# INVESTIGATION ON SOME OF THE ENGINEERING CHARACTERISTICS OF SOILS IN TIYA TOWN, ETHIOPIA


*BY:*

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# Acknowledgement

First of all, I would like to express my special thanks to my advisor, Prof.Alemayehu Teferra for his valuable advice and guidance. The efforts of my advisor are gratefully acknowledged. I would like to express my heartiest gratitude and thanks to my instructor Dr.-Ing Samuel Tadesse for his additional support to carry out this research work.

My appreciation goes to Ato Abey Fanta, Ato Mesfin Mekonen, W/o Shewagergesh Tadesse, Meteku kenenesa and all EIABC Soil laboratory staffs for their continuous support. I am thankful to them.

I would like to thank the Municipality of Buee Werda in providing facilities for collecting the soil samples from different parts of the Tiya Town. Special thanks will be forwarded for Ato Mesele Mengestu, Head of the Municipality of Tiya and Ato Yared Assefaw, staff of the tiya municipality and my heartiest gratitude for Cherenet Kassa for his valuable additional support to carry out this research work.

I am very much grateful to my parents and friends for their constant encouragement and support over the years. I must express my appreciation to my wife who not only tolerated many late nights and working weekends, but also encouraged me continuously in various ways to complete this work successfully.

Finally my all gratitude will go to Almighty of God.

# Abstract

The aim of this thesis is intended to investigate some of the engineering properties of Tiya soil. Tiya is a megalithic site located at about 80km south of Addis Ababa in the Soddo area on the road to Butajira.

In addition to being tourist center, investors are also attracted to construct buildings and roads in Tiya town and the nearby areas. However, the engineering properties of the soil in the town are not yet studied. This research is therefore directed to the study of the physical and mechanical properties of soils i.e. investigating the index properties, consolidation characteristic, and shear strength, identifying the characteristics of the soil and preparing a tentative soil map of the town.

After visiting the proposed site, ten test pit points were selected. Representative disturbed and undisturbed soil samples were collected from open pits by direct manual excavation. The laboratory tests that were carried out include index properties, one dimensional consolidation, shear strength tests. The tests yielded a specific gravity ranging from 2.42 to 2.67, plasticity index ranging from 18 to 51%, clay fraction ranging from 17.08 to 55.51%, free swell values from 34 to 102.5%.

From one-dimensional consolidation test conducted on undisturbed soil samples, compression index, Cc, ranges from 0.218 to 0.246 and measured swelling pressure of 250kPa.

The unconfined compression strength tests gave value that range from 84 to 313 kPa at natural water content ranging from 27.25 to 49.07 %.

The types of soils which are conducted in the research are CH, MH, ML and CL for the depth of 0.7m, 1.5m & 3m that is shown on the soil map. Low, Marginal and Highly potentially expansion soils according to free swell tests are presented on the tentative soil map.

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## SYMBOLS AND ABBREVIATIONS

AASHTO - American Association of Highway and Transportation Officials

ASTM - American Society for Testing Materials standard

Cc - Compression index

CL – Lean clay

e - Void ratio

LL - Liquid limit

MH – Inorganic Elastic silt

ML – Inorganic Silt

NMC - Natural moisture content

OCR - Over-consolidation ratio

Pc – Pre-consolidation pressure

Po - Over burden pressure

PI - Plastic Index

PL - Plastic limit

SM – Silty sand

TP – Test pit

USCS - Unified Soil Classification System

$\gamma d$ - Dry unit weight

$\gamma w$ - Wet unit weight

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# 1. Introduction

## 1.1. Back ground of the problem

A geotechnical engineer determines and designs the type of foundation, earthwork, and/or pavement sub grades required for the intended man-made structures to be built. Foundations are designed and constructed for the structures of various sizes such as high-rise buildings, bridges, medium to large commercial buildings, and smaller structures where the soil conditions do not allow code-based design .

Investigation of the underground conditions at a site is prerequisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies of the proposed project. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuing a building permit, particularly if there is a chance that the project will endanger the public health or safety or degrade the environment [1].

In a country like Ethiopia which is developing at high growth rate and which needs many construction works in the future, geotechnical investigation on the engineering property of soil is very essential. These data are very important for civil engineers in preliminary design and in designing foundation, pavement, retaining structures, etc. for future construction projects in the country.

The town of Tiya has adequate land for expansion and being an important commercial, educational and tourist center in the region. Due to its tourist attraction and proximity distance from Addis Ababa, investors and tourists are attracted to construct buildings or roads in Tiya town and the nearby areas. However, the engineering properties of the soil in the town are not yet studied. This research is therefore directed to the study of the physical and mechanical properties of soils i.e. investigating the index property and consolidation characteristic, identifying the characteristics of the soil and preparing tentative soil map of the town.

## 1.2. Objectives of the Study

The objectives of this thesis work are the following:

- To investigate some of the index properties of the Tiya soil like Natural moisture content, specific gravity, consistency limits, grain size analysis etc.
- To investigate shear strength of Tiya soil in different parts of the town.
- To investigate the consolidation characteristics of the study area.

## 1.3. Methodology

To achieve the above mentioned objectives ten sampling areas were selected. From the selected sampling areas pits were excavated to a depth of around three meters. Disturbed and undisturbed samples of soils were collected for laboratory testing.

In the field GPS reading was taken to locate the co-ordinate of sampling area.Field density and natural moisture content tests were done in the field.

The procedure used to perform the laboratory tests were AASHETO and ASTM standard. Analysis was made for soil classification after the test results were collected by using based on USCS and AASHETO classification.

From the samples collected, the following laboratory tests were done.

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

- One-dimensional consolidation test

All the above tests were done according to American Society for Testing Materials (ASTM) standard.

## 1.4. Scope of the Study

Nineteen samples of soil from ten pits were collected. The scope of this study is limited to investigating the index properties, and consolidation characteristic. Due to the budget constraint, the depth of investigation in this research is limited to the maximum depth of three meters.

## 1.5. Structure of the Thesis

This thesis work is divided in to nine Chapters, each covering a specific topic of the research work. In this introductory Chapter the background of the problem, objective, methodology and scope of the thesis work and structure of the thesis are presented. Chapter two deals with a brief literature review. Chapter three deals with the description of area in which this research is done. The fourth Chapter deals with the types of laboratory tests conducted and results obtained. The discussion on the laboratory results obtained from this work is covered in Chapter five.In Chapter six the conclusions and recommendations drawn from the research are presented. In Chapter seven soil map of Tiya Town was prepared based on information collected from GPS and laboratory data. Detailed tests are given in Appendix and references are presented in chapter eight and nine respectively.

# 2. Literature review

## 2.1General

For engineering purposes, soil is defined as the uncemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles. Soil is used as a construction material in various civil engineering projects, and it supports structural foundations. Thus, civil engineers must study the properties of soil, such as its origin, grain-size distribution, ability to drain water, compressibility, shear strength, and load-bearing capacity. Soil mechanics is the branch of science that deals with the study of the physical properties of soil and the behavior of soil masses subjected to various types of forces. Soils engineering is the application of the principles of soil mechanics to practical problems.

Geotechnical engineering is the subdiscipline of civil engineering that involves natural materials found close to the surface of the earth. It includes the application of the principles of soil mechanics and rock mechanics to the design of foundations, retaining structures, and earth structures.

To describe soils by their particle size, several organizations have developed particle-size classifications Table 2.1 shows the particle-size classifications developed by the Massachusetts Institute of Technology, the U.S. Department of Agriculture, the American Association of State Highway and Transportation Officials and the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation. In this table, the MIT system is presented for illustration Purposes only. This system is important in the history of the development of the size limits of particles present in soils; however, the Unified Soil Classification System is now almost universally accepted and has been adopted by the American Society for Testing and Materials (ASTM).[2]

Table 2.1 Particle-Size Classifications

| Name of organization | Grain size (mm) | | | |
|---|---|---|---|---|
| | Gravel | sand | Silt | clay |
| Massachusetts Institute of Technology (MIT) | >2 | 2 to 0.06 | 0.06 to 0.002 | <0.002 |
| U.S .Department of Agriculture (USDA) | >2 | 2 to 0.05 | 0.05 to 0.002 | <0.002 |
| American Association of State Highway and Transportation Officials ( AASHTO) | 76.2 to 2 | 2 to 0.075 | 0.075 to 0.002 | <0.002 |
| Unified Soil Classification System (U.S Army Corps of Engineers U.S. Bureau of Reclamation ,and American Society for Testing and Materials) | 76.2 to 4.75 | 4.75 to 0.075 | Fines (i.e., silts and clays) <0.075 | |

## 2.2. Soil formation and soil deposits

Soils are formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition. The properties of the soil materials depend upon the properties of the rocks from which they are derived [3].

The variety of soil materials encountered in engineering problems is almost limitless, ranging from hard,dense, large pieces of rock through to gravel, sand, silt, and clay to organic deposits of soft compressible peat. To compound the complexity, all of these materials may occur over a range of densities and water contents. At any given site, a number of different soil types may be present, and the composition may vary over intervals of a little as a few inches [4].

It has long been appreciated that the engineering classification of soils is greatly facilitated by taking into account the soil-forming processes by which nature has created the various types of soil conditions. Similar combinations of soil-forming processes in different parts of the world have been found to lead to materials of similar index properties and similar engineering characteristics [5].

### 2.2.1. Parent materials

There are two main variables in parent materials that affect soils: grain size and composition. Grain size is the main determinant of soil texture. Texture influences the soil structure, consistency, cation exchange capacity, profile drainage, moisture retaining capacity and organic content [6].

### 2.2.2. Topography and Drainage

Topography has a major influence on drainage characteristics which in turn is known to have major effect on soil mineralogy. Its control over soil properties is particularly strong in tropical environment reflecting the importance of lateral movement of water and soil materials [5].

### 2.2.3. Climate

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

The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system [7].

## 2.3. General types of soils

According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75 to 76.2 mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75 mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eyes is about 0.075 mm. Soil grains ranging from 0.075 to 0.002 mm are termed as silt and those that are finer than 0.002 mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials .[3]

## 2.4. Soil particle size and shape

The size of particles may range from gravel to the finest size possible. Their characteristics vary with the size. Soil particles coarser than 0.075 mm are visible to the naked eye or may be examined by means of a hand lens. They constitute the coarser fractions of the soils. The coarser fractions of soils consist of gravel and sand. The individual particles of gravel, which are fragments of rock, are composed of one or more minerals, whereas sand grains contain mostly one mineral which is usually quartz. The individual grains of gravel and sand may be angular, sub angular, sub-rounded, rounded or well-rounded. Gravel may contain grains which may be flat. Some sands contain a fairly high percentage of mica flakes that give them the property of elasticity. Silt and clay constitute the finer fractions of the soil. Any one grain of this fraction generally consists of only one mineral. The particles may be angular, flake-shaped or sometimes needle-like. [3]

## 2.5. Laboratory Tests

A wide variety of laboratory tests can be performed on soils to measure a wide variety of soil properties. Some soil properties are intrinsic to the composition of the soil matrix and are not affected by sample disturbance, while other properties depend on the structure of the soil as well as its composition, and can only be effectively tested on relatively undisturbed samples. Some soil tests measure direct properties of the soil, while other measure "index properties "which provide useful information about the soil without directly measuring the properties property desired. The main index properties of coarse grained soils are particle size and relative density. For fine grained soils, the main index properties are Atterberg limits and consistency. [2]

### 2.5.1. Index property tests

#### 2.5.1.1. Natural moisture content

For most soils, the water content may be an important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil [4].

#### 2.5.1.2. Atterberg limits

Atterberg Limits are defined as water contents at certain limiting or critical stages in soil behavior. They, along with the natural water content, are the most important items in the description of fine grained soils. They are used in classification of fine grained soils, and they are useful because they correlate with the engineering properties and engineering behavior of fine-grained soils. The liquid limit and plastic limit of soils (along with the shrinkage limit) are collectively referred to as the Atterberg Limits. The liquid limit is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm diameter threads without crumbling. The term shrinkage limit, expressed as moisture content in percent, represents the amount of water required just to fill all of the voids of a given cohesive soil at its minimum void ratio obtained by oven drying. The shrinkage limit can be used to evaluate the shrinkage potential, crack development potential, and swell potential of earthwork involving cohesive soils [8].

### 2.5.1.3. Specific gravity

A soil"s specific gravity largely depends on the density of the minerals making up the individual soil particles. However, as a general guide, some typical values for specific soil types are as follows. [2]

I) the specific gravity of the solid substance of most inorganic soils varies between 2.6 and 2.9.

II) Sand particles composes of quartz have a specific gravity ranging from 2.64 to 2.66.

II) Inorganic clays generally range from 2.7 to 2.9.

IV) Soils with large amount of organic matter or porous particle (such as diatomaceous earth) have specific gravity below 2.6.Some ranges as low as 2.0.

### 2.5.1.4. Free swell

Both the amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several Physico-chemical aspects of the soil. Among clay minerals montimorillonite influences the magnitude of swelling maximally as compared to Illites and Kaolinites [9].

To study the swelling property of the soils, the simplest test conducted is free swell test. This test is performed by slowly pouring 10ml of oven dry soil which has passed the No.40(0.425mm) sieve in to 100 ml graduated cylinder filled with distilled (tap) water. After 24 hours, final volume of the suspension being read. Hence, free swell is defined as:

$$\text{Free swell Index(FSI)} = \frac{\text{Final volume -Initial volume of the soil X 100\%}}{\text{Initial volume}} \qquad (4.1)$$

### 2.5.1.5. Soil classification

A soil classification system is an arrangement of different soils into groups having similar properties. The purpose of soil classification is to make possible the estimation of soil properties by association with soils of the same class whose properties are known and to provide the engineer with accurate method of soils description.The soils under investigation have been classified according to AASHTO M-145 and UCSC. [10]

### 2.5.1.5.1 Unified classification system (USCS)

This system describes a system for classifying minerals and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required [8]

### 2.5.1.5.2. AASHTO classification system

The AASHTO system uses similar techniques as that of USC 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 called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7.

The AASHTO system further uses a group index (GI) to rate a soil qualitatively within a group. The equation for the GI is

$$GI= (F-35) [0.2 + 0.005(LL-40)] +0.01(F-15) (PI-10)$$

Where F = percent passing No. 200 sieve

LL= Liquid Limit, in percent

PI = Plasticity Index, in percent

The lower the GI value of a soil, the better as sub grade material. As GI value goes up to 20 and above it is not suitable as sub grade material. [9]

Thus, based on the AASHTO system of classification, Tiya investigated soils are generally not suitable as subgrade material. [13]

## 2.5.1.5.3. Classifications of soils based on Activity chart

## i) Activity Number

The Atterberge limit of a given cohesive soil is controlled by the type and amount of clay mineral present in it. Skempton considers that the significant change in volume of a clay soil during shrinking or swelling is a function of plasticity index and the quantity of colloidal clay particles present in the soil. Hence, Activity number has been used as an index property to determine the swelling potential of clays. The activity of clay is expressed as: [10]

Activity (A) =Plasticity index (PI) /Percentage of clay fraction by weight(C) (4.2)

## ii) Liquidity Index

The Relative consistency of a cohesive soil can be defined by a ratio called liquidity index LI. It is defined as :

$$LI= (Wn-PL)/(Ip) \quad (4.3)$$

Where, PI Plasticity Index,

LI Liquidity index,

PL Plastic Limit,

Wn Natural moisture content.

For a natural soil deposit that is in plastic state (i.e., LL>Wn>PL), the value of the liquidity index varies between 1 and 0.A natural soil deposit with Wn>LL will have a liquidity index greater than1.In an undisturbed state, these soils may be stable: however, a sudden shock may transform them in to liquid state .Such soils are called sensitive clay.

## 2.5.1.6. Consolidation test

### 2.5.1.6.1. General

Structures are built on soils. They transfer loads to the subsoil through the foundations. The effect of the loads is felt by the soil normally up to a depth of about two to three times the width of the foundation. The soil within this depth gets compressed due to the imposed stresses. The compression of the soil mass leads to the decrease in the volume of the mass which results in the settlement of the structure.

The displacements that develop at any given boundary of the soil mass can be determined on a rational basis by summing up the displacements of small elements of the mass resulting from the strains produced by a change in the stress system. The compression of the soil mass due to the imposed stresses may be almost immediate or time dependent according to the permeability characteristics of the soil.

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

I. Compression of the solid matter.

II. Compression of water and air within the voids.

III. Escape of water and air from the voids.

It is quite reasonable and rational to assume that the solid matter and the pore water are relatively incompressible under the loads usually encountered in soil masses. The change in volume of a mass under imposed stresses must be due to the escape of water if the soil is saturated. But if the soil is partially saturated, the change in volume of the mass is partly due to the compression and escape of air from the voids and partly due to the dissolution of air in the pore water [3]. A study of the compressibility of soils is necessary to be able to forecast the settlement of structures on different type of soils.

Generally, the volume change in a soil deposit can be divided in to three stages: [11]

- Initial consolidation
- Primary consolidation
- Secondary consolidation

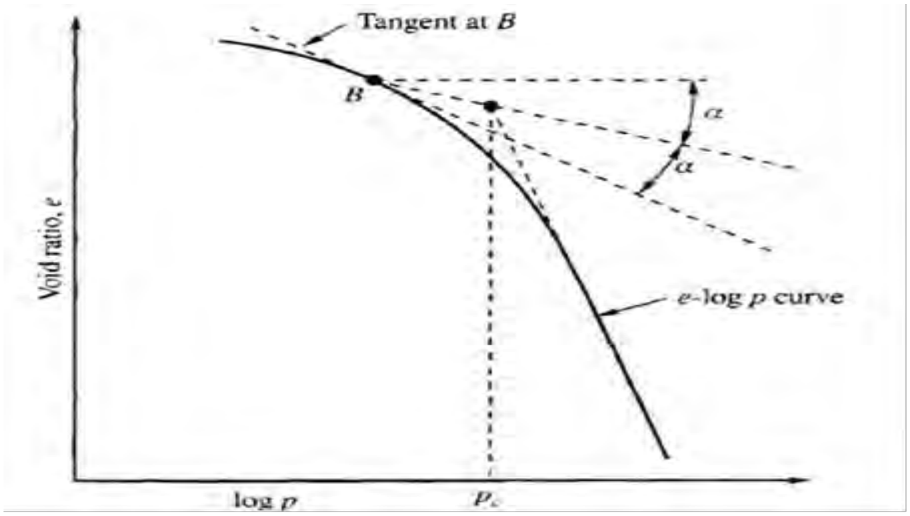
Consolidation is a process of compression by gradual reduction of pores under a steady applied pressure. When structures are built on saturated soils, the load is presumed to be carried initially by incompressible water within the soil voids. Due to the additional load on the soil, water will tend to be squeezed out from the voids causing a reduction in void volume and consequently settlement of the structure.

In soils of high permeability (coarse grained soils), this process takes a relatively short time for completion, with the result that almost all of the settlement will occur during the construction period. These rarely cause major problems. In low permeability soils (clays), this process takes place slowly and continuously over a long period of time - months, years and even decades - after completion of construction.

### 2.5.1.6.2. Pre-consolidation pressure

A soil may have been pre-consolidated during the geologic past by the weight of an ice which has melted away, or by other geologic overburden or and structural loads which no longer exist. For example, thick layers of overburden soil may have been eroded or excavated away or heavy structures may have been torn down. Also capillary pressures which may have acted on the clay layers in the past may have been removed for one reason or another. The practical significance of the pre-consolidation load appears in calculating settlements of structures [12].

There are a few graphical methods for determining the pre-consolidation pressure based on laboratory test data. No suitable criteria exist for appraising the relative merits of the various methods. The earliest and the most widely used method is the one proposed by Casagrande .[3] The method involves locating the point of maximum curvature, B, on the laboratory e-log p curve of an undisturbed sample as shown in Fig 4.10. From B, a tangent is drawn to the curve and a horizontal line is also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure, Pc [3].




**log of stress p**

Fig 2.1 Method of determining Pc according to Casagrande [3]

The relative amount of pre-consolidation is usually reported as the over-consolidation ratio (OCR) defined as

$$OCR = \frac{Pc}{Po} \qquad (4.2)$$

where: pc pre-consolidation pressure

Po over burden pressure

## 2.5.1.6.3. Compression index

The compression index, Cc, is equal to the slope of the linear portion of the void ratio versus log pressure plot. Thus:

$$Cc = \frac{\Delta e}{\log\left(1+\frac{\Delta P}{Po}\right)} \qquad (4.3)$$

Where: Cc compression index

Po over burden pressure

$\Delta$e Change in void ratio

$\Delta$p change in pressure

The compression index is useful for the determination of the settlement in the field.

## 2.5.1.7. Shear strength test

## 2.5.1.7.1 General

The shear strength of soils is an important aspect in many foundation engineering problems such as the bearing capacity of shallow foundations and piles, the stability of the slopes of dams and embankments, and lateral earth pressure on retaining walls. [13]

The main objectives of shear strength test in soil engineering, is generally to determine the shear strength parameters (i.e., the cohesion and angle of internal friction) in terms of total or effective stresses under known test condition.

Some of the inter particle forces which are believed to contribute to soil cohesion includes:

(a) Valence forces associated with surface

(b)Ionic forces associated with ions dissociated from polar materials

(c)Dipole forces and moments associated with polar materials

(d) Molecular attraction or van der Waal‟s forces.

The angle of internal friction includes the effect of interlocking. The interlocking effect itself is affected to some degree by the shape of particles and the grain-size distribution.

The interlocking action varies with the density and the angle of internal friction increases with increase in density. The two parameters cohesion (c) and angle of friction (ø) depend on the following factors; grading, particle shape and void ratio. The cohesion also depends on degree of saturation. [13]

## 2.5.1.7.2. Unconfined compression test (UC)

The UC test is the simplest and quickest test used to determine the shear strength of a cohesive soil. An undisturbed or remolded sample of cylindrical shape, about 38 mm in diameter and 76 mm in height is subjected to uni-axial compression until the soil fails .Hence the sample is laterally unconfined, only cohesive soils can be tested. The sample is tested quickly and there is no drainage. Therefore, it is a special case of the UU test in which in which the confining pressure is zero.

The strength of a soil determined by this test is influenced by the length to diameter ratio of the sample and the rate of strain. It is generally accepted that ratios of length to diameter of 2 to 2.5 are satisfactory. Similarly, satisfactory rates of strain are 0.5 to 2.0% per minute [13].
For the current investigation, length to diameter ratio of 2 and a strain rate of 2% per minute (about 1.5 mm per minute) is used.

