ADDIS ABABA UNIVERSITY
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Investigation of Index properties and swelling potential of expansive soils in Lege Tafo area

A Thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the Requirement of the Degree of Master of Science in Civil Engineering (Geotechniques)

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Symbols and Abbreviations

AASHTO	American association of state highway and transport official
	American Society for Testing and Materials
ASTM	Potential Volume Change
PVC	Specific gravity of solids
Gs	Swelling pressure
Sp	Plasticity index
PI	Shrinkage limit
SL	Dry density
γd	Liquid limit
LL	Plastic limit
PL	Free swell
Fs	Equation
Eqn	Activity
Ac	Cation Exchange Capacity
CEC	United states bureau of public roads classification
U.S.B.R	Test pit
T.P	

Abstract

This Study is conducted on Lege Tafo area which is located on flat plain just east of Addis Ababa City. The area is covered with thick clay soil and new infrastructures are under construction in the region as part of the fast growing urbanization and industrial development around Addis Ababa and this is one of the reasons why the area is selected for the study.

The objective of this research is to understand the nature of the soil and obtain sufficient information on type and characteristics of the soil in the area to provide general data for future construction projects. To achieve these objectives the surrounding of Lege Tafo is studied in the field, and representative clay soil samples are collected and analyzed in the laboratory.

Black soils in Ethiopian are derived from weathering of basalt volcanic rocks and are invariably clays or silty clays. Natural deposits of black cotton soils in the field are characterized by a general pattern of surface cracks during the dry season of the year. During wet seasons, the soil first expands horizontally, filling up the shrinkage cracks. Further volumetric expansion causes vertical heaving of the soil which may cause damage to an overlying structure. Deformations occurring in the soil affect the stability of structure negatively, and the consequence could be tremendous loss.

A total of 15 disturbed and undisturbed soil samples were collected from 9 test pits. Three undisturbed samples at 2 meter depth are tested for investigation of swelling pressure.

Expansive soils of Lege Tafo are generally black in color and underlain by gray soils that have significant swelling potential. From soil classifications, soil samples taken from 2 meter and 3 meter depths have shown the same capacity for expansion/ swelling potential. As a result of this swell consolidation test was conducted on three samples collected at 3 meter.

The soil in the study area is mostly clay ranging from 53.6-75.3%, silt 22.9-33.6%. According to consistency test results, liquid limit ranges from 91 - 116%, plastic limit from 27.8-46.6% and plastic index from 52.37-81.6%.

Within the depth of investigation, the specific gravity of the study area ranges from 2.60 to 2.85.

According to the Unified Soil Classification System, the soil in the study area is categorized as highly plastic inorganic clays. AASHTO classification system also shows that the soil is highly plastic with a potential for a considerable volume change.

Swelling pressure test carried out on undisturbed samples from the study yield results ranging from 76 kPa to 165 kPa. The results are compared with results of previous studies on similar soils around Addis Ababa.

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

INVESTIGATION OF INDEX PROPERTIES AND SWELLING POTENTIAL OF EXPANSIVE SOILS IN LEGE TAFO AREA

BY

SABA MESFIN

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DECLARATION

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CHAPTER 1
INTRODUCTION

1.1. General

A geotechnical engineer involved in a site investigation of soil properties on and below an area of interest to determine their engineering properties including how they will interact with, on or in a proposed construction. Site investigations are needed to gain an understanding of the area in or on which the engineering will take place.

Investigation of soil is needed to evaluate the general suitability of the site and also explore the sub surface condition of the area to provide general data for the proposed project. Result from the investigation relevant physical properties of the subsoil used for the purpose of design.

As a result of this expansive soil is has a potential for shrinking and swelling under changing moisture conditions. Damage to structures particularly light buildings and pavements can occur. Therefore determination of soil properties and quantification of the shrink /swell potential at the site is essential.

Like any other developing country urbanization is growing and more industrial and residential areas are developing in Ethiopia. Addis Ababa has shown unprecedented growth in recent years and it is expanding into the suburbs around the city. Lege Tafo area is one of the suburbs of Addis Ababa. Currently vast residential buildings, public centers and industrial zones are under development and it has high prospect of developing. Because of the wide residential, public and industrial construction that are under construction and prospect of anticipated fast growth and development in the area, Lege Tafo area is selected for this Master's Thesis Project.

1.2. Objectives

The overall aim of this thesis is to investigate the index and swelling potential of soils found in Lege tafo area.

1.2.1. General Objectives

- To investigate relevant physical properties of subsoil used for the purpose of design
- For investigation and evaluation of soil suitability for construction

1.2.2. Specific objectives

The specific **objectives** of the research are:-

- To investigate index properties
- To determine the swelling potential of soils in the area.

1.3. Methodology

The sample was taken from Lege Tafo because it is the potential area for construction of building in the country. Firstly, Visual site investigation and information were collected to avoid back fill areas and to take representative samples of expansive soil of the area after site investigation and identification was done. Accordingly, nine test pits were selected from different locations for which the number of test pits required for a project depends on primarily on uniformity of soil samples and type of construction on the area. Disturbed and undisturbed samples were taken from an area where there was a huge potential of expansive soil. Furthermore, a total of 15 disturbed and undisturbed soil samples were collected from the test pits out of which three undisturbed samples at 2 meter depth were tested for investigation of swelling pressure. Beside to this, atterberg limit tests, specific gravity, hydrometer and free swell tests were conducted on disturbed samples and also Swell Consolidation and UC tests were conducted on undisturbed samples

Finally, the following laboratory tests were carried out on the samples collected from the area.

- Specific gravity test
- Atterberg limit tests
    - Liquid limit
    - Plastic limit
- Grain size analysis
    - Sieve analysis(wet method)
    - Hydrometer
- Free swell test
- Unconfined Compression test
- Swell- consolidation test

All tests were done according to American Society for Testing Material (ASTM) standards.

1.4. Scope of the study

This thesis research was concentrated and delineating their study area only at Lega Tafo and also the research mainly focuses on extensive soil for determination of soil index properties and swelling potential of soil by digging of test pits up to 3 meter depth depends on primarily on uniformity of soil samples and type of construction. The type of construction which is mainly constructed on this particular area is residential building so that the soil samples were collected, conducted a laboratory test, consolidated and analyzed the collected data. .

1.5. Organization of the Thesis

This thesis is divided into six Chapters, each covering a specific topic of the research work. Chapter one introduces background of the problem, objective of the study, research methodology, scope of the thesis work and Organization of the thesis. Chapter two deals with a brief literature review on factors influencing the shrink swell potential, identification and classification of swelling soils and review of expansive soil properties. Clay mineralogy, formation, physical and swelling properties of expansive soil are discussed in this chapter.

In chapter three location, topography and climatic characteristics of the area (Lega Tafo) are described. Chapter four presents sampling, laboratory tests and their corresponding standard method of testing, discussions on different soil tests and test results.

The discussion of laboratory test results obtained from this work, classification of soil using different classification methods and comparison with results of previous research are works covered in Chapter five. Chapter six has deals with the conclusions and recommendations drawn from the research.

Detailed data from laboratory tests such as test pits for each, specific gravit , grain size ad hydrometer analysis , atterberge test, UCS, and swelling pressure are included in the appendix.

CHAPTER 2
LITERATURE REVIEW

2.1. General

Expansive soils are in abundance where the annual evaporation exceeds the precipitation. Potentially expansive soils can be found almost anywhere in the world. In the underdeveloped nations, many of the expansive soil problems may not have been recognized.

The Ethiopian black soils are the continuation of Gedaref soils in the eastern part of Sudan. Such residual soils are derived from weathering of basalt volcanic rocks and are invariable clays or silty clays. [9]

Natural deposits of black cotton soils in the field are characterized by a general pattern of cracks during the dry season of the year. During wet seasons, the soil first expands horizontally, filling up the shrinkage cracks and thus volumetric expansion causes vertical heaving of soil which may cause damage to an overlying structure.

Expansive soils which are also known as black cotton soils are rich in montimorillonite. Expansive soils are principally residual, derived from the weathering of basic volcanic rocks which cover most of the Ethiopian plateau.

Since volcanic rocks are fine textured rocks, they are invariably clays or silty clays. Expansive soils are found in areas with poor internal drainage and low to moderate rainfall .They contain montimorillonite as a principal clay mineral with additional kaolnite and halloysite.

A potentially expansive soil is not necessarily damaging unless it is subjected to moisture changes, which may result from seasonal climatic changes.

Plastic clays exhibiting volume changes when subjected to moisture variations due to seasonal climatic conditions or artificial causes are termed expansive soil. These soils are commonly known as black clays. The fact that they are found favorable in some regions for growing cotton in India has also given them the name black cotton soil [9].

Expansive soil in most cases has adverse effect on any engineering structure built on it.
Deformations occurring in the soil, affects the structure built on it negatively and the consequence causes tremendous loss.

2.2. Origin of Expansive Soils

Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition. The origin of expansive soils is related to a complex combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, will expand. The conditions and processes which determine the clay mineralogy include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected.[9]

2.3. Formation of clay minerals

Clay minerals are formed by weathering .This includes disintegration, oxidation, hydration and leaching. The setting for the formation of Montimorillonite is extreme disintegration, strong hydration and restricted leaching .
Magnesium, calcium, sodium, iron cations may accumulate in the system of leaching. The above conditions are favorable in semi-arid regions with relatively low rainfalls or highly seasonal moderate rainfall, particularly where evaporations exceed rainfall, or rainfall with restricted leaching.(Chen,1988)

2.4. Identification of swelling soils

There are three different methods of Identifying potentially expansive soils.

2.4.1. The mineralogical identification

The mineralogical composition of expansive soils has an important bearing on the swelling potential. The negative electric charges on the surface of the clay minerals, the strength of the interlayer bonding, and the cation exchange capacity all contribute to the swelling potential of the clay. Hence, the swelling potential of any clay can be evaluated by identification of the constituent mineral of this clay.

Mineralogical identification can be made through various methods such as x-ray diffraction, Differential thermal analysis, Dye Adsorption, chemical Analysis and Electron microscope resolution. [9]

- X-ray diffraction method- used in determining the proportion of the various minerals present in a colloidal clay consists essentially of comparing the ratios of the intensities of diffraction lines from the different minerals with intensities of lines from the standard substance.

- Differential thermal Analysis- used in conjunction with x-ray diffraction and chemical analysis enables the identification of otherwise difficult materials. It is well established as a technique for the control of materials which undergo characteristic changes on heating.

- Dye adsorption- dyestuffs and other reagents which exhibit characteristic colors when adsorbed by clay have been used to identify clay. When a clay sample has been pretreated with acid, the color assumed by the adsorbed dye depends on the base exchange capacity of the various clay minerals present. The presence of montmorillonite can be detected if its amount is greater than about 5 to 10 percent.

