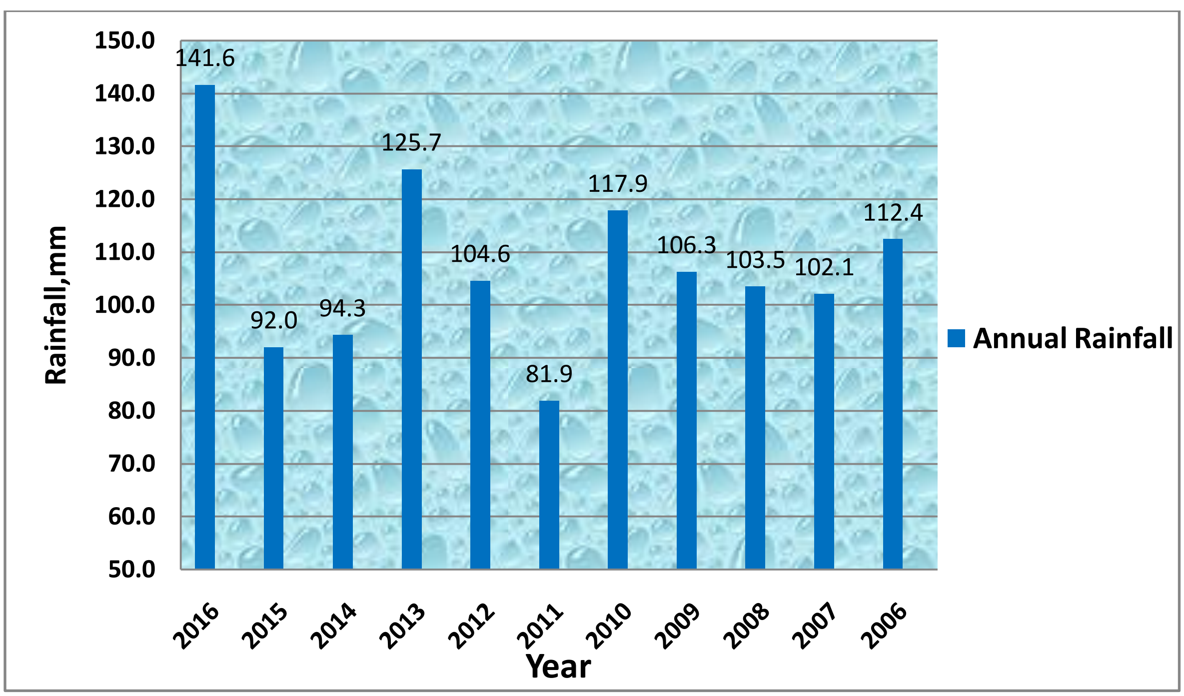

Fig 3.6 Mean Annual Rainfall

3.7.2 Temperature

The average temperatures of Ethiopia are typically tropical to sub-tropical and fluctuate by 5^0C between the coldest and warmest months (Griffiths, 1972; as cited in Habtamu Solomon, 2010). Fluctuating temperatures help break down mineral grains in rocks. Warmer temperatures increase chemical weathering. As a result, and being a tropical region, Addis Ababa has thick weathered profile in most of its areas, especially in gentle and flat lands. Although temperature has no direct influence on the engineering properties of foundation materials, its long term effect of accelerating weathering of near surface rocks cannot be denied. Weathering weakens the strength of earth materials through altering the mineralogy as well as their physical properties.(Griffiths, 1972)

The mean monthly maximum and minimum temperature records of National Meteorological Services Agency (NMSA) for the last ten years between 2006 and 2016 were utilized to calculate annual average temperature. The computed average maximum and minimum temperature is presented. (Table3.3)Furthermore, Entoto station which is located at a higher elevation records smallest amount of average annual temperature. This shows that, like the rainfall, there is also variation in the amount of temperature within Addis Ababa.

Table 3.3 Maximum and Minimum Annual Temperature (2006-2016) Source: National Meteorological Services Agency

Average Annual Temperature(^{0}c)	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Minimum	9.2	10.2	10.4	9.5	9.7	10	9.8	10.1	10.5	10.2	11.4
Maximum	22.2	20.7	17	21.8	20	21.1	21.2	20.7	21.4	21.4	22.4

3.8 Drainage

Addis Ababa lies within the Awash River Basin. The water divide between Awash Basin and Blue Nile Basin lies on the top of Entoto Ridge. The catchment area of Akaki River basin that totally includes Addis Ababa area is divided into two sub basins - the Big Akaki River (Eastern) sub basin and the Little Akaki River (Western) sub basin(Habtamu Solomon, 2010).

The streams of Addis Ababa drain towards south from Entoto ridge, South East from Mt. Wechecha and Mt. Furi and towards south west from Mt. Yerer and other elevated areas of the eastern outskirts of the city. The potential streams in the city are Little Akaki, Bantyiketu, Kurtume, Kebena, Ginifile, and Big Akaki. Other streams are intermittent in nature. Streams are dense with deep valleys on top of mountains such as Entoto ridge forming radial and dendritic drainage patterns.

The volcanic mountains surrounding the city include Entoto Chain Mountain in the North, Wechecha range in the southwest, and Mount Furi, and further south-East Mount Yerer. There is a general decrease in elevation from north to south direction.

3.9 Hydrogeology

According to a study conducted by Tamiru Alemayehu *et al*. (2006), the major ground water aquifers in Addis Ababa are basalts, rhyolities, trachytes, scoria, trachy basalts, welded tuffs, unwelded tuffs and the unconsolidated materials of volcanic origin as depicted from boreholes previously drilled for the water supply. The main aquifers in Addis Ababa area can be categorized in to three groups which include shallow aquifers of the weathered volcanic rocks and alluvial sediments along the river courses, deep aquifers of the fractured volcanic rocks that tap fresh ground water and thermal aquifers along Filwoha fault (Kebede Tsehayu *et a*l. 1990),

According to Tamiru Alemayehu and Taddese Alemayehu,2006 most of the aquifers are confined below the clay (paleosoil) and hence storage coefficient is very low.

CHAPTER 4 DATA PROCESSING AND ANALYSIS

4.1 Introduction

A literature review has revealed that the geotechnical characteristics and engineering behavior of red soils depend mainly on the genesis and degree of weathering. Good understandings of the soil on which highways and other facilities are constructed are very important.

The current study discussed some common tests to determine the engineering property of red soil in the western Addis Ababa. For this study more than 150 collected geotechnical data and five test pit dug in areas of Addis Ababa;Kolfe,Arada, Addis Ketema, Gulele and Asko at different depths to collect representative disturbed and undisturbed samples. The location of the test pits decided based on the lesser secondary data availability in the areas. (Fig 4.1) shows location of the five test pits in the study area.

This chapter discusses some of the most common soil tests used for the characterization of engineering properties of soil. Collected Data from secondary sources includes drilled borehole and laboratory test results. This has been grouped as an index tests and mechanical test results. The data used to perform a statistical analysis, is done based on log reports from more than 150 different projects in the study area and results of laboratory tests.

The distribution and location of collected geotechnical investigation bore hole data from different organizations is presented in(Fig 4.1) Geotechnical data of two condominium sites;around Asko and Kolfe Keraniyo site BH-data were included during the collection and analysis work for the current study.

4.2 Laboratory Analyses

Laboratory test is an examination by which the quality of soil is determined. The process of examining a soil under known conditions in order to determine quality, identify its constituents. The physical properties of material are tested in order to determine their ability to satisfy particular requirements. The inherent mineralogical and chemical composition of residual soils of the material has a pronounced influence on the engineering behavior and measurement of the index and mechanical properties of soils.

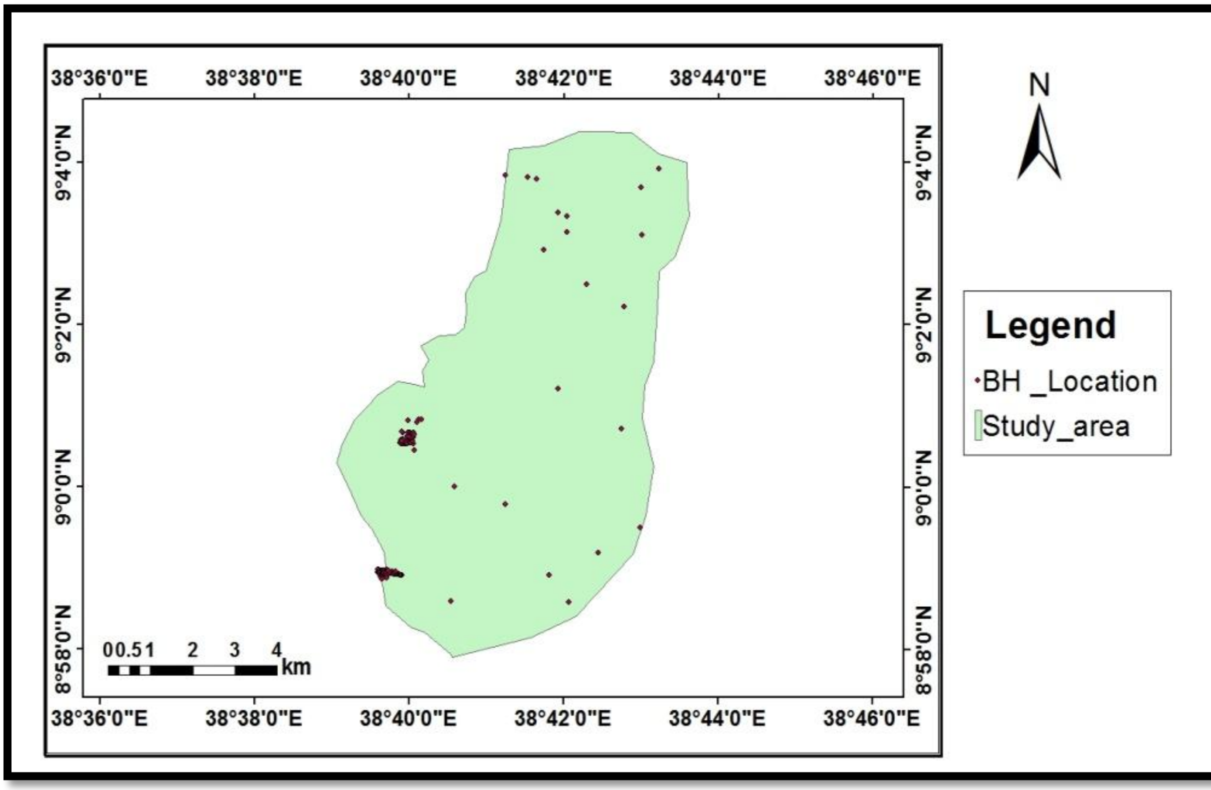

Fig4.1 Bore Hole Data Location

4.2.1 Index Property Tests

Representative Red soil samples for Index property study asses from both primary and secondary data sources from the study area. Laboratory test analysis of the index properties includes particle size distribution (sieve and hydrometer analysis) and Atterberg Limits, Natural Moisture Content (NMC), free swell and specific gravity.

4.2.1.1 Grain Size Distribution

Grain size distribution has been done in an effort to determine the percentage of different grain sizes contained within the soil. The mechanical or sieve analysis performed at natural moisture content to determine the distribution of the coarser, larger-sized particles and For fine-grained soils(<0.075mm) hydrometer analysis is used.

The property of cohesion less soil is greatly based on grain size distribution while the property of fine-grained soil is influenced by inter particle force. It is quite necessary then, to clearly know the proportion of different grains or particles a soil system contains. Wet sieve analysis employed to determine the grain size distribution of soil samples in accordance (AASHTO T 88).

The grain size distribution of selected 38secondary data from different geotechnical bore hole in the study area are presented. (Table 4.1)

Table 4.1 Percentage Grading of Sand, Silt and Clay of Red Soil

		Grading					Grading		
Location	**Depth(m)**	**Sand%**	**Silt%**	**Clay%**	**Location**	**Depth(m)**	**Sand%**	**Silt%**	**Clay%**
Asko	1	3	34	63	Burayu	2	9	55	36
Asko	2	3	44	53	Burayu	2	4	42	54
Asko	2	4	42	54	Burayu	2	5	39	56
Asko	2	6	43	51	Burayu	2	3	31	66
Asko	2	3	31	66	Burayu	2	9	60	31
Asko	2	9	60	31	Burayu	2.5	8	60	32
A.Ketema	2.5	8	55	37	Kolfe	2	3	31	66
A.Ketema	2	3	36	61	Kolfe	4	9	60	31
A.Ketema	2.5	3	44	53	Kolfe	6	8	61	31
A.Ketema	4.5	4	42	54	Kolfe	2	9	60	31
A.Ketema	3.5	5	46	49	Kolfe	4	3	44	53
A.Ketema	3.5	3	31	66	Kolfe	6	4	42	54
Arada	3	9	60	31	Kolfe	4	4	42	54
Arada	2	8	49	43	Kolfe	6	3	31	66
Arada	2.5	3	34	63	Kolfe	2	9	60	31
Arada	4	3	44	53	Kolfe	4	4	40	56
Arada	3.5	4	42	54	Kolfe	6	9	60	31
Arada	2	4	53	43	Kolfe	2.5	3	38	59
Arada	2	3	44	53	Kolfe	5.5	2	52	46

The primary data of the present study has five test pits, summary results of grain size distribution analysis for each test pits are given. (Table4.2)

Table 4.2 Grain size distribution of five samples

Sieve Size (mm)	Percent Passing (%)				
	Gulele	Asko	Kolfe	Arada	A.Ketema
4.75	100.00	100	100	100	100
2	100.00	100	100	100	100
1.18	99.98	95.36	95.64	99.62	99.84
0.6	99.72	83.98	89.14	98.86	98.84
0.3	98.82	78.14	85.36	98.46	96.66
0.15	96.94	71.8	82.44	97.86	92.8
0.075	95.92	67.42	80.42	97.32	88.84
0.033	73.33	67.59	80	96.67	64.24
0.021	70.00	64.21	76.67	90	61.03
0.012	66.67	57.45	70	83.33	57.82
0.009	63.33	50.69	63.33	73.33	54.61
0.006	56.67	43.93	56.67	60	48.18
0.003	53.33	27.03	46.67	43.33	41.76
0.001	43.33	16.9	40	30	38.55

Soil grading or the percentage of silt, clay and sand can be also classified using different subgroups of soil in a triangular format. The sub groups include clay,silty clay, silty clay loam, sandy clay. Collected data results of percentage grading grouped the red soil as a silty clay,clay and few results grouped as silty clay loam.(Fig. 4.2)

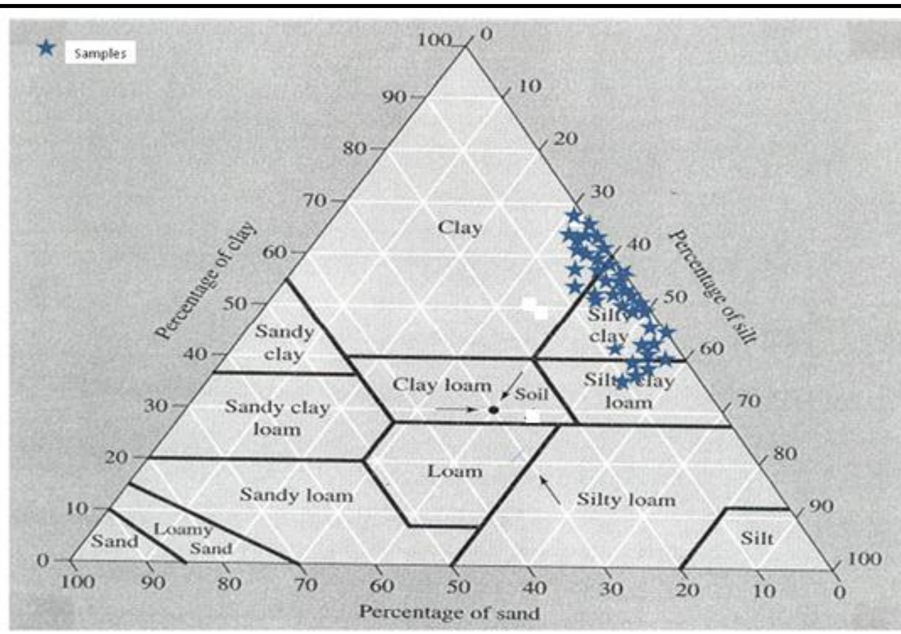

Fig 4.2 Triangular classification of soil Grading

4.2.1.2. Moisture Content

Determination of moisture content of a soil is further required as a guide to classification of soils and to evaluate the behavior of soils during construction. This is determined by using the oven drying method. The moisture content relates only to the water which is removable by oven drying at 105-110°C (Das, 2005).Moisture is considered to be present in most soils. The amount of moisture, expressed as a proportion of the mass of the dry solid particles, has a profound effect on the soil characteristics and engineering behavior.