# 3. DESCRIPTION OF THE STUDY AREA

## 3.1. General

Tiya with its historical site is located in the Ethiopian highlands, about 80 km south of Addis Ababa in the Soddo area on the road to Butajira. Butajira is a town and separate woreda in south-central Ethiopia located about 40 km from Tiya. The exact history of the monuments is unknown, but it is thought that they are the remains of medieval Ethiopia culture apparently dated back to the $12^{th}$-$14^{th}$ centuries. The stelae from the Soddo region, with their enigmatic configuration, are highly representative of an expression of the Ethiopian megalithic period. Soddo lies to the south of Addis Ababa, beyond the Aouache river. Among the most important of the roughly 160 archaeological sites discovered so far in the Soddo region is Tiya, lying 38 km south of the river, which is also one of the most representatives.

Tiya is one of nine megalithic pillar sites in the Gurage Zone. As of 1997, 118 stelae were reported in the area. Along with the stelae in the Hadiya Zone, the structures are identified by local residents as *Yegragn Dingay* or "Gran's stone", in reference to Imam Ahmad ibn Ibrahim al-Ghazi (Ahmad "Gurey" or "Gran"), ruler of the Adal Sultanate.[14]

Even though Tiya is one of UNESCO World heritage Sites, and is expanding, the engineering properties of the site have not yet been not studied.

| Coordinates: **8°26′N, 38°37′E** | |
|---|---|
| **Country** | Ethiopia |
| **Region** | Southern Nations, Nationalities, and Peoples' Region |
| **Zone** | Gurage |
| **UNESCO World Heritage Site** | |
| **Official name** | Tiya |
| **Type** | Cultural |
| **Designated** | 1980 (4th session) |
| **Region** | Africa |


Fig.3.2 Location of SNNP region on map of Ethiopia.

Fig. 3.1Location of the research area on the map of Ethiopia.

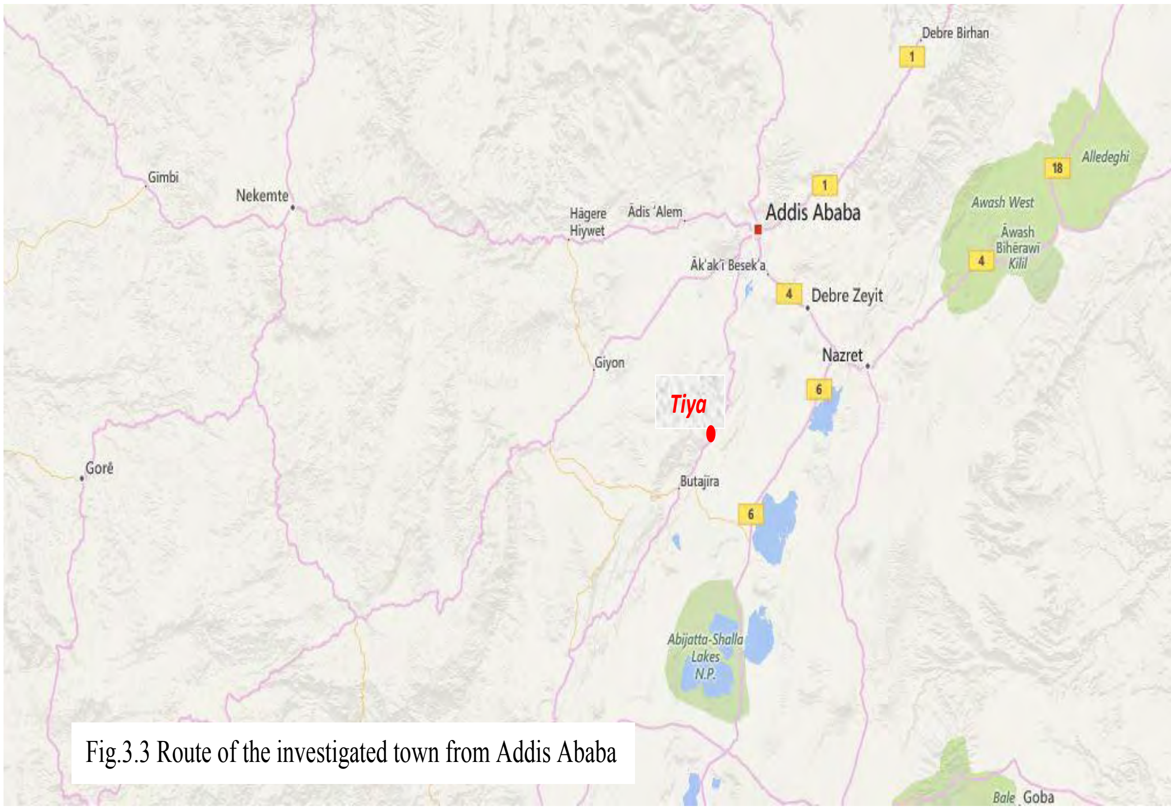



Fig.3.3 Route of the investigated town from Addis Ababa

Fig.3.4Archeological site of Tiya.

## 3.2. Soil and Geology

The geology of Ethiopia underlies by rock types range in age from the geology of the country underlies by rock types range in age from Precambrian to Recent. These rocks are categorized into the following geological formations: - [15]

1. Precambrian rocks
2. Paleozoic – Mesozoic sedimentary rocks
3. Cenozoic volcanic rocks and associated sediments

### 3.2.1. Precambrian rocks of Southern and Southwestern Ethiopia

The Precambrian rocks of southern and southwestern Ethiopia were traditionally divided into lower, middle and upper complex based on the variation in grade of metamorphism. The metamorphic grade was thought to decrease from the Lower to the Upper Complex. These authors also noted that the Lower Complex is Archean whereas the Upper Complex is Neoproterozoic in age.The high-grade gneisses and granulites of the Lower Complex may correlate with the high-grade granulites of Uganda. In southwestern Ethiopia the lithological boundaries and structural trends are transected by the granulite isograd. They conclude that the granulite facies metamorphism represented a younger event in the metamorphic evolution of the regionThe high-grade gneiss and granulites are old Archean lithosphere similar to those found in Uganda. The high-grade gneisses and granulites are not necessarily older than the low-grade volcano-sedimentary rocks.

The Precambrian of south and southwestern Ethiopia comprises both high-grade gneissic terrain of the Mozambique Belt and low-grade metavolcano-sedimentary sequences of the Arabian-Nubian Shield. Various models have been proposed to explain the relationship between the Mozambique Belt and the Arabian-Nubian Shield. The high-grade rocks of the Mozambique belt extend beneath the low-grade rocks of the Arabian-Nubian Shield forming a basement-cover relationship. The N-trending structures in southern Ethiopia are the roots of northward expulsion of the Arabian-Nubian Shield from the Mozambique Belt, following a Tibetan-type continent-continent collision between east and west Gondwana along the Mozambique Belt after the consumption of the Mozambique Ocean. Age data indicate that magmatism and possibly metamorphism and deformation in southern Ethiopia occurred between about 900 and 500 Ma. However, detrital zircon ages of 1657 Ma from a meta-rhyolite and ages between 1300 and 2050 Ma from diorite gneiss are evidence for the existence of Archean to Mesoproterozoic continental lithospheric component in southern Ethiopia. [15]

# 4. In-situ Properties and Laboratory tests results

## 4.1. In-situ properties

### 4.1.1. Identification of Soil in the Study Area

Before selecting sampling areas, visual site investigation and information from resident, and construction firms were collected to consider the different soil types and to take sample evenly in the whole town. Accordingly, ten sampling areas were selected from different locations of the town. Pits were excavated to the maximum depth of three meters, but in one pit intact rock was encountered making the digging difficult .Disturbed and undisturbed samples were taken .

Tiya municipality office is refused to give structural map of the town and as a result of the test pits are located on the map taken from Google earth.

The global coordinates of sampling locations i.e. northing, easting and elevations are shown in Table 4.1.and the locations also presented in the attached Google map.

Table 4.1 coordinates of sample location

| Designation | Location | Northing | Easting | Elevation (m) |
|---|---|---|---|---|
| TP-1 | Tiya market | 0456983 | 0932161 | 2323 |
| TP-2 | Around Tiya Stele(2) | 0456533 | 0932248 | 2319 |
| TP-3 | IN front of Tiya School | 0457272 | 0933226 | 2325 |
| TP-4 | Meserete Kirestos | 0456587 | 0932609 | 2328 |
| TP-5 | Noc | 0457159 | 0932784 | 2322 |
| TP-6 | Around Tiya Stele(1) | 0456839 | 0932124 | 2318 |
| TP-7 | Entrance to Amawete | 0456308 | 0931966 | 2305 |
| TP-8 | World Vision | 0456922 | 1932929 | 2320 |
| TP-9 | Sutan Market | 0456866 | 0931483 | 2311 |
| TP-10 | Saint Mariam Church | 0456228 | 0932878 | 2343 |

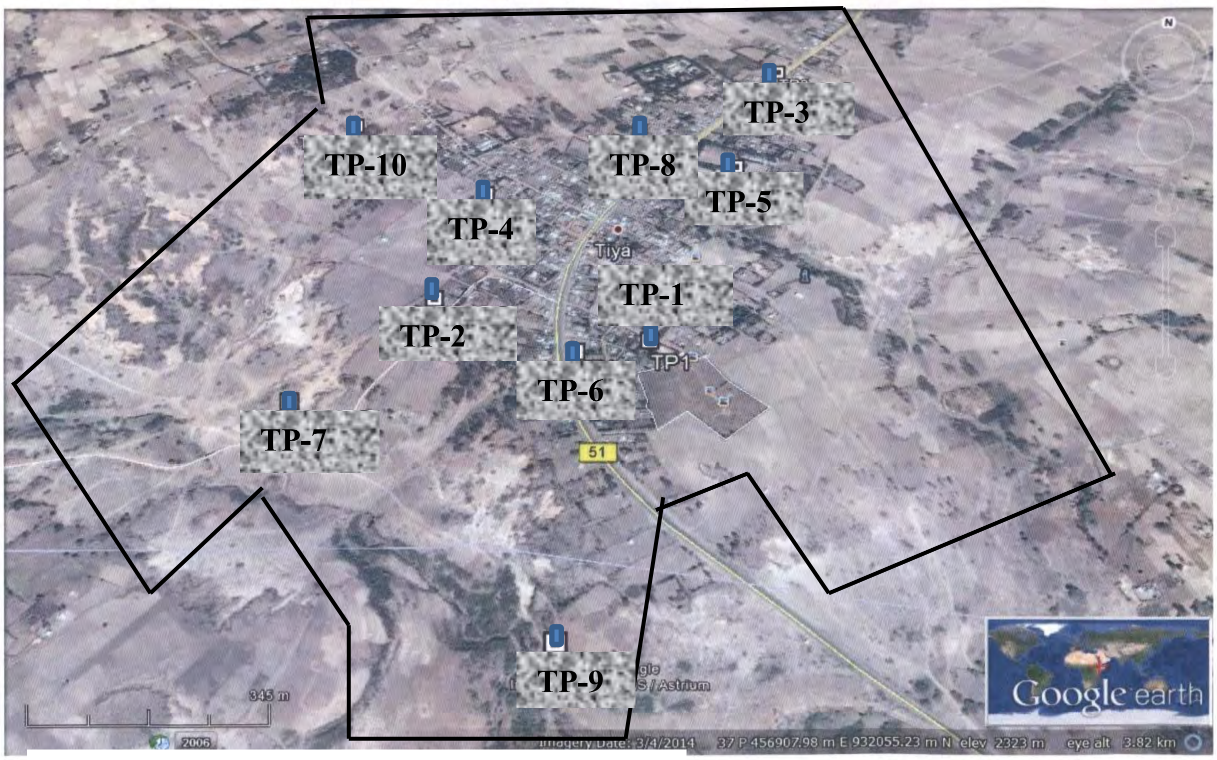



Fig.4.1 sampling locations from Google map.

## 4.1.2. In-situ properties Description

### 4.1.2.1. Natural moisture content procedure and test result

Since it was difficult to bring undisturbed samples to the laboratory, this test was done by taking moisture can and balance to the field. In the site, the weight of the moisture can and the weight of can with moist soil was measured. Then the sample was brought to the laboratory and put it in to drying oven at a temperature of 105°c for 24 hours. Then after, the natural moisture content was determined. The natural moisture content of the ten pits for each profile is shown in Table 4.2.

## 4.1.2.2. In situ density procedure and test result

The bulk density is the ratio of mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil to the volume the soil sample. The in-place density of soils is used to determine density of compacted soils used in the construction of structural fills, highway embankments, or earth dams.

Table 4.2 In-situ density and natural moisture contents of soil samples.

| Test Pit No | Depth(m) | Natural moisture content (%) | In-situ density (g/cm3) | Dry density (g/cm3) |
|---|---|---|---|---|
| TP-01 | 0.70 | 28.76 | 19.60 | 15.22 |
| | 1.60 | 28.00 | 19.57 | 15.29 |
| TP-02 | 1.50 | 45.25 | 17.6 | 12.12 |
| | 3.00 | 39.33 | 17.78 | 12.76 |
| TP-03 | 1.50 | 24.19 | 20.00 | 16.10 |
| | 3.00 | 32.74 | 18.62 | 14.03 |
| TP-04 | 1.50 | 26.47 | 19.51 | 15.43 |
| | 3.00 | 44.35 | 17.55 | 12.16 |
| TP-05 | 1.50 | 30.40 | 19.26 | 14.77 |
| | 3.00 | 33.19 | 19.36 | 14.54 |
| TP-06 | 1.50 | 38.60 | 17.83 | 12.86 |
| | 3.00 | 35.98 | 17.83 | 13.11 |
| TP-07 | 1.50 | 47.49 | 17.13 | 11.61 |
| | 3.00 | 37.25 | 17.67 | 12.87 |
| TP-08 | 1.50 | 28.61 | 18.86 | 14.66 |
| | 3.00 | 49.07 | 16.93 | 11.36 |
| TP-09 | 1.50 | 32.83 | 17.19 | 12.94 |
| | 3.00 | 37.38 | 14.67 | 10.68 |
| TP-10 | 1.50 | 27.25 | 18.02 | 14.16 |
| | 3.00 | | | Rock |

## 4.2. Laboratory test procedure and results

### 4.2.1. General

A bulk of soil, as it exists in nature, is more or less randomly assembled soil particles, water and air. The properties of soils are complex and variable. Every civil engineering work involves the determination of soil type and its associated engineering application; certain properties are more significant than others. The common problems faced by civil engineers are related to bearing capacity and compressibility of soil and seepage through the soil. The possible solution to these problems is arrived at based on the study of the physical and index properties of the soil [11].

Soil is a heterogeneous material. The properties and characteristics of soils vary from point to point. The tests required for determination of engineering properties are generally elaborate 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. Theproperties of soils which are indicative of the engineering properties are called index properties [11].

## 4.2.2. 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 a soil is used in the phase relationship of air, water, and solids in a given volume of the soil [4].

The specific gravity of the soil samples for the 10 test pits are given in Table 4.3.The detailed test procedure is presented in Appendix G.

Table 4.3 Specific Gravity of the Soil of the Study Area.

| *Location* | *Depth(M)* | *Specific Gravity* |
|---|---|---|
| *Tiya Market(TP-1)* | 0.70 | **2.59** |
| | 1.60 | **2.44** |
| *Around Tiya stele(2)(TP-2)* | 1.50 | **2.52** |
| | 3.00 | **2.53** |
| *Infront of Tiya School(TP-3)* | 1.50 | **2.46** |
| | 3.00 | **2.59** |
| *Meserete Kirestos(TP-4)* | 1.50 | **2.51** |
| | 3.00 | **2.57** |
| *NOC(TP-5)* | 1.50 | **2.47** |
| | 3.00 | **2.43** |
| *Around Tiya stele(1)(TP-6)* | 1.50 | **2.67** |
| | 3.00 | **2.42** |
| *Entrance to Amawete(TP-7)* | 1.50 | **2.46** |
| | 3.00 | **2.53** |
| *World Vision(TP-8)* | 1.50 | **2.52** |
| | 3.00 | **2.49** |
| *Sutan Market(TP-9)* | 1.50 | **2.57** |
| | 3.00 | **2.51** |
| *Mariam Church(TP-10)* | 1.50 | **2.58** |
| | 3.00 | **Rock** |

### 4.2.3. Grain-size distribution of soil

The procedure followed to run this test is according to ASTM standard with designations D422-63 and D1140-97.[8]

According to ASTM D422-63 the distribution of particles, finer than 75µm can be done by hydrometer test and courser than 75µm by mechanical sieve. The detailed test procedure is presented in Appendix c.

The combined grain size distribution curves are shown in Fig 4.2 and 4.3 respectively. The gradation of soils in the study area varies considerably (Table 4.4). From the grain size analysis result clay content ranging from 17.08 to 55.51 %, silt fraction 34.79 to 75.52%, sand fraction 6.20 to 35% and gravel content from 0.0 to 0.5%.

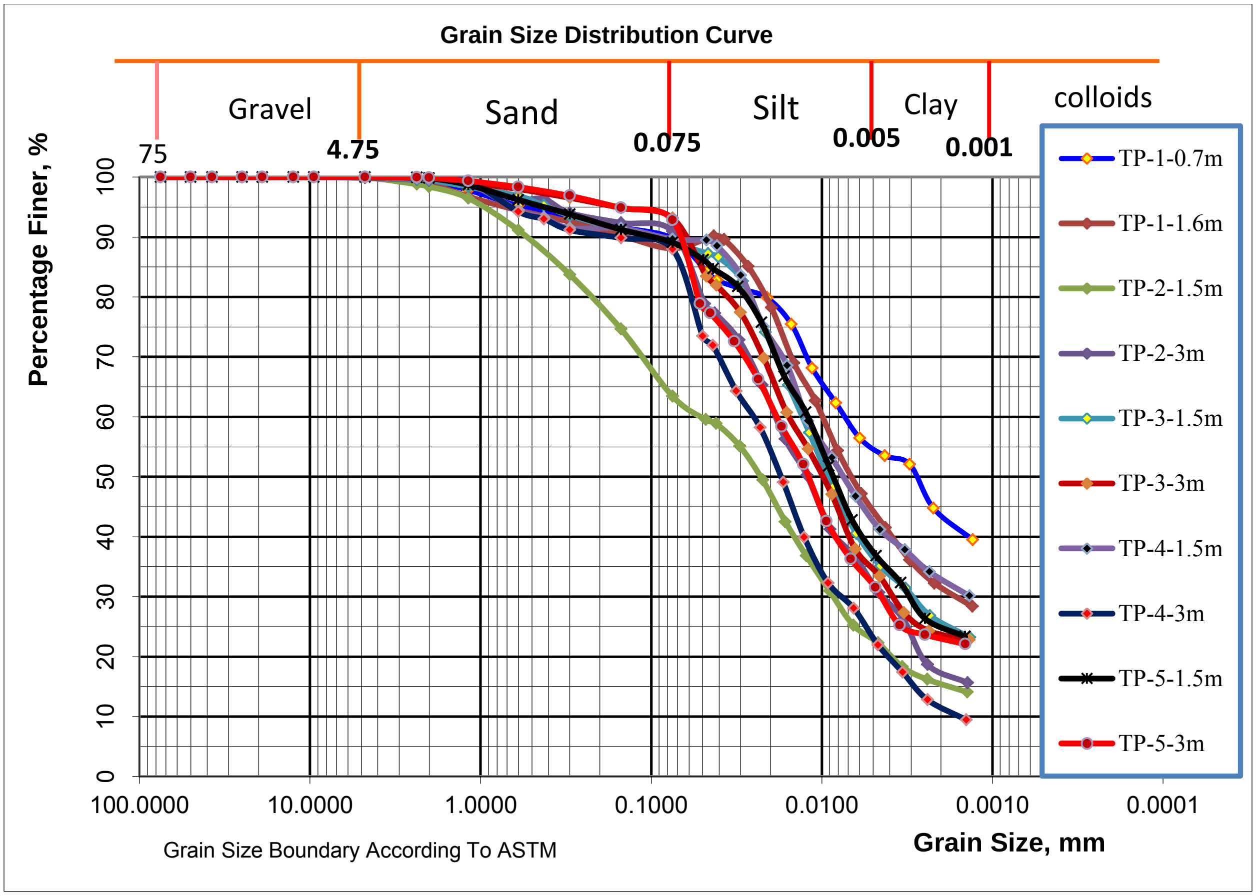



Fig 4.2 Grain size distribution cure for samples from test pits 1 to 5

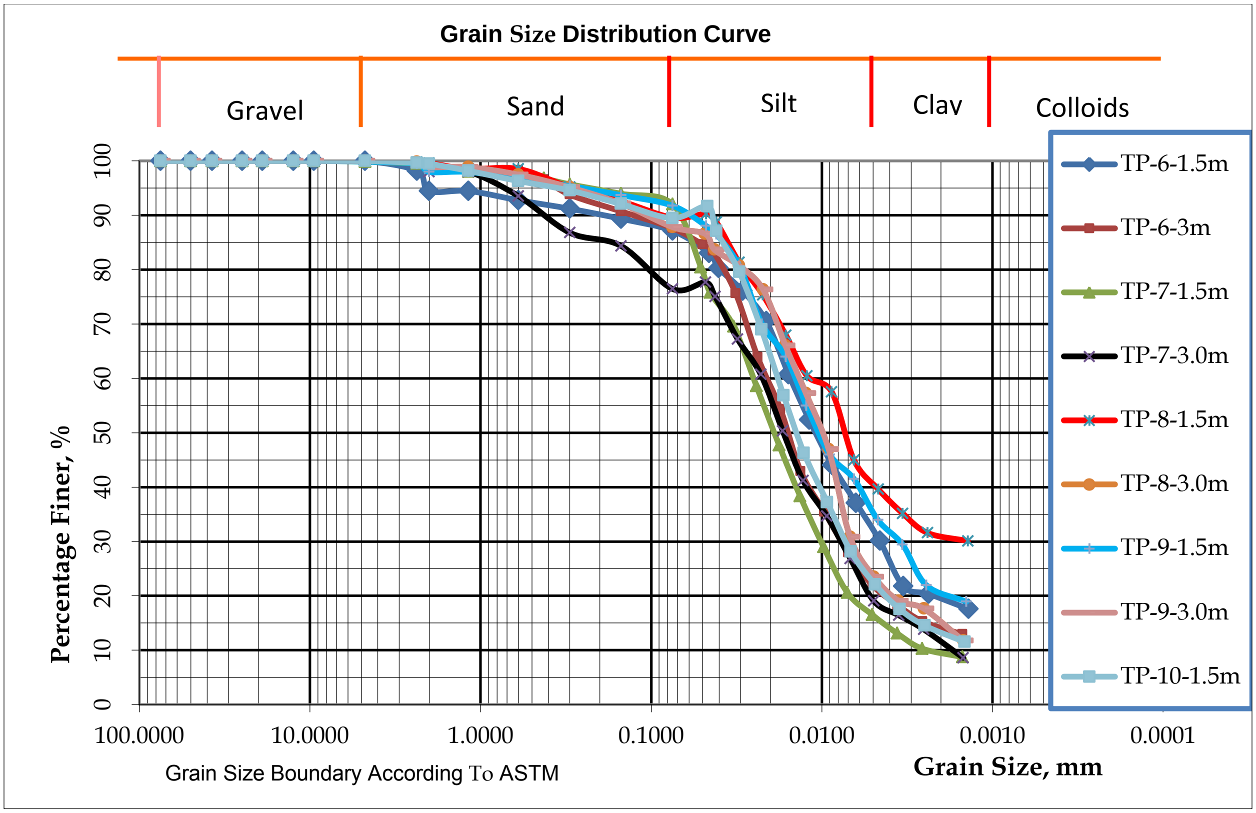



Fig 4.3 Grain size distribution cure for samples from test pits 6 to 10

Table 4.4 Summary of grain size analysis result using ASTM.

| LOCATION | Depth(M) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|
| TP-1 | 0.70 | 0 | 9.70 | 34.79 | 55.51 |
| | 1.60 | 0 | 11.00 | 43.76 | 45.24 |
| TP-2 | 1.50 | 0.1 | 35.00 | 40.65 | 24.25 |
| | 3.00 | 0.1 | 8.40 | 58.99 | 32.51 |
| TP-3 | 1.50 | 0 | 10.50 | 46.06 | 43.44 |
| | 3.00 | 0 | 6.60 | 58.76 | 34.64 |
| TP-4 | 1.50 | 0 | 10.20 | 47.15 | 42.65 |
| | 3.00 | 0 | 11.80 | 65.00 | 23.20 |
| TP-5 | 1.50 | 0 | 10.70 | 51.63 | 37.67 |
| | 3.00 | 0 | 7.08 | 61.32 | 31.60 |
| TP-6 | 1.50 | 0 | 7.30 | 55.42 | 37.28 |
| | 3.00 | 0 | 11.80 | 65.72 | 22.48 |
| TP-7 | 1.50 | 0.1 | 7.30 | 75.52 | 17.08 |
| | 3.00 | 0 | 21.5 | 57.44 | 21.06 |
| TP-8 | 1.50 | 0 | 10 | 49.06 | 40.94 |
| | 3.00 | 0 | 11.1 | 64.35 | 24.55 |
| TP-9 | 1.50 | 0.1 | 6.2 | 56.57 | 37.13 |
| | 3.00 | 0.5 | 9.9 | 65.29 | 24.31 |
| TP-10 | 1.50 | 0 | 10 | 67.39 | 22.61 |

## 4.2.4. Atterberg limits

Atterberg Limits were determined for oven-dried samples. It was done based on the Standard Reference: ASTM D 4318-98 –Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. The oven dried samples at a temperature of 105 $^{o}$c after 24hrs which passed No.40 (0.425mm) sieve were used for the preparation of the sample for this test. [8]

The Atterberg Limits for soil in Tiya town are summarized in Table 4.5 .The details are presented in Appendix B. From this we can observe that liquid limit ranges from 44 – 83%, plastic limit ranges from 18 – 37% and plasticity index from 18 – 51%.