- Chemical Analysis- can be a valuable supplement to other methods such as x-ray analysis in identifying clays. In the montmorillonite group of clay minerals, chemical analysis can be used to determine the nature of isomorphism and to show the origin and location of the charge on the lattice.

- Electron Microscope Resolution- Microscopic examination of clay minerals offers a direct observation of the material. Two clays may give the same x-ray pattern and the same differential thermal curve but will show distinct morphological characteristics under electron microscope resolution. The main purpose of the microscopic examination is to determine mineralogic composition, texture, and internal structure. [9]

2.4.2. The Indirect methods

This method includes the index propriety, Potential Volume Change (PVC) method and activity method.

a) Index Property Tests

Index property is a property, which helps in distinguishing the characteristics of a soil. Soil grain property and soil aggregate property are two main categories under this term. Soil grain property is based on the individual grains and depends on size, shape and Mineralogical characteristics. Soil aggregate property, on the other hand is based on the property of the soil mass as a whole.

Atterberg limit test, hydrometer analysis, specific gravity and free swell tests are among the tests which show the index property of a soil.

Holtz and Gibbs demonstrated in 1956 that the plasticity index and the liquid limit are useful indices for determining the swelling characteristics of most clays.

i) Atterberg limit tests

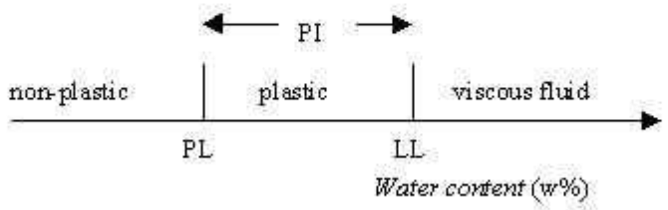
The objective of the Atterberg limits test is to obtain basic index information about the soil used to estimate strength and settlement characteristics. It is the primary form of classification for cohesive soils. The test indicates the range of plastic state and other state. The water content corresponding to the transition from one state to another are termed as atterberg limit.

- ✓ The transition from the liquid state to a plastic state is called liquid limit
- ✓ The transition from the plastic state to a semisolid state is called plastic limit

Fine-grained soil is tested to determine the liquid and plastic limits, which are moisture contents that define boundaries between material consistency states. These standardized tests produce comparable numbers used for soil identification, classification and correlations to strength.

The liquid (LL) and plastic (PL) limits define the water content boundaries between non-plastic, plastic and viscous fluid states. The plasticity index (PI) defines the complete range of plastic state. Figure 1 illustrates it nicely.

Figure 2.1: Atterberg limits illustration.



Particle size distribution

Soil consist mostly different sized soil particles as major constituent ingredient. The determination of the fractions of the particles will help to identify the soil type as well as to estimate many other engineering properties such as strength and permeability and to identify the soil is suitable for construction projects such as highways, dams and backfill.

Two methods are mostly used to determine grain size distribution: .

- Sieve analysis(dry method and wet method)- for coarse grained portion of the soil and .

- Hydrometer analysis for fine grained portions.

This method covers the quantitative determination of the distribution of particle size in soils. The distribution of particle size larger than 0.075mm is determined by sieving, while the distribution of particle finer than 0.075mm is determined by hydrometer.

Grading of soils is the distribution of particles of different sizes in a soil mass. The grading of soils can be determined from particle size distribution curves.
Different soil classification system designates range of grain size for different soils as shown on the table below,

Table 2.1 Ranges of grain size analysis based on ASTM

Classification System	**Grain size (mm)**			
	Gravel	**Sand**	**Slit**	**Clay**
Unified	4.75 – 75	0.075 – 4.75	Clay and silt are identified by their plasticity character	
AASHTO	2.00 – 75	0.05 – 2.00	0.002 – 0.05	< 0.002
MIT	2.00 –100	0.06 – 2.00	0.002 – 0.06	< 0.002
ASTM	2.00 – 100	0.075 – 2.00	0.005 – 0.075	< 0.005
USDA	2.00 – 75	0.05 – 2.00	0.002 – 0.05	< 0.002

The hydrometer analysis assumes that the soil particles are sphere, the soil suspicion is sufficient low concentration to permit individual setting of grain without interference by other. Hydrometer analysis uses to determine particle size distribution of soil finer than 75 micrometer.

Liquid Limit (LL)

The liquid limit defines the boundary between plastic and viscous fluid states. It is determined using a standard "Liquid Limit Device," which drops a shallow cupfull of soil 1 cm consistently. When a groove cut through the sample closes 1/2", the number of drops is recorded and a moisture content sample processed.

Repeating the procedure for a total of four drop-count ranges provides enough data to plot on a semi-log scale. From the plot, the moisture content at 25 drops defines the Liquid Limit.

Plastic Limit

Plastic Limit is the moisture content at the boundary between the plastic and semisolid states. It is determined by ascertaining the lowest moisture content at which the material can be rolled into threads 3mm in diameter before crumbling.

Plastic Index

Plastic Index is the numerical difference between the liquid limit and the plastic limit and indicates the magnitude of the range of moisture content over which the soil remains plastic.

PI=LL-PL

It is the measure of the cohesion qualities of the binder resulting from the clay content. Also it gives some indication of the amount of swelling and shrinkage that will result in the wetting and drying of the fraction tested.

Table 2.2 : Expansive soil classification based on plasticity

Plasticity Index	plasticity
0	**Non-plastic**
< 7	**Low plastic**
7-17	**Medium**
>17	**High plastic**

Swell Potential	**Plasticity Index**
Low	0-15
Medium	10-35
High	20-55
Very High	35 and above

Specific gravity

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of soil is used in calculating the phase relationships of soils, such as void ratio and degree of saturation. These test methods cover the determination of the specific gravity of soil that pass the 4.75-mm (No. 4) sieve, by means of a water pycnometer.
Determination of specific gravity is important for it is useful to determine the diameter of the soil grains in hydrometer analysis.

There are two methods for performing the specific gravity

Method A-Procedure for Moist Specimens is preferred for organic soils; highly plastic, fine grained soil, tropical soils and soils containing halloysite.

Method B-for oven dried specimen

For this research method A is used

Typical values of specific gravity are given below for roughly assessing the soil type (from Bowles, foundation analysis and design)

Table 2.3. Specific gravities of soil (Bowles)

soil type	**Specific Gravity, Gs Ranges**
Gravel	2.65 - 2.68
Sand	2.65 - 2.68
Silty sand	2.66 - 2.70
Silt, inorganic	2.62 - 2.68
Clay Organic	2.58 - 2.65
Clay inorganic	2.68 - 2.7

The above values are important for the determination of other soil properties.

(ii) Linear shrinkage: The swell potential is presumed to be related to the opposite property of linear shrinkage measured in a very simple test

(iii) Free swell:

The free swell test is one of the most commonly used simple tests for estimating soil swelling potential. This test is performed by pouring 10cc of dry soil, passing through Sieve no 40 (0.425mm diameter), into a 100 cc graduated cylinder.

The cylinder is then filled with distilled water and the swelled volume of the soil is measured after the material settles.

Free swell is then given by:

Fs = (V- Vo) / initial volume x100

Where: Fs = Free Swell

V = Final Volume after swell

Vo= Volume of dry soil, 10 cm3

(iv) Colloid content: the grain size characteristics of clay appear to have a bearing on its swelling potential, particularly the colloid content.

b) PVC Meter

The soil PVC meter is a standardized apparatus for measuurng the swelling pressure of a compacted sample. The PVC meter can be used in the field or laboratory. The advantages of the test are its simplicity and standardization.

c) Cation Exchange Capacity

Cation exchange capacity (CEC) has major significance in determining clay mineral properties, particularly the conditions with which they adsorb water.

In clay minerals, the most common exchangeable cations are Ca++, mg++, H+, K+, NH4+, Na.The existence of such charges is indicated by the ability of the clay to absorb ions from the solutions.

Cations (positive ions) are more ready absorbed than an ions (negative ions). Hence negative charge must be predominant on the clay surface.

Montimorillonite, on the other hand, have high cation exchange capacity.

2.4.3. The Direct Measurement

The most satisfactory and convenient method of determining the swelling property of expansive soil is by direct measurement. Direct measurement of expansive soils can be achieved by the use of the conventional one-dimensional consolidometer.

- Swell-Consolidation test

  In this test the sample under a 6.9kPa applied load is wetted and allowed to fully swell. At this point a standard consolidation test is conducted by applying incremental loads starting with 25kPa and ending with 1600kPa. The pressure required to revert the specimen to its initial void ratio is used to define the swelling pressure.

2.5. Factors Influencing swelling and shrinking of a soil

Many of the factors influencing the mechanism of swelling also affect or are affected by, physical soil properties as plasticity or density. The factors influencing the shrink swell potential of a soil can be considered in three different groups, the soil characteristics that influence the basic nature of the internal force field, the environmental that influence the change that may occur in the internal force system, and the state of stress. [9]

2.5.1. The Soil Characteristics

The soil characteristics influence the basic nature of the internal force field between particles. Soil characteristics may be considered either as microscale or macro scale factors. Micro scale factors include the mineralogical and chemical properties of the soil. Macro scale factors include the engineering properties of the soil, which in turn are dictated by the micro scale factors. (Chen, 1988)

2.5.1.1. Microscale Factors: Clay mineralogy and Soil Water Chemistry

Clay minerals of different types typically exhibit different swelling potentials because of variations in the electrical field associated with each mineral. The swelling capacity of an entire soil mass depends on the amount and type of clay mineral in the soil, the arrangement and specific surface area of the clay particles, and the chemistry of the soil water surrounding those particles.

Three structural groups of clay minerals are Kaolinite group generally non expansive, Mica-like group includes illites and Vermiculites, which can be expansive but generally do not pose significant problems and Smectite group includes montmorillonites, which are highly expansive.

Soil water chemistry is important in relation to potential swell magnitude. Salt cations, such as sodium, calcium, magnesium, and potassium, are dissolved in the soil water and are adsorbed on the clay surfaces as exchangeable cations to balance the negative electrical surface charges. Hydration of these cations and adsorptive forces exerted by the clay crystals themselves can cause the accumulation of a large amount of water between the clay particles.[9]

In air dry soils, salt cations are held close to the clay crystal surfaces by strong electrostatic forces. As water becomes available, cation hydration energies are sufficiently large to overcome interparticle attraction forces. Thus, initially desiccated and densely packed particles are forced apart as adsorbed cations hydrate and become enlarged on the addition of water. When sufficient water is present, adsorbed cations are no longer held so tightly by the clay surfaces.