Collected data test results for natural moisture content of red soil in the study area lies in a range of 14-59, the arithmetic mean is 33 and coefficient of variation26% which shows good variation between data.

4.2.1.3 Free Swell

Free swell tests are known to indicate the presence of swelling clays in soils. Free swell test results indicate the potential expansiveness of soil samples without being loaded. The free swell tests conducted on the fraction of soil samples. It is done by pouring slowly 10 cm^3 of dry soil passing No.40 (0.42mm) sieve in to a 100cm^3 graduated measuring cylinder.

Free swell results from collected 120 Geotechnical data in the study area range from a minimum of 5 % for a non-plastic soil (sandy silt),up to a maximum of 80 % for a medium plastic soil obtained from Kolfe area of Western Addis Ababa. Free swell result lies in a range of 5-80 with an average value 52. According to classification of free swell by Holtz and Gibbs (1956) the red soil in the study area shows low to medium potential of expansiveness.

4.2.1.4 Atterberg Limits

The liquid limit of a soil is determined by using the device specified to plot a curve of the number of taps necessary to obtain a specific consistency of the soil fines against the moisture contents in three trials. The procedure is as per the standard on (AASHTO T 89).

At very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid. Hence, on an arbitrary basis, depending on the moisture content, the behavior of soil can be divided into 4 basic states: solid, semisolid, plastic, and liquid. Liquid Limit test empirically establish moisture content at which a soil pass from liquid state to plastic state. It is the minimum water content at which the soil is still in the liquid state, but has a small shearing strength against flowing. The plastic limit is represented by the percentage moisture content at which point the soil passes from the plastic state to the solid state. The plastic limit is determined by hand-rolling a sample of soil into a 'thread', on a glass plate, until it begins to crumble due to gradual drying. The range of percentage moisture content over which a soil is plastic is defined as the plasticity index (PI) and provides a measure of the overall plasticity of the material.

According to Burmister,(1949) qualitative classification of soil plasticity index results of collected data shows the PI value between 9 to 40 which is low plasticity to very high plastic soil group.

4.2.1.5 Activity

From the activity chart activity of the soil increases as Plasticity index increases and it can be assumed that the average value of activity in the study area is 0.37 contains in a group of Kaolinite mineral. Red soils are inactive or normal due to the sesquioxides suppress the activity of the clay particles.

4.2.1.6. Specific Gravity

The specific gravity, Gs, is used to calculate parameters such as clay fraction, void ratio and porosity. In residual soils the specific gravity may be unusually high or unusually low (Blight,1997).It is thus essential that the specific gravity be determined in the laboratory.(AASHTOT -100).From collected 120 data of Specific Gravity test results lies in a range of 2.6-2.8 having 4% of coefficient of variability which indicates more uniform results. The higher value of residual red soil could be due to the fact that there is high iron content.

4.3 Soil Classification

The most widely used soil classification systems for engineering purposes are American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS). The AASHTO system of soil classification comprises seven groups of inorganic soils from A-l to A-7 with 12 subgroups in all. The system is based on particle-size distribution, liquid limit and plasticity index. On the other hand the Unified Soil Classification System is based on the recognition of the type and predominance of the constituents considering grain-size, gradation, plasticity. It divides soil into three major divisions: coarse-grained soils, fine grained soils and highly organic soils.

On Bases of more than 150 data, According to USCS classification scheme soil in the study area falls in ML,MH and CL, region which shows that the soil is non expansive. From the plot of plasticity chart the soils in the study area are silts, silty sand, sand clayey silt soil.

The test results analysis in general shows that the red soil classified as A-7-5 and A-7-6 according to AASHTO system.

4.4. Mechanical Property Tests

Mechanical Properties of soil such as Swelling and shrinkage behavior of clay soils are directly related to plastic properties of clay. The observed actual amount of swell or shrinkage as a result of wetting and drying depends not only on the mineralogy but also particle arrangement, initial water content and confining pressure.

The consequence of volume change such as settlement due to compression and heave due to expansion makes this property very useful in engineering problems. Moreover, changes in volume have a tendency to lead to change in strength and deformation behavior which in turn can affect stability of the soil.

The laboratory test result analysis of the mechanical properties of a number of red soil samples from the study area is compiled. This include evaluating the Shear strength, compressive strength, compaction and deformability, one dimensional consolidation test result of the red soil are discussed here.

4.4.1 Shear Strength

Shear strength of a soil is the internal frictional resistance of a soil to shearing forces. The shear strength of a soil is the maximum shearing stress the soil structure can resist before failure. Shear strength 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 purpose of shear strength testing is to establish representative values for the shear strength parameters from laboratory and field testes. The most common laboratory methods employed to obtain shear strength parameters are direct shear test, triaxial compression test and unconfined compression test.

4.4.1.1 Direct Shear Test

The purpose of these laboratory tests is to obtain the effective shear strength of the soil based on the failure envelope in terms of effective stress (effective cohesion, c‟, and effective friction angle, Φ‟). These types of shear strength tests are often referred to as ‟ drained‟ shear strength tests (Day, 2001).

For the current study red soil laboratory test results for drained direct shear test results data summarized. The shear strength test result obtained from soil samples evidenced that mean of cohesion(C) is 21KN/m^2 but some of the data shows very cohesive nature with large cohesion(C) value and reasonable angle of internal friction range 11-34^0.

4.4.2 Unconfined Compressive Strength (UCS)

The unconfined compression test is one of the simplest tests used for the determination of the shear strength of cohesive soils. The unconfined compression test is a special type of a triaxial compression test in which all round pressure is zero. The axial load is increased rapidly until the soil sample fails. The tests are carried out only on saturated samples which can stand without any lateral support. This test is applicable to cohesive soils only. There is no moisture loss during the test.

The results from unconfined compression tests can be used to estimate the short-term bearing capacity of fine-grained soils for foundations estimate the short-term stability of slopes, Compare the shear strength of soils. The unconfined compressive strength (q_u) is the load per unit area at which the cylindrical specimen of a cohesive soil falls in compression.

The purpose of this test is to determine the undrained shear strength of saturated clays quickly. It gives a measure of the shearing strength of cohesive soils. In this test, a cylindrical specimen of selected red soil without any lateral support is subjected to axial loading, till the sample fails, either due to shear along a diagonal plane or by the lateral bulging.

4.4.3 Consolidation

Consolidation of a saturated soil occurs due to expulsion of water under static, sustained load. The consolidation characteristics of soils are required to predict the magnitude and the rate of settlement. The one dimensional consolidation test is carried out to study the stress-strain and compressibility of the soil under different conditions using the apparatus called Oedometer.

The consolidation parameters of a soil are compression index (Cc) and coefficient of consolidation (Cv). The compression index relates to how much consolidation or settlement will takes places while the coefficient of consolidation relates to the time of consolidation to take place.

The reading taken from the dial gage micrometer of one dimensional consolidation apparatus and plotted against the respective loading also illustrates that the coefficient of consolidation, Cv, varies on the early stages of loadings but more or less comes to comparable state for the later stages of higher loadings, in which the ability of soil for compression decreases or takes longer time and void ratio decreases to minimum value, Void ratio versus Log pressure curves of the three consolidation tests results attached in Appendex-4.

4.4.4 Proctor Compaction

Performing a laboratory compaction test on the foundation soil is important in order to set the appropriate compaction specifications. The two commonly performed tests are: (1) standard Proctor compaction test and (2) modified Proctor compaction test (Das, 2002). The two types of tests are required to determine the optimum moisture content and maximum dry density of a soil.

For the current study Standard Proctor Compaction tests carried out for a number of bulk samples in the study area were collected and analyzed. This method used with the Standard (AASHTO T-99) Density Test for determining the percent of Maximum Density.

In an effort to effectively determine the optimum moisture content and maximum dry densities of the material, air-drying of selected sub-samples was specified to effectively plot the variation of achieved density with moisture content. Tests have shown that moisture content has a great influence on the degree of compaction achieved by a given type of soil. In addition to moisture content, there are also other factors that affect compaction. The soil type has a great influence because of its various classifications, such as grain size distribution, shape of the soil grains, specific gravity of soil solids, and amount and type of clay mineral present.

4.5 Chemical Property Tests

4.5.1 PH of Soil

From engineering point of view, determination of the pH of the soil mass is essential. For the acidic and basic nature of soil must be known for construction works, highly acidic soil will affect the bitumen stability of roads and have adverse effects on concrete strength. Salinity of soils will also increase maintenance costs.

4.5.2 Sulphate, Chloride and Organic Content

Most salts are active participants in the corrosion process. Subsurface soils and surface water should be tested for chloride and Sulphate content, if the presence of sea Chlorides and sulphates have been identified as being chief agents in promoting corrosion.

By Using a test procedure on BS 1377 (Part 3:1990) Sulphate and Chloride content determination, representative disturbed red soil sample from the study area around Kolfe Keraniyo were tested.

Determinations of Organic Content in Soils were tested using laboratory test. For engineering design purposes the Ignition Loss test is used, which measures how much of a dried sample's mass burns off when placed in a furnace. The results are presented as a percentage of the total solid mass.

4.5.3 Clay Mineralogy (XRF Result) Analysis

The field of clay mineral property is diverse and complex. The clay mineral composition is one of the factors that affect the physical properties of soils, and a knowledge of it is required to promote a fuller understanding of the origin of these properties. Mineral content is the main factor controlling the physical and chemical properties of soil mechanics.

Two disturbed fine samples of red soil were selected from Asko and Kolfe Keraniyo areas for the mineral composition determination. The percentage of oxides (Wt.%) in the soils was determined by X-ray spectrometric powder technique.

X-ray fluorescence was employed to determine the major oxide geochemistry elemental abundances of the red soils in terms of major oxidesSiO_2, Al_2O, CaO, Fe_2O_3, MgO. By using test result of XRF to explain the degree of laterization of red soil in the study area.

Clay mineralogical composition is also discussed with reference to kaolinite, illite and montmorillonite, which are applicable to engineering practice. However, because of lack of XRD equipment this test cannot be done. Instead the minerals present in the soils are also inferred from the consistency limits in general by using the Activity of clay minerals present.

4.5 Soil Thickness in the Study Area

Soil thickness map is a map which shows diversity in thickness of a certain soil type. The geotechnical bore hole data collected from different localities in the study area were used to see the thickness variability of red soil in the study area. The bedrock surface configuration and the thickness of soil that overlies the bedrock has practical applications in construction activities in the area. The soil thickness map clearly shows that the map uses combined terms; high and low in the legend; which refer to Deep and Shallow soil thickness respectively. The deepest soil thickness depth is 15m encountered at Kolfe Keraniyo and around Addis Ketema areas developed over Basalt unit and a shallow red soil thickness found in areas of Asko, Gulele and southern parts of Kolfe sub-city under laying on Trachyitic,Ignimbrite and Basalt units. (Fig 4.3) Areas which covered with a shallow bedrock can be beneficial in respect to construction purposes as it provides necessary stability for large construction projects such as bridges and high-rise buildings.

For the current study, the work was initiated with procurement of historical geotechnical borehole logs from three organizations Transport construction Design, Building Design and Saba Engineering plc. These borehole logs are the most important set of data for determining the bed rock topography. Only those boreholes which have known geographic coordinates and elevations were filtered out and 136 boreholes used in the compilation process. The elevation of the bed rock surface is computed by subtracting depth to bedrock from the surface elevation of boreholes (Appendix-1).

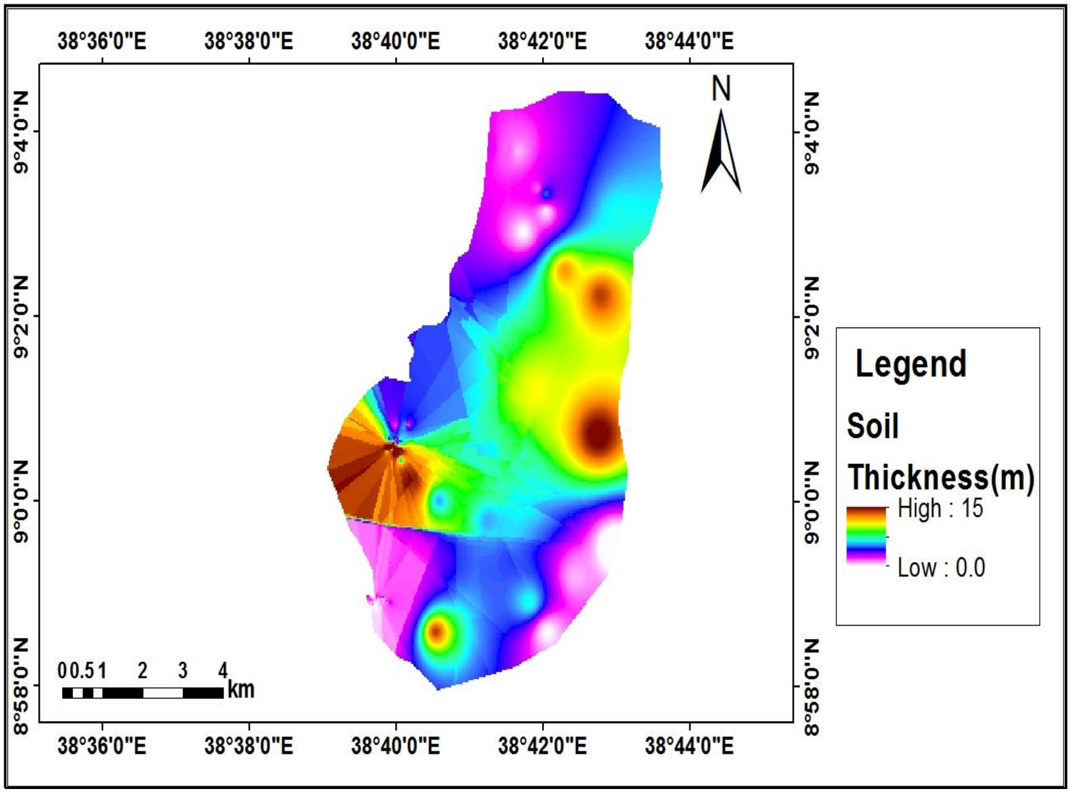

Fig 4.3 Soil Thickness Map of the Study Area

Other useful data for the compilation of this map includes outcrops of bedrock and engineering geological maps. The soil thickness map has been produced using surface grids in ArcGIS, the Spatial Analyst extension employs interpolation tools. This helps to predict the values of cells at locations that lack sampled points. It is based on the principle of spatial auto correlation which measures degree of relationship between near and distant points.