Table 4.5 Atterberg Limit Result.

| Location | Depth(m) | Liquid Limit | Plastic Limit | Plasticity Index |
|---|---|---|---|---|
| TP-1 | 0.70 | 73 | 31 | 42 |
| | 1.60 | 65 | 27 | 38 |
| TP-2 | 1.50 | 64 | 33 | 31 |
| | 3.00 | 78 | 37 | 41 |
| TP-3 | 1.50 | 55 | 25 | 30 |
| | 3.00 | 7 8 | 37 | 41 |
| TP-4 | 1.50 | 60 | 28 | 32 |
| | 3.00 | 56 | 27 | 29 |
| TP-5 | 1.50 | 57 | 20 | 37 |
| | 3.00 | 74 | 31 | 43 |
| TP-6 | 1.50 | 69 | 21 | 48 |
| | 3.00 | 67 | 19 | 48 |
| TP-7 | 1.50 | 51 | 27 | 24 |
| | 3.00 | 44 | 21 | 23 |
| TP-8 | 1.50 | 66 | 23 | 43 |
| | 3.00 | 47 | 29 | 18 |
| TP-9 | 1.50 | 83 | 32 | 51 |
| | 3.00 | 76 | 34 | 42 |
| TP-10 | 1.50 | 59 | 18 | 41 |
| | 3.00 | | | Rock |

## 4.2.5. Free swell

Free swell test results for oven dried samples at a temperature of 105 $^{o}$c are summarized in Table 4.7. From the test result one can see that the free swell of the soil under investigation ranges from 34% to 102.5%.

Those soils having a free swell greater than 200% are described as very high .FSI between 50 and 100 are described as high .FSI between 50 and 100 are described as medium. FSI less than 50 are described as low degree of expansion. [16]

Table 4.6 Free swell test results of the study area.

| Location | Depth(M) | Free swell (%) |
|---|---|---|
| Tiya Market(TP-1) | 0.70 | 92.5 |
| | 1.60 | 82.5 |
| Around tiya stela(2)(TP-2) | 1.50 | 97.5 |
| | 3.00 | 102.5 |
| In front of tiya school(TP-3) | 1.50 | 52.5 |
| | 3.00 | 95.0 |
| Meserete Kirestos(TP-4) | 1.50 | 69.5 |
| | 3.00 | 60.0 |
| Noc( TP-5) | 1.50 | 55.0 |
| | 3.00 | 87.5 |
| Around tiya stela(1) (TP-6) | 1.50 | 70.0 |
| | 3.00 | 100.0 |
| Entrance to Amawete(TP-7) | 1.50 | 67.5 |
| | 3.00 | 34.0 |
| World Vision(TP-8) | 1.50 | 87.5 |
| | 3.00 | 45.5 |
| Sutan Market(TP-9) | 1.50 | 89.5 |
| | 3.00 | 87.0 |
| St.Mariam church (TP-10) | 1.50 | 82.5 |
| | 3.00 | Rock |

# 4.2.6. Classification of the Soils

## 4.2.6.1 Classification of soils based on Unified soil classification (USC) system

The soils under investigation have been classified according to AASHTO M-145 and UCSC.[10].This system describes a system for classifying minerals and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required[8].The classification of the soils are presented in Table 4.7 and Fig 4.5.

Table 4.7 Classifications of soils based on USCS Classification system.

| Location | Depth (m) | Percent amount of particle size | | | | LL (%) | PI (%) | Classification USCS |
|---|---|---|---|---|---|---|---|---|
| | | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | | | |
| TP-1 | 0.70 | 0 | 9.7 | 45.16 | 45.14 | 73 | 42 | CH |
| | 1.60 | 0 | 11 | 55.95 | 33.05 | 65 | 38 | CH |
| TP-2 | 1.50 | 0.1 | 35 | 47.12 | 17.78 | 64 | 31 | MH |
| | 3.00 | 0.1 | 8.4 | 72.44 | 19.06 | 78 | 41 | MH |
| TP-3 | 1.50 | 0 | 10.5 | 62.08 | 27.42 | 55 | 30 | CH |
| | 3.00 | 0 | 6.6 | 68.98 | 24.42 | 78 | 41 | MH |
| TP-4 | 1.50 | 0 | 10.2 | 55.39 | 34.41 | 60 | 32 | CH |
| | 3.00 | 0 | 11.8 | 75.14 | 13.06 | 56 | 29 | CH |
| TP-5 | 1.50 | 0 | 10.7 | 62.61 | 26.69 | 57 | 37 | CH |
| | 3.00 | 0 | 7.08 | 69.29 | 23.63 | 74 | 43 | CH |
| TP-6 | 1.50 | 0 | 7.3 | 66.76 | 25.94 | 69 | 48 | CH |
| | 3.00 | 0 | 11.8 | 72.42 | 15.78 | 67 | 48 | CH |
| TP-7 | 1.50 | 0.1 | 7.3 | 81.68 | 10.92 | 51 | 24 | CH |
| | 3.00 | 0 | 21.5 | 62.58 | 15.92 | 44 | 23 | CL |
| TP-8 | 1.50 | 0 | 10 | 57.86 | 32.14 | 66 | 43 | CH |
| | 3.00 | 0 | 11.1 | 70.23 | 18.67 | 47 | 18 | ML |
| TP-9 | 1.50 | 0.1 | 6.2 | 69.76 | 23.94 | 83 | 51 | CH |
| | 3.00 | 0.5 | 9.9 | 70.97 | 18.63 | 76 | 42 | CH |
| TP-10 | 1.50 | 0 | 10 | 74.87 | 15.13 | 59 | 41 | CH |
| | 3.00 | | | | rock | | | Rock |

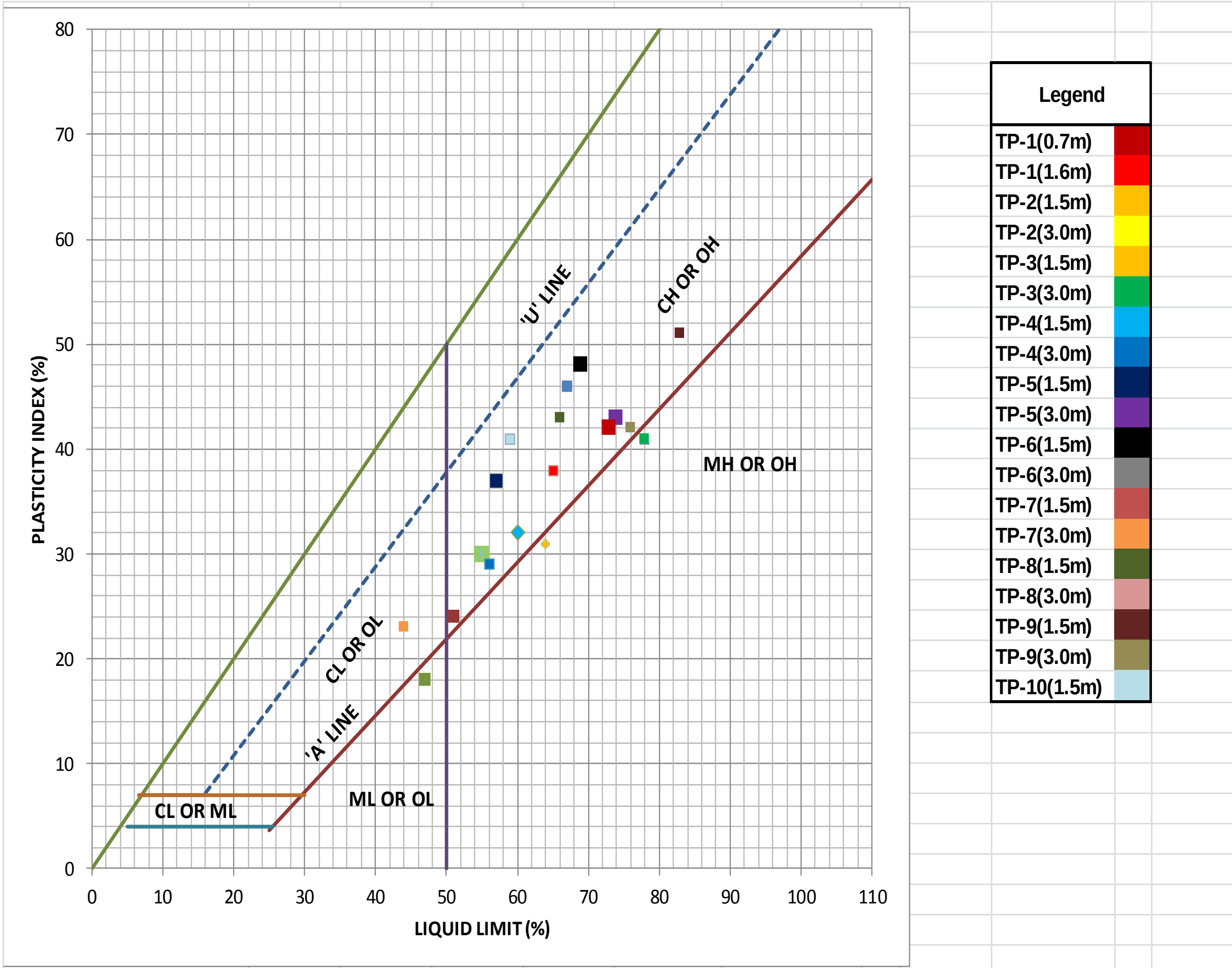



Fig.4.4 Plasticity Chart of the study area according to Unified soil classification System.

### 4.2.6.2 Classifications of soils based on AASHTO Classification system

The AASHTO system uses similar techniques as that of USC 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 called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7.

As it can be observed from AASHTO Classification system (Fig.4.6 and Table 4.10) ,the usual types of significant constituent materials are clayey soil.The group classification of all the samples are A-7-5 and A-7-6 which are clayey soils.

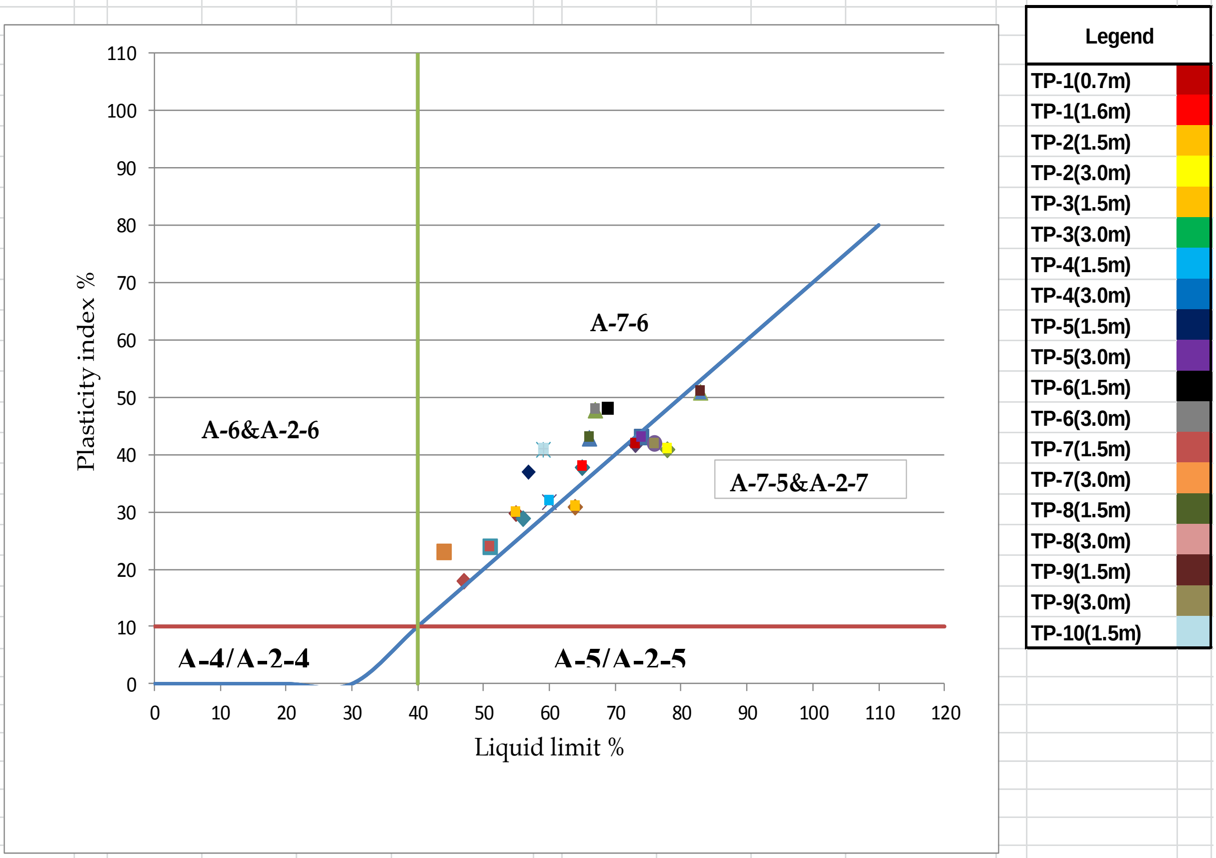



Fig 4.5 Plasticity Chart of soil in the study area according to AASHTO system of classification.

Table 4.8 Classifications of soils based on AASHTO Classification system.

| Location | Depth (m) | Percent passing on sieve No.10 | No.40 | No.200 | GROUP INDEX | LL (%) | PI (%) | Classification AASHETO | Usual types ofsignificant constituent materials | General rating as sub-grade materials |
|---|---|---|---|---|---|---|---|---|---|---|
| TP-1 | 0.70 | 99.5 | 95.2 | 90.3 | 20(max) | 73 | 42 | A-7-5(44) | Clayey soils | poor |
| | 1.60 | 99.1 | 94.5 | 89 | 20(max) | 65 | 38 | A-7-6(38) | Clayey soils | poor |
| TP-2 | 1.50 | 98.4 | 91.1 | 64.9 | 20(max) | 64 | 31 | A-7-5(20) | Clayey soil | poor |
| | 3.00 | 99.4 | 96.3 | 91.5 | 20(max) | 78 | 41 | A-7-5(46) | Clayey soils | poor |
| TP-3 | 1.50 | 99.5 | 95.3 | 89.5 | 20(max) | 55 | 30 | A-7-6(30) | Clayey soils | poor |
| | 3.00 | 99.8 | 98 | 93.4 | 20(max) | 78 | 41 | A-7-5(47) | Clayey soil | poor |
| TP-4 | 1.50 | 99.8 | 93.3 | 89.8 | 20(max) | 60 | 32 | A-7-6(33) | Clayey soils | poor |
| | 3.00 | 99.8 | 93 | 88.2 | 20(max) | 56 | 29 | A-7-6(29) | Clayey soils | poor |
| TP-5 | 1.50 | 99.8 | 96.2 | 89.3 | 20(max) | 57 | 37 | A-7-6(36) | Clayey soils | poor |
| | 3.00 | 99.9 | 98.3 | 92.92 | 20(max) | 74 | 43 | A-7-5(47) | Clayey soils | poor |
| TP-6 | 1.50 | 94.5 | 92.8 | 92.7 | 20(max) | 69 | 48 | A-7-6(49) | Clayey soils | poor |
| | 3.00 | 99.4 | 96.6 | 88.2 | 20(max) | 67 | 48 | A-7-6(46) | Clayey soils | poor |
| TP-7 | 1.50 | 99.3 | 96.8 | 92.6 | 20(max) | 50 | 24 | A-7-6(25) | Clayey soils | poor |
| | 3.00 | 98 | 93.5 | 78.5 | 20(max) | 44 | 23 | A-7-6(18) | Clayey soils | poor |
| TP-8 | 1.50 | 99.6 | 97 | 90 | 20(max) | 66 | 43 | A-7-6(43) | Clayey soils | poor |
| | 3.00 | 98.9 | 97.5 | 88.9 | 20(max) | 47 | 18 | A-7-5(17) | Clayey soils | poor |
| TP-9 | 1.50 | 98 | 96.7 | 93.7 | 20(max) | 83 | 51 | A-7-5(57) | Clayey soils | poor |
| | 3.00 | 96.1 | 93.1 | 89.6 | 20(max) | 76 | 42 | A-7-5(45) | Clayey soils | poor |
| TP-10 | 1.50 | 99.5 | 96.3 | 90 | 20(max) | 59 | 41 | A-7-6(39) | Clayey soils | poor |
| | 3.00 | | | | | | | | ROCK | |

### 4.2.6.3.Classifications of soils based on Activity chart

The clay soil can be classified inactive, normal or active. With this observation Skempton defined a parameter A called Activity. Activity has been used as an index property to determine the swelling potential of expansive clays. [13]

Table 4.9 Activity for different type of soils.

| S/N | Activity | Soil type |
|---|---|---|
| 1 | <0.75 | In active |
| 2 | 0.75-1.25 | Normal |
| 3 | >1.25 | Active |

The respective values for the investigated soils are presented in Table 4.10 and Fig. 4.7

Table 4.10 Activity values of the investigated soils.

| Location | Depth | PI | % Clay | Ac |
|---|---|---|---|---|
| Tiya Market | 0.70 | 42 | 55.51 | 0.76 |
| | 1.60 | 38 | 45.24 | 0.84 |
| Around Tiya Stele(2) | 1.50 | 31 | 32.51 | 0.95 |
| | 3.00 | 41 | 32.51 | 1.26 |
| In front of Tiya School | 1.50 | 30 | 43.44 | 0.69 |
| | 3.00 | 41 | 34.64 | 1.18 |
| Meserte kiristos | 1.50 | 32 | 42.65 | 0.75 |
| | 3.00 | 29 | 23.20 | 1.25 |
| Noc | 1.50 | 37 | 37.67 | 0.98 |
| | 3.00 | 43 | 31.60 | 1.36 |
| (1) Around Tiya stele | 1.50 | 48 | 37.28 | 1.29 |
| | 3.00 | 48 | 22.48 | 2.14 |
| Entrance to Amawete | 1.50 | 24 | 17.08 | 1.41 |
| | 3.00 | 23 | 21.06 | 1.09 |
| World vision | 1.50 | 43 | 40.94 | 1.05 |
| | 3.00 | 18 | 24.55 | 0.73 |
| Sutan market | 1.50 | 51 | 37.13 | 1.37 |
| | 3.00 | 42 | 24.31 | 1.73 |
| St. Mariam church | 1.50 | 41 | 22.61 | 1.81 |
| | 3.00 | | | rock |

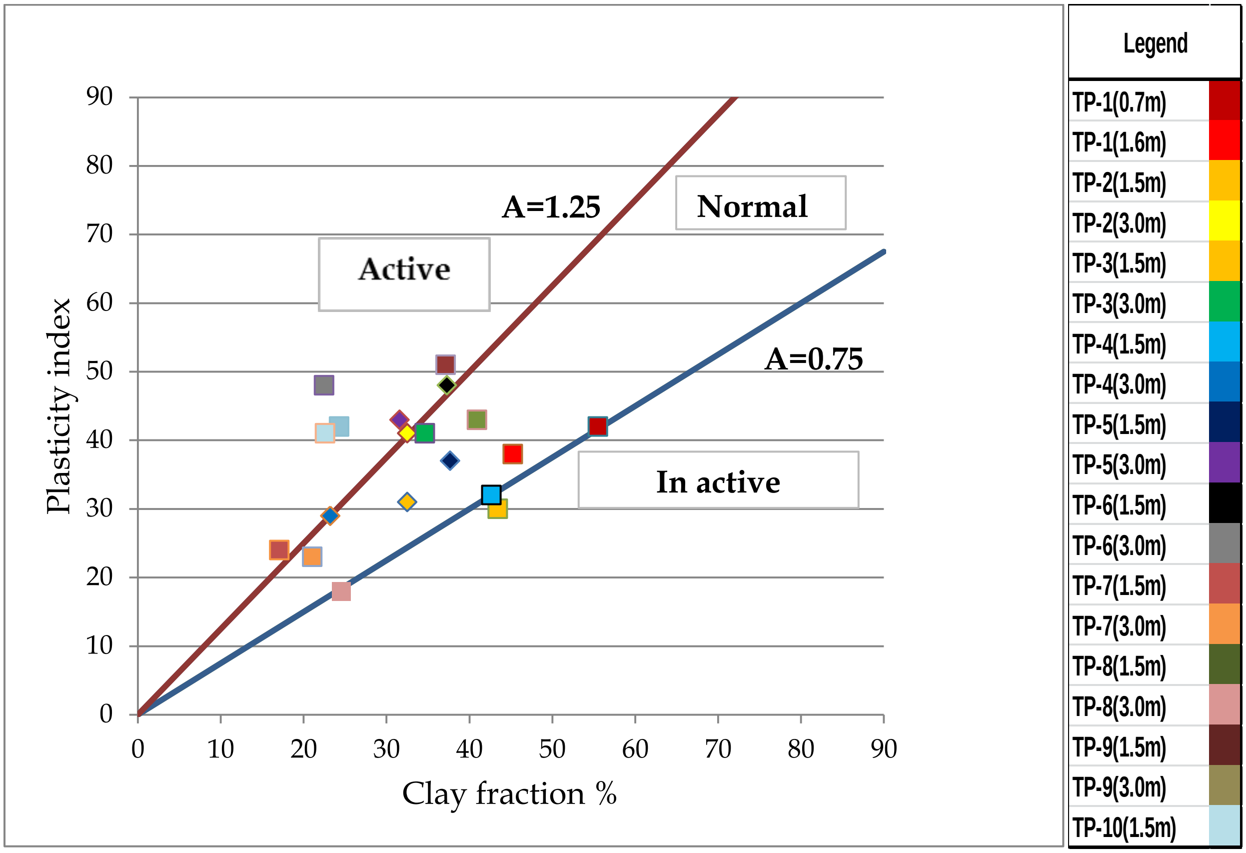



Fig 4.6 soil classification system of the study area according to Activity Chart.