2.5.1.2. Macroscale Factors: Plasticity and Density

Macroscale soil properties reflect the microscale nature of the soil. Because they are more conveniently measured in engineering work than microscale factors, macro scale characteristics are primary indicators of swelling behavior.

Atterberge limits, is the most widely used indicator of expansive potential. Most expansive soils can exist in a plastic condition over a wide range of moisture contents due to the capacity of expansive clay minerals to contain large amounts of water between particles and yet retain a coherent structure through the inter particle electrical forces. Soil plasticity is influenced by the same microscale factors that control swell potential and provides a useful indicator of swell potential.[9]

2.5.2. Environmental Factors

Environmental factors influence the changes that may occur in the internal force system. The potential for a soil to imbibe or expel water will depend on the water content relative to the water deficiency of the soil. Initial moisture content influences the shrink swell potential relative to possible limits, or ranges, in moisture content. Moisture content alone is not a good indicator or predictor of shrink swell potential. The moisture content relative to limiting moisture contents such as the plastic limit and shrinkage limit must be known. Water content changes below the shrinkage limit produce little or no change in volume. There are indications that as a soil imbed water, little volume change occurs at water content above the plastic limit.

The availability of water to an expansive soil profile is influenced by many environmental and manmade factors. Generally, the upper few meters of the profile are subjected to the widest ranges of potential moisture variation.

These factors are mostly associated with moisture. They are:

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

A fine-grained soil can exist in any of several states; which state depends on the amount of water in the soil system. When water is added to a dry soil, each particle is covered with a film of adsorbed water. If the addition of water is continued, the thickness of the water film on a particle increases. Increasing the thickness of the water films permits the particles to slide past one another more easily. The behavior of the soil, therefore, is related to the amount of water in the system.

2.5.3. Stress Condition

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

- Stress history
- Loading
- Soil profile

- Insitu condition

2.6. Unconfined compression Test

The primary purpose of the unconfined compression test is to quickly obtain the approximate compressive strength of soils that posses sufficient cohesion to permit testing in the unconfined state.

Is an undrained test and is based on the assumption that there is no moisture loss during the test. The unconfined compression test is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils.

The strength of a soil determined by compression testing varies with extremes of the length to diameter ratio and the rate of strain. Unconfined compressive strength is calculated the same as for any material, with an additional calculation of the area change from bulging.
The shear strength is defined as half the compressive strength.
Where the equation is given as:

qu =P/A

qu = unconfined compressive strength (Kpa)

P = Compressive force (KN)

A = cross sectional area (m2)

Since soils tend to deform much more (say, than concrete), the area of the specimen changes through the test to maintain constant volume.
Thus, the averages cross sectional area at a particular deformation during the test is calculated using:

A=Ao/1-Ɛ

Where; A = corrected cross sectional area (m2)

Ao = original cross sectional area (m2)

Ɛ = axial strain (mm/mm), =ΔL/Lo

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

3.1. The Project Area

Lege Tafo area is located just Northeast of Addis Ababa. The selected project area is about 20 km from the center of Addis Ababa. It spreads on both sides of the Addis Ababa – Debre Brhan highway and is easily accessible. The terrain is undulating plain and cut by several river valleys. Currently, thousands of residential buildings are under construction by real estate developers and individuals .

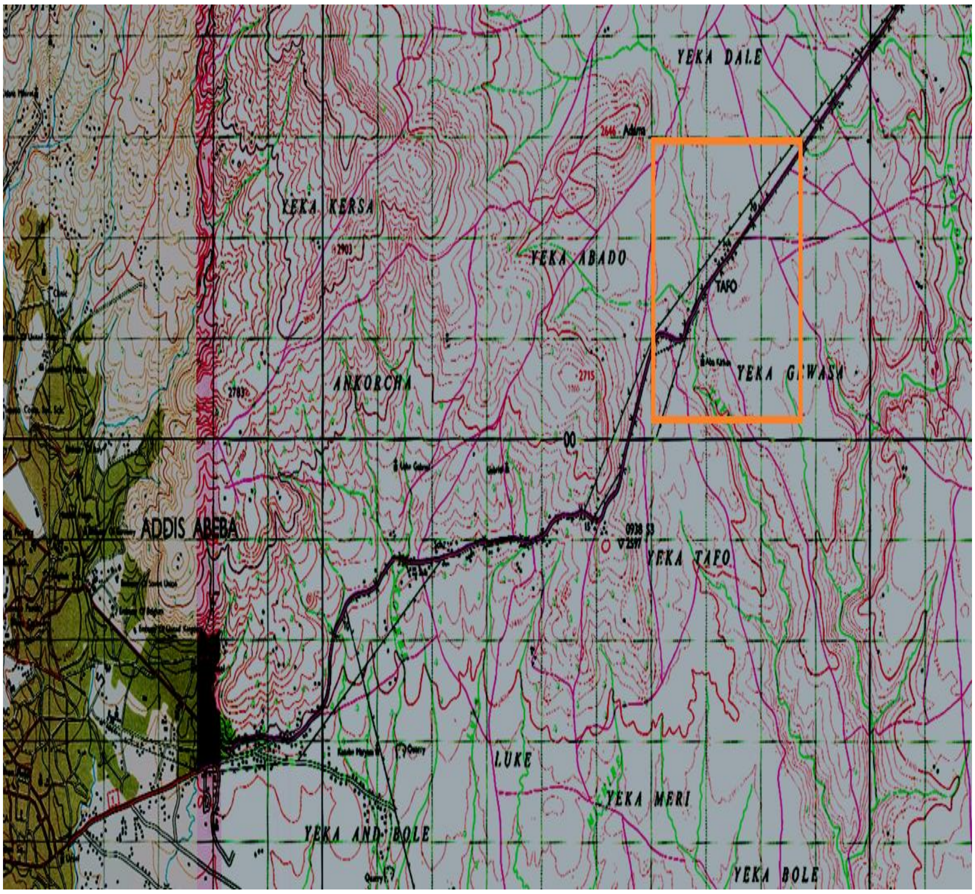


Fig 3.1: Location of Lege tafo area

3.2. Topography Characteristics

As per elevation data taken with GPS from the research area, the elevation difference of the sample area was varied from 2452 m to 2477 m. it implies that the area is categories under semi-arid area. Besides to this, the area is falling under undulating plain for which the difference in slope gradients was shown minimum.

3.3. Climatic Characteristics

- The climate characteristicof the research area is similar to Addis Ababa.
- The average annual rainfall of Addis Ababa is 1089 mm (42.9 in) and average monthly rainfall of the same area is 90.8 mm (3.6 in).
- The driest weather is in November when an average of 9 mm (0.4 in) of rainfall (precipitation) occurs.
- The wettest weather is in August when an average of 269 mm (10.6 in) of rainfall (precipitation) occurs.

Table 3.1: Monthly climate of Addis Ababa

	J	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	De	Annual
Average Precipitation mm (in)	20 (0.79)	32 (1.3)	80 (3.1)	96 (3.8)	56 (2.2)	112 (4.4)	245 (9.6)	269 (10.6)	117 (4.6)	40 (1.6)	9 (0.4)	13 (0.5)	1089 (42.9)
Precipitation Litres/m² (Gallons/ft²)	20 (0.49)	32 (0.78)	80 (1.96)	96 (2.35)	56 (1.37)	112 (2.75)	245 (6.01)	269 (6.6)	117 (2.87)	40 (0.98)	9 (0.22)	13 (0.32)	1089 (26.71)
Number of Wet Days (probability of rain on a day)	4 (13%)	5 (18%)	10 (32%)	13 (43%)	9 (29%)	19 (63%)	28 (90%)	28 (90%)	23 (77%)	5 (16%)	2 (7%)	2 (6%)	148 (41%)
Percentage of Sunny (Cloudy) Daylight Hours	70 (30)	56 (44)	61 (39)	48 (52)	61 (39)	45 (55)	23 (77)	25 (75)	43 (57)	69 (31)	75 (25)	85 (15)	56 (4

Average monthly climate indicators in ADDIS ABABA based on 8 years of historical weather readings. Temperature by: **Fahrenheit**

ADDIS ABABA 8 98 N, 38 80 E, 7726 feet (2355 meters) above sea level.

Table 3.2: Mean monthly Temperature of Addis Ababa

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Avg. Temperature	61	63	64	65	65	62	60	59	61	62	60	60
Avg. Max Temperature	73	76	75	76	76	72	68	68	70	71	72	72
Avg. Min Temperature	46	48	52	52	53	52	53	53	51	48	46	44
Avg. Rain Days	1	1	3	4	3	8	11	11	7	2	0	0
Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0

CHAPTER 4
SAMPLING AND LABORATORY TESTS

4.1. Sampling

Before selecting sample areas, visual site investigation was done and information was collected to avoid back fill areas and to take representative samples. After assessing the area, nine test pits were dug at different locations. Both disturbed and undisturbed samples were collected from the pits.

The number of test pits required for a project depends primarily on uniformity of soil samples and type of construction on the area. A total of 15 disturbed and undisturbed soil samples were collected from the test pits. Three undisturbed samples at 2 meter depth are tested for investigation of swelling pressure.