For the study area by using eight bore hole logs at selected areas; Burayu, Addis Ketema, Asko, Gulele, Arada were chosen to produce a soil profile geologic cross section. This were done using Auto cad software bore hole log correlating technique.

The soil profiles in the study area were grouped in five divisions on the basses on the residual red soil thickness at different areas. (Fig 4.4) By using different colors to differentiate in depth the pink color indicates shallow soil thickness from zero to 2m and the brown color indicates areas of thick red soil profile which is above10m.

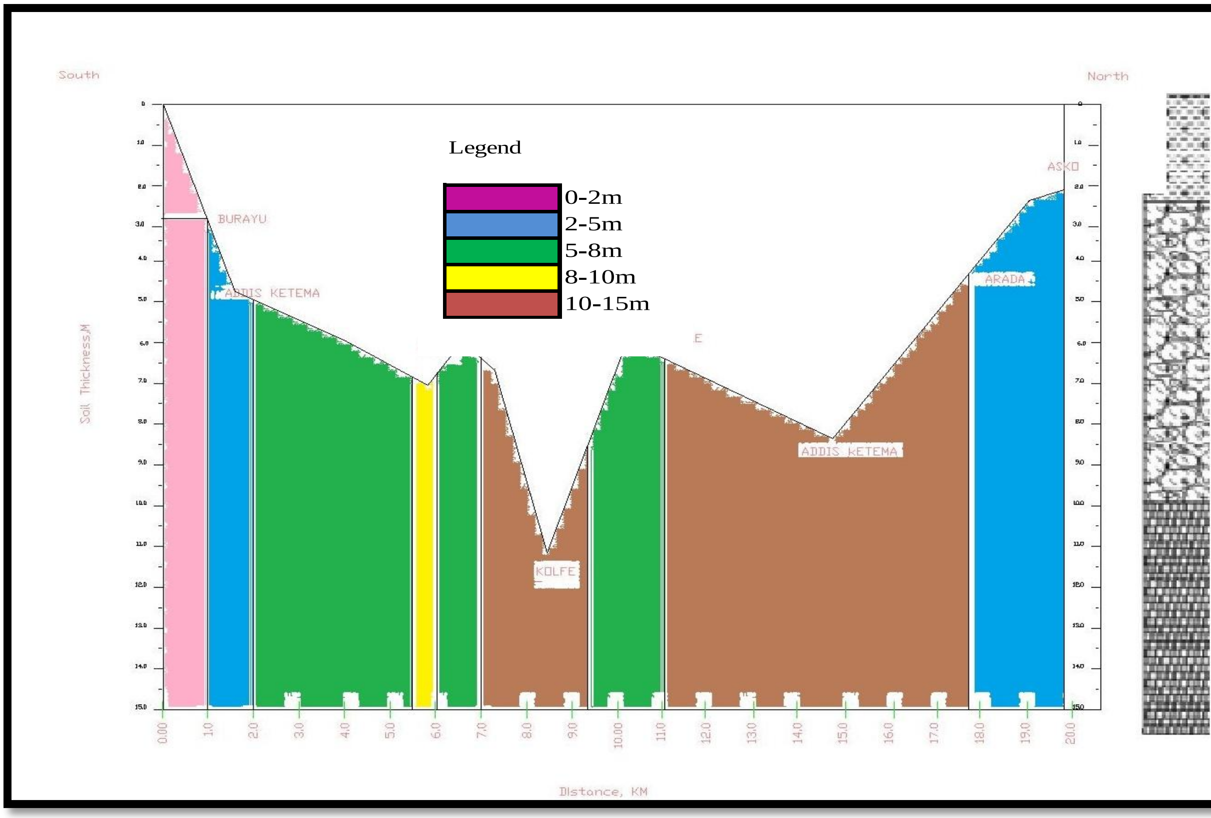

Fig 4.4 Soil Profile Cross Section

4.6 Comparison of Results with Other researches

The comparison of red soil data between the current study and previously done researches is presented in (Table 4.3). The values are compared in order to identify the characteristic of the red soil with respect to lateritic soil from different areas. The comparison is made on the bases of various Laboratory test results for red soil in the country.

According to the research done by (Samuel, 1989) on red clays of Addis Ababa in different places presents a liquid limit in a range of 61-68 which shows variation with the present study in the western Addis Ababa, results which could be the effect of degree of weathering of parent material and the type of rock. This could also affects the clay content and free swell of red soil in Addis Ababa red soil. However, these soils grouped in a similar group according to unified and AASHTO classification of soil.

Table 4.3 Comparison of red clay soil data from previous researches

		Previous research				
	Morin & Parry	(Zelalem,2005)	(Wakuma,2007)	(Samuel,1989)	(Abegna,2003)	Current Research
Soil Type	Red clay	Lateritic	Lateritic	Red Clay	Red clay	Red Soil
Location	Ethiopia	Nejo -Mendi	Asossa	Addis Ababa	Bahir Dar	Western Addis Ababa
Clay Content	34-76	2-20.6	2.5-60	53-68	74-82	55-65
Activity	-	0.97-0.98	0.62-1.02	-	0.56	0.11-0.70
Liquid Limit (%)	44-46	48-67	41-72	57-76	61-68	39-106
Plastic Index (%)	14-30	17-27	20-48	33-47	24-31	9 -40
Shrinkage Limit (%)	10-30	7.1-15.7	-	14-20	9-12	12-20
Freeswell(%)		20-40	11.0-45.0	30-40	-	5- 80
Specific Gravity	2.61-2.9	2.78-3.03	2.19-2.94	-	2.75-2.83	2.6-2.8
UCS(KN/M^2)	-	165-553	-	-	148-220	64 - 213
Plasticity Chart	-	MH	CH,SC,M,H,CL & SM	CH	-	CH,CL,MH,

CHAPTER 5 RESULTS, INTERPRETATION AND DISCUSSION

5.1 Introduction

The most important property of soil for a foundation analysis can be grouped as Index property, Mechanical and Chemical property of a soil. The test results of Physico-Chemical tests from the study area ;Kolfe,Arada, Addis Ketema, Gulele and Asko discussed, analyze and characterized here. Grain size analysis is one of the index property tests, the soil of the study area is examined for its grain size distribution. Grain size divides soil into two distinctive groups, Cohesionless and cohesive soil. The results were collected and analysis is done, some of the most important engineering properties of red clays in Western Addis Ababa in terms of arithmetic mean, range and coefficient of variation is defined for each test results.

5.1.1 Index Property Test Results and Discussion

Grain size analysis was done in an effort to determine the percentage of different grain sizes contained within the soil from various parts of the study area. Hence, the behavior of a soil mass is dependent on the size of the particles it has. The range of gradation curves for red soil in the study area is relatively less uniform and the soil type contains variable proportion of Sand, silt and clay. This is due to the fact that residual soils are the sequence of materials ranging from a true soil to soft rock is obtained depending on the degree of weathering. From Hydrometer and sieve analysis results of five samples shows 27-53 % clay, 21-54% silt, and 3-45% sand. (Table5.1)

Table 5.1 Percentage of Grain size distributions

Location	S. Depth(m)	Sand (%)	Silt (%)	Clay (%)
Kolfe	2.00	18	53	29
Arada	1.50	3	54	43
Addis Ketema	2.00	45	21	34
Gulele	1.50	33	40	27
Asko	1.50	4	43	53

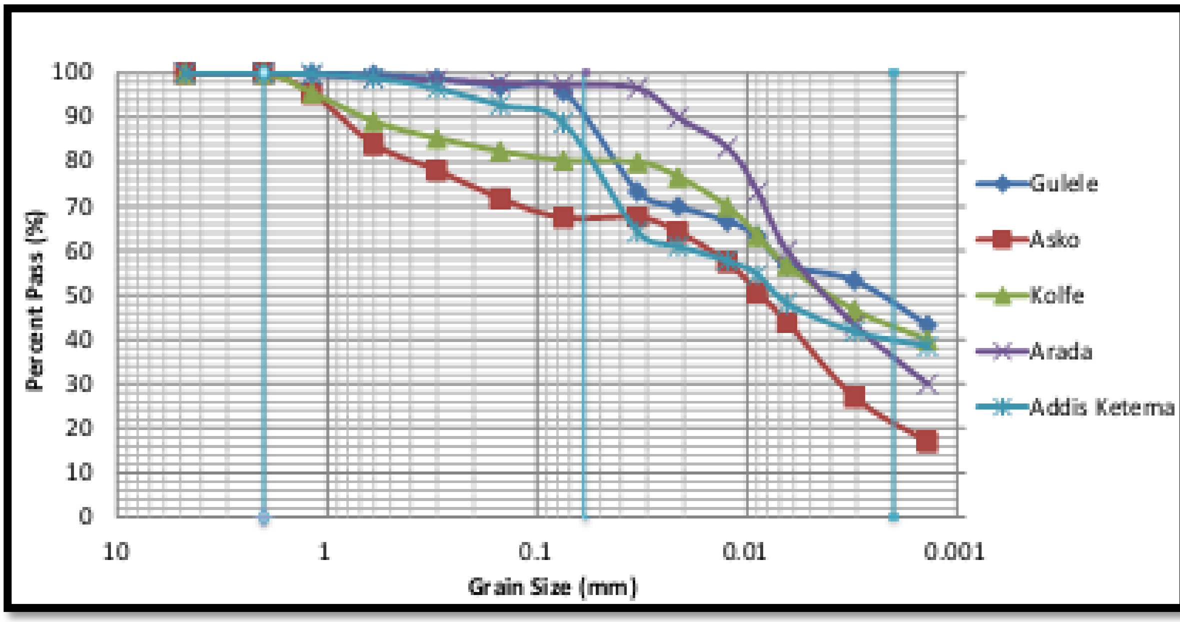

Fig 5.1 Grain size distribution of five samples

Atterberg Limit tests were conducted on soil samples collected from different localities in the western Addis Ababa, all soil Samples are oven dried for 24hrs.Liquid limit test results for the samples varies between 32 to 60%, which indicates an intermediate to high plasticity, while the plasticity index value ranges from 13 to 23% which ranges from moderate level to extreme plastic nature. According to EBCS-7 (1995), soils with PI value between 15% and 35% are considered as moderately plastic. Accordingly, red clays in study area are found to be in a range of moderate plastic nature with an average PI of 29%.

Table 5.2 Swelling Potential and Plasticity Index Ranges (Chen, 1998)

Swell Potential	Plasticity Index,%
Low	0-15
Medium	10-35
High	20-55
Very High	35 >

A high numerical value of plasticity index is an indication of the presence of high percentage of clay in the soil sample. Based on the grouping of soil PI value by Burmister, (1949) the test results of the samples Plasticity index indicates the red soil has a medium plasticity.

Plasticity Index parameter can be used as a preliminary indicator of the swelling characteristics of a soil. The PI value between 13-23% indicates the soil has a medium swell potential.Such clays belong to the CL and ML groups of the unified classification system.

The Shrinkage Limit test is also used as a guide to the determination of potential expansiveness. Results of three Linier shrinkage tests range in between 12-14.Which shows it has a marginal degree of expansion. As the degree of expansion becomes critical if the value of LS below 10 (Chen, 1998). Free swell test result of samples show variability which could be the effect of depth of soil sample variability and the content of expansiveness of clay minerals in the soil. (Table 5.3)

Table 5.3 Test Result of Shrinkage Limit and Free Swell

Station	Depth (m)	Linear Shrinkage In, %	Free Swell,%
Asko	1.5	10	70.00
Addis Ketema	2.00	13	50.00
Arada	1.5	12	60.00

According to Altmeyer (1955) correlation between percent swell and linear Shrinkage limit (Table 5.5) the Linear shrinkage limit test results of three red soil samples from Asko,Addis Ketema and Arada is 10,13 and 12%, respectively which can be grouped as a probable swell potential having a critical degree of expansion. The variability on the test results from shrinkage limit could be the effect of depth of sampling and PI value.

Table 5.4 Correlation between percent swell and linear Shrinkage (Altmeyer,1955)

Linear Shrinkage,%	Probable swell,%	Degree of expansion
<5	<0.5	Non critical
5-8	0.5-1.5	Marginal
>8	>1.5	Critical

The variations in the plasticity indices in each group increase as the soils become progressively more plastic. The values for the Skempton activity of the soils range from 0.50 to 1.24 which classifies the soils as inactive to moderately active clays (Altmeyer, 1955).

From summary of result activity value distinguish the range of values lies between 0.11 to 0.7 with an average of Activity value 0.37 which lies in the group of inactive clay, A<0.75. Active clays are expected to cause problems for engineering practices.

Fig 5.2 shows in blue dots for 75 collected data of Activity of red clay from the study area,which fall in a group of Kaolinite clay content.

The primary clay mineral was kaolinite, with this high kaolinite content, the activity of the red clay is found to be low at approximately 0.11–0.7 and classified as inactive to active clay

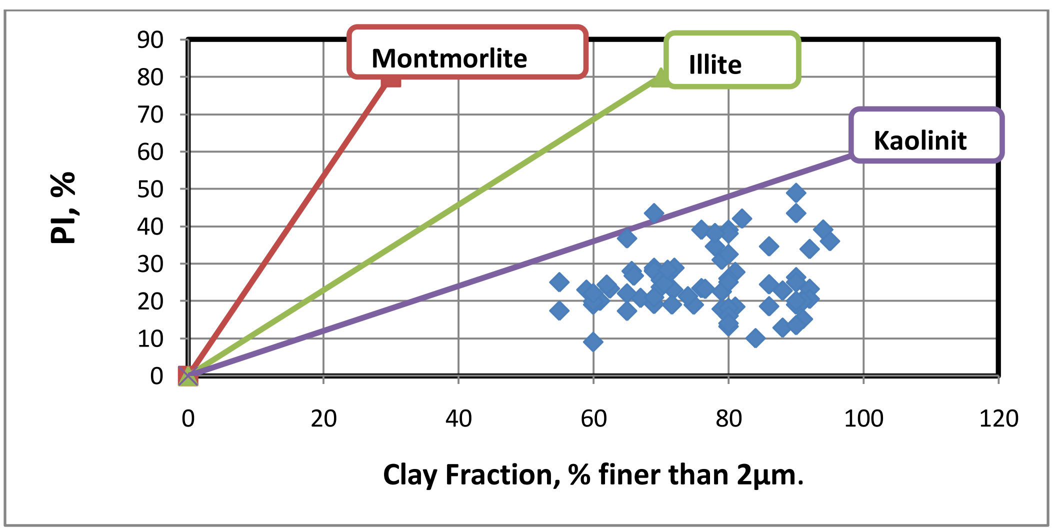

Fig. 5.2 Activity chart

5.1.3. Classification of the Soils

The basis for USCS (Unified Soil Classification System) is Liquid Limit and Plasticity Index of a soil. According to this classification scheme soil samples from the study area falls in CL,ML, MH region, this shows that the soil is more of high to low silt with lesser amount of clay soil.(Fig 5.3)

According to AASHTO soil classification system the red soil samples results falls in the region of A-7-5 and A-7-6 (Fig 5.4). Which indicates the soil is moderate plastic clay which could have a volume change capacity between wet and dry states.