## 4.2.7. Consolidation

This test was done according to the procedure called standard test method for one-dimensional consolidation properties of soils on the ASTM standard,Designation D2435-96.[8]

After carefully trimming undisturbed sample at its top and bottom, it is placed inside the metal ring with porous stone at its top and bottom(Fig 4.8). A setting load of 7 kPa is applied until the soil is fullysaturated. Load was applied through the lever arm and compression dial reading was taken at a time interval of 0.1,0.25,0.5,1, 2,4,8,15,30minutes and 1,2,4,8, and 24hours. The load is doubled every 24 hours strarting from 25kPa to1600kPa. This procedure was followed for all the samples. Plots of void ratio versues logarithem of pressure for all the samples are done. (See Appendix C for detail calculations of the consolidation test result.)

Consolidation tests for selected three sites are presented in Appendix C. The summary of the test results are presented in Table 4.13

Table 4.13 Summary of the consolidation test results.

| Test pit Designation | Depth (m) | Natural moisture content | Total unit wt (kPa) | Pressure p (kPa) | Void Ratio $e_f$ | Comp. Index Cc | Over burden press. Po | Pre-conso Press. Pc | Over cons. Ratio OCR |
|---|---|---|---|---|---|---|---|---|---|
| TP-3 | 3.00 | 32.74 | 18.62 | 7 | 0.27 | 0.224 | 55.95 | 150.0 | 2.7 |
| | | | | 50 | 0.25 | | | | |
| | | | | 100 | 0.23 | | | | |
| | | | | 200 | 0.19 | | | | |
| | | | | 400 | 0.14 | | | | |
| | | | | 800 | 0.08 | | | | |
| | | | | 1600 | 0.01 | | | | |
| TP-7 | 3.00 | 37.25 | 17.13 | 7 | 1.09 | 0.218 | 51.39 | 330.0 | 6.4 |
| | | | | 50 | 1.08 | | | | |
| | | | | 100 | 1.07 | | | | |
| | | | | 200 | 1.06 | | | | |
| | | | | 400 | 1.04 | | | | |
| | | | | 800 | 1.00 | | | | |
| | | | | 1600 | 0.93 | | | | |
| TP-8 | 3.00 | 49.07 | 16.77 | 7 | 1.06 | 0.246 | 50.31 | 350.0 | 7.0 |
| | | | | 50 | 1.05 | | | | |
| | | | | 100 | 1.04 | | | | |
| | | | | 200 | 1.01 | | | | |
| | | | | 400 | 0.98 | | | | |
| | | | | 800 | 0.93 | | | | |
| | | | | 1600 | 0.86 | | | | |

### 4.2.8. Unconfined compression test (UC)

Unconfined compressive strength is calculated the same as for any material, with an additional calculation of the area change from bulging. [10]

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 average cross sectional area at a particular deformation during the test is calculated using:

$$A = Ao/(1 - \varepsilon) \qquad (4.5)$$

Where; A = corrected cross sectional area ($m^2$)

Ao = original cross sectional area ($m^2$)

$\varepsilon$ = axial strain (mm/mm),$\varepsilon = \Delta L/Lo$

The shear strength is defined as half the compressive strength.

Where the equation is given as:

$$qu = \frac{P}{A} \qquad (4.4)$$

Where, $q_u$ = unconfined compressive strength (kPa)

P = Compressive force (kN)

A = cross sectional area ($m^2$)

Typical values of $q_u$ for different consistencies are presented in Table 4.14

Table 4.14 Consistency & unconfined compression strength of clays.

| Consistency | (unconfined compressive strength ) $q_u$(kN/m2) |
|---|---|
| Very soft | 0-24 |
| Soft | 24-48 |
| Medium | 48-96 |
| Stiff | 96-192 |
| Very stiff | 192-383 |
| Hard | >383 |

The laboratory investigations of UCS tests are conducted on undisturbed samples collected from six different areas of Tiya town.

The detailed test results of samples from 6 pits are presented in Appendix A. The summary of the results are given in Table 4.15

Table 4.15 Unconfined strength of soils of the Tiya town.

| Location | Designation | Depth (m) | UCS (kPa) | NMC (%) | USCS Classification Group | State of Consistency |
|---|---|---|---|---|---|---|
| Around Tiya stele(1) | TP-6 | 3.00 | 178.00 | 35.98 | MH | Stiff |
| Entrance to Amawete | TP-7 | 1.50 | 108.00 | 47.49 | CL | Stiff |
| World Vision | TP-8 | 3.00 | 84 | 49.07 | ML | Medium |
| Sutan Market | TP-9 | 1.50 | 122.00 | 32.83 | CH | Stiff |
| | TP-9 | 3.00 | 313 | 37.38 | CH | Very Stiff |
| St. Mariam Church | TP-10 | 1.50 | 119.00 | 27.25 | CH | Stiff |

# 5. Discussions of the laboratory test results and Comparisons with previously done research

- Index tests conducted in soil laboratory are indicating that the minimum types of soils that are available in Tiya Town. Simply free swell test are conducted to evaluate the expansiveness of the investigated soil. Investigated soils which are found in the town are:

  1. High plastic clay soils (CH)

     - Highly plastic clay soils with high degree of expansiveness are investigated at TP-6 for the depth of 3m is under this category.
     - Highly plastic clay soils with marginal degree of expansiveness are investigated at TP-1, TP-4, TP-3, TP-5, and TP-9 at depth of 1.5m and 3m; TP-3, TP-6, TP-7, TP-8 and TP-10 only for a depth of 1.5 are under this category.

  2. Low plastic clay soils (CL)

     - Low plastic clay soils with low degree of expansiveness are investigated at TP-7 for the depth of 3m is under this category.

  3. High plastic silt soils (MH)

     - Highly plastic silt soil with high degree of expansiveness is investigated at TP-2 for the depth of 3m is under this category.

     - A highly plastic silt soil with Marginal degree of expansiveness is investigated at TP-2 for of a depth of 1.5m and TP-3 of a depth of 1.5 m is under this category.

  4. Low plastic silt soils (ML)

     - Low plastic silt soils with low degree of expansiveness are investigated at TP-8 for the depth of 3m is under this category.

  5. Rock

     - Intact rock is investigated around Saint Mary church which is made digging difficult to take a sample. Soils are investigated at TP-10 for the depth of 3m is under this category.

From the plasticity Chart, of according to the Unified Soil Classification System, one observes that the soil under investigation lies below the A-line in the region of inorganic silt and inorganic elastic silt. That means inorganic silt with low to high plasticity. This chart also shows that all samples located above A-line. In USCS classification CL, CH, MH &ML are to describe:

C = Clay, M=Silt L and H are show liquid limits less than or greater than 50% respectively.

Classifications of soils according to AASHTO Classification system it can be observed that soil in the study area is classified in group A-7-5 and A-7-6.It shows that Usual types of significant constituent materials are clayey soil.

The unconfined compression strength test conducted for selected undisturbed samples of soils for Tiya are between medium to very stiff state of consistency i.e. 84-313 kPa at natural water content ranging from 27.25 to 49.07 %.

The compression index of the soils is calculated from the straight portions of the loading e-logp curves.This calculation shows that the compression index, Cc, ranges from 0.218-0.246 .Swelling pressure measured 250kPa in the study area.

Over-consolidation ratios(OCR) of the soils are more than one, so the soil in the study area is over consolidated in its natural state.

Table 5.1 Summary of degree of expansiveness for the study area.

| Location | Depth(M) | Degree of expansiveness |
|---|---|---|
| Tiya Market(TP-1) | 0.70 | Marginal |
| | 1.60 | Marginal |
| Around Tiya stele(2)(TP-2) | 1.50 | Marginal |
| | 3.00 | High |
| In front of Tiya school(TP-3) | 1.50 | Marginal |
| | 3.00 | Marginal |
| Meserete Kirestos(TP-4) | 1.50 | Marginal |
| | 3.00 | Marginal |
| Noc( TP-5) | 1.50 | Marginal |
| | 3.00 | Marginal |
| Around Tiya stele(1) (TP-6) | 1.50 | Marginal |
| | 3.00 | High |
| Entrance to Amawete(TP-7) | 1.50 | Marginal |
| | 3.00 | Low |
| World Vision(TP-8) | 1.50 | Marginal |
| | 3.00 | Low |
| Sutan Market(TP-9) | 1.50 | Marginal |
| | 3.00 | Marginal |
| St.Mariam church (TP-10) | 1.50 | Marginal |
| | 3.00 | Rock |

Finally the test results obtained from this research are compared to Durame Soil which is found in Southern Nations, Nationalities and People Region by other previous researcher. The comparison is shown in Table 5.2.

Table 5.2 Comparisons with previously done researcher.

| | Previous Research Fitsum ,M.(2013) | Current Research |
|---|---|---|
| Location | Durame | Tiya |
| Clay Content (%) | 15-75 | 17.08-55.51 |
| Activity | 0.24-1.23 | 0.69-2.14 |
| Liquid Limit (%) | 44-79 | 44-83 |
| Plasticity Index (%) | 16-42 | 18-51 |
| Free swell (%) | 20-70 | 34.0-102.5 |
| Specific gravity | 2.52-2.97 | 2.42-2.67 |
| From plasticity chart | MH and CH | CH, MH,CL,ML |
| UCS | 121-302 | 84-313 |

# 6. Tentative soil map of Tiya town

- Soil map of Tiya Town was prepared based on information collected from GPS data, field visual observation of different areas and laboratory test results.
- Test pits are excavated to a maximum depth of 3m.
- Investigated soil types at a depth of 3 meter are CH, MH, ML and rock.
- All investigated soils at a depth of 1.5m are CH.
- Index tests conducted in soil laboratory are indicating that the minimum types of soils that are available in Tiya Town. Simply free swell test are conducted to evaluate the expansiveness of the investigated soil.

  Investigated soils which are found in the town are:

  1. High plastic clay soils (CH)
     - Highly plastic clay soil with high degree of expansiveness.
  2. Low plastic clay soils (CL)
     - Low plastic clay soil with Low degree of expansiveness.
  3. High plastic silt soils (MH)
     - Highly dominantly plastic silt soil with highly expansive to low degree of expansiveness.
  4. Low plastic silt soils (ML)
     - Low plastic silt soil with low degree of expansiveness.
  5. Rock
     - Intact rock is investigated around Saint Mary church which is difficult to take a sample.

The degree of expansiveness for investigated soils is shown in Table 7.1.

Table 6.1 Degree of expansiveness for investigated soil of the study area.

| Location | Depth(M) | Degree of expansiveness |
|---|---|---|
| Tiya Market(TP-1) | 0.70 | Marginal |
| | 1.60 | Marginal |
| Around Tiya stele(2)(TP-2) | 1.50 | Marginal |
| | 3.00 | High |
| In front of Tiya school(TP-3) | 1.50 | Marginal |
| | 3.00 | Marginal |
| Meserete Kirestos(TP-4) | 1.50 | Marginal |
| | 3.00 | Marginal |
| Noc( TP-5) | 1.50 | Marginal |
| | 3.00 | Marginal |
| Around Tiya stele(1) (TP-6) | 1.50 | Marginal |
| | 3.00 | High |
| Entrance to Amawete(TP-7) | 1.50 | Marginal |
| | 3.00 | Low |
| World Vision(TP-8) | 1.50 | Marginal |
| | 3.00 | Low |
| Sutan Market(TP-9) | 1.50 | Marginal |
| | 3.00 | Marginal |
| St.Mariam church (TP-10) | 1.50 | Marginal |
| | 3.00 | Rock |

Finally a tentative soil map of the study area is attached for layers 1.5meter and 3.0 meter are presented respectively in Fig.6.1 and Fig.6.2

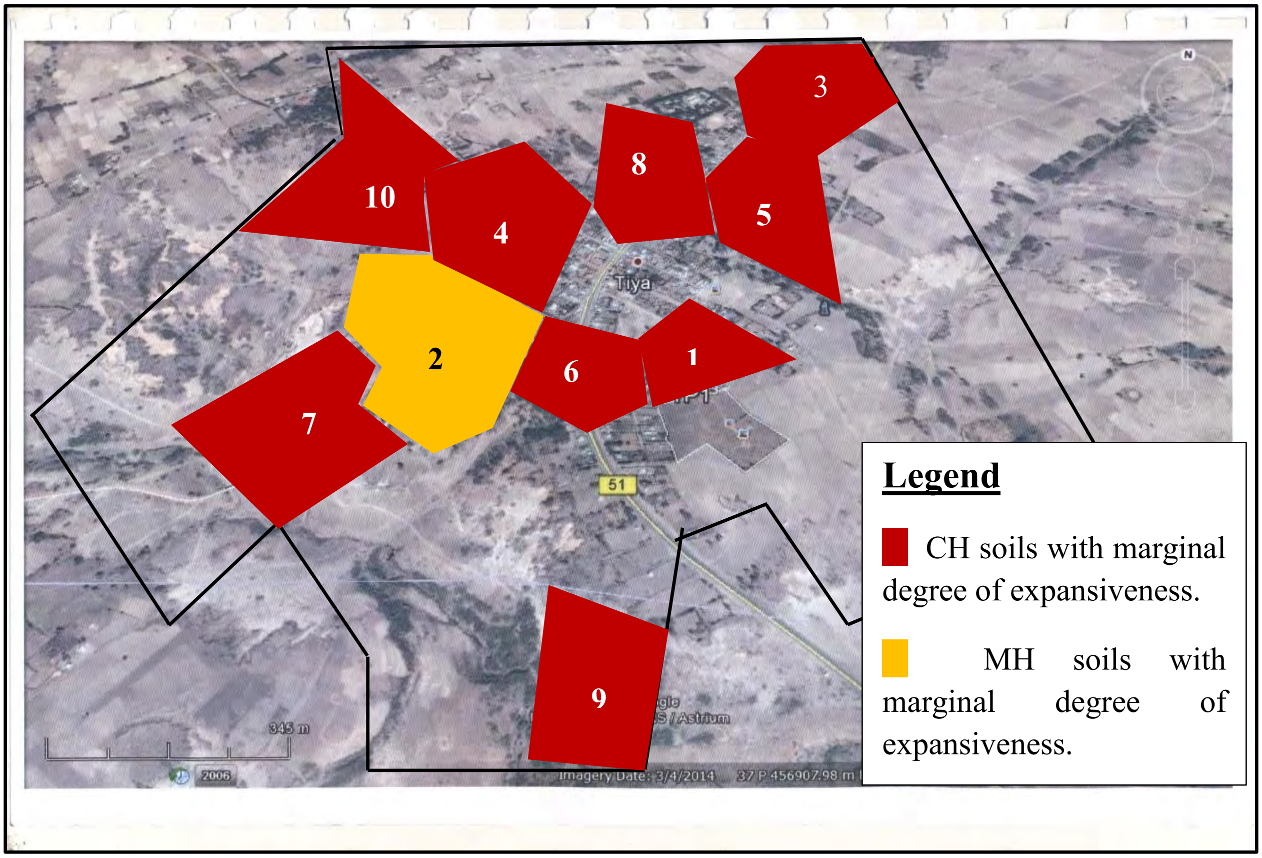



Fig 6.1 Tentative soil map nearly at top surface to 1.5m.

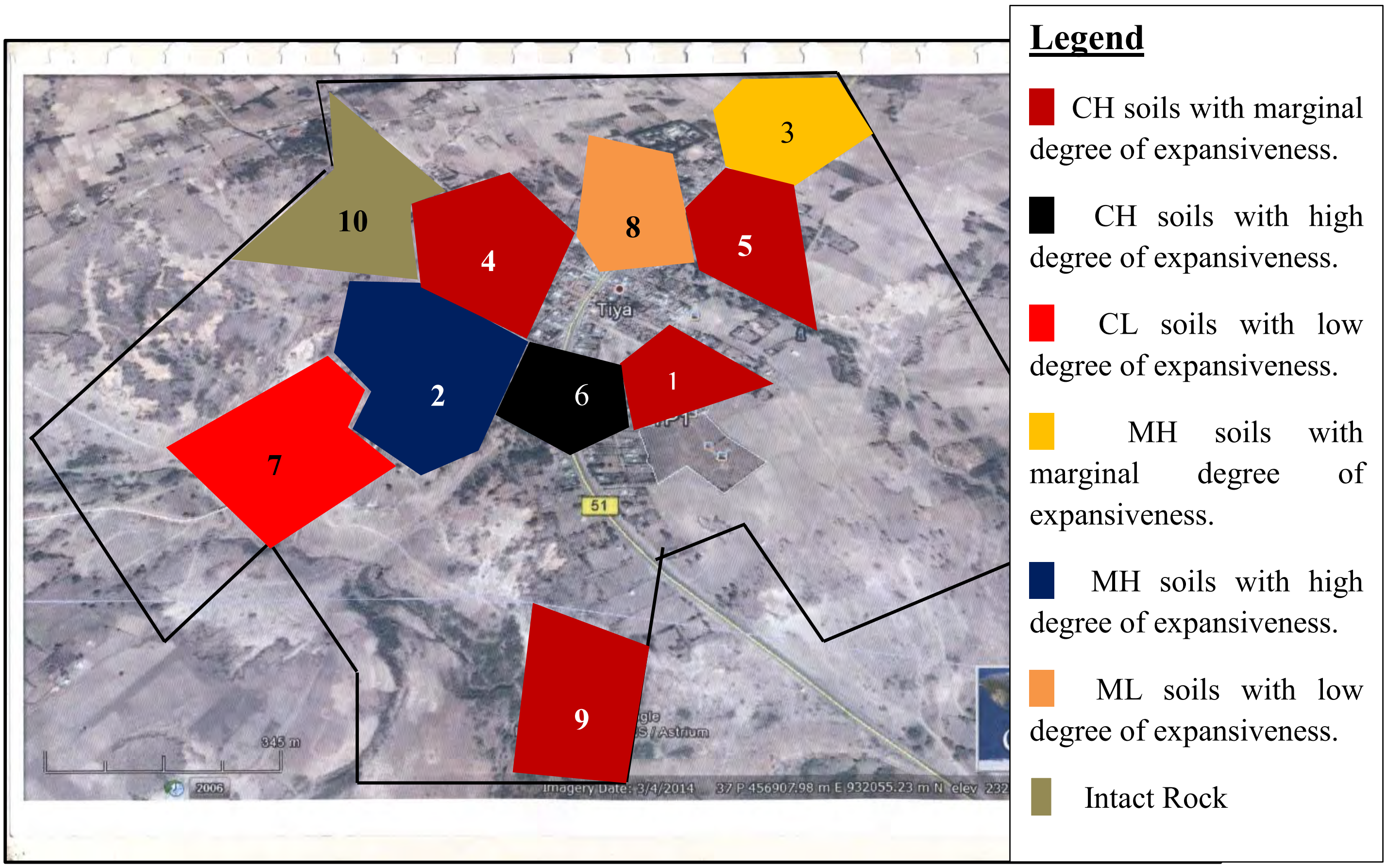



Fig.6.2 Tentative soil map at depth of 3m.

# 7. Conclusion and recommendation

## 7.1. Conclusion

1. Grain size analysis tests revealed that, starting from few centimeters below the ground level to the depth of investigation which is three meters, the soil in Tiya town is mostly clay and silt soil in which the percentage of clay ranges from 17.08 to 55.51%, silt from 40.65 to 75.52%, sand from 6.2 to 35% and gravel 0.0 to 0.5%.A tentative soil map is presented in Fig 6.2 and Fig 6.3.

2. The specific gravity of Tiya soil is ranges from 2.42 to 2.67

3. The samples show free swell value between 34% to 102.5%. This show in the study area is ranges from low to very high expansive soils.

4. From consistency limit test results the liquid limit of the area ranges from 44 to 83%, plastic limit rages from 18 to 37% %and plastic index from18 to 51%.

5. As determined from the one-dimensional consolidation test conducted from undisturbed soil samples, compression index, Cc, ranges from 0.218 to 0.246, and measured swelling pressure of 250kPa.

The unconfined compression strength test conducted for selected undisturbed samples of soils for Tiya are between medium to very stiff state of consistency i.e. 84 to 313 kPa at natural water content ranging from 27.25 to 49.07 %.