Table 4.1 Location of sample in UTM coordinates

Test Pit	Location	Zone	Easting	Northing	Elevation(m)
TP1	Gewasa	37P	0487363	1000751	2452
TP2	Near ropak eth.	37P	0487228	1002776	2478
TP3	Yeka sede	37P	0486252	1003836	2495
TP4		37P	487100	1001980	2466
TP5	Near 140 housing	37P	488428	1001403	2470
TP6		37P	489779	1003086	2473
TP7	Zobel	37P	489207	100247	2477
TP8	Near 140 housing	37P	488318	1001221	2471
TP9	Near ropak eth.	37P	487270	1002745	2477

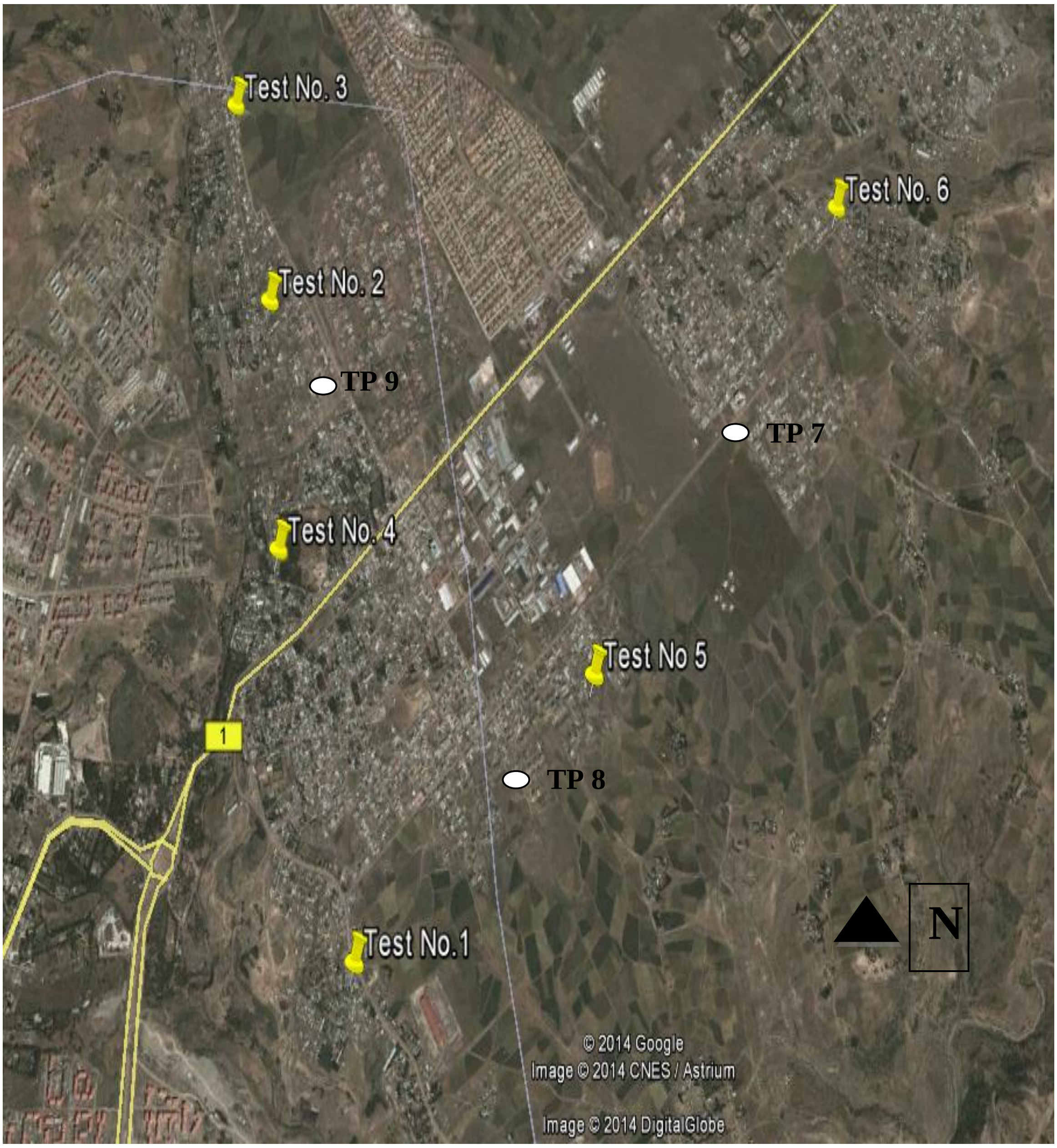


Fig 4.1: Location of test samples

4.2. Laboratory Tests and Discussion

Laboratory tests carried out in this research are

- Grain size distribution
- Natural moisture content

- Atterberge limits
- Specific gravity of soil solids (Gs)
- Free Swell test
- Dry density
- Swelling Pressure test
- UCS

All tests are in accordance with the ASTM standard testing methods. Include the ASTM designations for each.

4.2.1. Grain size distribution analysis

This test is performed to determine the distribution of particle size distribution of the soil in the study area using ASTM D422-standard test method. The distribution of particle sizes larger than 75µm (retained on the No.200 sieve) was determined by sieving, while the distribution of particle sizes smaller than 75µm was determined by a sedimentation process, using a hydrometer.

For this test it was difficult to pulverize soil sample to individual particles Therefore, wet sieve analysis was used for all of the samples collected from the site for accurate determination of particles finer than 75µm in soil prior to dry sieving.

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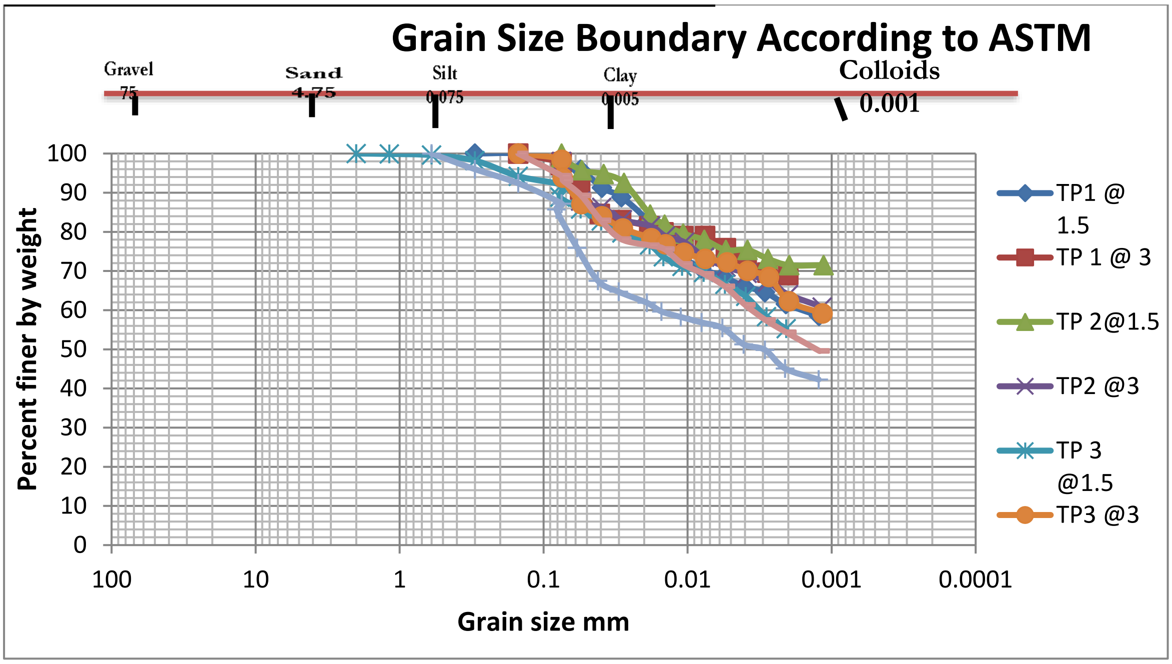

Fig 4.2 Grain size distribution curve for samples test pit 1-4

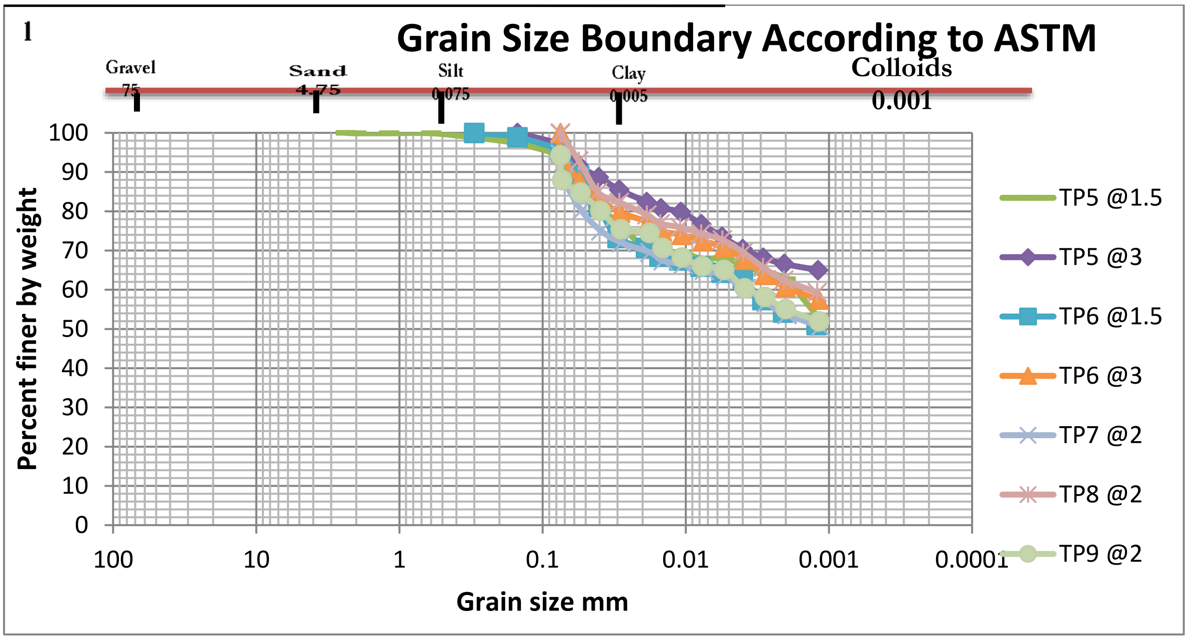

Fig 4.3 Grain size distribution curve for samples test pit 5-9

Grain size analysis test results are summarized in table 4.1

From the grain size analysis results sand content range is in between 0 and 12.8%,silt 22.9-33.6%, clay content is in between 53.58-75.3% and the percentage of colloidal particles (less than 0.001mm in diameter) content is in between 45.79-71.48%.

Tabel 4.2 summary of grain size analysis based on ASTM

Location	**Depth**	**Sand (%)**	**Silt(%)**	**Clay (%)**
TP 1	1.5	3.9	30.6	65.47
TP 1	3.0	2.2	22.9	74.9
TP 2	1.5	0	24.63	75.37
TP 2	3.0	0	29.44	70.56
TP 3	1.5	5.8	25.6	68.63
TP 3	3.0	1.6	26.67	71.73
TP 4	1.5	12.8	33.6	53.58
TP 4	3.0	5.7	29.8	64.49
TP 5	1.5	5.7	27.3	67
TP 5	3.0	2.7	24.9	72.38
TP 6	1.5	4.3	31.7	64
TP 6	3.0	0	30	70
TP7	2.0	5.5	31.6	62.87
TP8	2.0	0	28.33	71.67
TP9	2.0	5.7	30.5	63.80

From grain size analysis results, at all depths greater than 50% of the soil passes sieve No.200 which show that all samples are fine grained soils according to Unified Soil Classification System.

4.2.2.Natural Moisture Content

Natural moisture content of the soil is determined in the laboratory by using undisturbed sample. In the laboratory this test is done by referring ASTM D

2216-98 standard. Moisture content measurement is used for performing weight-volume calculation in soils.