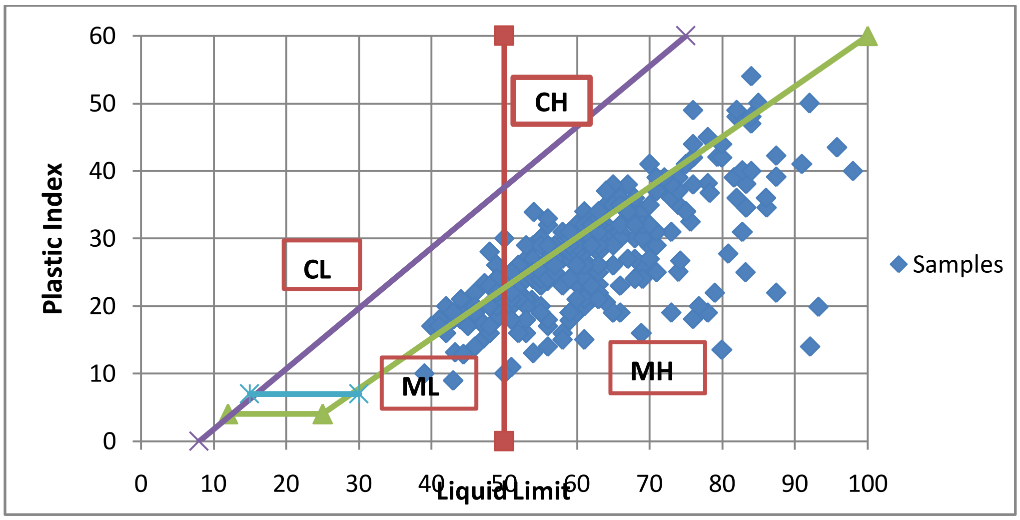

Fig. 5.3 Unified Classification of soil in the study area

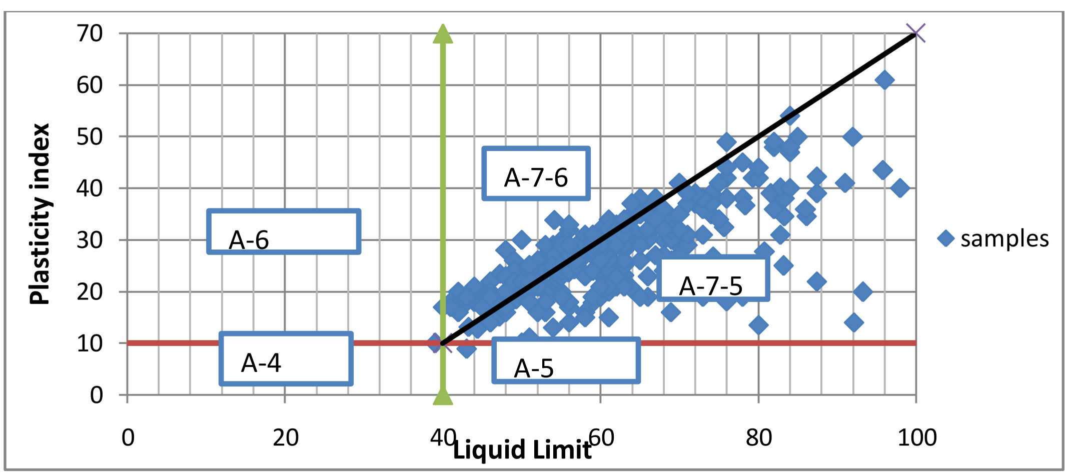

Fig 5.4 AASHTO Classification of soil in the study area

Table 5.5 Summary of Index and Mechanical Property Test results

Test Type	Range	Mean	Coefficient of Variation (%)
Moisture Content	14 - 59	33	30
Free Swell	5- 80	52	47
Liquid Limit(LL)	39-106	62.8	20
Plasticity Index(PI)	9 -40	27.9	30
Activity	0.11-0.70	0.37	31
Specific Gravity	2. 6-2.8	2.56	40
Cohesion(C), KN/m2	6 - 63	21	6
Angle of Friction (Ø),(^{0})	11 - 34	23	2
Unconfined Compressive Strength, KPa	64 - 213	159	47
Compression Index(Cc)	0.124 - 0.33	0.19	2
Maximum dry density, g/cm^3	1.25-1.64	1.50	6
Optimum moisture content,%	19 - 34	24	3

5.1.4 Mechanical Properties Results and Discussion

The unconfined compressive strength tests of collected results from the study area ranges from 64 to 213KPa which indicate a firm to stiff consistency. (Table 5.5)

The relationship between unconfined compressive strength and consistency of soil has a relation.(Table5.6). the average value of UCS result 159kpa fall in a range of stiff consistency.

Table 5.6 Relationship between Consistency of Clay and Qu (Arora,2004)

Qu,Kpa	Consistency
<25	Very soft
25-50	Soft
50-100	Medium
100-200	Stiff
200-400	Very Stiff
>400	Hard

The shear strength test result obtained from two undisturbed soil samples evidenced that cohesion(C) is 71 and 19Kpa at a depth of 1.50mfrom the two samples in Arada and Asko areaand angle of internal friction is 6 and 23 degree. Direct shear test conducted on drained condition gives results at a depth of 1.50m and 3.00m shows that the cohesion and Angle of friction vary in depth at a specific location. (Table 5.7)

Table 5.7 Test Result of Direct shear

Station	Depth,m	C(Kpa)	Ø(Degrees)
Arada	**1.50**	71	6
Asko	**1.50**	19	23

Table 5.8 Representative values of Cohesion for clay (From Arora, 2004)

Soil	Cohesion,(Kpa)
Very soft clay	<12
Soft to medium clay	12-25
Stiff clay	50-100
Very stiff	100-200
Hard	>200

The undrained shear strength (s) of the soil is equal to the one half of the UCS. From the results the average undrained shear strength gives 159Kpa.From the two undisturbed soil sample collected from Arada and Gulele Areas at different depths the UCS test was conducted to evaluate the unconfined compressive strength of red soil.(Table 5.9)

Table 5.9 Test results of unconfined compressive strength

Station	Arada	Gulele
Depth,m	3.00	1.50
Natural Moisture Content %	37	38
Bulk Density g/cm^3	1.96	1.90
Dry Density g/cm^3	1.43	1.37
Qu, Kpa	151	70
C_u = qu/2 ,Kpa	75	34
Strain at failure (%)	3.23	2.77

The strain at which the samples fail due to the applied vertical load is at 3.22 and 2.77% for the undisturbed red soil samples at 3.00 and 1.50m depth.(Figure5.5)

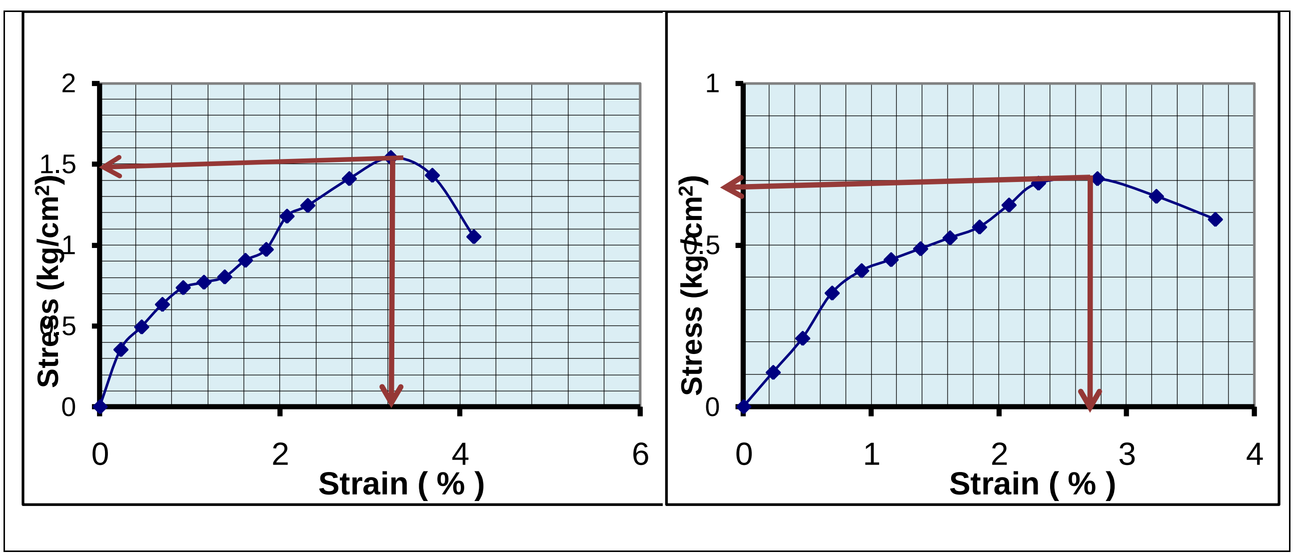

Fig 5.5 Stress Vs Strain Graph of UCS test result

According to Bell (2007), cohesive soils with compression index (Cc) in the range of 0.15 to 0.3 are considered to have high compressibility. Test results for compression index property of red soil shows medium to high degree of compressibility.

Table 5.10 Degree of Compressibility (After Bell, 2007)

Range(Cc)	Degree of Compressibility
>0.3	Very High
0.3-0.15	High
0.15-0.075	Medium
<0.075	Low

Results of these parameters for the three undisturbed red soil samples collected from Test Pits around Arada and Kolfe Keraniyo summarized.(Table 5.11) The results revealed that red clays in the study area are moderately plastic with a marginal degree of expansion. They have also relatively low free swell values. Correlation between results of the three station and collected data shows that the Cc values in general increases with increasing Liquid limit and Plastic index of a soil. This serves to suggest that the compressibility of soils generally increases with plasticity and vice versa. Generally void ratios for all of samples were reduced to lower value since increasing intensity of loadings at each steps of loading brought soil grains more closely to each other.

The test results of collected data for one dimensional consolidation in the study area Compression Index (Cc) range is 0.12 to 0.33 and the Swelling index (Cs) lies in a range of 0.013 to 0.12. The Swell pressure ranges in 4.9 to 91.9Kpa.

Table-5.11 Results of Consolidation Test for three samples

Station	Depth (m)	PI (%)	Compression (Cc)	Swelling index(Cs)	Swell pressure (Kpa)
Arada	1.5	23	0.146	0.037	11
Kolfe	2.00	20	0.129	0.029	-
Gulele	1.5	24	0.163	0.031	31

Table 5.12 Consolidation Test Result

Locations	Compression Index(Cc)	Swelling index (Cs)	Swell pressure (Kpa)
Kolfekeraniyo	0.15	0.04	5
Kolfekeraniyo	0.17	0.04	14
Kolfekeraniyo	0.15	0.04	11
Kolfekeraniyo	0.17	0.04	43
Addis Sefer	0.15	0.04	5
Addis Sefer	0.12	0.04	14
Addis Sefer	0.18	0.04	11
Addis Sefer	0.13	0.08	92
Addis Sefer	0.15	0.03	17
Addis Sefer	0.17	0.03	31
Addis Sefer	0.16	0.11	62
Addis Sefer	0.15	0.04	42
Asko	0.15	0.11	62
Asko	0.14	0.08	92
Arada	0.14	0.01	61
Arada	0.17	0.04	43
Arada	0.13	0.03	31
Arada	0.16	0.12	56

The Standard Proctor test variables and results of summary are presented. (Table 5.12). The maximum dry density (MDD) values obtained for the investigated samples are in average1.47,1.43 and 1.59 g/cm^3 for Asko, Kolfe and Gulele area, respectively. While the optimum moisture content (OMC) values are relativelysmaller and almost similar for Asko and Kolfe soil samples (average of 24 and 21%), it is Higher for Gulele soil sample (26%).

In general, MDD is higher when OMC is lower. However, the discrepancy of these parameters in the samples may be due to the different degree of weathering profiles and Increasing in compaction energy causes appreciable increase in the maximum dry densities (MDD) of the soils. The relation between Moisture content and maximum dry density of three soil samples represent graphically in (Figure 5.6, 5.7, 5.8).