## 7.2. Recommendation

1. In this research samples of soil were collected only from ten test pits, by increasing the number of sampling additional investigation should be done in future.

2. Detail investigation has to be done for the soil profile along the depths. The maximum depth for this investigation was 3 m.

3. This study didn"t include x-ray diffraction test. Therefore this test should be done to identify and characterize the minerals of the soils under investigation.

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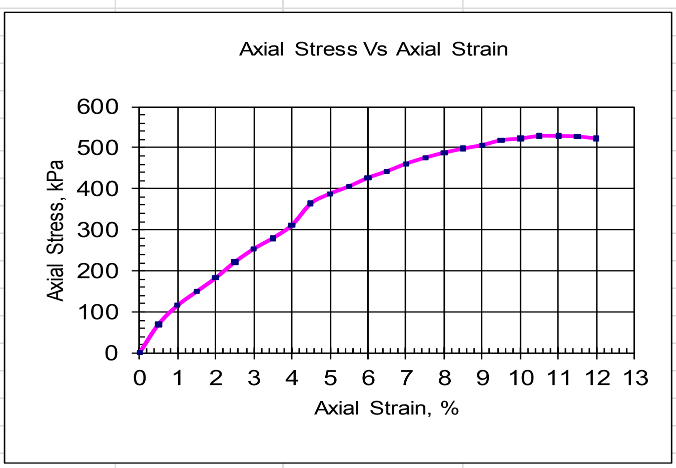
## Appendix A

### Unconfined Compression Test

| | | | |
|---|---|---|---|
| Location of project: | Around Tiya Stele(1) | | |
| Test Pit No | | | |
| Test Pit Depth , m | 1.5m | Ring Calibration Factor, kN/div | 0.00133 |
| Diameter of sample , mm | 38 | Moisture content, % | 38.60 |
| Length of sample , mm | 76 | Wet unit weight, kN/m3 | 16.93 |

**Sample 1**

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 60 | 0.0798 | 0.00114 | 69.91 |
| 1 | 1.32 | 100 | 0.1330 | 0.00115 | 115.74 |
| 1.5 | 1.97 | 130 | 0.1729 | 0.00116 | 149.46 |
| 2 | 2.63 | 160 | 0.2128 | 0.00116 | 182.72 |
| 2.5 | 3.29 | 195 | 0.2594 | 0.00117 | 221.18 |
| 3 | 3.95 | 225 | 0.2993 | 0.00118 | 253.47 |
| 3.5 | 4.61 | 250 | 0.3325 | 0.00119 | 279.71 |
| 4 | 5.26 | 280 | 0.3724 | 0.00120 | 311.11 |
| 4.5 | 5.92 | 330 | 0.4389 | 0.00121 | 364.12 |
| 5 | 6.58 | 354 | 0.4708 | 0.00121 | 387.87 |
| 5.5 | 7.24 | 373 | 0.4961 | 0.00122 | 405.81 |
| 6 | 7.89 | 395 | 0.5254 | 0.00123 | 426.70 |
| 6.5 | 8.55 | 413 | 0.5493 | 0.00124 | 442.96 |
| 7 | 9.21 | 433 | 0.5759 | 0.00125 | 461.06 |
| 7.5 | 9.87 | 450 | 0.5985 | 0.00126 | 475.69 |
| 8 | 10.53 | 465 | 0.6185 | 0.00127 | 487.96 |
| 8.5 | 11.18 | 478 | 0.6357 | 0.00128 | 497.92 |
| 9 | 11.84 | 490 | 0.6517 | 0.00129 | 506.64 |
| 9.5 | 12.50 | 505 | 0.6717 | 0.00130 | 518.25 |
| 10 | 13.16 | 513 | 0.6823 | 0.00131 | 522.50 |
| 10.5 | 13.82 | 523 | 0.6956 | 0.00132 | 528.65 |
| 11 | 14.47 | 527 | 0.7009 | 0.00133 | 528.63 |
| 11.5 | 15.13 | 530 | 0.7049 | 0.00134 | 527.55 |
| 12 | 15.79 | 529 | 0.7036 | 0.00135 | 522.47 |
| 12.5 | 16.45 | 525 | 0.6983 | 0.00136 | 514.47 |
| 13 | 17.11 | 520 | 0.6916 | 0.00137 | 505.56 |




Unconfined Compressive Strength($q_u$),kPa = 529

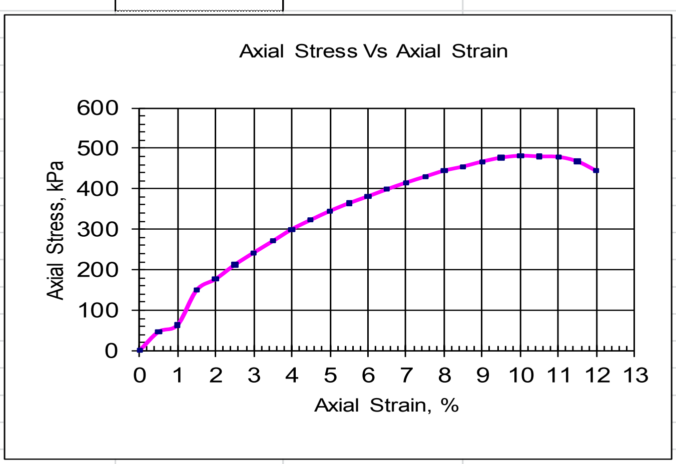
Undrained Shear Strengh (cu), kPa = 264

**Unconfined Compression Test**

| | | | |
|---|---|---|---|
| **Location of project:** | **Infront of tiya school** | | |
| **Test Pit No** | | | |
| Test Pit Depth , m | 3.0m | Ring Calibration Factor, kN/div | 0.00133 |
| Diameter of sample , mm | 38 | Moisture content, % | 32.74 |
| Length of sample , mm | 76 | Wet unit weight, kN/m3 | 18.62 |

**Sample 1**

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 40 | 0.0532 | 0.00114 | 46.60 |
| 1 | 1.32 | 55 | 0.0732 | 0.00115 | 63.66 |
| 1.5 | 1.97 | 130 | 0.1729 | 0.00116 | 149.46 |
| 2 | 2.63 | 155 | 0.2062 | 0.00116 | 177.01 |
| 2.5 | 3.29 | 187 | 0.2487 | 0.00117 | 212.11 |
| 3 | 3.95 | 215 | 0.2860 | 0.00118 | 242.21 |
| 3.5 | 4.61 | 242 | 0.3219 | 0.00119 | 270.76 |
| 4 | 5.26 | 270 | 0.3591 | 0.00120 | 300.00 |
| 4.5 | 5.92 | 293 | 0.3897 | 0.00121 | 323.29 |
| 5 | 6.58 | 315 | 0.4190 | 0.00121 | 345.14 |
| 5.5 | 7.24 | 335 | 0.4456 | 0.00122 | 364.47 |
| 6 | 7.89 | 353 | 0.4695 | 0.00123 | 381.33 |
| 6.5 | 8.55 | 372 | 0.4948 | 0.00124 | 398.98 |
| 7 | 9.21 | 390 | 0.5187 | 0.00125 | 415.28 |
| 7.5 | 9.87 | 407 | 0.5413 | 0.00126 | 430.24 |
| 8 | 10.53 | 424 | 0.5639 | 0.00127 | 444.94 |
| 8.5 | 11.18 | 437 | 0.5812 | 0.00128 | 455.21 |
| 9 | 11.84 | 452 | 0.6012 | 0.00129 | 467.35 |
| 9.5 | 12.50 | 465 | 0.6185 | 0.00130 | 477.20 |
| 10 | 13.16 | 473 | 0.6291 | 0.00131 | 481.76 |
| 10.5 | 13.82 | 475 | 0.6318 | 0.00132 | 480.13 |
| 11 | 14.47 | 477.5 | 0.6351 | 0.00133 | 478.97 |
| 11.5 | 15.13 | 470 | 0.6251 | 0.00134 | 467.82 |
| 12 | 15.79 | 450 | 0.5985 | 0.00135 | 444.44 |




Unconfined Compressive Strength($q_u$),kPa = 482

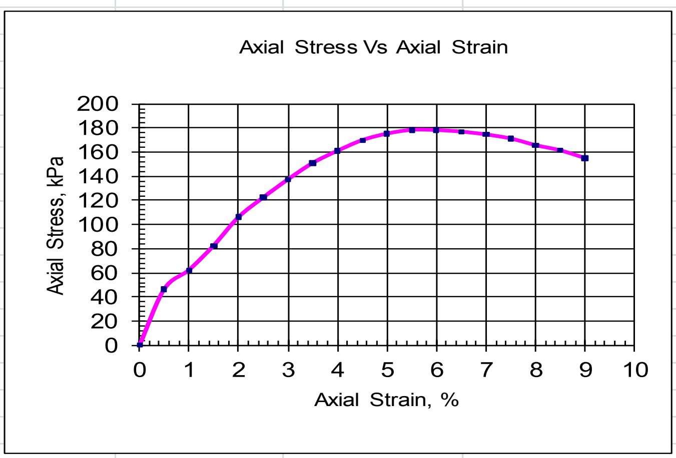
Undrained Shear Strengh (cu), kPa = 241

## Unconfined Compression Test

| | | | |
|---|---|---|---|
| Location of project: | Around Tiya Stele(1) | | |
| Test Pit No | | | |
| Test Pit Depth , m | 3.0m | Ring Calibration Factor, kN/div | 0.00133 |
| Diameter of sample , mm | 38 | Moisture content, % | 35.98 |
| Length of sample , mm | 76 | Wet unit weight, kN/m3 | 17.83 |

**Sample 1**

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 40 | 0.0532 | 0.00114 | 46.60 |
| 1 | 1.32 | 54 | 0.0718 | 0.00115 | 62.50 |
| 1.5 | 1.97 | 72 | 0.0958 | 0.00116 | 82.78 |
| 2 | 2.63 | 93 | 0.1237 | 0.00116 | 106.20 |
| 2.5 | 3.29 | 108 | 0.1436 | 0.00117 | 122.50 |
| 3 | 3.95 | 122 | 0.1623 | 0.00118 | 137.44 |
| 3.5 | 4.61 | 135 | 0.1796 | 0.00119 | 151.04 |
| 4 | 5.26 | 145 | 0.1929 | 0.00120 | 161.11 |
| 4.5 | 5.92 | 154 | 0.2048 | 0.00121 | 169.92 |
| 5 | 6.58 | 160 | 0.2128 | 0.00121 | 175.31 |
| 5.5 | 7.24 | 164 | 0.2181 | 0.00122 | 178.43 |
| 6 | 7.89 | 165 | 0.2195 | 0.00123 | 178.24 |
| 6.5 | 8.55 | 165 | 0.2195 | 0.00124 | 176.97 |
| 7 | 9.21 | 164 | 0.2181 | 0.00125 | 174.63 |
| 7.5 | 9.87 | 162 | 0.2155 | 0.00126 | 171.25 |
| 8 | 10.53 | 158 | 0.2101 | 0.00127 | 165.80 |
| 8.5 | 11.18 | 155 | 0.2062 | 0.00128 | 161.46 |
| 9 | 11.84 | 150 | 0.1995 | 0.00129 | 155.09 |




Unconfined Compressive Strength($q_u$),kPa = 178

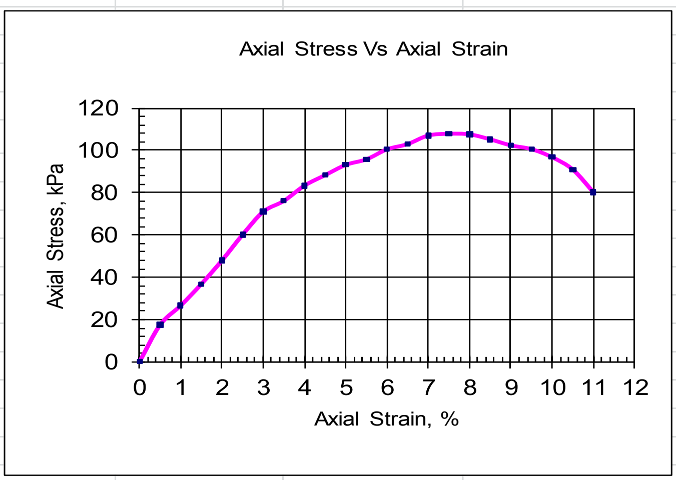
Undrained Shear Strengh (cu), kPa = 89

## Unconfined Compression Test

| | | | |
|---|---|---|---|
| **Location of project:** | **Entrance to Amawete** | | |
| **Test Pit No** | | | |
| Test Pit Depth , m | 1.5m | Ring Calibration Factor, kN/div | 0.00133 |
| Diameter of sample , mm | 38 | Moisture content, % | 47.49 |
| Length of sample , mm | 76 | Wet unit weight, kN/m3 | 17.13 |

**Sample 1**

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 15 | 0.0200 | 0.00114 | 17.48 |
| 1 | 1.32 | 23 | 0.0306 | 0.00115 | 26.62 |
| 1.5 | 1.97 | 32 | 0.0426 | 0.00116 | 36.79 |
| 2 | 2.63 | 42 | 0.0559 | 0.00116 | 47.96 |
| 2.5 | 3.29 | 53 | 0.0705 | 0.00117 | 60.12 |
| 3 | 3.95 | 63 | 0.0838 | 0.00118 | 70.97 |
| 3.5 | 4.61 | 68 | 0.0904 | 0.00119 | 76.08 |
| 4 | 5.26 | 75 | 0.0998 | 0.00120 | 83.33 |
| 4.5 | 5.92 | 80 | 0.1064 | 0.00121 | 88.27 |
| 5 | 6.58 | 85 | 0.1131 | 0.00121 | 93.13 |
| 5.5 | 7.24 | 88 | 0.1170 | 0.00122 | 95.74 |
| 6 | 7.89 | 93 | 0.1237 | 0.00123 | 100.46 |
| 6.5 | 8.55 | 96 | 0.1277 | 0.00124 | 102.96 |
| 7 | 9.21 | 100.5 | 0.1337 | 0.00125 | 107.01 |
| 7.5 | 9.87 | 102 | 0.1357 | 0.00126 | 107.82 |
| 8 | 10.53 | 102.5 | 0.1363 | 0.00127 | 107.56 |
| 8.5 | 11.18 | 101 | 0.1343 | 0.00128 | 105.21 |
| 9 | 11.84 | 99 | 0.1317 | 0.00129 | 102.36 |
| 9.5 | 12.50 | 98 | 0.1303 | 0.00130 | 100.57 |
| 10 | 13.16 | 95 | 0.1264 | 0.00131 | 96.76 |
| 10.5 | 13.82 | 90 | 0.1197 | 0.00132 | 90.97 |
| 11 | 14.47 | 80 | 0.1064 | 0.00133 | 80.25 |

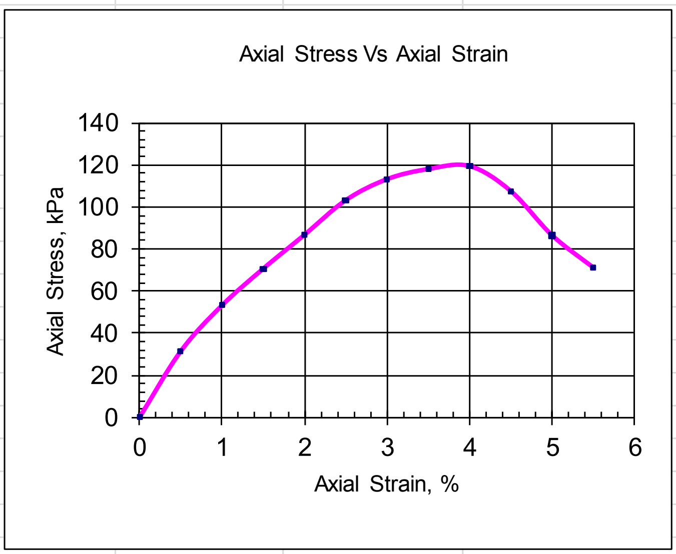



Unconfined Compressive Strength($q_u$),kPa = **108**

Undrained Shear Strengh (cu), kPa = **54**

| | | Unconfined Compression Test | | | |
|---|---|---|---|---|---|
| **Location of project:** | | **Mariam Church** | | | |
| **Test Pit No** | | | | | |
| Test Pit Depth , m | | 1.5m | Ring Calibration Factor, kN/div | | 0.00133 |
| Diameter of sample , mm | | 38 | Moisture content, % | | 27.25 |
| Length of sample , mm | | 76 | Wet unit weight, kN/m3 | | 18.02 |

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 27 | 0.0359 | 0.00114 | 31.46 |
| 1 | 1.32 | 46 | 0.0612 | 0.00115 | 53.24 |
| 1.5 | 1.97 | 61.5 | 0.0818 | 0.00116 | 70.71 |
| 2 | 2.63 | 76 | 0.1011 | 0.00116 | 86.79 |
| 2.5 | 3.29 | 91 | 0.1210 | 0.00117 | 103.22 |
| 3 | 3.95 | 100.5 | 0.1337 | 0.00118 | 113.22 |
| 3.5 | 4.61 | 105.5 | 0.1403 | 0.00119 | 118.04 |
| 4 | 5.26 | 107.5 | 0.1430 | 0.00120 | 119.44 |
| 4.5 | 5.92 | 97.5 | 0.1297 | 0.00121 | 107.58 |
| 5 | 6.58 | 79 | 0.1051 | 0.00121 | 86.56 |
| 5.5 | 7.24 | 65.5 | 0.0871 | 0.00122 | 71.26 |



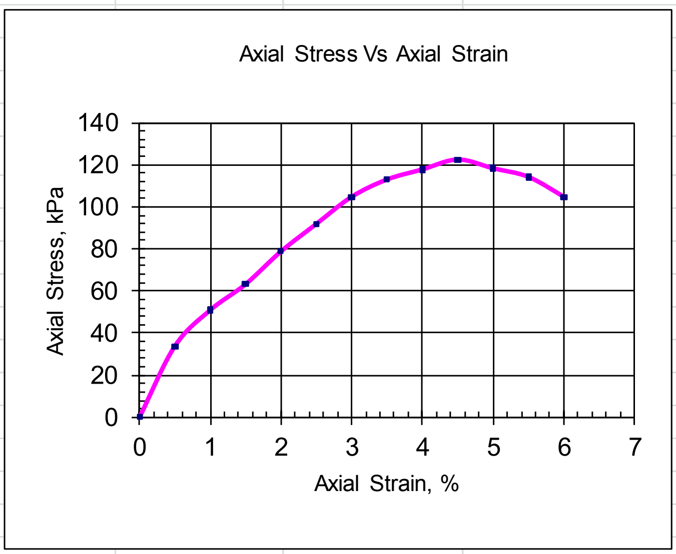

Unconfined Compressive Strength($q_u$),kPa = 119

Undrained Shear Strengh (cu), kPa = 60

## Unconfined Compression Test

| | | | | | |
|---|---|---|---|---|---|
| Location of project: | | Sutan Market | | | |
| Test Pit No | | | | | |
| Test Pit Depth , m | | 1.5m | Ring Calibration Factor, kN/div | | 0.00133 |
| Diameter of sample , mm | | 38 | Moisture content, % | | 32.83 |
| Length of sample , mm | | 76 | Wet unit weight, kN/m3 | | 17.19 |

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 29 | 0.0386 | 0.00114 | 33.79 |
| 1 | 1.32 | 44 | 0.0585 | 0.00115 | 50.93 |
| 1.5 | 1.97 | 55 | 0.0732 | 0.00116 | 63.23 |
| 2 | 2.63 | 69 | 0.0918 | 0.00116 | 78.80 |
| 2.5 | 3.29 | 81 | 0.1077 | 0.00117 | 91.88 |
| 3 | 3.95 | 93 | 0.1237 | 0.00118 | 104.77 |
| 3.5 | 4.61 | 101 | 0.1343 | 0.00119 | 113.00 |
| 4 | 5.26 | 106 | 0.1410 | 0.00120 | 117.78 |
| 4.5 | 5.92 | 111 | 0.1476 | 0.00121 | 122.48 |
| 5 | 6.58 | 108 | 0.1436 | 0.00121 | 118.33 |
| 5.5 | 7.24 | 105 | 0.1397 | 0.00122 | 114.24 |
| 6 | 7.89 | 97 | 0.1290 | 0.00123 | 104.78 |
| | | | | | |
| | | | | | |
| | | | | | |




Unconfined Compressive Strength($q_u$),kPa = 122

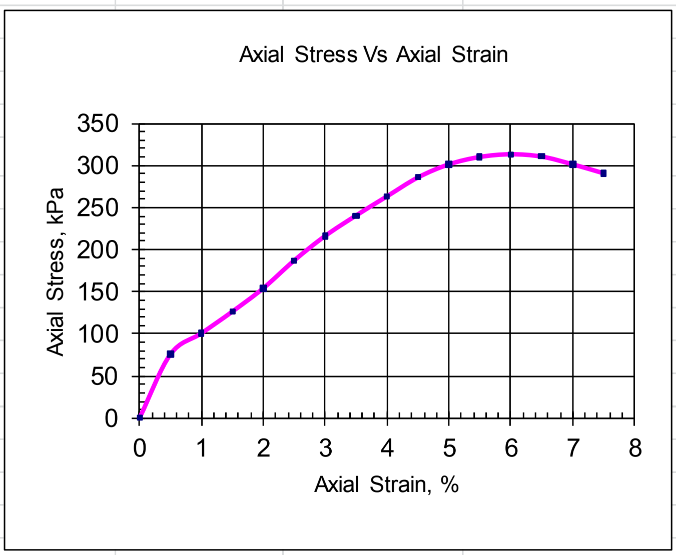
Undrained Shear Strengh (cu), kPa = 61

## Unconfined Compression Test

| | | | |
|---|---|---|---|
| Location of project: | Sutan market | | |
| Test Pit No | | | |
| Test Pit Depth , m | 3.0m | Ring Calibration Factor, kN/div | 0.00133 |
| Diameter of sample , mm | 38 | Moisture content, % | 37.38 |
| Length of sample , mm | 76 | Wet unit weight, kN/m3 | 14.67 |