The moisture content of the test pits are presented in Table 4.3

Table 4.3: Natural Moisture Content (%)

Location	**Depth (m)**	**Natural moisture content (%)**
TP 1	1.5	28.1
TP 1	3.0	48.3
TP 2	1.5	52.4
TP 2	3.0	26.7
TP 3	1.5	47.2
TP 3	3.0	31.5
TP 4	1.5	30.7
TP 4	3.0	31.9
TP 5	1.5	44.3
TP 5	3.0	34.2
TP 6	1.5	32.7
TP 6	2.0	38.6
TP 7	2.0	32.4
TP8	2.0	38.6
TP 9	2.0	32.6

4.2.3. Index properties

Atterberg limit test, hydrometer analysis, specific gravity and free swell tests are among the tests which show the index properties of a soil.

4.2.3.1. Atterberg limit tests

Atterberg Limits were determined on air dried samples. ASTM D 4318-98 Standard Test method for Liquid Limit, Plastic Limit, and Plasticity Index of soil were followed.

A typical plot of water content against the log of blows was made as shown in Fig 4.4.

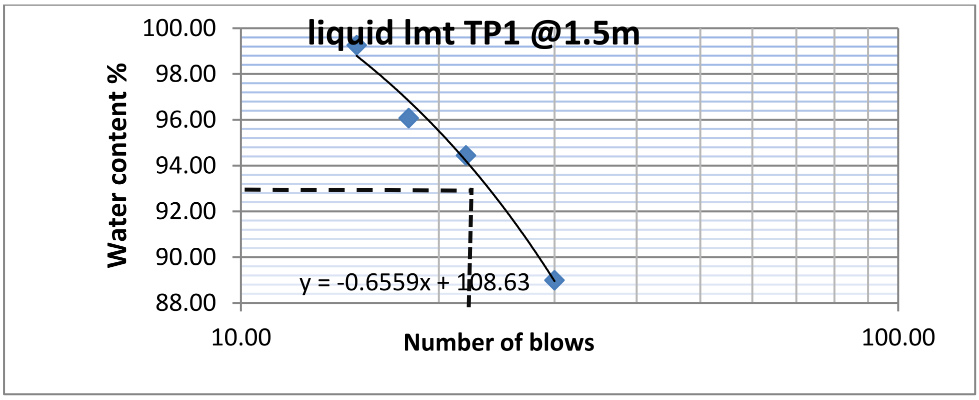

Fig 4.4 Typical water content against log of number of blows. The Aterberg Limits for soil of the study are are summarized in Table 4.4

Table 4.4: Attergerge limit

Location	**Depth (m)**	**Liquid Limit (%)**	**Plastic Limit (%)**	**PI (%)**
TP 1	1.5	**92**	**36.4**	**55.9**
TP 1	3.0	**100**	**39.3**	**60.8**
TP 2	1.5	**91**	**38.5**	**52.6**
TP 2	3.0	**109**	**27.8**	**81.6**
TP 3	1.5	**98**	**36.9**	**61.4**
TP 3	3.0	**112**	**42.9**	**68.7**
TP 4	1.5	**110**	**42.1**	**67.6**
TP 4	3.0	**109**	**43.8**	**65.4**

TP 5	1.5	**106**	**45.7**	**60.7**
TP 5	3.0	**109**	**43.5**	**65.1**
TP 6	1.5	**94**	**36.8**	**57.3**
TP 6	3.0	**103**	**43.3**	**60.1**
TP7	2.0	**116**	**46.6**	**68.9**
TP8	2.0	**107**	**42.9**	**63.8**
TP9	2.0	**103**	**37.1**	**66.3**

From the results shown in Table 4.5 Liquid limit, Plastic limit and plastic index range from 91 -116%, 27.8-46.6% & 52.37-81.6% respectively.

4.2.4.Specific Gravity test

Determination of specific gravity is important for it is useful to determine the size of the soil grains in hydrometer analysis.
ASTM D 854-98 Standard Test was used; there are two methods for performing the specific gravity

Method A-Procedure for Moist Specimens is preferred for organic soils; highly plastic, fine grained soil, tropical soils and soils containing halloysite.

Method B-for oven dried specimen

For this research method A is used to determine the specific gravities that range from 2.62 to 2.85. The test results are shown in Table 4.5.

Table 4.5: Specific gravity

Location	**Depth (m)**	**Specific gravity**
TP 1	1.5	2.73
TP 1	3.0	2.68
TP 2	1.5	2.62
TP 2	3.0	2.69
TP 3	1.5	2.67

TP 3	3.0	2.71
TP 4	1.5	2.65
TP 4	3.0	2.70
TP 5	1.5	2.66
TP 5	3.0	2.73
TP 6	1.5	2.66
TP 6	3.0	2.70
TP7	2.0	2.85
TP8	2.0	2.68
TP9	2.0	2.77

4.2.5. Free Swell Test

Holtz and Gibbs (1956) suggested this method to measure the expansive potential of soil. The test results are presented in table 4.6.

Table 4.6: Free swell result

Location	**Depth (m)**	**Free Swell (%)**
TP 1	1.5	110
TP 1	3.0	135
TP 2	1.5	115
TP 2	3.0	135
TP 3	1.5	120
TP 3	3.0	125
TP 4	1.5	100
TP 4	3.0	125
TP 5	1.5	135
TP 5	3.0	130

TP 6	1.5	130
TP 6	3.0	145
TP 7	2.0	140
TP8	2.0	135
TP 9	2.0	135

4.2.6.Dry Density

The dry density is an important parameter in determining the magnitude of volume change. Dry density is directly related to initial moisture content, the dry density of the clay is another index of expansion. The swell or the swelling pressure of an expansive soil increases with increasing dry density for constant moisture content. The reason is that higher densities result in closer particles spacing, therefore large amount of swelling clays are packed with in small volume. The Densities of the sample were determined using ASTM D 2937-00 Standard Test for Density.

They are calculated from the relation of γ_{dry} = (weight of wet soil/ volume of the ring). The values of dry density are presented in table 4.7

Table 4.7: Dry density result

Location	**Depth (m)**	**Dry Density** γ_{dry} **(KN/m³)**
TP 1	1.5	14.6
TP 1	3	12
TP 2	1.5	12
TP 2	3	12.6
TP 3	1.5	12.9
TP 3	3	13.3
TP 4	1.5	14.5
TP 4	3	14.8
TP 5	1.5	13.8

TP 5	3	13
TP 6	1.5	15.2
TP 6	2.0	15.1
TP 7	2	13.1
TP8	2	12.6
TP 9	2	13.2

4.3. Classification of the soils

4.3.1.Unified Soil Classification System

The Unified Soil Classification System (USCS) was first developed by Casagrande in 1948. The system is the most popular system for use in all types of engineering problems involving soils.

The soils are first classified into two categories

i) Coarse grained soils – are designated as gravel (G) if 50% or more of coarse fraction (plus 0.075mm) is retained on No 4 (4.75mm)sieve otherwise it is termed sand (S). If the coarse grained soil contains less than 5% fines and are well graded (W), they are given the symbols GW and SW, and if poorly graded (P).

ii) Fine grained soil based on percentage of the soil passing No. 200 sieve. From the result sieve analysis the 50% of the sample soil passes No. 200 sieve therefore fine grained soils. Fine grained soils are further divided into two types. Soils of low plasticity (L) if the liquid limit is 50% or less, Soils of high plasticity (H) if the liquid limit is more than 50%.

As shown in the figure 4.5 plasticity chart of the soil , the A- line has the equation Ip = 0.73(wl-20) separates the clays from silts. In the same plot of the chart, the soils around the area are classified as CH which is Inorganic clays of high plasticity.

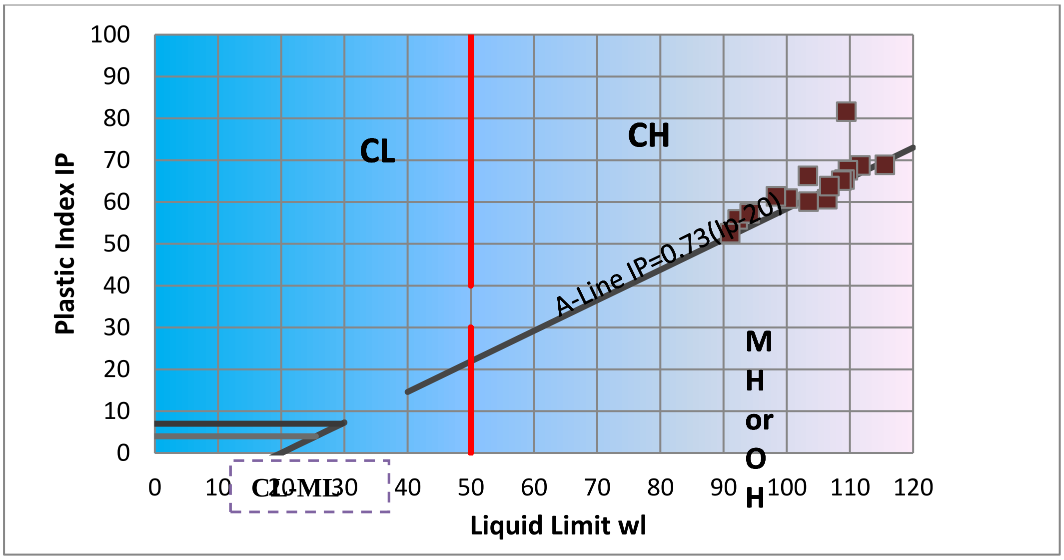

Fig 4.5: Plasticity chart of soil in the study area (USCs)

Table 4.8: USCS classification of Lege Tafo soil samples

Location	**Depth**	**Liquid Limit (%)**	**PI (%)**	**Soil Classification USCS***
TP 1	1.5	**92**	**55.9**	**CH**
TP 1	3.0	**100**	**60.8**	**CH**
TP 2	1.5	**91**	**52.6**	**CH**
TP 2	3.0	**109**	**81.6**	**CH**
TP 3	1.5	**98**	**61.4**	**CH**
TP 3	3.0	**112**	**68.7**	**CH**
TP 4	1.5	**110**	**67.6**	**CH**
TP 4	3.0	**109**	**65.4**	**CH**
TP 5	1.5	**106**	**60.7**	**CH**
TP 5	3.0	**109**	**65.1**	**CH**
TP 6	1.5	**94**	**57.29**	**CH**
TP 6	3.0	**103**	**60.1**	**CH**
TP 7	2.0	**116**	**68.9**	**CH**
TP 8	2.0	**107**	**63.8**	**CH**
TP 9	2.0	**103**	**66.3**	**CH**

4.3.2. AASHTO Classification System

The American Association of State Highway and Transportation Official (AASHTO) Classification system is useful for classifying soils for highways. The particle size analysis and the plasticity characteristics are required to classify a soil. The classification system classifies both coarse grained and fine grained soils.