Table 5.13 Summary of Proctor Compaction Test Results

Location	MDD,g/cm^3	OMC,%	Location	MDD, g/cm^3	OMC,%
Kolfe Keraniyo	1.36	32	Gulele	1.64	22
Kolfe Keraniyo	1.44	28	Gulele	1.61	24
Kolfe Keraniyo	1.53	29	Awelya	1.59	24
Kolfe Keraniyo	1.55	24	Awelya	1.56	24
Kolfe Keraniyo	1.25	26	Shegole	1.48	29
Asko	1.37	34	Shegole	1.54	27
Asko	1.39	34	Arada	1.37	23
Asko	1.55	25	Arada	1.52	23
Asko	1.53	25	Arada	1.53	25
Asko	1.63	20	Arada	1.51	27
Asko	1.57	21	Arada	1.53	26
Asko	1.57	25	Arada	1.54	23
Asko	1.62	21	Arada	1.58	26
Gulele	1.58	21	Arada	1.59	23
Gulele	1.63	23	Arada	1.46	24

Table 5.14 Standard Proctor Compaction Result

Location	Sample Depth, m	Atterberg Limits		Standard Proctor		Soil Classification	
		LL,%	PI,%	MDD, g/cm^3	OMC, %	AASHTO	USCS
Asko	1.50	48	16	1.47	24	A-7-5(3)	MH
Kolfe	2.00	54	18	1.43	21	A-7-5(15)	MH
Gulele	1.50	58	20	1.59	26	A-7-5(16)	MH

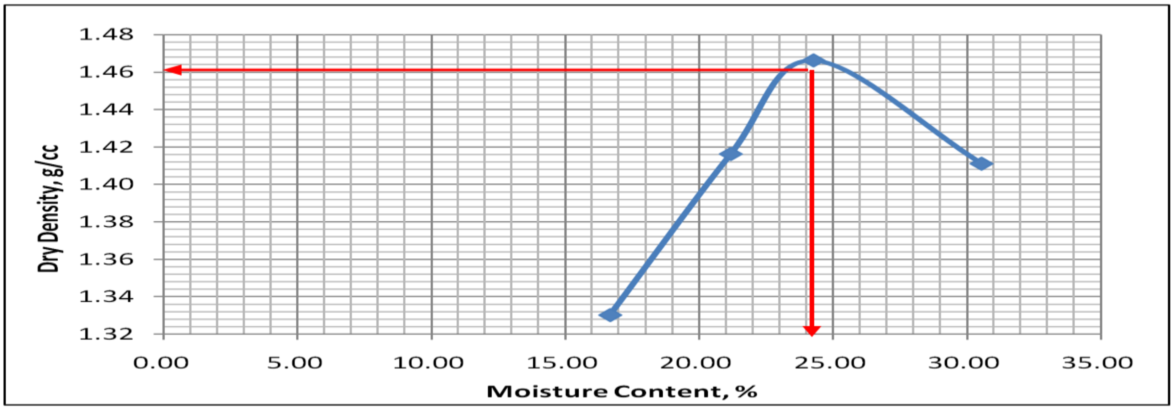

Fig 5.6 Standard Proctor Test Result (Asko at 1.5m)

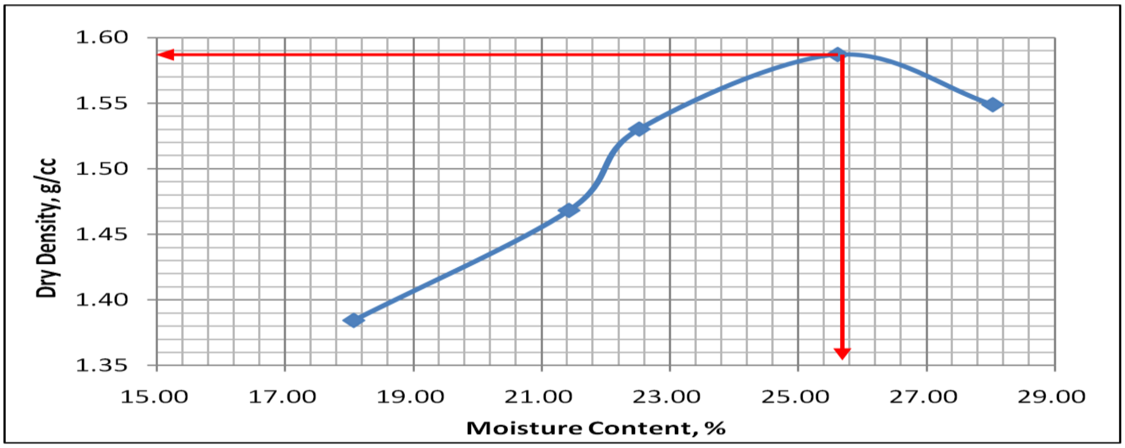

Fig 5.7 Standard Proctor Test Result (Gulele at 1.5m)

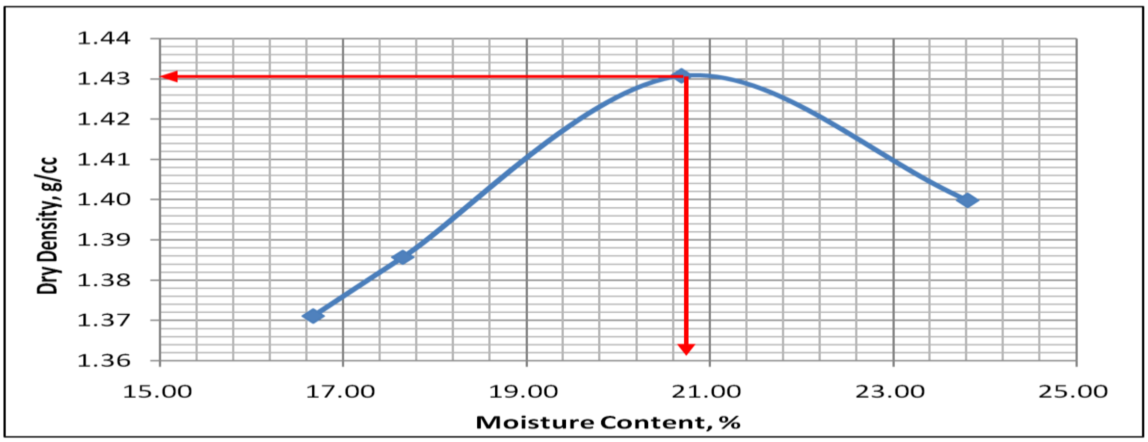

Fig 5.8 Standard Proctor Test Result (Kolfe at 2m)

5.1.5 Chemical Test Results and Discussion

Soil pH expresses amount of acidity in a soil. PH Test conducted on the sample of red soil from the study area around Kolfe Keraniyo gives a Ph value of 7.05. Form the soil Ph-Range value.(Table 5.15**)** Red Soil PH range value lies between 6.6-7.3 which shows an intermediate property between Acid and Alkaline.

Table 5.15 Soil pH ranges

PH	
Strongly Acidic	<5
Moderately Acidic	5.2--6
Slightly Acidic	6.1--6.5
Neutral	6.6--7.3
Moderately Alkaline	7.4--8.4
Strongly Alkaline	>8

Results of chloride and Sulphate content in Percentage are 0.031 and 0.27 respectively. This shows very small percentage of Chloride and Sulphate content in red soil sample from Kolfe area. Presented in(Table5.16). Test result of one red soil sample from Kolfe Area gives 0.82% of Organic matter content which indicates a very small content of organic matter in the soil.

Table 5.16 Summary of Chemical Test Result

Sample Location	PH value	Chloride content,%	Sulphate Content,%	Organic Matter,%
Kolfe Keraniyo X : 468345 Y : 999281	7.05	0.0311	0.27	0.82

Table 5.17 Red soil XRF Analysis Test Result

Sample Id	Station	Amount of Oxide in Percent (%)					Silica-Sesqoxide Ratio (SiO_2 / (Fe_2O_3 + Al_2O_3))	Soil Classification
		SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO		
Sample A	Asko	42.46	22.68	1.78	20.08	2.55	0.99	True laterite
Sample B	Kolfe Keraniyo	47.1	22.18	2.01	14.33	1.5	1.29	True laterite
Average		44.78	22.75	1.9	17.21	2.03	1.12	True laterite

The chemical composition of the samples given in (Table 5.17) shows the presence of 20.08 wt.% of Fe_2O_3 , 42.46 wt.% of SiO_2 and 22.68 wt.% of Al_2O_3 and weak content of 1.78wt.% of CaO and 2.55 wt.% of MgO. This result indicated that quartz, iron-rich minerals and alumino-silicates are the dominant phases in the two soil samples.

Rossiter (2004), compiled the classification of soils according to the degree of laterization by evaluating silica–sesquioxide (S-S) ratio (SiO_2 / (Fe_2O_3 + Al_2O_3)) (Table 5.17). Accordingly, soils having S-S ratio >2 are considered as non-lateritic soils. For lateritic soils, this S-S ratio lies between 1.33 and 2 and for true laterites the ratio is <1.33. The soil samples for the present investigation have S-S ratio (average of 1.12) lower than 1.33 suggesting that they are true laterite soils.

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of rocks in the tropical and sub-tropical regions with hot, humid climatic conditions. Their formation also consists of leaching out of free silica and bases and accumulation of oxides of iron or aluminum. This process is called laterization. Laterites are rich in sesquioxides (iron oxides, aluminum oxides or both) and low silicates but may contain appreciable amounts of kaolinite. Due to the presence of iron oxides lateritic soils are red in color.(Rossiter, 2004)

5.2. Suitability of Red Soil for Construction

The suitability of the soil for using it for engineering purpose interpreted according to standard set by Ethiopia Building Codes(EBC),ERA (2002) and AACRA (2004) manuals.

Performing gradation analysis is the easiest but the most indicative test for most soil use for construction purposes, which separate the soil into the various particle sizes. the more the fines proportion in a soil, the poorer the quality as a construction material. Fine grained soils in the silt and clay class may undergo volume changes on contact with water which results in weakening of the soil structure and consequent reduction in overall strength. The grading characteristics of soils are important factors for soils to attain high dry density when compacted.

The success or failure of a roadway section is often dependent upon the underlying subgrade. The strength, stiffness, compressibility and moisture characteristics of the subgrade can have significant influences on pavement performance and long-term maintenance requirements. The subgrade must be strong enough to resist shear failure and have adequate stiffness to minimize vertical deflection. Stronger and stiffer materials provide a more effective foundation for the riding surface and will be more resistant to stresses from repeated loadings and environmental conditions. The sub-grade soil was characterized using soil samples collected from the study area by considering the laboratory tests of grain size analysis, mineralogy, Atterberg limits, linear shrinkage, Proctor compaction test.
To evaluate the performance of red soil to be used as a sub-grade soil laboratory tests have been conducted on three disturbed red soil samples from Asko, Kolfe and Gulele areas. According to the laboratory test results of the natural soil samples obtained during the present study, with proportion of fines passing no 200 sieve results given for liquid limits 48%,54% and 58% and plasticity index 16%,18% and 20%, the soils classified in to A-7-5 as per the AASHTO and MH in the USCS classification system

According to standard manual soil material as sub-grade should full fill a maximum value of 30% and 60% for PI and LL values, respectively. This is the maximum requirement for most of standard manuals. However, the comparisons above confirm that soil samples full fill the requirements. Yet CBR test were not included in the current study.

Table.5.18 Summary of results as compared to ERA (2001), AACRA (2004) and EBCS-7 (1995).

Parameter	Station	ERA (2002)	AACRA	EBCS-7 (1995)

	Asko	**Kolfe**	**Gulele**	**Requirement**	**(2004) Requirement**	
PI	16	18	20	< 30%	<30%	15-35%,Moderate plastic
LL	48	54	58	<60%	-	50-60%,Marginal expansion

The physical and engineering properties of red clays have been characterized. According to EBCS-7 (1995), soils with PI value between 15% and 35% are considered as moderately plastic. Accordingly, red clays in Western Addis Ababa are found to be moderately plastic with an average PI value of 29% and according to USACE(1994), soils with LL 50-60% and PI 25-35% are considered to have marginal degree of expansion.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

In this research work, some geotechnical and geo-chemical characteristics have been investigated on red soils from western Addis Ababa area. This investigation is undertaken through the preparation of geotechnical data base. Drilling and laboratory testing data both from preexisting and ongoing projects have been utilized. The extracted laboratory test results data were systematically organized and a geotechnical data base has been created in Microsoft Excel and GIS software were used to produce meaningful geo-database and to make the soil thickness map.

Investigations on the lateral and vertical variability of the engineering properties and various engineering characteristics of red soil in the western Addis Ababa were studied in detail for this research. The various tests carried out included particle size distribution, Atterberg limits, linear shrinkage, specific gravity, Free Swell, Standard Proctor Compaction, One dimensional Consolidation, UCS and Direct shear tests.

The classification scheme developed by AASHTO is a useful guide to determine the quality of soils as a construction material for pavement constructions. Classification of most of soil samples from study area fall in groups of A-7-5 and A-7-6.

As the soil in the study area has lower Plastic Index, therefore problems may arises because of higher plasticity index are not common on road ways in the study area.Linear shrinkage tests were carried out to determine the water content at which no further decrease in the volume of the soil mass will be experienced.

Atterberg's consistency limit test indicates that the soil has a moderate to high plastic soils with moderate swelling potential. The results of the assessment revealed that red clays in the study area are moderately plastic with a marginal degree of expansion. They have also relatively low free swell values. Correlation between results of the three station and collected data shows that the Cc values in general increases with increasing Liquid limit and Plastic index of the soil. This serves to suggest that the compressibility of soils generally increases with plasticity.

Skempton activities were calculated from the results of the plasticity index and percentage of clay obtained from the hydrometer tests, values of 0.11-0.70 on an average are 0.37 were obtained. This classify soils as inactive clay mineral having low sensitivity. The clay mineral contents indirectly indicated using the activity chart of major clay minerals; Illite, Kaolinite and Montmorillonite. From the results of soil samples collected Kaolinite is the main clay mineral in the red clay indicates that the low swell potential of this soil.The test results show that, the values on liquid limit versus plasticity index graph lie below the A – line. It indicates that the soil samples contain the mineral kaolinite.

From the moisture-density relationships of the soils were determined by the standard Proctor test. They yield moderate dry density when compacted at the optimum moisture content of the standard proctor method. The maximum dry density (MDD) values obtained for the investigated samples are in average1.47, 1.43 and 1.59 g/cm^3 for Asko, Kolfe and Gulele area respectively. While the optimum moisture content (OMC) values are relatively smaller and almost similar for Asko and Kolfe soil samples (average of 24 and 21%), it is Higher for Gulele soil sample (26%).The discrepancy on the compaction result may be due to the different degree of weathering profiles in the soil.

From Unconfined compressive strength test results indicates these soils fall in a range of medium to stiff consistency due to compaction process at the optimum water content.

The shear strength test result obtained from undisturbed soil samples evidenced that cohesion(C) is 71 and 19Kpa at a depth of 1.50m and angle of internal friction is 6 and 23 degree.

The chemical results and the PH test conducted on the sample from the study area around KolfeKeraniyo gives a PH value of 7.05 which shows neutral property,Organic matter content 0.82% indicated a very small content of organic matter in the soil, in additionchloride and Sulphate content tests gives 0.0311 and 0.27 in Percentage respectively. This shows very small percentage of Chloride and Sulphate content in red soil sample.

The major oxides composition of the soils were determined by X-ray fluorescence analysis and result indicated that quartz, iron-rich minerals and alumino-silicates are the dominant phases in the samples.The classification of two soils according to the degree of laterization by evaluating silica–sesquioxide (S-S) ratioas on average of 1.12 which classify the soil as a true laterite soil.

To summarize, as the objective of this study to recommend on using red soil in the study area of Addis Ababa for construction purpose the test results of collected different project geotechnical data and primary data collected during the present study from five areas gives a reasonably good result to make use it as a foundation soil.

In General, from the summarized geotechnical data in the study area the test results prevail that the red soil is less expansive and have less swelling potential clay as it contain kaolinite than Montmorlonite in it therefore red soil is less problematic soil than a black cotton soil.

6.2 RECOMMENDATIONS

The following recommendations are forwarded from the results of the current study;

- Detailed study on the mineral composition through XRF/XRD test is essential for red soil as not much researches has been done on it.Therefore, it needs further investigation as such study is beyond the scope of the present research.
- In general, geotechnical database are essential for many researches and design/analysis works. Their availability in sufficient quantity and quality is of crucial importance to the success of similar works. Organizations in similar tasks should be committed to a quality data base.
- In the present study, an attempt has been done to determine the average physical-Chemical properties of red soil in western Addis Ababa. However, due to lack of a well-organized geotechnical database, not all available historical geotechnical data were compiled to produce the soil thickness map.
- Detailed study on bearing capacity of red soil is essential as it is part of the engineering geology study and it is adviced to have a further study on this.