**Sample 1**

| Axial Deformation [mm] | Axial Strain [%] | Proving Ring Reading [div] | Axial Load [kN] | Corrected Area [m2] | Axial Stress [kPa] |
|---|---|---|---|---|---|
| 0 | 0.00 | 0 | 0.0000 | 0.00113 | 0 |
| 0.5 | 0.66 | 65 | 0.0865 | 0.00114 | 75.73 |
| 1 | 1.32 | 87 | 0.1157 | 0.00115 | 100.69 |
| 1.5 | 1.97 | 110 | 0.1463 | 0.00116 | 126.47 |
| 2 | 2.63 | 135 | 0.1796 | 0.00116 | 154.17 |
| 2.5 | 3.29 | 165 | 0.2195 | 0.00117 | 187.15 |
| 3 | 3.95 | 192 | 0.2554 | 0.00118 | 216.30 |
| 3.5 | 4.61 | 215 | 0.2860 | 0.00119 | 240.55 |
| 4 | 5.26 | 237 | 0.3152 | 0.00120 | 263.33 |
| 4.5 | 5.92 | 259 | 0.3445 | 0.00121 | 285.78 |
| 5 | 6.58 | 275 | 0.3658 | 0.00121 | 301.31 |
| 5.5 | 7.24 | 285 | 0.3791 | 0.00122 | 310.07 |
| 6 | 7.89 | 290 | 0.3857 | 0.00123 | 313.27 |
| 6.5 | 8.55 | 289.5 | 0.3850 | 0.00124 | 310.50 |
| 7 | 9.21 | 283 | 0.3764 | 0.00125 | 301.34 |
| 7.5 | 9.87 | 275 | 0.3658 | 0.00126 | 290.70 |




Unconfined Compressive Strength($q_u$),kPa = 313

Undrained Shear Strengh (cu), kPa = 157

## Appendix B

### Around tiya stele(1) 1.5m

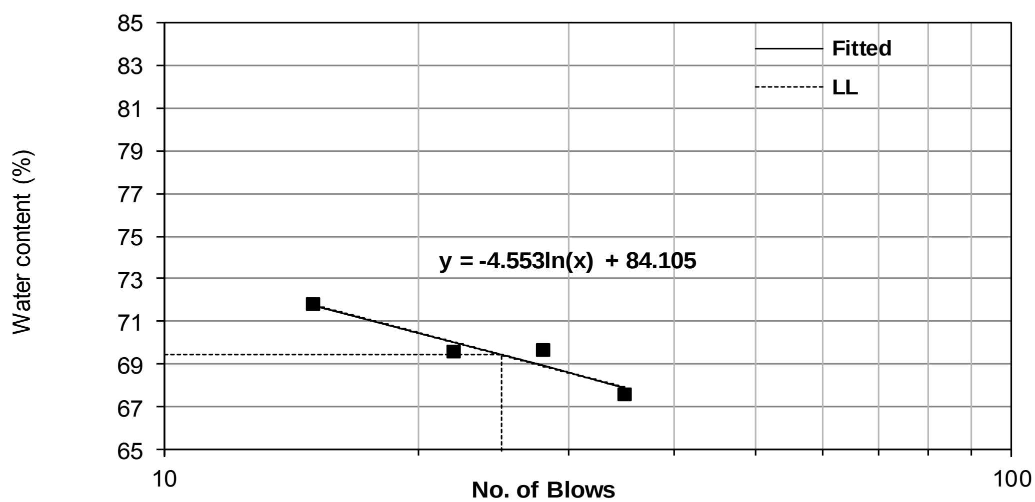
| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.00* | *45.40* | *40.40* | *35* | 67.57 | 67.92 |
| *2* | *33.70* | *44.90* | *40.30* | *28* | 69.70 | 68.93 |
| *3* | *32.60* | *44.30* | *39.50* | *22* | 69.57 | 70.03 |
| *4* | *32.70* | *44.90* | *39.80* | *15* | 71.83 | 71.78 |
| *5* | *33.50* | *40.90* | *39.60* | | 21.31 | |
| *6* | *33.20* | *40.00* | *38.80* | | 21.43 | |

Slope of flow line = 0.065

Liquid limit (%) = 69.45 Plastic limit (%) = 21.37

plasticity index = 48.08

**Flow Curve**



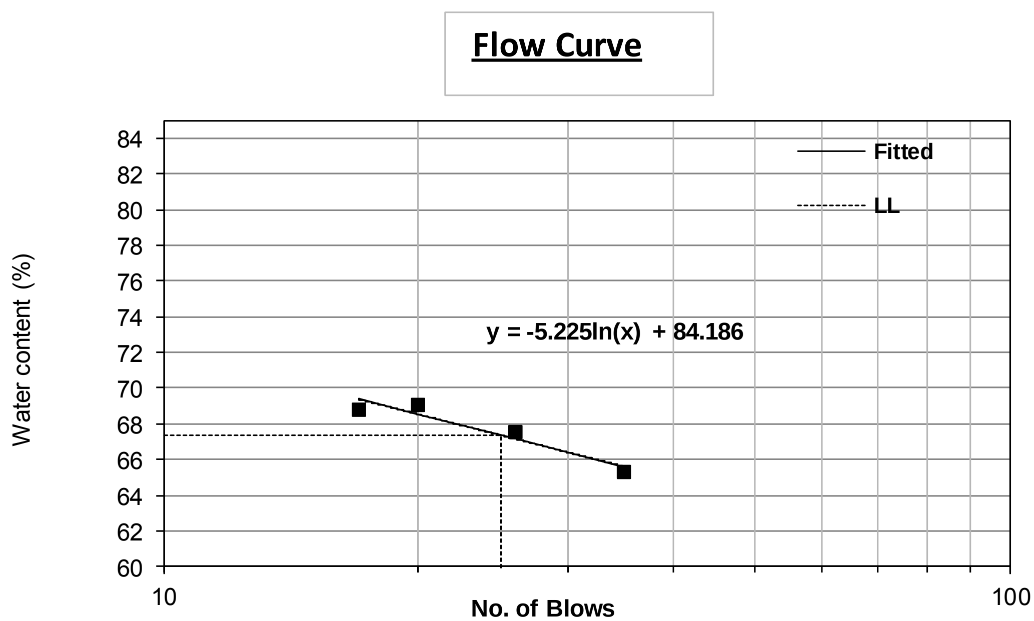
## Around tiya stela(1) 3m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.60* | *49.30* | *43.10* | *35* | 65.26 | 65.61 |
| *2* | *32.80* | *51.90* | *44.20* | *26* | 67.54 | 67.16 |
| *3* | *33.60* | *50.00* | *43.30* | *20* | 69.07 | 68.53 |
| *4* | *33.20* | *51.60* | *44.10* | *17* | 68.81 | 69.38 |
| *5* | *33.40* | *38.80* | *37.90* | | 20.00 | |
| *6* | *33.00* | *39.20* | *38.20* | | 19.23 | |

Slope of flow line = 0.078

Liquid limit (%) = 67.37 Plastic limit (%) = 19.62

plasticity index = 47.75



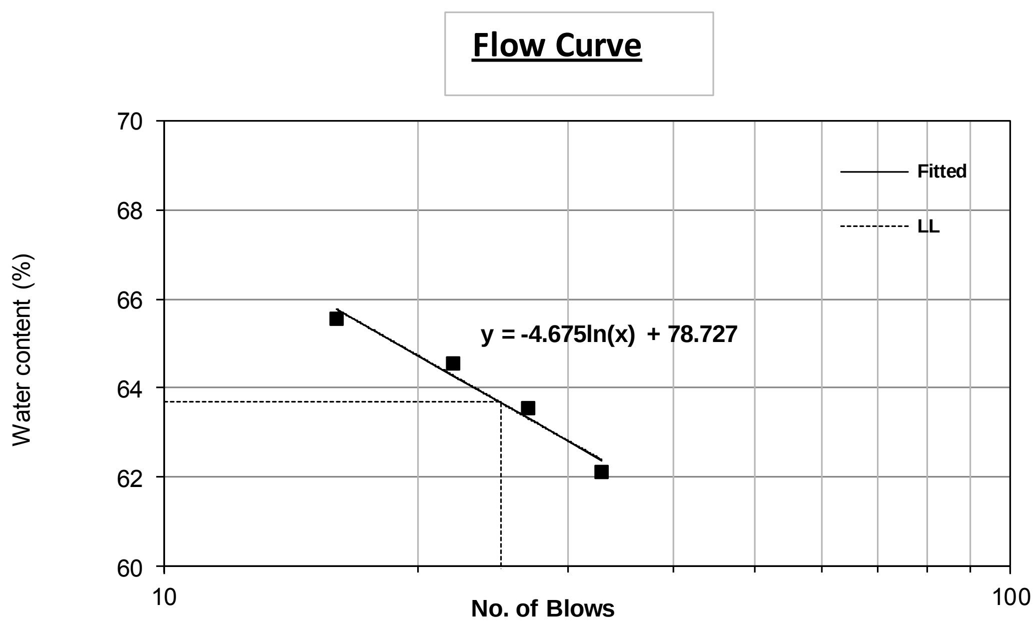
## Around tiya stele (2)1.5m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.20* | *48.60* | *42.70* | *33* | 62.11 | 62.38 |
| *2* | *33.80* | *49.50* | *43.40* | *27* | 63.54 | 63.32 |
| *3* | *32.70* | *50.80* | *43.70* | *22* | 64.55 | 64.28 |
| *4* | *33.30* | *48.20* | *42.30* | *16* | 65.56 | 65.77 |
| *5* | *32.90* | *39.30* | *37.70* | | 33.33 | |
| *6* | *29.50* | *40.60* | *37.90* | | 32.14 | |

Slope of flow line = 0.073

Liquid limit (%) = 63.68 Plastic limit (%) = 32.74

plasticity index = 30.94



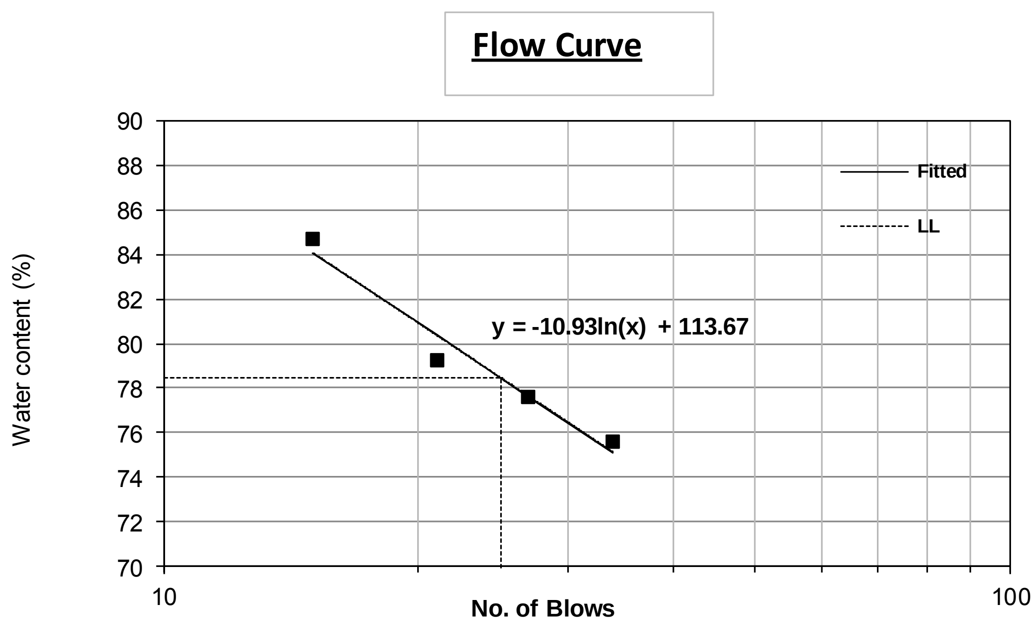
## Around tiya stele 3m(2)

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.50* | *48.60* | *42.10* | *34* | 75.58 | 75.12 |
| *2* | *33.20* | *46.70* | *40.80* | *27* | 77.63 | 77.64 |
| *3* | *32.90* | *47.60* | *41.10* | *21* | 79.27 | 80.38 |
| *4* | *33.50* | *46.80* | *40.70* | *15* | 84.72 | 84.06 |
| *5* | *32.70* | *39.40* | *37.60* | | 36.73 | |
| *6* | *33.60* | *39.80* | *38.10* | | 37.78 | |

Slope of flow line = 0.136

Liquid limit (%) = 78.48 Plastic limit (%) = 37.26

plasticity index = 41.22



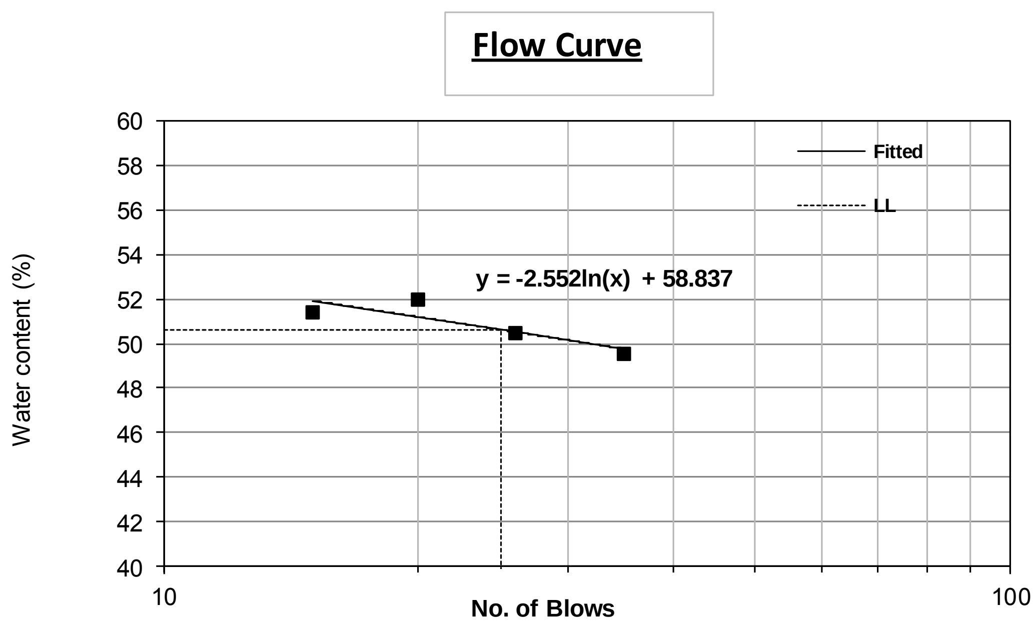
## Entrance to Amawete 1.5m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.60* | *49.30* | *44.10* | *35* | 49.52 | 49.76 |
| *2* | *32.80* | *48.30* | *43.10* | *26* | 50.49 | 50.52 |
| *3* | *33.40* | *48.90* | *43.60* | *20* | 51.96 | 51.19 |
| *4* | *32.60* | *48.50* | *43.10* | *15* | 51.43 | 51.92 |
| *5* | *33.40* | *41.90* | *40.10* | | 26.87 | |
| *6* | *33.30* | *42.50* | *40.60* | | 26.03 | |

Slope of flow line = 0.050

Liquid limit (%) = 50.62 Plastic limit (%) = 26.45

plasticity index = 24.17



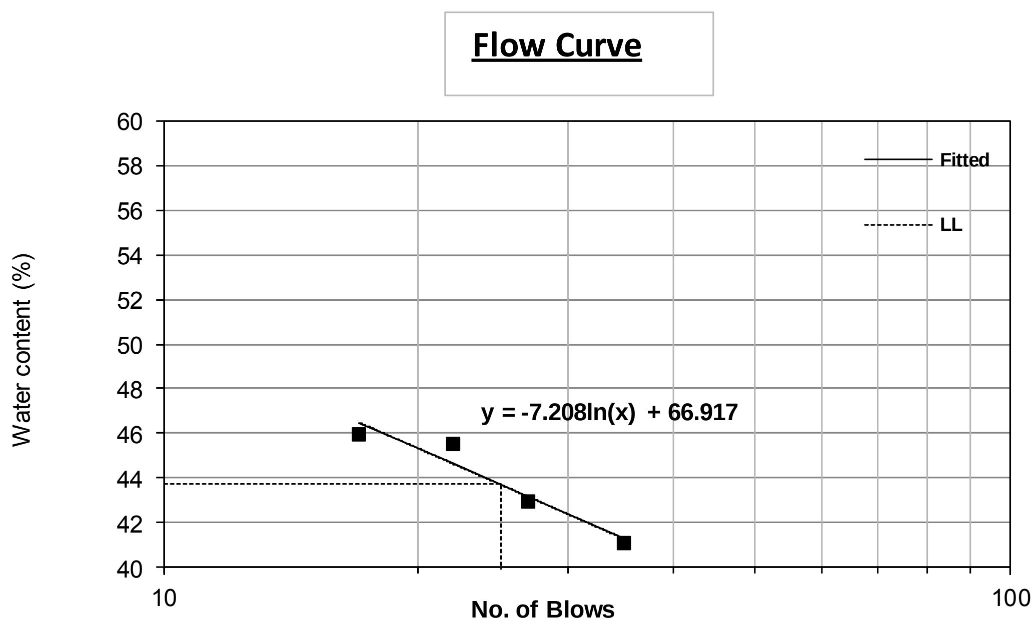
Entrance to Amawete 3m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 32.90 | 51.10 | 45.80 | 35 | 41.09 | 41.29 |
| 2 | 32.90 | 49.20 | 44.30 | 27 | 42.98 | 43.16 |
| 3 | 32.90 | 50.80 | 45.20 | 22 | 45.53 | 44.64 |
| 4 | 32.80 | 52.80 | 46.50 | 17 | 45.99 | 46.49 |
| 5 | 33.80 | 41.80 | 40.40 | | 21.21 | |
| 6 | 33.40 | 40.90 | 39.60 | | 20.97 | |

Slope of flow line = 0.165

Liquid limit (%) = 43.72 Plastic limit (%) = 21.09

plasticity index = 22.63



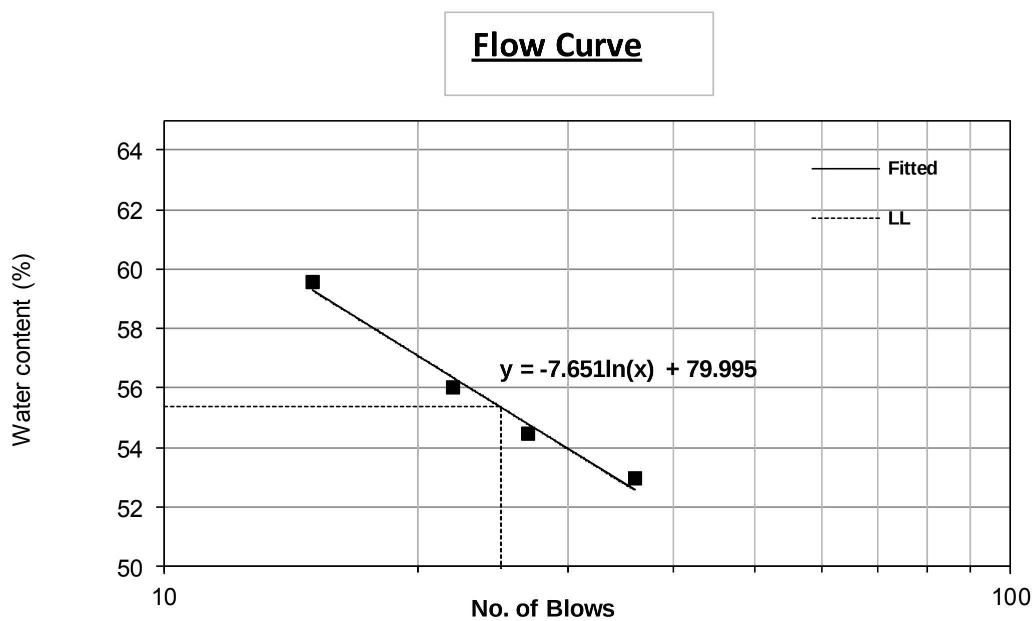
## Infront of tiya school 1.5m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 32.90 | 48.50 | 43.10 | 36 | 52.94 | 52.58 |
| 2 | 32.70 | 50.00 | 43.90 | 27 | 54.46 | 54.78 |
| 3 | 33.60 | 49.20 | 43.60 | 22 | 56.00 | 56.35 |
| 4 | 33.30 | 48.30 | 42.70 | 15 | 59.57 | 59.28 |
| 5 | 33.70 | 41.20 | 39.70 | | 25.00 | |
| 6 | 32.90 | 41.50 | 39.80 | | 24.64 | |

Slope of flow line = 0.136

Liquid limit (%) = 55.37 Plastic limit (%) = 24.82

plasticity index = 30.55



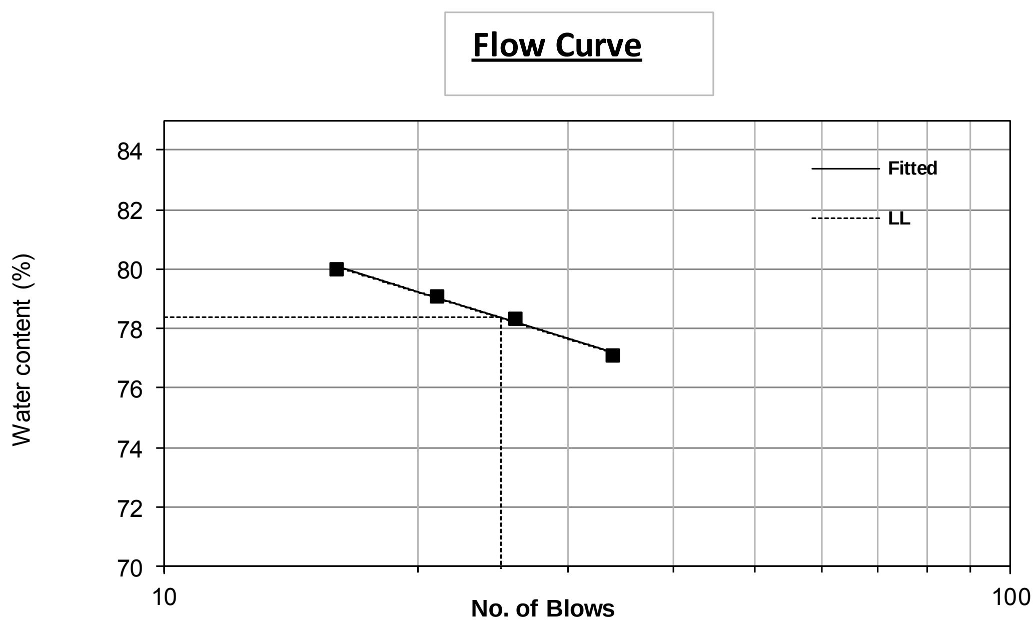
## Infront of tiya school 3m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.40 | 50.40 | 43.00 | 34 | 77.08 | 77.19 |
| 2 | 33.00 | 50.30 | 42.70 | 26 | 78.35 | 78.22 |
| 3 | 32.70 | 52.40 | 43.70 | 21 | 79.09 | 79.04 |
| 4 | 33.80 | 50.00 | 42.80 | 16 | 80.00 | 80.08 |
| 5 | 32.80 | 41.10 | 38.90 | | 36.07 | |
| 6 | 33.00 | 41.30 | 39.00 | | 38.33 | |