The AASHTO system uses similar techniques but the dividing line has an equation of the form PI=LL-30. It generally classifies a soil broadly into granular material and silt clay material.

The granular material is further divided into three groups which are A-1, A-2 and A-3. The silt clay material is in turn divided into four groups A-4, A-5, A-6 and A-7.

According to this system the soil of the study area falls in the reign of A-7-5 (Fig 4.6)

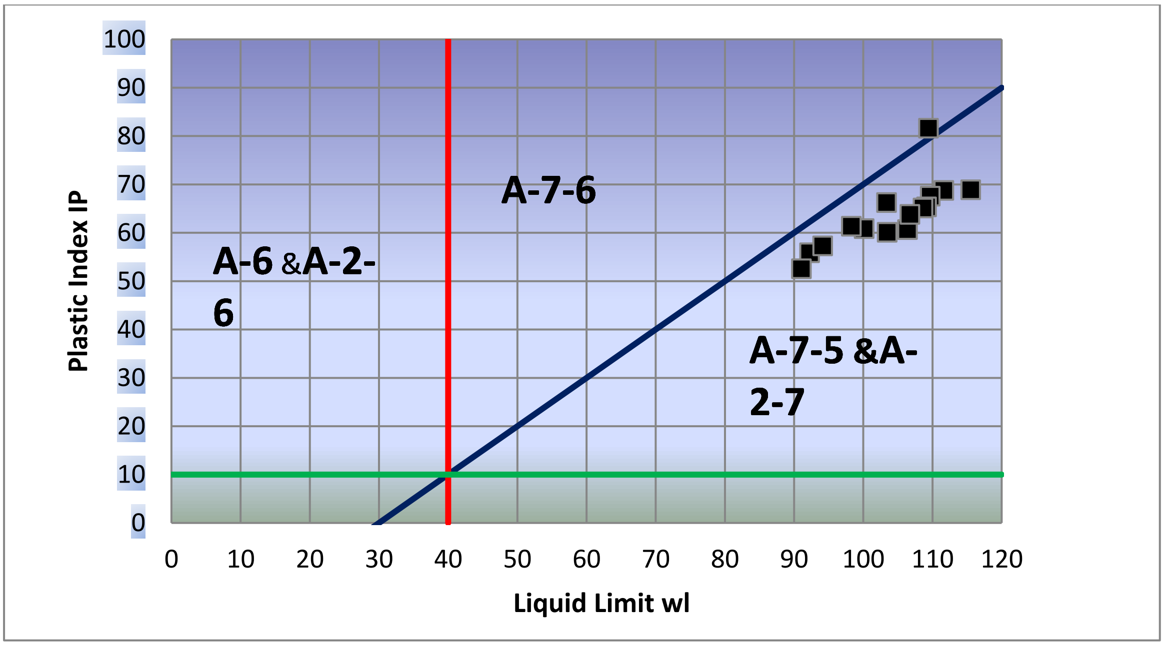

Fig 4.6: Plasticity chart of soil in the study area (AASHTO)

According to figure 4.6 the system classifies the soil as A-7-5.

Activity (Colloidal Activity)

Skempton's colloidal activity is determined as the ratio of the plasticity index to the clay content in the fines. This method is developed by combining Atterberg limits and clay content into a single parameter called Activity.

The activity here is defined as:

Ac= PI/C

Where, Ac= activity number

C= Percentage of clay size finer than 0.002mm and

PI= plasticity index

Table 4.9 Degree of Colloidal activity

Activity Number, Ac	**Soil Type**
<0.75	Inactive
0.75-1.25	Normal
>1.25	Active

These values are presented in the form of chart, which is called Activity Chart, and the soil of the study area is compared to the values and it falls in the range of normal clay. (Fig 4.7)

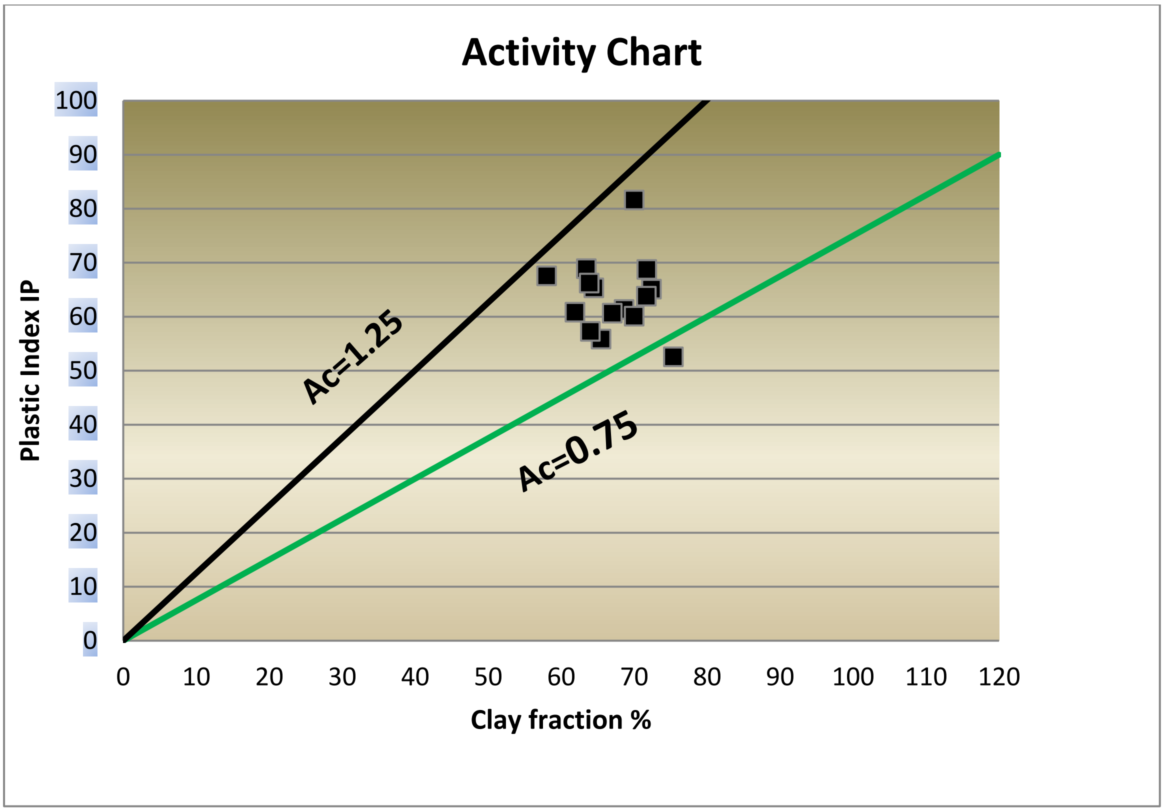

Fig 4.7: Activity Chart

4.4. Unconfined compression Test

The objective of the Unconfined compression test is to determine the UU (unconsolidated, undrained) strength of a cohesive soil.

The unconfined compression strength test was conducted on undisturbed samples of Lege Tafo area using ASTM D 2166.The results show that the soils are in stiff to very stiff consistency, range 97-160- KN /m2 at natural water content ranging from 26.7 to 52.4 (Table 4.10)

Table 4.10: UCS test results

Location	**Depth (m)**	**Unconfned compressive strength (kN/m2)**	**Natural Water content (%)**	**Consistency**
TP 1	1.5	117.3	28.1	Very stiff
TP 1	3.0	149.5	48.3	Very stiff
TP 2	1.5	88.6	52.4	stiff
TP 2	3.0	146.78	26.7	Very stiff
TP 3	1.5	97	47.2	stiff
TP 3	3.0	105.2	31.5	Very stiff
TP 4	1.5	126.8	30.7	Very stiff
TP 4	3.0	102.9	31.9	Very stiff
TP 5	1.5	86.1	44.3	stiff
TP 5	3.0	101.1	34.2	Very stiff
TP 6	1.5	106.3	32.7	Very stiff
TP 6	3.0	159.8	38.6	Very stiff
TP 7	2.0	126.3	32.4	Very stiff
TP 8	2.0	152.2	38.6	Very stiff
TP 9	2.0	122.5	32.6	Very stiff

4.5. Consolidation and Swelling Pressure Tests

4.5.2. Consolidation Test

This test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the pre-consolidation pressure (or maximum past pressure) of the soil. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil.

The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earth fill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

Table 4.10. Summary of consolidation test result

Test Pit	Depth	Natural Moisture Content %	Pressure P kPa	Void ratio	Coefficient of Consolidation Cv 10^{-3} cm^2/sec	Compression Index Cc	Pre-consolidation pressure Pc, (kPa)
TP 02	3	27	2	1.3124053		0.466	200
			50	1.2937998	8.586		
			100	1.2675671	1.695		
			200	1.242074	2.48		
			400	1.1967273	2.483		
			800	1.081211	2.482		
			1600	0.9411108	3.516		
TP 03	3	32	7	1.3593		0.371	80
			50	1.3428	3.516		
			100	1.3057	8.585		
			200	1.2579	3.516		
			400	1.2079	4.84		
			800	1.1408	2.482		
			1600	1.0213	1.696		
	3	34	7	1.1299		0.226	100
			50	1.0975	2.48		
			100	1.0769	1.6959		

			200	1.0523	4.843		
			400	1.0138	3.516		
			800	0.9681	6.51		
TP 05			1600	0.9000	27.13		
TP 07	2	32	7	1.2015		0.373	100
			50	1.2013	1.696		
			100	1.1574	3.516		
			200	1.0719	4.843		
			400	0.9697	8.584		
			800	0.8809	6.51		
			1600	0.7687	27.12		
TP 08	2	39	7	1.3202		0.426	90
			50	1.3171	8.586		

			100	1.2850	27.13		
			200	1.1697	66.24		
			400	1.0745	137.35		
			800	0.9762	137.34		
			1600	0.8480	27.13		
TP 09	2	33	7	1.3324		0.226	80
			50	1.3320	1.696		
			100	1.2930	27.13		
			200	1.2079	137.37		
			400	1.1243	66.24		
			800	1.0332	8.58		
			1600	0.9361	137.33		