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Appendix -1 SUMMARY OF COLLECTED DATA LOCATION & SOIL THICKNESS

Locality	UTM_E	UTM_N	Elevation(m)	Thickness(m)
Addis Ketema	468893	1000496	2507	5.5
Kolfe	464351	992168	2316	10
Gullele	473921	1000541	2535	1
Arada	471741	999192	2411	0.4
Kolfe	468470	998870	2455	10
Kolfe	467104	1000909	2497	4.5
Kolfe	467586	999375	2453	9
Kolfe	466897	996986	2357	8
Kolfe	468412	996091	2323	11
Arada	471610	999003	2398	12
Arada	471741	999192	2411	10
Kolfe	465659	994370	2386	5
Gulele	469018	1002911	2623	2
Gulele	469299	1002004	2651	2
Asko	467239	1001048	2535	0.5
Kolfe	468345	999281	2482	2
A.Ketema	741512	999975	2206	2
Gulele	468452	1000831	2546	1.5
keraniyo	466030	998722	2476	3
Ashewa meda	465747	997676	2465	5
Arada	472650	998295	2446	1.5
Gulele	468858	1001574	2564	1.5
kolfe	466727	998734	2433	3
kolfe	466397	995292	2433	2.5
kolfe	467092	996716	2381	1.5
Addis Ketema	470636	1002082	2652	2.4
Addis Ketema	470446	1002856	2612	2
Addis Ketema	470446	1001643	2621	3.5
Alem Bank	465700	997621	2460	3.5
Alem Bank	467333	99785	2417	2
Addis Ketema	469476	100182	2415	2.4
Atikelt Tera/Arada	463200	992758	2232	1.9
Atikelt Tera/Arada	463176	992753	2356	2
Atikelt Tera/Arada	463152	992759	2410	3
A.A. H,Kolfe site	463134	992772	2415	0.8
A.A. H,Kolfe site	463092	992785	2395	3
A.A. H,Kolfe site	463068	992781	2435	2.4
A.A. H,Kolfe site	463039	992782	2233	3.5
Alem Bank	463551	996229	2436	2.5

Alem Bank	463599	996306	2458	3
Alem Bank	463661	996293	2415	5
Alem Bank	464600	1003075	2620	5.5
Alem Bank	463266	1001971	2600	2
Burayu	465600	1003075	2545	0.5
Burayu	465651	1001855	2540	1.5
Gullele	464433	994782	2442	2.5
Gullele	466686	992756	2316	2.5
Alem Bank	467856	993259	2276	1.7
Asco	467100	1000550	2517	10
Asko	466400	1001760	2560	10
Gulele	469198	995712	2354	10
Asco	463158	995774	2356	10
A.A. H,Kolfe site	462899	992832	2276	1
A.A. H,Kolfe site	462863	992876	2214	1
A.A. H,Kolfe site	462833	992880	2145	1.5
A.A. H,Kolfe site	462856	992844	2562	2
A.A. H,Kolfe site	462833	992840	2415	2
A.A. H,Kolfe site	462809	992841	2498	2.8
A.A. H,Kolfe site	462779	992849	2435	5.5
A.A. H,Kolfe site	462760	992860	2295	1.6
A.A. H,Kolfe site	462739	992872	2275	3
A.A. H,Kolfe site	462696	992869	2365	2.4
A.A. H,Kolfe site	462670	992871	2416	1
A.A. H,Kolfe site	462645	992878	2436	2.8
A.A. H,Kolfe site	462624	992889	2465	2.5
A.A. H,Kolfe site	462616	992787	2487	3.9
A.A. H,Kolfe site	462613	992756	2493	4.5
A.A. H,Kolfe site	462618	992817	2433	2
A.A. H,Kolfe site	462642	992823	2436	1
A.A. H,Kolfe site	462665	992818	2452	2.8
A.A. H,Kolfe site	462686	992808	2416	3
A.A. H,Kolfe site	462880	992874	2468	1.5
A.A. H,Kolfe site	462674	992746	2510	3
A.A. H,Kolfe site	462747	992727	2498	3
A.A. H,Kolfe site	462779	992721	2458	3
A.A. H,Kolfe site	462720	992732	2499	2
A.A. H,Kolfe site	462724	992760	2500	2.8
A.A. H,Kolfe site	462729	992801	2456	1.5
A.A. H,Kolfe site	462750	992804	2398	1
A.A. H,Kolfe site	462774	992801	2378	0.7

A.A. H,Kolfe site	462804	992794	2369	1.2
A.A. H,Kolfe site	462824	992783	2225	2.4
A.A. H,Kolfe site	462845	992769	2189	2.6
A.A. H,Kolfe site	462839	992737	2145	5
A.A. H,Kolfe site	462833	992707	2332	5
A.A. H,Kolfe site	462732	992668	2465	2.5
A.A. H,Kolfe site	463257	995804	2535	2.5
A.A. H,Kolfe site	463348	996285	2433	5.5
A A.H,Jemo gara site	463207	995751	2413	10
A A.H,Jemo gara site	463239	995746	2236	10
A A.H,Jemo gara site	463249	995772	2213	15
A A.H,Jemo gara site	463257	995804	2415	15
A A.H,Jemo gara site	463270	995757	2356	15
A A.H,Jemo gara site	463289	995737	2248	15
A A.H,Jemo gara site	463288	995796	2521	15
A A.H,Jemo gara site	463310	995751	2123	10
A A.H,Jemo gara site	463162	995795	2356	10
A A.H,Jemo gara site	463165	995833	2356	10
A A.H,Jemo gara site	463216	995858	2356	10.5
A A.H,Jemo gara site	463238	995832	2354	10.5
A A.H,Jemo gara site	463189	995801	2458	10.5
A A.H,Jemo gara site	643225	995796	2365	10.5
A A.H,Jemo gara site	463465	995757	2235	10.5
A A.H,Jemo gara site	643475	995785	2236	15
A A.H,Jemo gara site	463417	995775	2236	15
A A.H,Jemo gara site	463428	995801	2123	10
A A.H,Jemo gara site	463389	995778	2692	12
A A.H,Jemo gara site	463369	995800	2248	15
A A.H,Jemo gara site	463333	995843	2333	15
A A.H,Jemo gara site	463310	995909	2336	5
A A.H,Jemo gara site	463383	995856	2335	5
A A.H,Jemo gara site	463405	995843	2365	5
A A.H,Jemo gara site	463431	995830	2356	2
A A.H,Jemo gara site	463453	995819	2126	2
A A.H,Jemo gara site	463481	995606	2213	2.5
A A.H,Jemo gara site	463430	995880	2222	2.5
A A.H,Jemo gara site	463459	995886	2316	2.5
A A.H,Jemo gara site	463406	995893	2245	2.5
A A.H,Jemo gara site	463359	995926	2213	10

Appendix-2 Atterberg Limit Test Result

SAMPLE OF :	Disterbed Red soil
STATION/LOCATION :	Kolfe
TEST REQUESTED :	Atterberg Limits

ATTERBERG LIMITS

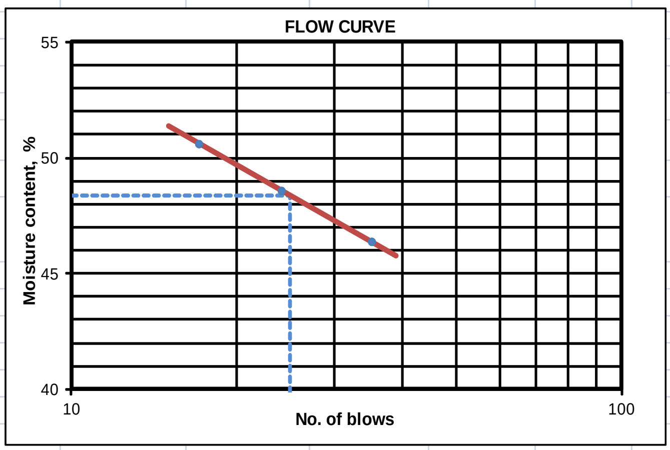
TEST METHODS: AASHTO T-89 & T-90

		Liquid Limit (LL)			Plastic Limit (PL)	
No. of blows		35	24	17	-	-
Container No.		VH	KL	AC	CG	AT
Mass of Wet Soil + Container	g	42.69	43.18	40.08	19.56	20.98
Mass of Dry Soil + Container	g	36.13	35.93	34.22	19.04	20.01
Mass of Water	g	6.56	7.25	5.86	0.52	0.97
Mass of Container	g	22.00	21.02	22.65	17.12	16.65
Mass of Dry Soil	g	14.13	14.91	11.57	1.92	3.36
Moisture Content	%	46.4	48.6	50.6	27.1	28.9
					Avg PL, %=	28.0

Liquid Limit (LL) :- 48 %

Plastic Limit (PL) :- 28 %

Plasticity Index (PI) :- 20 %



SAMPLE OF : **Disterbed soil**

STATION/LOCATION : **Asko**

TEST REQUESTED : **Atterberg Limits**

ATTERBERG LIMITS

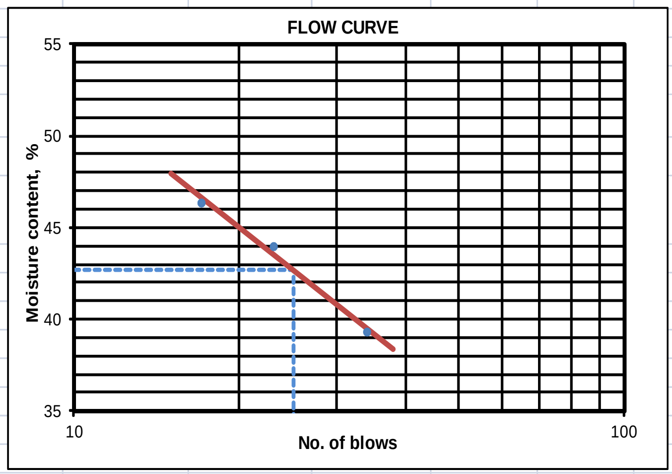
TEST METHODS: AASHTO T-89 & T-90

		Liquid Limit (LL)			Plastic Limit (PL)	
No. of blows		34	23	17	-	-
Container No.		B	A	C	AD	AE
Mass of Wet Soil + Container	g	42.98	41.09	41.31	20.73	20.81
Mass of Dry Soil + Container	g	37.13	34.93	35.17	19.92	19.93
Mass of Water	g	5.85	6.16	6.14	0.81	0.88
Mass of Container	g	22.26	20.93	21.93	17.20	17.05
Mass of Dry Soil	g	14.87	14.00	13.24	2.72	2.88
Moisture Content	%	39.3	44.0	46.4	29.8	30.6
					Avg PL, %=	**30.2**

Liquid Limit (LL) :- 43 %

Plastic Limit (PL) :- 30 %

Plasticity Index (PI) :- 13 %



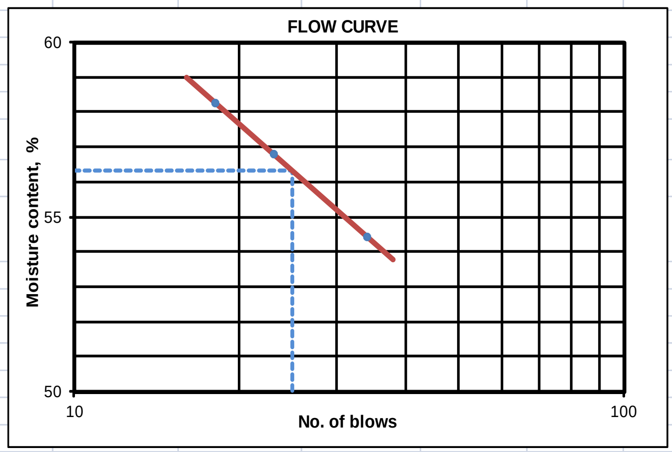
SAMPLE OF : **Disterbed Red soil**
STATION/LOCATION : **Gulele**
TEST REQUESTED : **Atterberg Limits**

ATTERBERG LIMITS
TEST METHODS: AASHTO T-89 & T-90

		Liquid Limit (LL)			Plastic Limit (PL)	
No. of blows		34	23	18	-	-
Container No.		YD	AB	G2	T6	EA
Mass of Wet Soil + Container	g	50.62	52.21	52.35	20.51	21.1
Mass of Dry Soil + Container	g	40.60	40.6	41.10	19.65	20.14
Mass of Water	g	10.02	11.61	11.25	0.86	0.96
Mass of Container	g	22.20	20.17	21.80	17.00	17.15
Mass of Dry Soil	g	18.40	20.43	19.30	2.65	2.99
Moisture Content	%	54.5	56.8	58.3	32.5	32.1
					Avg PL, %=	32.3

Liquid Limit (LL) :- 56 %
Plastic Limit (PL) :- 32 %

Plasticity Index (PI) :- 24 %



SAMPLE OF : Disterbed Red soil

STATION/LOCATION : Arada

TEST REQUESTED : Atterberg Limits

ATTERBERG LIMITS

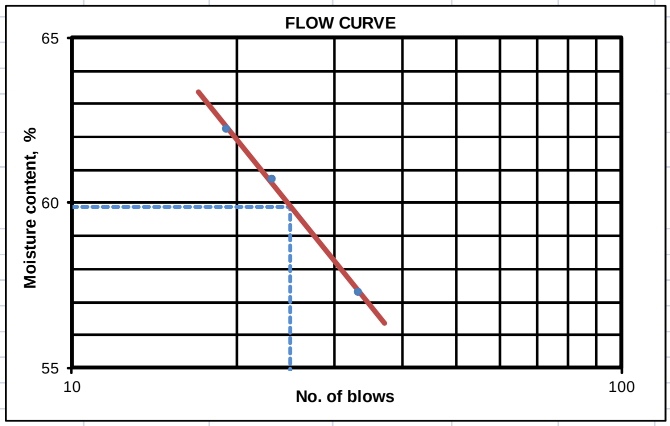
TEST METHODS: AASHTO T-89 & T-90

		Liquid Limit (LL)			Plastic Limit (PL)	
No. of blows		33	23	19	-	-
Container No.		K	P	6	T23	SE
Mass of Wet Soil + Container	g	56.39	55.81	50.96	21.45	21.63
Mass of Dry Soil + Container	g	43.98	42.75	39.48	20.13	20.68
Mass of Water	g	12.41	13.06	11.48	1.32	0.95
Mass of Container	g	22.34	21.26	21.05	16.64	18.02
Mass of Dry Soil	g	21.64	21.49	18.43	3.49	2.66
Moisture Content	%	57.3	60.8	62.3	37.8	35.7
					Avg PL, %=	36.8

Liquid Limit (LL) :- 60 %

Plastic Limit (PL) :- 37 %

Plasticity Index (PI) :- 23 %



SAMPLE OF : **Red soil**
STATION/LOCATION : **Asko**
TEST REQUESTED : **Atterberg Limits**