Slope of flow line = 0.049

Liquid limit (%) = 78.37 Plastic limit (%) = 37.20

plasticity index = 41.17



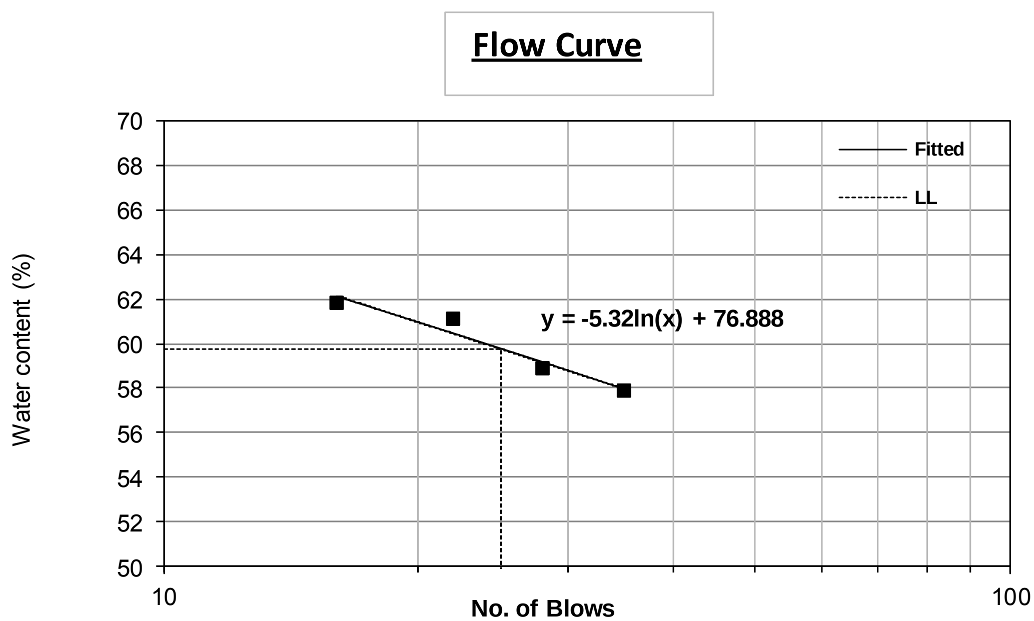
## Meserete Kirestos 1.5m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.30 | 48.30 | 42.80 | 35 | 57.89 | 57.97 |
| 2 | 33.10 | 47.40 | 42.10 | 28 | 58.89 | 59.16 |
| 3 | 32.80 | 41.50 | 38.20 | 22 | 61.11 | 60.44 |
| 4 | 32.50 | 41.40 | 38.00 | 16 | 61.82 | 62.14 |
| 5 | 33.70 | 39.10 | 37.90 | | 28.57 | |
| 6 | 33.60 | 40.10 | 38.70 | | 27.45 | |

Slope of flow line = 0.089

Liquid limit (%) = 59.76 Plastic limit (%) = 28.01

plasticity index = 31.75



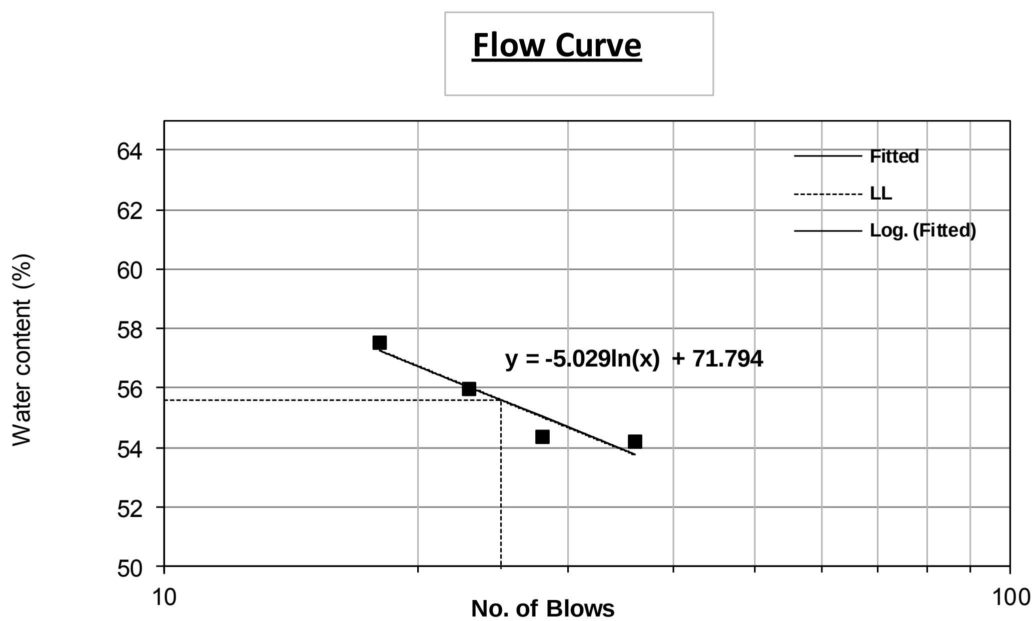
## Meserete Kirestos 3m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.30 | 55.20 | 47.50 | 36 | 54.23 | 53.77 |
| 2 | 32.60 | 55.60 | 47.50 | 28 | 54.36 | 55.04 |
| 3 | 33.70 | 54.60 | 47.10 | 23 | 55.97 | 56.03 |
| 4 | 33.60 | 61.80 | 51.50 | 18 | 57.54 | 57.26 |
| 5 | 33.00 | 44.90 | 42.30 | | 27.96 | |
| 6 | 33.50 | 44.40 | 42.10 | | 26.74 | |

Slope of flow line = 0.090

Liquid limit (%) = 55.61　　Plastic limit (%) = 27.35

plasticity index = 28.26



## Mariam Church 1.5m

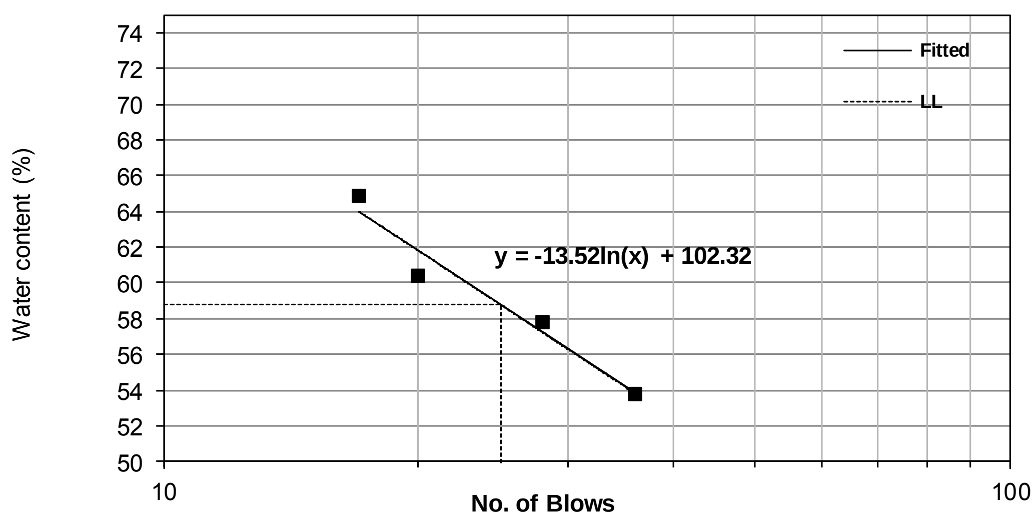
| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.40* | *45.70* | *41.40* | *36* | 53.75 | 53.85 |
| *2* | *33.10* | *49.20* | *43.30* | *28* | 57.84 | 57.25 |
| *3* | *33.00* | *47.60* | *42.10* | *20* | 60.44 | 61.80 |
| *4* | *33.80* | *52.10* | *44.90* | *17* | 64.86 | 64.00 |
| *5* | *33.70* | *40.10* | *39.10* | | 18.52 | |
| *6* | *33.60* | *39.40* | *38.50* | | 18.37 | |

Slope of flow line = 0.229

Liquid limit (%) = 58.78 Plastic limit (%) = 18.44

plasticity index = 40.34

**Flow Curve**



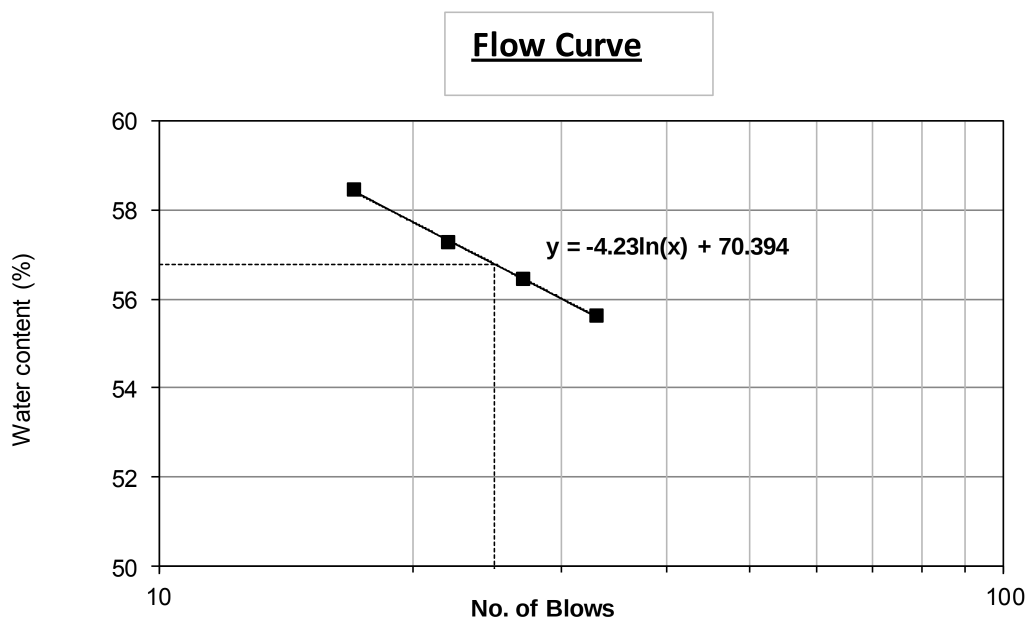
## Noc 1.5m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.00 | 60.70 | 50.80 | 33 | 55.62 | 55.60 |
| 2 | 32.90 | 55.90 | 47.60 | 27 | 56.46 | 56.45 |
| 3 | 33.40 | 52.90 | 45.80 | 22 | 57.26 | 57.32 |
| 4 | 33.40 | 57.80 | 48.80 | 17 | 58.44 | 58.41 |
| 5 | 32.70 | 43.40 | 41.60 | | 20.22 | |
| 6 | 33.70 | 42.50 | 41.00 | | 20.55 | |

Slope of flow line = 0.074

Liquid limit (%) = 56.78 Plastic limit (%) = 20.39

plasticity index = 36.39



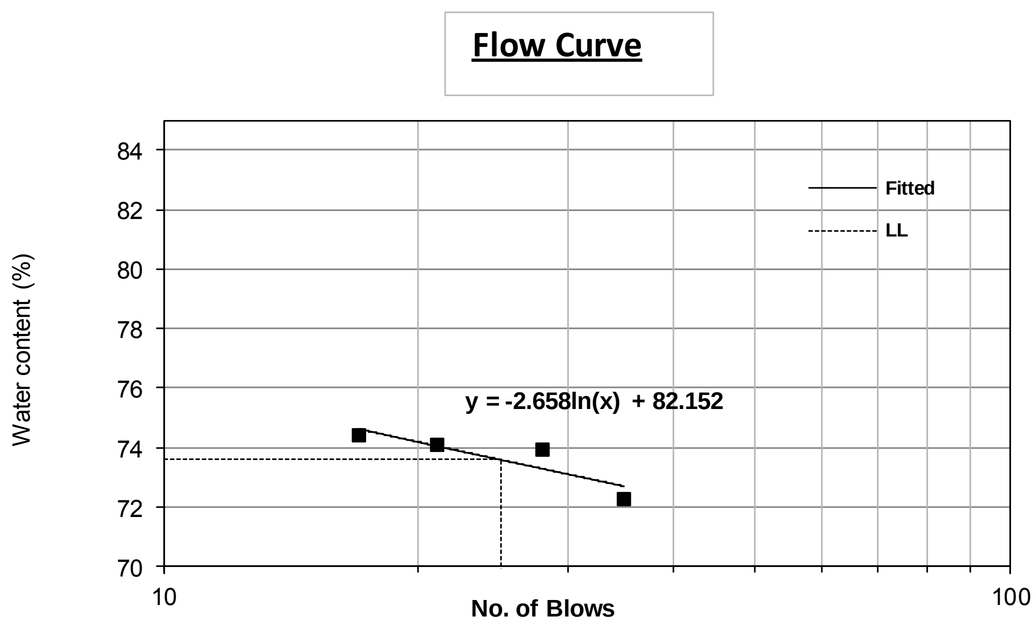
**Noc 3m**

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *32.80* | *53.30* | *44.70* | *35* | 72.27 | 72.70 |
| *2* | *33.70* | *53.70* | *45.20* | *28* | 73.91 | 73.29 |
| *3* | *33.80* | *57.30* | *47.30* | *21* | 74.07 | 74.06 |
| *4* | *32.80* | *55.30* | *45.70* | *17* | 74.42 | 74.62 |
| *5* | *32.80* | *42.90* | *40.50* | | 31.17 | |
| *6* | *32.80* | *41.40* | *39.40* | | 30.30 | |

Slope of flow line = 0.036

Liquid limit (%) = 73.60 Plastic limit (%) = 30.74

plasticity index = 42.86



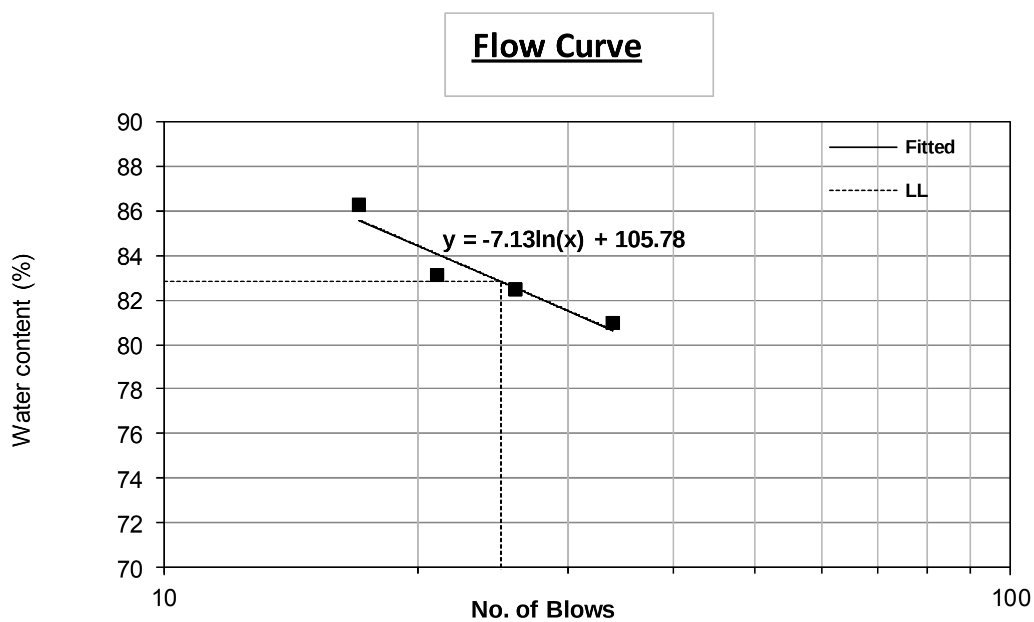
## Sutan Market 1.5m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.50 | 48.70 | 41.90 | 34 | 80.95 | 80.64 |
| 2 | 33.40 | 48.00 | 41.40 | 26 | 82.50 | 82.55 |
| 3 | 32.90 | 48.10 | 41.20 | 21 | 83.13 | 84.07 |
| 4 | 33.50 | 48.40 | 41.50 | 17 | 86.25 | 85.58 |
| 5 | 33.50 | 39.70 | 38.20 | | 31.91 | |
| 6 | 32.70 | 40.00 | 38.20 | | 32.73 | |

Slope of flow line = 0.085

Liquid limit (%) = 82.83 Plastic limit (%) = 32.32

plasticity index = 50.51



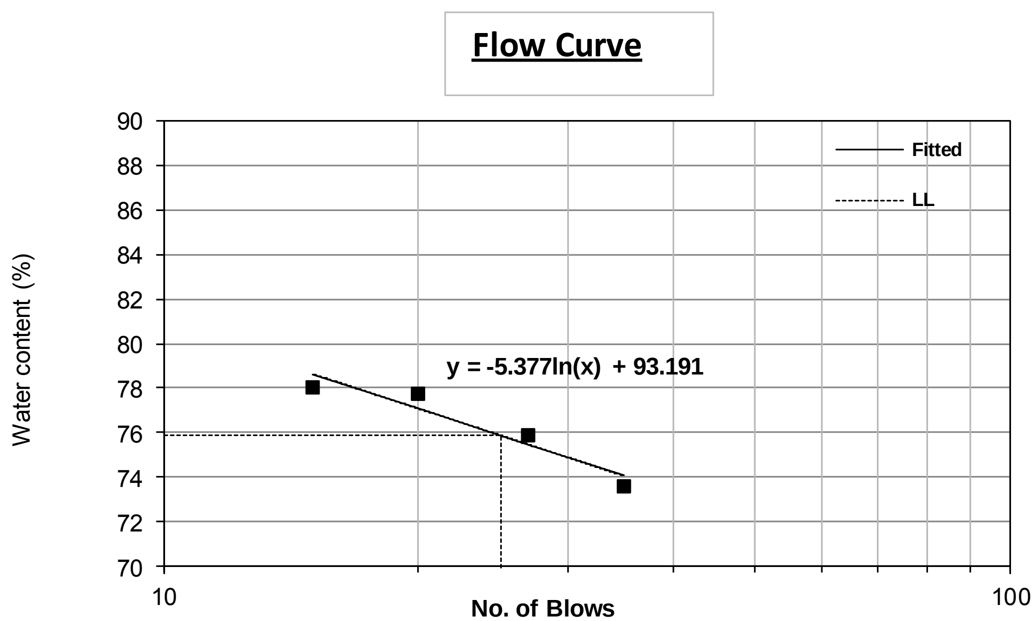
## Sutan Market 3m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.20 | 48.30 | 41.90 | 35 | 73.56 | 74.07 |
| 2 | 33.30 | 48.60 | 42.00 | 27 | 75.86 | 75.47 |
| 3 | 33.00 | 47.40 | 41.10 | 20 | 77.78 | 77.08 |
| 4 | 32.90 | 47.50 | 41.10 | 15 | 78.05 | 78.63 |
| 5 | 33.70 | 41.30 | 39.40 | | 33.33 | |
| 6 | 34.00 | 41.50 | 39.60 | | 33.93 | |

Slope of flow line = 0.071

Liquid limit (%) = 75.88  Plastic limit (%) = 33.63

plasticity index = 42.25



## Tiya market 0.7m

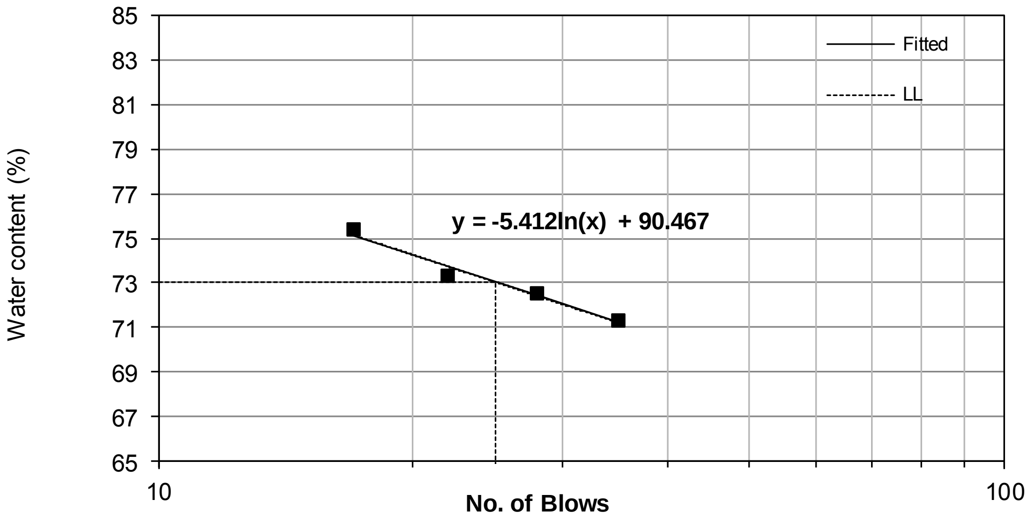
| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.10 | 56.40 | 46.70 | 35 | 71.32 | 71.23 |
| 2 | 33.10 | 53.80 | 45.10 | 28 | 72.50 | 72.43 |
| 3 | 33.50 | 54.30 | 45.50 | 22 | 73.33 | 73.74 |
| 4 | 33.00 | 56.50 | 46.40 | 17 | 75.37 | 75.13 |
| 5 | 33.40 | 44.50 | 41.90 | | 30.59 | |
| 6 | 33.40 | 45.90 | 42.90 | | 31.58 | |