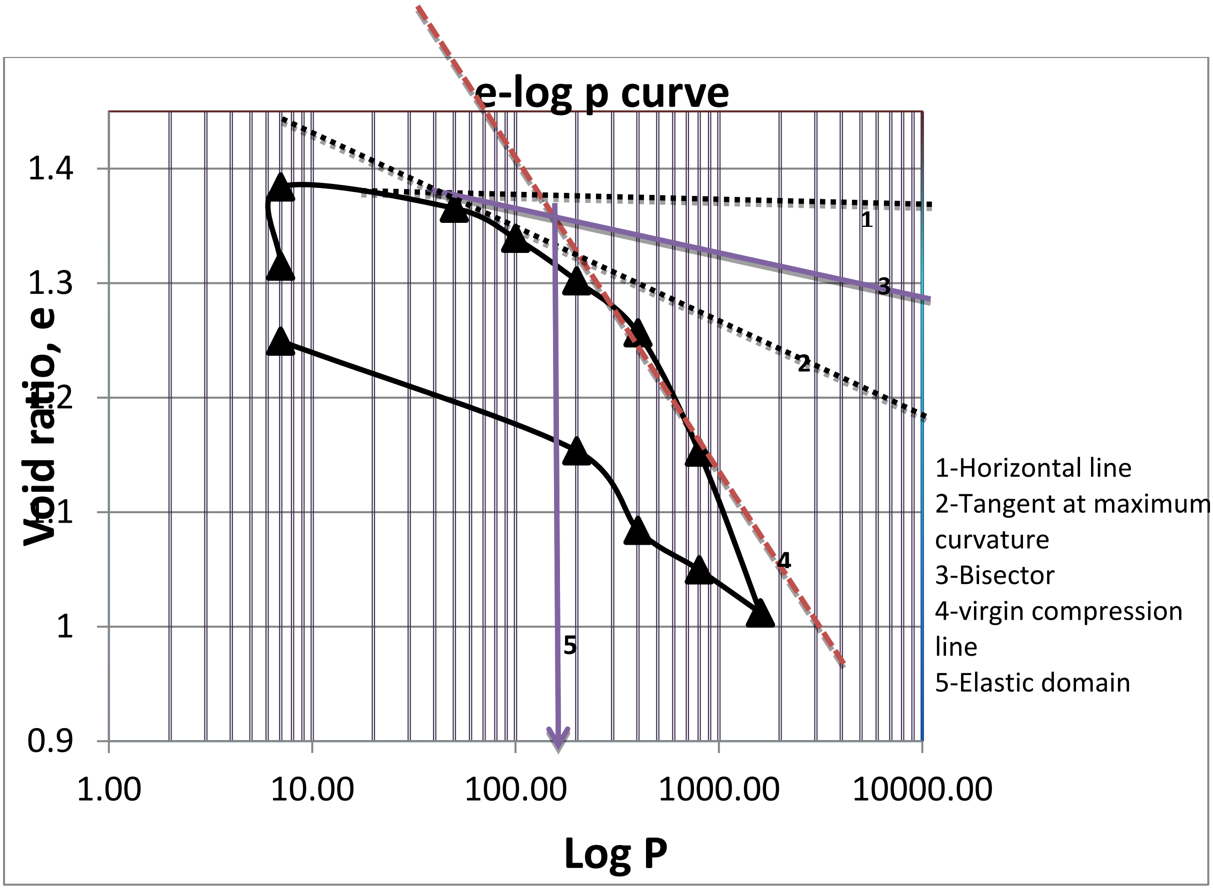

Fig 4.7: Typical consolidation test result

4.5.3. Swelling Pressure

Swelling pressure is defined as the pressure which prevents the specimen from swelling or that pressure which is required to return the specimen back to its original state (void ratio, height) after swelling (ASTM, 1996).

Basically, the methods of measuring swelling pressure can be either strain controlled or stress controlled. Strain controlled method is based on the principle of controlling the strain that is developed as water is added. In such a test, modification to the conventional oedometer is required to allow the control of strain during testing and measurement of the resulting loads. Stress controlled tests use the conventional oedometer.

The samples are placed in the consolidation ring trimmed to the height of the ring. After loading with a standard load of 1psi (6.9kpa), water is added to the sample. When swelling of the sample is ceased, the vertical stress is increased in increments until the sample is compressed back to its original height. The stress required to compress the sample to its original height is the zero volume change swelling pressure or simply swelling pressure. Swelling pressure is an integral soil property, hence whether determining it through strain or stress controlled, the result is expected to be the same (Chen, 1988).

Stress controlled method is used to investigate swelling pressure of Lege Tafo expansive soils. Undisturbed samples from six different test pits.

Table 4.12 Swelling Pressure Test Results of Lege Tafo area

Test Pit No	**Sample depth (m)**	**Swelling Pressure** kPa	**Initial moisture content (%)**	**Dry Density** γ_{dry} **(KN/m3)**
TP2	3	165	27	12.6
TP3	3	135	32	13.3
TP5	3	121	35	13
TP7	2	128	33	13.1
TP8	2	76.20	38	12.6
TP9	2	133.33	32	13.2

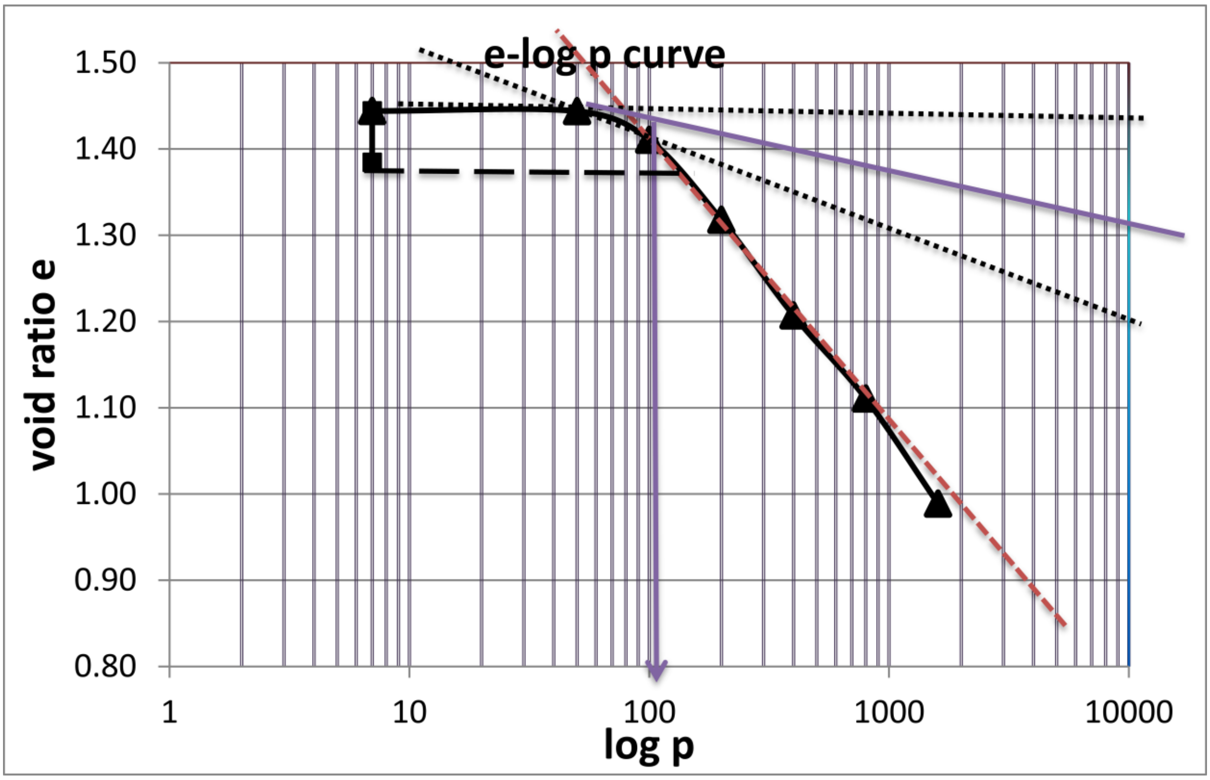

Fig 4.8: Typical swell consolidation test result

CHAPTER 5
DISCUSSION OF LABORATORY TEST RESULTS

5.1. Discussions of Test Results

5.1.1. Grain size analysis

Nine test pits were selected from different locations for which the number of test pits required for a project depends on primarily on uniformity of soil samples and type of construction on the area. Disturbed and undisturbed samples were taken from an area where there was a huge potential of expansive soil. Furthermore, as per the grain size analysis results, sand content range is in between 0 and 12.8%, silt 22.9-33.6% and clay content is between 53.58-75.3% and also the percentage of colloidal particles (less than 0.001mm in diameter) content is varies between 45.79-71.48%.As a result, all soil depths greater than 50% of the soil passes sieve No.200 which show that all samples were categories as fine grained soils under Unified Soil Classification System. Besides to this, all test pits it was identified on the top layer was either grey or black .however, all test conducted at about 3 meter depth was fell under grey in colour. Moreover, as shown in Fig 4.2 & 4.3 Grain size distribution curve discussed that hydrometer analysis is used to determine particle size distribution of soil finer than 75 micro meter so that as shown in the above figure, all sample soil test result laid above the curve which contained fine grained particles of soil.

The particle size distribution curve is extremely useful for identified coarse-grained soils. The behavior of fine grained soils (minus 75µ) depends upon the plasticity characteristic and not on the particle size. Hence, according to Holtz & Gibb soils containing colloid particles greater than 28% have high degree of expansion. Soil contained 23-13%of colloid particle have medium to high degree of expansion while those contained colloidal particles less than 13% have low degree of expansion. This is concluded that the soil which is found in the study area has high degree of expansion.

5.1.2.Natural Moisture Content and Initial Dry Density Test

The moisture content and initial dry density of the soil affected by a number of factors, some of them are soil type (soil texture, soil structure etc), prevailing moisture content of the soil, climate, soil depth and the like.
Natural moisture content of the soil is determined in the laboratory using undisturbed sample and the soil test is done by referring ASTM D 2216-98 standard. Moisture content of the soil is measured using performing weight-volume calculation of the soils. As shown in the table 4.3 natural moisture content depicted that soil samples was taken at different depth of soil , its amount was varied from 28.1-52.4 % at 1.5 m depth, 32.4-38.6% at 2 m depth and 26.7-48.3% at 3m depth, The infiltration rate of the soil increase with increase the particle size so that the moisture content of the soil is higher when it become deeper and deeper and vice verse. Similarly, the infiltration rate of the soil increase with decreasing of particle size so that higher moisture content has found at lower depth of soil.

Irrespective of high swelling potential, if the moisture content of the clay remains unchanged, there will be no volume change, structures founded on clays with constant moisture content will not be subject to movement caused by heaving. This is to conclude that the natural moisture content of the soil in the study area varies between 26.7%-52.4%.

5.1.3.Atterberge Limit tests

The results of the Atterbergs limits are presented in Table 4.4. The results of liquid limit, Plastic limit and plastic index range from 91 -116%, 27.8-46.6% & 52.37-81.6% respectively.
Based on the standard test method of liquid limit, and plasticity index Unified soil classification (USC) system is used to classify soil of the study area.
According to Unified Soil Classification System, plasticity chart (Fig 4.5), the soil under investigation lies in group CH (inorganic clay with high plasticity).