ATTERBERG LIMITS
TEST METHODS: AASHTO T-89 & T-90

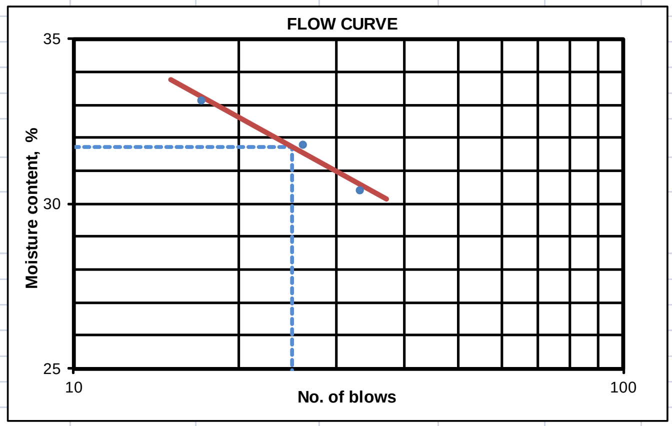
		Liquid Limit (LL)			Plastic Limit (PL)	
No. of blows		33	26	17	-	-
Container No.		BD	AR	KL	J	E
Mass of Wet Soil + Container	g	46.2	47.10	47.5	21.55	21.98
Mass of Dry Soil + Container	g	40.60	40.6	41.10	20.86	21.24
Mass of Water	g	5.60	6.50	6.40	0.69	0.74
Mass of Container	g	22.20	20.17	21.80	17.00	17.15
Mass of Dry Soil	g	18.40	20.43	19.30	3.86	4.09
Moisture Content	%	30.4	31.8	33.2	17.9	18.1
					Avg PL, %=	18.0

32
14

18

Liquid Limit (LL) :- 32 %
Plastic Limit (PL) :- 18 %

Plasticity Index (PI) :- 14 %



Appendix-3 Standard Proctor Compaction Test Results

STATION: Disturbed Red soil / Asko at 1.00m

TEST REQUESTED: Standard Proctor test

MOISTURE - DENSITY RELATION OF SOIL

Standard (AASHTO T-99) :- ☑ Modified (AASHTO T-180) :- ☐

No. of blows : 25 Weight of hammer,kg : 2.5

No. of layers : 3 Volume of mold,cm^3 : 944

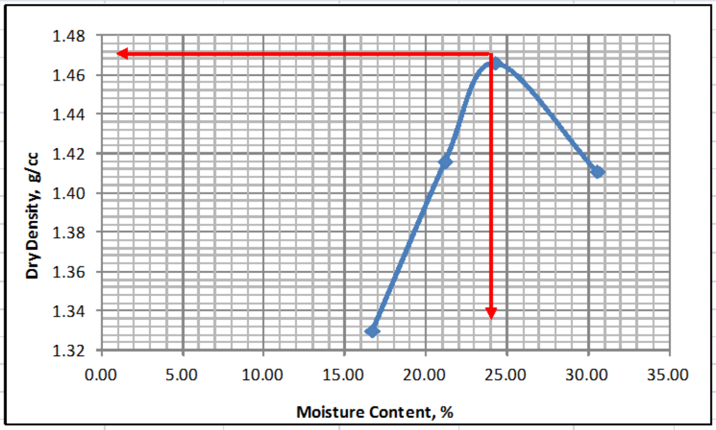
Trial		1	2	3	4	5	I.M.C
Wt. of Mold + Wet Soil	gram	4396	4551	4651	4670	4665	
Wt. of Mold	gram	2931					
Wt. Wet Soil	gram	1465	1620	1720	1739	1734	
Volume of Mold	cu.cm.	944					
Wet Density	gr/cu.cm.	1.552	1.716	1.822	1.842	1.837	
Container No.		B	FB	S	H2	B	H
Wt. Cont + Wet soil	grams	128	119	144	157	156	117
Wt. Cont + Dry soil	grams	112	101	119	124	121	103
Weight of Water	grams	16	18	25	33	35	14
Weight of Container	grams	16	16	16	16	16	16
Weight of Dry Soil	grams	96	85	103	108	105	87
Moisture Content	%	16.67	21.18	24.27	30.56	33.33	16.09
Dry Density	gr/cu.cm.	1.330	1.416	1.466	1.411	1.378	

Maximum Dry Density (MDD)

MDD = 1.466 gm/cc

Optimum Moisture Content (OMC)

OMC = 24.0 %



STATION:	Gulele at 1.50m							
TEST REQUESTED:	Standard Proctor Test							

MOISTURE - DENSITY RELATION OF SOIL

Standard (AASHTO T-99) :- ☑ Modified (AASHTO T-180) :- ☐

No. of blows :	25	Weight of hammer,kg :	2.5
No. of layers :	3	Volume of mold,cm^3 :	944

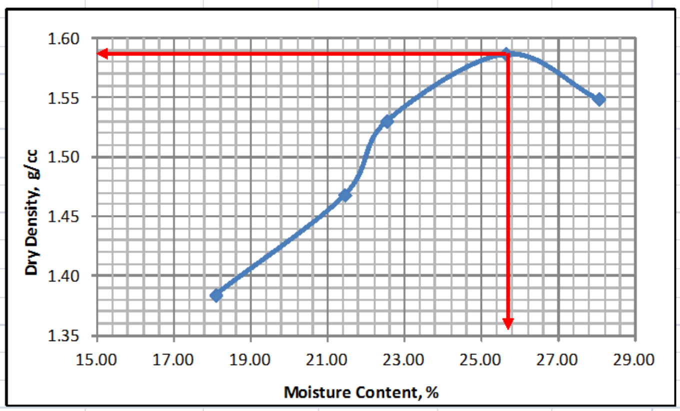
Trial		1	2	3	4	5	
Wt. of Mold + Wet Soil	gram	4386	4526	4613	4725	4715	
Wt. of Mold	gram	2843					
Wt. Wet Soil	gram	1543	1683	1770	1882	1872	
Volume of Mold	cu.cm.	944					
Wet Density	gr/cu.cm.	1.635	1.783	1.875	1.994	1.983	
							I.M.C
Container No.		T	ZS	LK	G	AQ	8
Wt. Cont + Wet soil	grams	114	118	152	168	153	104
Wt. Cont + Dry soil	grams	99	100	127	137	123	91
Weight of Water	grams	15	18	25	31	30	13
Weight of Container	grams	16	16	16	16	16	16
Weight of Dry Soil	grams	83	84	111	121	107	75
Moisture Content	%	18.07	21.43	22.52	25.62	28.04	17.33
Dry Density	gr/cu.cm.	1.384	1.468	1.530	1.587	1.549	

Maximum Dry Density (MDD)

MDD = 1.587 gm/cc

Optimum Moisture Content (OMC)

OMC = 26.0 %



STATION:	Kolfe at 2.00m depth
TEST REQUESTED:	Standard proctor test

MOISTURE - DENSITY RELATION OF SOIL

Standard (AASHTO T-99) :- ☑ Modified (AASHTO T-180) :- ☐

No. of blows :	25	Weight of hammer,kg :	2.5
No. of layers :	3	Volume of mold,cm^3 :	944

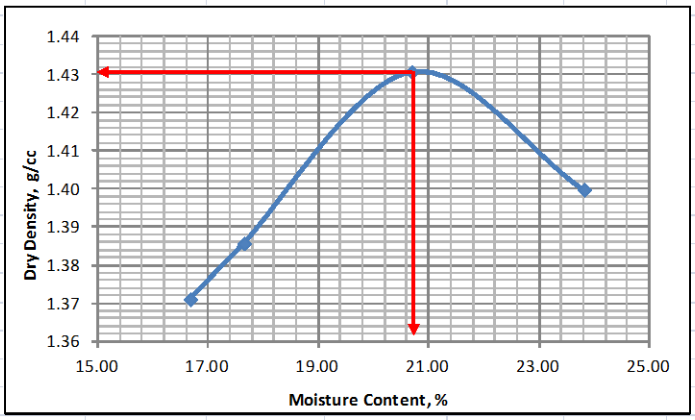
Trial		1	2	3	4	I.M.C
Wt. of Mold + Wet Soil	gram	4386	4415	4506	4512	
Wt. of Mold	gram	2876				
Wt. Wet Soil	gram	1510	1539	1630	1636	
Volume of Mold	cu.cm.	944				
Wet Density	gr/cu.cm.	1.600	1.630	1.727	1.733	
Container No.		G	R	P	AS	Q
Wt. Cont + Wet soil	grams	128	116	156	146	106
Wt. Cont + Dry soil	grams	112	101	132	121	97
Weight of Water	grams	16	15	24	25	9
Weight of Container	grams	16	16	16	16	16
Weight of Dry Soil	grams	96	85	116	105	81
Moisture Content	%	16.67	17.65	20.69	23.81	11.11
Dry Density	gr/cu.cm.	1.371	1.386	1.431	1.400	

Maximum Dry Density (MDD)

MDD = 1.431 gm/cc

Optimum Moisture Content (OMC)

OMC = 21.0 %



APPENDIX- 4 CONSOLIDATION TEST RESULTS

SAMPLE OF: (Undisturbed)
STATION: Gulele
DEPTH: 1.50m
TEST REQUESTED: Consolidation Test (AASHTO T-216)

SPECIMEN DATA

BEFORE TEST

Type of specimen	Remolded
Specimen Diameter(D),mm	63.50
Specimen Thickness(Ho),mm	25.00
Area(A),cm2	31.65
Volume(V),cm3	79.13
Mass of Ring,gm	90.55
Mass of Ring +Specimen,gm	243.03
Mass of specimen,gm	141.16

Specific Gravity(Gs)	2.72
Initial moisture (wo),%	30.22
Bulk Density(Do),gm/cc	2.04
Dry Density(Do),gm/cc	1.57
Initial Void Ratio:eo=(Gs/Dd)-1	0.73
Hightof Solid:Hs=Ho/(1+eo),mm	14.43
Initial Saturation:So=WoGs/eo,%	112.16

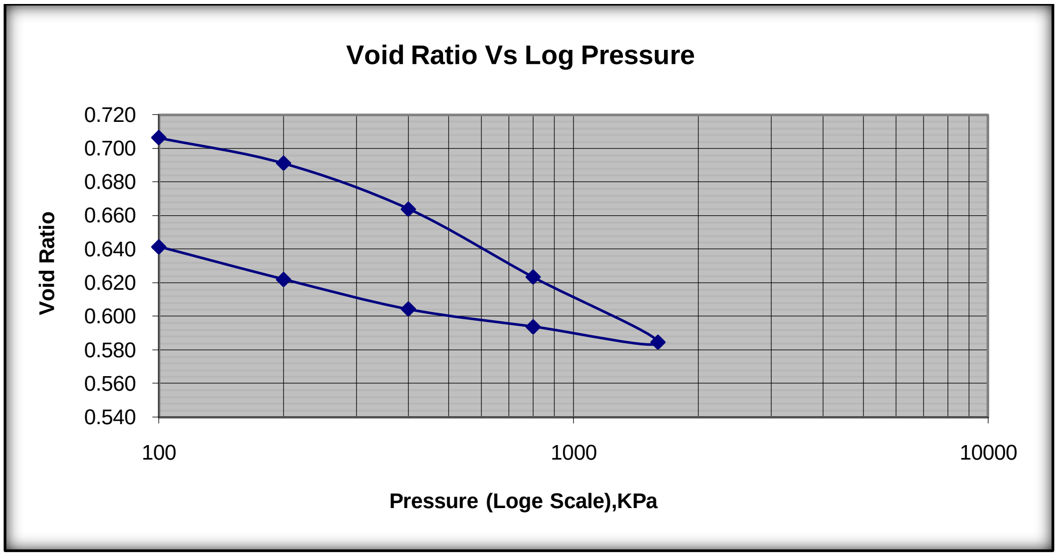
AFTER TEST

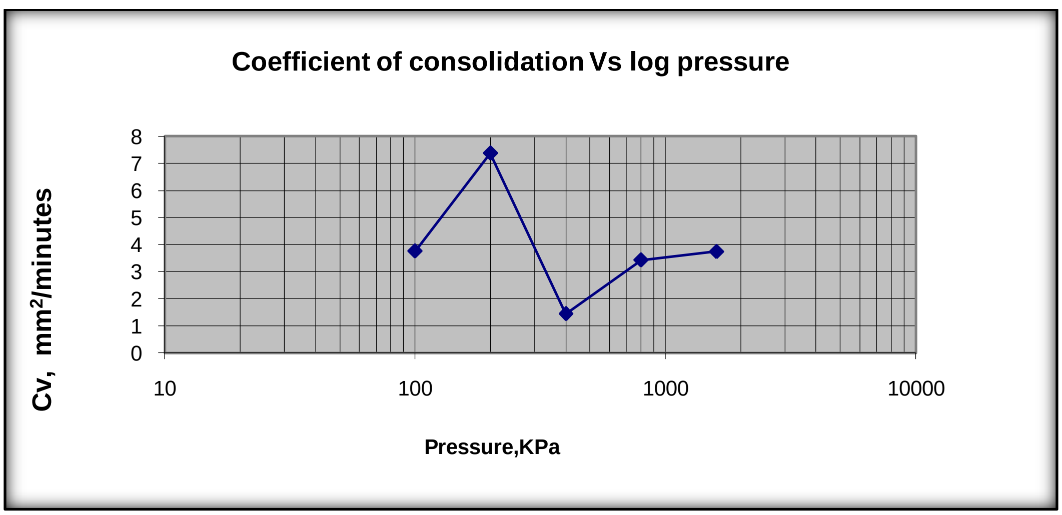
Mass of Wet Specimen+Ring,gm	250.81
Mass of Dry Specimen+Ring,gm	210.23
Mass of Ring,gm	90.55
Mass of wet Specimen,gm	160.26
Mass of water,gm	40.58
Final Moisture Content,%	33.91

Overall settlement,mm	1.32
Final volume,cm3	74.95
Final bulk Density,g/cc	2.14
Final dry Density,g/cc	1.60
Final void ratio	0.70
Final saturation,%	131.11

Pressure	Void Ratio %	Cv,mm^2/minutes ($0.197*H^2/t_{50}$)
100	0.706	3.75
200	0.691	7.37
400	0.664	1.43
800	0.623	3.43
1600	0.585	3.74
800	0.594	
400	0.604	
200	0.622	
100	0.641	

Copression Index(Cc)=	**0.129**
Swelling index(Cs)=	**0.031**
Swell pressure (Kpa)	**31**





SAMPLE OF: (Undisturbed)
STATION: Arada
DEPTH: 1.50m
TEST REQUESTED: Consolidation Test (AASHTO T-216)

SPECIMEN DATA

BEFORE TEST

Type of specimen	Remolded
Specimen Diameter(D),mm	63.50
Specimen Thickness(Ho),mm	25.00
Area(A),cm2	31.65
Volume(V),cm3	79.13
Mass of Ring,gm	97.46
Mass of Ring +Specimen,gm	243.03
Mass of specimen,gm	141.16

Specific Gravity(Gs)	2.74
Initial moisture (wo),%	30.56
Bulk Density(Do),gm/cc	1.78
Dry Density(Do),gm/cc	1.37
Initial Void Ratio:eo=(Gs/Dd)-1	1.01
Hightof Solid:Hs=Ho/(1+eo),mm	12.47
Initial Saturation:So=WoGs/eo,%	83.28