According to AASHTO Classification system, (Fig 6), soil of the study area fall under A-7-5. For all tests Liquid Limit greater than 50% the soil group in Inorganic silt and clay of high plasticity.

Skempton's colloidal activity method was also use to classify and estimate heave of expansive soil, the result can be seen on fig 4.7 which falls into normal clay.

Generally, the soil under investigation consists mainly of inorganic clay of high plasticity with some fractions of silty or clayey sands.

The amount of volume change exhibited by various soils under various placement conditions varies greatly. Soil obtained from beneath a 2 meter may not possess high swell potential due to low ranges of potential moisture variation therefore soil samples at 2 meter from ground level were taken for swelling pressure test.

5.1.4. Specific Gravity test

Based on Table 2.2 and from grain size distribution, percentage passing sieve no 200 it is possible to classify soils with specific gravity > 2.65 are either silty inorganic or Clay inorganic. Accordingly, test results are shown in Table 4.5, the specific gravities ranges from 2.62 to 2.85.

5.1.5. Free Swell

Free swell percent ranged from 100%-145% (Table 4.6). Soils having a free swell greater than 100% are considered expansive. Therefore, soils under investigation have high swelling potential.

5.2. Swell consolidation Test

The swelling pressure and the amount of swell of the soil were measured by means of one dimensional compression tests. The swelling pressure obtained is 76 -165kPa. Thus the degree of expansion can be categorized as Medium to High (Chen, 1988).

5.2.1.Swelling Pressure and Natural Moisture Content and Dry Density

The results show (Fig 5.1.) a general trend of decreasing swelling pressure with increment of natural moisture content manifested in a linear relation.

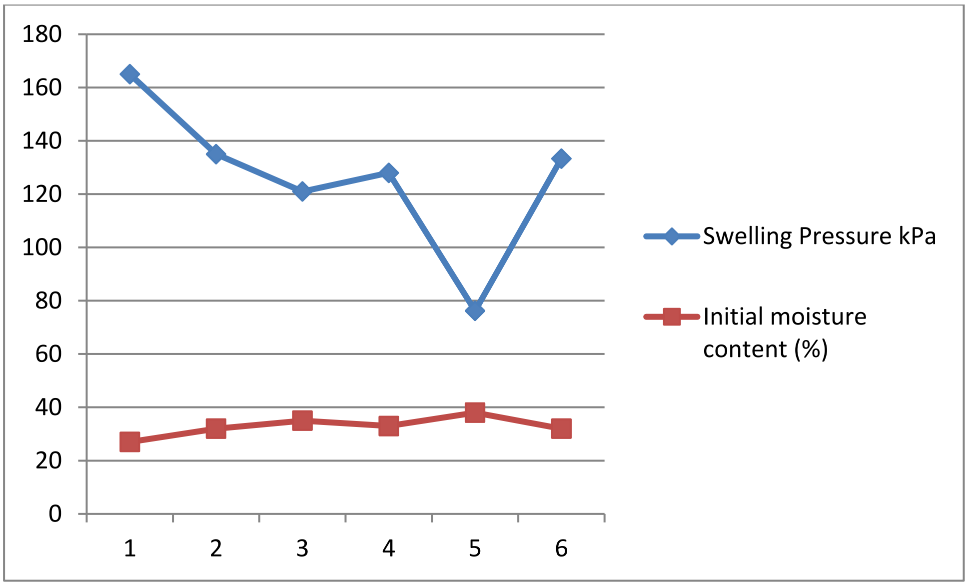

Fig 5.1. Swelling Pressure and Natural Moisture Content and Dry Density

Moist clays may desiccate due to the lowering of the water table or other changes in physical conditions and upon subsequent wetting will again exhibit swelling potential.

Directly related to initial moisture content, the dry density of the clay is another index of expansion. Soils with high dry densities generally exhibit high swelling potential.

5.3. Relationship Among Different Soil Properties of the Study Area

For the soil under investigation; index properties were studied and a comparison was made with studies around Addis Ababa in Table 5.1.

Table –5.1 Index property Test Results in different part of Addis Ababa

	Thesis *	Thesis **	Current study
Soil type	Expansive soil	Expansive soil	Expansive soil
Location	Addis Ababa	Addis Ababa	Lege tafo
Clay Content (%)	50-81	65-71	58-75
Silt fraction (%)		22-46	25-36
Sand fraction (%)	1-4	2-4	0-10
Liquid Limit (%)	79-121	78-100	91-111
Plastic limit (%)	25-50	25-27	36-46
Plasticity Index (%)	38-84	68-74	52-81
Dry density γ_{dry} KN/m^3			12-15.2
Moisture content (%)	32-45.5	25-41	26-52
Specific Gravity	2.77-2.85	2.8-2.84	2.6-2.85
Swelling pressure	37-420	80-300	76-165
From Plasticity chart			CH

* Daniel Tekele

** Mesfin Kassa

As show in the above Table 5.1, Index property of soil test result was conducted in different part of Addis Ababa and compared the same with the thesis research result currently conduced at lege tafo. Some of the properties used for comparison are Sieve analysis, liquid Limit, Plastic Index and specific gravities and the like. As a result, Soils found in Lege tafo area shown lower swelling pressure compared to the result carried out by other researchers conducted on similar soils. The results of swelling pressure are smaller due to the fact that the initial moisture content of the soil was higher. Except the above, the overall data show that there is a considerable similarity in the physical properties of the area.

CHAPTER 6
CONCLUSION AND RECOMENDATION

6.1. Conclusion

In most of the area gray clay is found beneath black clays, shows no significant distinction between physical properties and amount of volume change.
Grain size analysis tests revealed that, the soil in the study area is mostly clay with particle sizes ranging from 58-75%, silt 24-34% and sand content ranges from 0 to 12.8 (%) indicating the presence of high clay content.

All samples have free swell of greater than 100% which shows that the soil is expansive soil. The overall free swell of the clay samples ranges between 100-145%.

According to the Atterberg test results the liquid limit, plastic limit and plastic index range between 91 -116%, 27.8-46.6% & 52.37-81.6% respectively. The soils in the study area have high Atterberg limit values showing that the soils are highly plastic.

The specific gravity range is 2.60-2.85. The unconfined compression strength of the soils in the study area range from 97 to 160kN/m, based on which the consistency of the soil ranges from stiff to Very stiff.

According to the Unified Soil Classification System the soil is categorized as highly plastic inorganic clay. AASHTO classification system also shows that the soil is highly plastic as well as subject to considerable volume change.

The swelling pressure ranges from 76kPa to 165kPa these is due to time of sample collected from field was after rainy season in October and also high initial moisture content of the sample during the test. Considering the result from index property, the highest swelling value should be taken. Also the results show a general trend of decreasing swelling pressure with increment of natural moisture content manifested in a linear relation

6.2. Recommendation

Uplift movement can be tolerated in certain structures in the same manner as some settlement can be tolerated in certain structures such as residential buildings. It is possible to allow certain amounts of uplift movement so as to minimize the required dead load pressure.

Construction considerations should identify subsurface condition that will encounter in the field during construction. In addition the site should be preserved from local watering or any other means which can allow water to enter to the foundation.

Swell can be prevented if expansive clays can be loaded with a surcharge large enough to counteract the expected swell pressure. This method can be used on the study area for large projects involving high foundation pressures. As the swell pressure increases the use of a surcharge is less efficient because of the nonlinear nature of the pressure swell relationship.

Other Treatment methods should be chosen considering the construction size, phase, Nature and use and cost comparisons of alternative methods of the construction. Finally, by taking into consideration the result which was analyzed and discussed in the above, the types of soil texture and range of swelling pressure of the soil can with stand any load it can be dead and live load which can exerted from residential building in to soil foundation. As a result, it is possible for construction of residential building in research area below a foundation depth of 3meter because to increase surcharge on the foundation

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APPENDICES

(Test Results)

Appendix 5:GRAIN SIZE ANALYSIS
Project: Investigation of Index properties and swelling potential of expansive soils in Lege Tafo area
Sample Location: Lege Tafo
Sample discripition: Clay soil
Determination of Grain Size

Wet Sieve Analysis **TP 4 3.0mt** *Total mass of sample, gm=* 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing
No 4	*4.75*	*431.0*	*431.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 8	*2.36*	*389.0*	*389.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 10	*2*	*377.0*	*377.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 16	*1.18*	*355.0*	*355.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 30	*0.6*	*312.0*	*312.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 50	*0.3*	*291.0*	*291.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 100	*0.15*	*276.0*	*276.0*	*0.0*	*0.0*	*0.0*	*100.0*
No 200	0.075	254	*274.0*	20	*2.0*	*2.0*	*98.0*
pan	-------	325.7	*1305.7*	980	*98.0*	*100.0*	*0.0*

Hydrometer Analysis **specific gravity of soil 2.65**

Elapsed Time, T (min)	Actual Hydrometer Reading, R_A	test tempratu re(oC)	Composite Correction	Corrected Hydrometer Reading, R_c	Effective Depth, L (cm)	Coefficient, K	Percent finer	Grain size (mm)	Percent finer for combined analysis
0.25	1.0315	19	-0.0029	1.0286	7.968	0.01361	*90.85*	0.077	89.03
0.5	1.0285	19	-0.0029	1.0256	8.761	0.01361	*81.32*	0.057	81.32
1	1.0280	19	-0.0029	1.0251	8.893	0.01361	*79.73*	0.041	79.73
2	1.0275	19	-0.0029	1.0246	9.026	0.01361	*78.14*	0.029	78.14
5	1.0270	19	-0.0029	1.0241	9.158	0.01361	*76.55*	0.018	76.55
8	1.0265	20	-0.0027	1.0238	9.290	0.01344	*75.60*	0.014	75.60
15	1.0255	19	-0.0029	1.0226	9.555	0.01361	*71.79*	0.011	71.79
30	1.0245	20	-0.0027	1.0218	9.819	0.01344	*69.25*	0.008	69.25
60	1.0235	20	-0.0027	1.0208	10.084	0.01344	*66.07*	0.006	66.07
120	1.0220	20	-0.0027	1.0193	10.481	0.01344	*61.31*	0.004	61.31
240	1.0210	19	-0.0029	1.0181	10.745	0.01361	*57.49*	0.003	57.49
480	1.0200	19	-0.0029	1.0171	11.010	0.01361	*54.32*	0.002	54.32
1440	1.0185	19	-0.0029	1.0156	11.406	0.01361	*49.55*	0.001	49.55