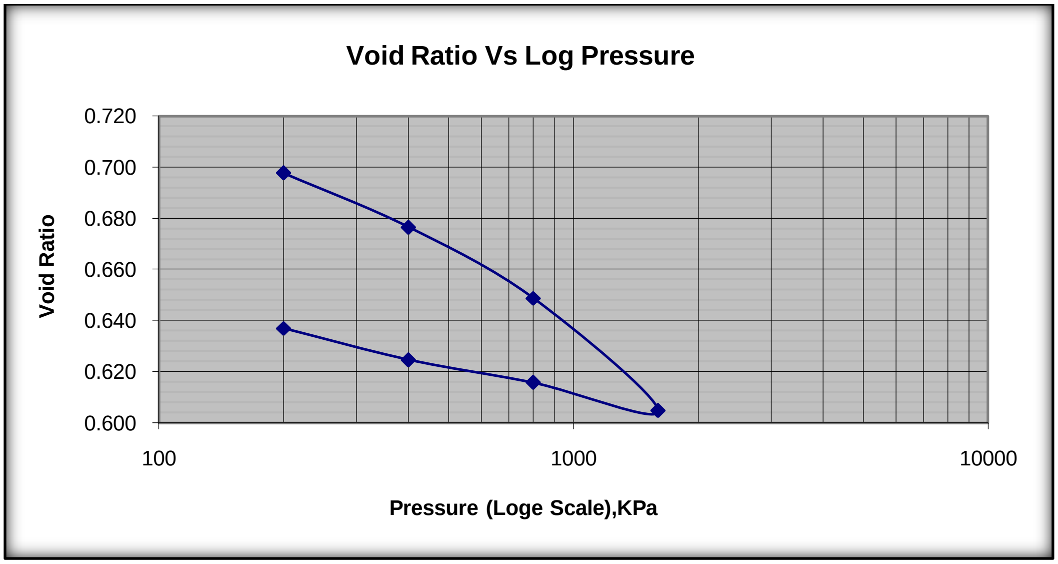
AFTER TEST

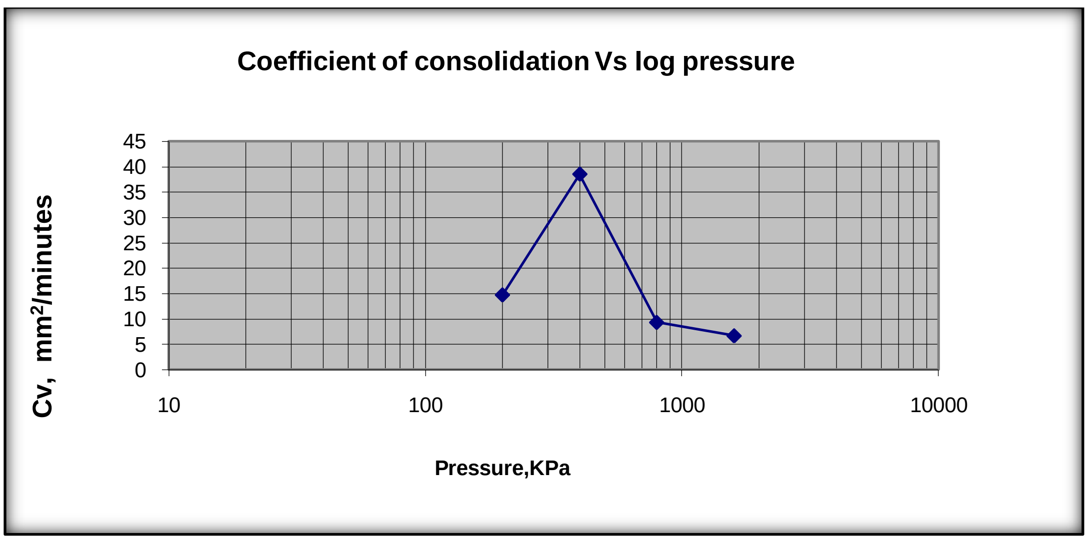
Mass of Wet Specimen+Ring,gm	266.26
Mass of Dry Specimen+Ring,gm	220.32
Mass of Ring,gm	97.46
Mass of wet Specimen,gm	168.80
Mass of water,gm	45.94
Final Moisture Content,%	37.39

Overall settlement,mm	1.35
Final volume,cm3	74.87
Final bulk Density,g/cc	2.25
Final dry Density,g/cc	1.64
Final void ratio	0.67
Final saturation,%	152.97

Pressure	Void Ratio %	Cv,mm^2/minutes (0.197*H^2/t$_{50}$)
100	0.714	10.05
200	0.698	14.77
400	0.677	38.54
800	0.649	9.33
1600	0.605	6.67
800	0.616	
400	0.625	
200	0.637	
100	0.646	

Copression Index(Cc)=	0.146
Swelling index(Cs)=	0.037
Swell pressure (Kpa)	11





APPENDIX- 5 PHOTOS

Photo 1- Remolded sample for Test

Photo 2-Data recording during UCS Test

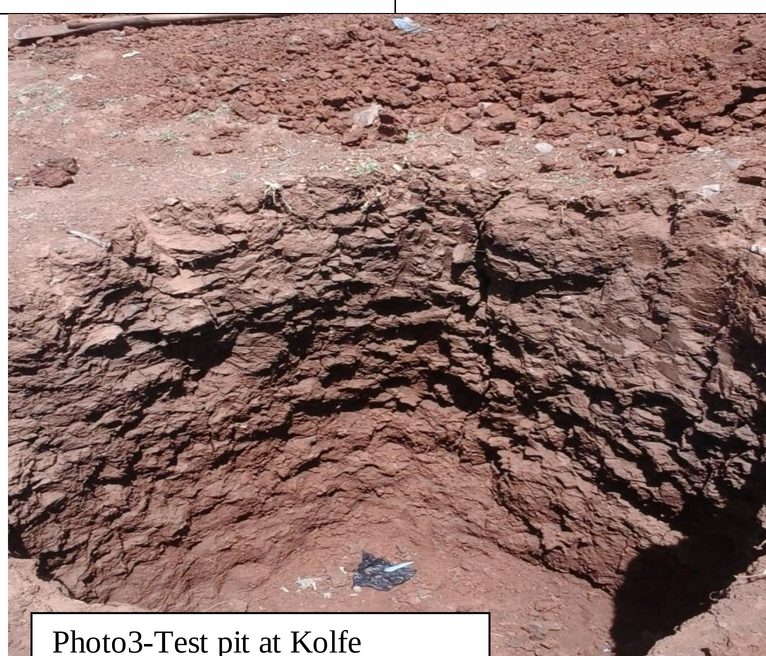


Photo3-Test pit at Kolfe

APPENDIX- 6 SUMMARY OF LABORATORY TEST RESULT

Atterberg Limits,Sieve Analysis, Free Swell & Specific Gravity Test Results												
Station	**Depth,m**	**Material Description**	**Sieve Analysis mm,AASHTO T 27-84**					**Atterberg Limit**		**Unified Soil Classificaton**	**Free Swell %**	**Specific Gravity**
								LL	**PI**			
			9.5	**4.75**	**2.00**	**0.425**	**0.075**	**%**	**%**			
Addis Ketema	2	High Plastic Silt	100	99.9	99.7	89	87.2	57	25	MH	54	2.5
Addis Ketema	2	High Plastic Silt	100	99.98	99	95	90.4	46	19	MH	47	2.5
Addis Ketema	2.8	High Plastic Silt	100	99.8	99	95	91.5	57	26	MH	54	2.5
Addis Ketema	5.5	High Plastic Silt	100	99.5	99	97	95.4	51	22	MH	50	2.5
Addis Ketema	1.6	High Plastic Silt		100	99.9	95	90.5	55	19	MH	53	2.6
Addis Ketema	3	High Plastic Silt		100	86	85	83.1	51	18	MH	54	2.6
Addis Ketema	4	High Plastic Silt		100	99.9	98	94.7	64	32	MH	40	2.6
Addis Ketema	6	High Plastic Silt		100	99	97	94.8	60	28	MH	40	2.6
Addis Ketema	2	High Plastic Clay		100	99.8	98	95.9	65	35	CH	70	2.4
Addis Ketema	4	High Plastic Silt		100	99	94	92.5	56	27	MH	50	2.6
Addis Ketema	5	Low Plastic Silt		100	99.6	92	86.0	63	29	MH	69	2.6
Alem Bank	2.4	High Plastic Silt		100	99.9	98	97.1	61	30	MH	35	2.5
Alem Bank	1	High Plastic Silt		100	99.96	99	97.0	56	24	MH	35	2.5

Alem Bank	2.8	High Plastic Silt	100	99.9	99	95	91.6	59	27	MH	60	2.6
Alem Bank	2.5	High Plastic Silt	100	99.9	99	96	93.5	51	22	MH	50	2.6
Alem Bank	3.9	High Plastic Silt			100	99.5	96.5	57	27	CH	60	2.5
Alem Bank	4.5	High Plastic Silt		100	99.8	99	95.9	62	31	MH	80	2.5
Alem Bank	2	High Plastic Silt	100	99.97	99	97	94.5	61	32	MH	80	2.6
Alem Bank	1	Low Plastic Silt		100	99.8	97	93.0	45	18	CH	35	2.6
Arada	3	High Plastic Clay		100	99	97	94.2	75	41	CH	70	2.5
Arada	1.5	High Plastic Clay		100	99.9	99	97.0	59	29	CH	40	2.6
Arada	1.5	High Plastic Silt		100	99.99	99	95.7	41	18	ML	15	2.6
Arada	2	High Plastic Silt		100	99.6	97	93.4	55	25	MH	40	2.6
Arada	4.1	High Plastic Silt		100	99.9	99	98.0	59	28	MH	65	2.6
Arada	7.6	High Plastic Clay		100	99.9	99	96.3	70	41	CL	65	2.4
Arada	1.8	Low Plastic Clay	100	99.97	99.6	95	90.3	40	17	CL	15	2.6
Arada	4.9	High Plastic Silt	100	99.97	98	93	90.3	56	25	MH	40	2.7
Arada	7	High Plastic Clay		100	99.97	99.7	98.9	53	29	CH	20	2.5
Asco	4	High Plastic Silt		100	99	96	94.6	73	38	MH	90	2.6
Ashewameda	3.5	High Plastic Clay		100	99.9	99	96.7	54	29	CH	40	2.5
A A.H,Jemogara site	2.5	High Plastic Silt		100	99.9	99	97.0	71	37	MH	60	2.4
A A.H,Jemogara site	2	High Plastic Clay		100	100	99	96.9	56	29	CH	40	2.5
A A.H,Jemogara site	2	High Plastic Silt	100	99.98	99.5	97	95.3	60	28	MH	60	2.3
A A.H,Jemogara site	5	Low Plastic Clay	100	99.9	99.5	98	95.3	48	23	CL	20	2.5
A A.H,Jemogara site	3	High Plastic Silt	100	99.97	99.5	96	93.3	80	42	MH	80	2.5

A A.H,Jemogara site	6	Low Plastic Clay		100	99.7	98	94.7	49	26	CL	40	2.4
A A.H,Jemogara site	7	High Plastic Silt		100	99	96	94.0	80	44	MH	110	2.6
A A.H,Jemogara site	2	Low Plastic Clay		100	99.6	99	97.3	49	24	CL	60	2.5
A A.H,Jemogara site	4.1	Low Plastic Clay		100	99.9	99	95.9	46	20	CL	20	2.6
A A.H,Jemogara site	7.6	Low Plastic Clay		100	99.8	98	90.1	39	10	CL	25	2.6
A A.H,Jemogara site	1.8	High Plastic Silt		100	99.6	97	94.9	52	23	ML	50	2.5
A A.H,Jemogara site	4.9	High Plastic Silt		100	99	94	89.7	51	22	MH	45	2.6
A A.H,Jemogara site	7	Low Plastic Clay	100	99.98	99.4	96	92.0	52	21	ML	50	2.6
A A.H,Jemogara site	4	Low Plastic Clay		100	99.8	97	92.4	46	20	CL	40	2.6
A A.H,Jemogara site	3.5	High Plastic Silt		100	99	96	93.4	84	48	MH	80	2.5
A A.H,Jemogara site	2	High Plastic Silt	100	99.9	99	96	94.4	76	38	MH	90	2.5
A A.H,Jemogara site	2	High Plastic Silt	100	99.96	98	92	88.9	51	22	MH	40	2.4
A A.H,Jemogara site	3	High Plastic Silt		100	99	96	93.9	61	28	MH	60	2.6
Asko	3	High Plastic Clay	100	99.9	99.6	97	94.3	66	36	CL	60	2.6
AtikeltTera	2	High Plastic Silt		100	99.8	99	97.6	85	50	MH	95	2.4
AtikeltTera	2.5	High Plastic Clay	100	99.96	99	95	92.4	84	54	CH	50	2.5
Burayu	3.5	High Plastic Silt	100	99.9	99	96	93.4	65	38	MH	50	2.4
Burayu	3.5	High Plastic Silt	100	99.9	99	97	93.9	63	30	MH	35	2.6
Gulele	13	High Plastic Silt	100	99.9	99	96	93.1	57	27	MH	40	2.5
Gulele	2	Low Plastic Silt		100	99.97	99.5	96.6	45	17	ML	20	2.6
Gulele	2	High Plastic Clay		100	99.9	97	93.6	82	48	CH	80	2.4
Gulele	2	High Plastic Silt		100	99.6	98	95.0	62	30	MH	45	2.5
Gulele	4	Low Plastic Clay		100	99.97	99	97.5	48	28	MH	40	2.4
Gulele	6	High Plastic Clay	100	99.96	99.9	98	93.9	49	24	CL	25	2.5

Gullele	2	Low Plastic Clay	100	99.9	99	95	91.5	49	26	CL	45	2.4
Gullele	4	Low Plastic Clay	100	99.99	99.9	98	92.3	46	22	CL	30	2.5
Gullele	6	Low Plastic Clay	100	99.9	99.6	98	95.8	49	22	CL	30	2.6
keraniyo	2.5	High Plastic	100	99.70	99	98	95.1	54	27	MH	25	2.5
A.A. H,Kolfe site	2.5	High Plastic Silt		100	99.7	98	94.9	51	18	MH	41	2.4
A.A. H,Kolfe site	4	High Plastic Silt	100	99.9	99	91	86.5	51	25	MH	43	2.5
A.A. H,Kolfe site	6	High Plastic Silt		100	99.9	96	90.8	53	24	MH	46	2.5
A.A. H,Kolfe site	2	High Plastic Clay	100	99.8	98	88	81.0	60	32	CH	50	2.6
A.A. H,Kolfe site	4	Low Plastic Clay		100.0	99	91	85.4	49	21	CL	40	2.5
A.A. H,Kolfe site	6	High Plastic Clay	100	99.9	99.6	96	93.2	68	36	CH	55	2.6
A.A. H,Kolfe site	4	High Plastic Silt	98	96	92	87	85.0	102	59	MH	90	2.6
A.A. H,Kolfe site	6	High Plastic Silt	100	99.9	99.7	98	96.5	56	18	MH	52	2.5
A.A. H,Kolfe site	2	High Plastic Clay	100	97	94	87	82.7	96	61	CH	80	2.6
A.A. H,Kolfe site	4	High Plastic Silt	100	99.8	99.5	96	92.8	65	29	MH	60	2.6
A.A. H,Kolfe site	6	High Plastic Clay	100	99.8	99	94	89.5	61	32	CH	62	2.6
A.A. H,Kolfe site	3.45	High Plastic Silt		100	99	96	94.0	66	32	MH	67	2.5
Kolfe Keraniyo	3	High Plastic Clay		100	99	98	95.5	55	29	CH	54	2.5