Slope of flow line = 0.074

Liquid limit (%) = 73.05 Plastic limit (%) = 31.08

plasticity index = 41.96

**Flow Curve**



## Tiya market 1.6m

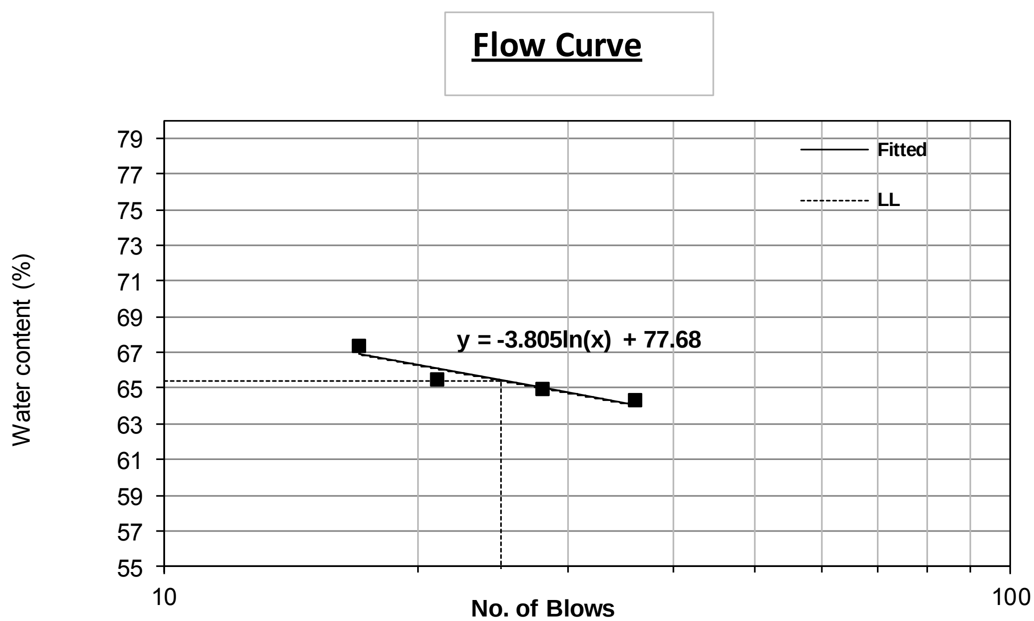
| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.40 | 42.60 | 39.00 | 36 | 64.29 | 64.05 |
| 2 | 33.50 | 42.90 | 39.20 | 28 | 64.91 | 65.00 |
| 3 | 33.60 | 42.70 | 39.10 | 21 | 65.45 | 66.10 |
| 4 | 33.50 | 41.20 | 38.10 | 17 | 67.39 | 66.90 |
| 5 | 33.60 | 41.50 | 39.80 | | 27.42 | |
| 6 | 33.70 | 41.30 | 39.70 | | 26.67 | |

Slope of flow line = 0.058

Liquid limit (%) = 65.43

Plastic limit (%) = 27.04

plasticity index = 38.39



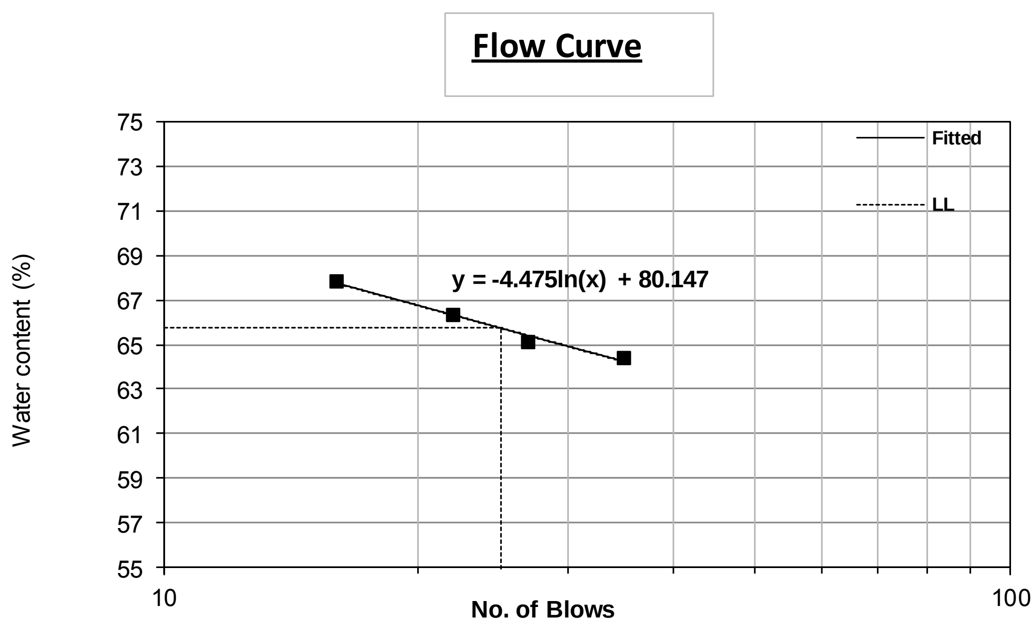
## World Vision 1.5

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| 1 | 33.70 | 50.80 | 44.10 | 35 | 64.42 | 64.24 |
| 2 | 33.30 | 50.80 | 43.90 | 27 | 65.09 | 65.40 |
| 3 | 32.70 | 50.50 | 43.40 | 22 | 66.36 | 66.31 |
| 4 | 33.60 | 48.20 | 42.30 | 16 | 67.82 | 67.74 |
| 5 | 33.30 | 41.30 | 39.80 | | 23.08 | |
| 6 | 33.20 | 40.70 | 39.30 | | 22.95 | |

Slope of flow line = 0.068

Liquid limit (%) = 65.74    Plastic limit (%) = 23.01

plasticity index = 42.73



## World Vision 3m

| Set number | Tare mass (g) Wc | Tare with wet soil (g) Ww | Tare with dry soil (g) Wd | Blow count N | Water content (%) w | Water content fitted (%) |
|---|---|---|---|---|---|---|
| *1* | *33.20* | *51.20* | *45.60* | *34* | 45.16 | 45.38 |
| *2* | *33.30* | *49.00* | *44.00* | *27* | 46.73 | 46.63 |
| *3* | *33.20* | *51.30* | *45.40* | *21* | 48.36 | 47.99 |
| *4* | *33.40* | *50.60* | *44.90* | *15* | 49.57 | 49.81 |
| *5* | *33.50* | *41.00* | *39.30* | | 29.31 | |
| *6* | *33.60* | *40.60* | *39.00* | | 29.63 | |

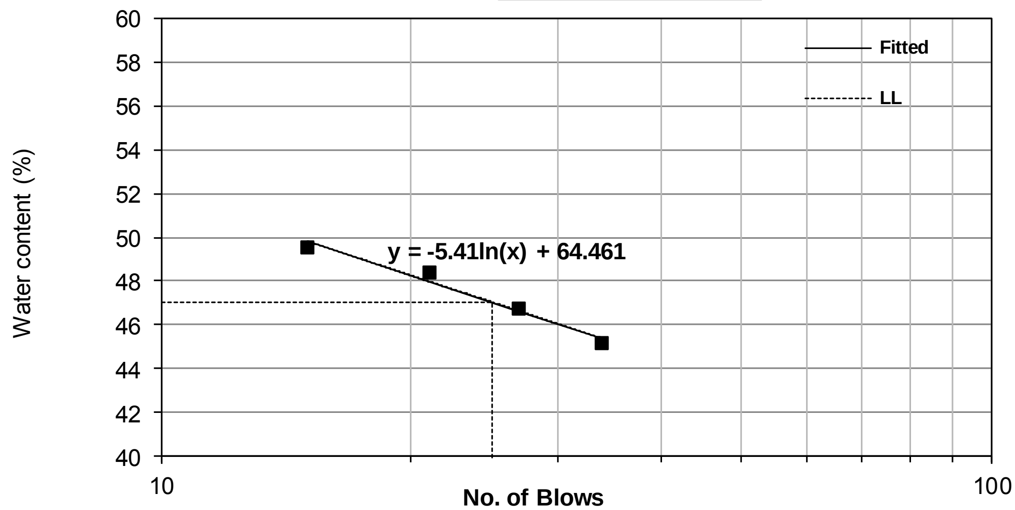
Slope of flow line = 0.114

Liquid limit (%) = 47.05

Plastic limit (%) = 29.47

plasticity index = 17.58

**Flow Curve**



# Appendix C

**Location:** **Infront of Tiya School**

**Test Pit No** **3**

**Depth, m** **3.00**

**[A] In the beginning of the test**

Sample type : Undisturbed

Ring Area,$cm^2$: 19.63

Height of sample, mm: 20

Seating Load,kPa 7

Initial Void Ratio, $e_o$: 0.27

Initial moisture content,% 50.07

Specific Gravity: 2.59

Wet density,$g/cm^3$ 3.09

**[B] In the end of the test**

Final Moisture Content,% 40.06

Dry specimen wt. ($m_s$), gm: 86.62

Dry density,$g/cm^3$ 2.56

Height of Solids($H_s$), mm 17.04

Final Void Ratio, $e_f$: 0.08

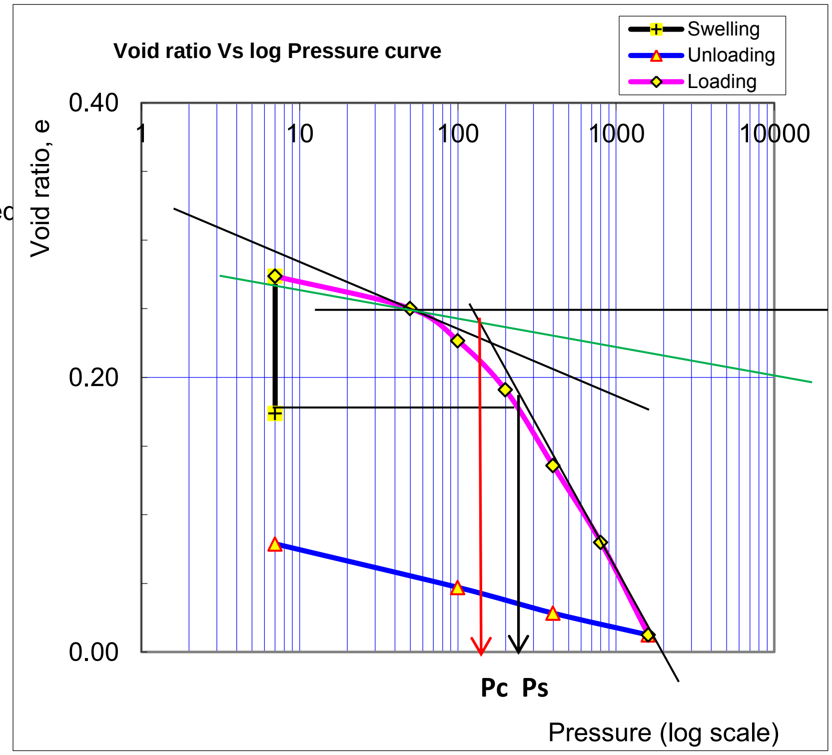



Fig 4.10 e vs log p

## [C]Calculation table:

Table:4.10

| Applied pressure P (kPa) | Final Dial Reading (mm) | Change In Specimen Height (mm) | Final Specimen Height (mm) | Void Height,$H_v$ (mm) | Void Ratio, E |
|---|---|---|---|---|---|
| **Loading** | | | | | |
| 7 | 5.000 | 0.00 | 20.00 | 2.96 | 0.17 |
| 7 | 6.700 | 1.70 | 21.70 | 4.66 | 0.27 |
| 50 | 6.300 | 1.30 | 21.30 | 4.26 | 0.25 |
| 100 | 5.900 | 0.90 | 20.90 | 3.86 | 0.23 |
| 200 | 5.290 | 0.29 | 20.29 | 3.25 | 0.19 |
| 400 | 4.350 | -0.65 | 19.35 | 2.31 | 0.14 |
| 800 | 3.400 | -1.60 | 18.40 | 1.36 | 0.08 |
| 1600 | 2.250 | -2.75 | 17.25 | 0.21 | 0.01 |
| **Unloading** | | | | | |
| 1600 | 2.250 | -2.75 | 17.25 | 0.21 | 0.01 |
| 400 | 2.520 | -2.48 | 17.52 | 0.48 | 0.03 |
| 100 | 2.840 | -2.16 | 17.84 | 0.80 | 0.05 |
| 7 | 3.380 | -1.62 | 18.38 | 1.34 | 0.08 |

| | |
|---|---|
| Measured swelling pressure (kPa) | 250.00 |
| Preconsolidation Pressure (kPa) | 150.00 |
| Compression Index, Cc | 0.224 |

| | |
|---|---|
| Location | World Vision |
| Test Pit No | TP-8 |
| Depth, m | 3.00 |

**[A] In the beginning of the test**

| | |
|---|---|
| Sample type : | Undisturbed |
| Ring Area,$cm^2$: | 19.63 |
| Height of sample, mm: | 20 |
| Seating Load,kPa | 7 |
| Initial Void Ratio, $e_o$: | 1.06 |
| Initial moisture content,% | 44.68 |
| Specific Gravity: | 2.49 |
| Wet density,$g/cm^3$ | 1.66 |

**[B] In the end of the test**

| | |
|---|---|
| Final Moisture Content,% | 46.70 |
| Dry specimen wt. ($M_S$), gm. | 45.4 |
| Dry density,$g/cm^3$ | 1.34 |
| Height of Solids($H_s$), mm | 9.29 |
| Final Void Ratio, $e_f$: | 0.89 |

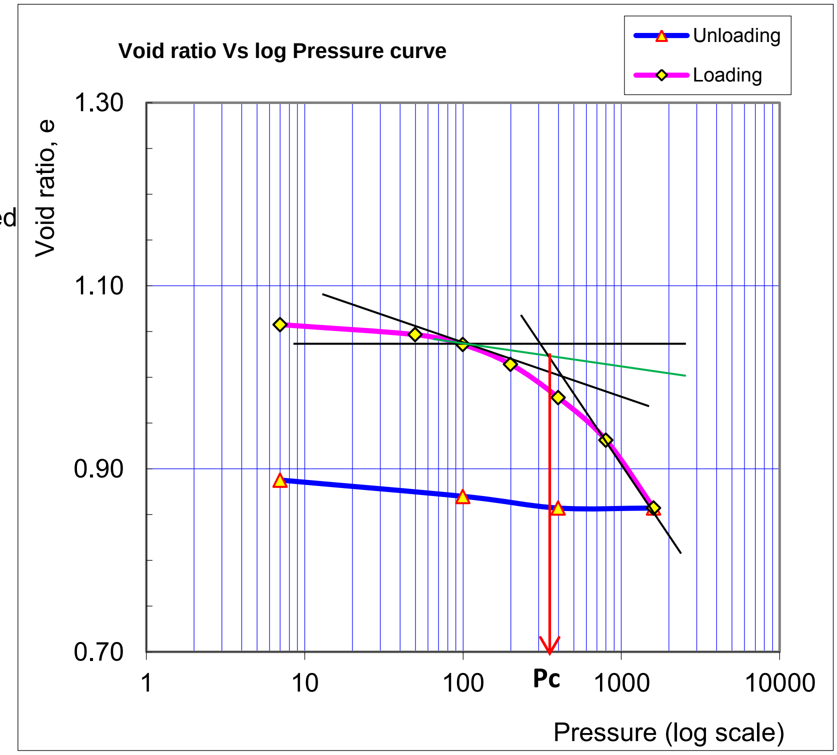



Fig 4.11 e vs log p

## [C]Calculation table:

Table: 4.11

| Applied pressure P (kPa) | Final Dial Reading (mm) | Change In Specimen Height (mm) | Final Specimen Height (mm) | Void Height,$H_v$ (mm) | Void Ratio, E |
|---|---|---|---|---|---|
| **Loading** | | | | | |
| 7 | 14.800 | 0.00 | 20.00 | 10.71 | 1.15 |
| 7 | 13.911 | -0.89 | 19.11 | 9.82 | 1.06 |
| 50 | 13.809 | -0.99 | 19.01 | 9.72 | 1.05 |
| 100 | 13.708 | -1.09 | 18.91 | 9.62 | 1.04 |
| 200 | 13.508 | -1.29 | 18.71 | 9.42 | 1.01 |
| 400 | 13.171 | -1.63 | 18.37 | 9.08 | 0.98 |
| 800 | 12.739 | -2.06 | 17.94 | 8.65 | 0.93 |
| 1600 | 12.050 | -2.75 | 17.25 | 7.96 | 0.86 |
| **Unloading** | | | | | |
| 1600 | 12.050 | -2.75 | 17.25 | 7.96 | 0.86 |
| 400 | 12.050 | -2.75 | 17.25 | 7.96 | 0.86 |
| 100 | 12.169 | -2.63 | 17.37 | 8.08 | 0.87 |
| 7 | 12.334 | -2.47 | 17.53 | 8.25 | 0.89 |

| | |
|---|---|
| Preconsolidation Pressure (kPa) | 350.00 |
| Compression Index, Cc | 0.246 |

| | |
|---|---|
| Location | Entrance to Amawete |
| Test Pit No | TP-7 |
| Depth, m | 3.00 |

**[A] In the beginning of the test**

| | |
|---|---|
| Sample type : | Undisturbed |
| Ring Area,$cm^2$: | 19.63 |
| Height of sample, mm: | 20 |
| Seating Load,kPa | 7 |
| Initial Void Ratio, $e_o$: | 1.09 |
| Initial moisture content,% | 42.78 |
| Specific Gravity: | 2.53 |
| Wet density,$g/cm^3$ | 1.70 |

**[B] In the end of the test**

| | |
|---|---|
| Final Moisture Content,% | 44.87 |
| Dry specimen wt. ($M_S$), gm.: | 46.8 |
| Dry density,$g/cm^3$ | 1.31 |
| Height of Solids($H_s$), mm | 9.42 |
| Final Void Ratio, $e_f$: | 0.96 |

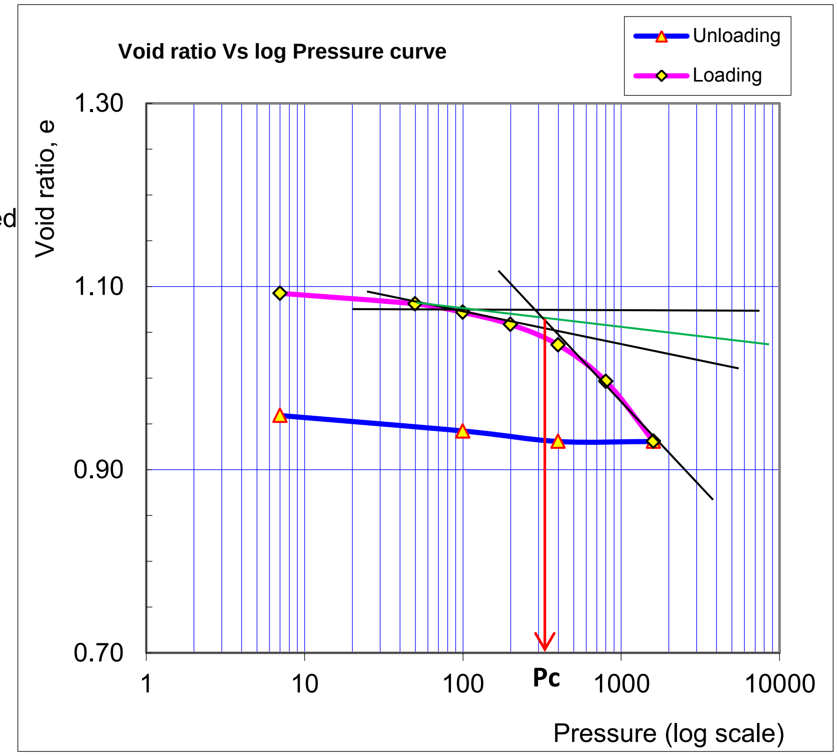



Fig 4.12 e vs log p

## [C]Calculation table:

Table 4.12

| Applied pressure P (kPa) | Final Dial Reading (mm) | Change In Specimen Height (mm) | Final Specimen Height (mm) | Void Height,$H_v$ (mm) | Void Ratio, E |
|---|---|---|---|---|---|
| **Loading** | | | | | |
| 7 | 14.870 | 0.00 | 20.00 | 10.58 | 1.12 |
| 7 | 14.589 | -0.28 | 19.72 | 10.30 | 1.09 |
| 50 | 14.480 | -0.39 | 19.61 | 10.19 | 1.08 |
| 100 | 14.392 | -0.48 | 19.52 | 10.10 | 1.07 |
| 200 | 14.268 | -0.60 | 19.40 | 9.97 | 1.06 |
| 400 | 14.058 | -0.81 | 19.19 | 9.76 | 1.04 |
| 800 | 13.683 | -1.19 | 18.81 | 9.39 | 1.00 |
| 1600 | 13.065 | -1.81 | 18.20 | 8.77 | 0.93 |
| **Unloading** | | | | | |
| 1600 | 13.065 | -1.81 | 18.20 | 8.77 | 0.93 |
| 400 | 13.065 | -1.81 | 18.20 | 8.77 | 0.93 |
| 100 | 13.173 | -1.70 | 18.30 | 8.88 | 0.94 |
| 7 | 13.332 | -1.54 | 18.46 | 9.04 | 0.96 |

| | |
|---|---|
| Preconsolidation Pressure (kPa) | 330.00 |
| Compression Index, Cc | 0.218 |

## Appendix D

### Determination of natural moisture content

**Location**: Tiya Market

**Depth**: 0.7m

| Determination No. | 1 | 2 |
|---|---|---|
| Container No. | 115 | 121 |
| Mass of container, gm | 33.60 | 32.90 |
| Mass of container +wet soil, gm | 77.20 | 81.50 |
| Mass of container +dry soil, gm | 67.50 | 70.60 |
| Mass of water, gm | 9.70 | 10.90 |
| Mass of dry soil, gm | 33.90 | 37.70 |
| Water content, % | 28.61 | 28.91 |
| Average water content, % | 28.76 | |

**Depth :** 1.6m

| Determination No. | 1 | 2 |
|---|---|---|
| Container No. | 127 | 101 |
| Mass of container, gm | 33.20 | 33.40 |
| Mass of container +wet soil, gm | 82.70 | 59.60 |
| Mass of container +dry soil, gm | 72.00 | 53.80 |
| Mass of water, gm | 10.70 | 5.80 |
| Mass of dry soil, gm | 38.80 | 20.40 |
| Water content, % | 27.58 | 28.43 |
| Average water content, % | 28.00 | |

**Location**: (2)Around Tiya Stele

**Depth :1.5m**

| Determination No. | 1 | 2 |
|---|---|---|
| Container No. | 37 | 77 |
| Mass of container, gm | 33.70 | 34.00 |
| Mass of container +wet soil, gm | 83.10 | 55.20 |
| Mass of container +dry soil, gm | 67.70 | 48.60 |
| Mass of water, gm | 15.40 | 6.60 |
| Mass of dry soil, gm | 34.00 | 14.60 |
| Water content, % | 45.29 | 45.21 |
| Average water content, % | 45.25 | |

**Depth :3.0m**

| Determination No. | 1 | 2 |
|---|---|---|
| Container No. | 128 | 130 |
| Mass of container, gm | 32.90 | 33.30 |
| Mass of container +wet soil, gm | 71.20 | 40.80 |
| Mass of container +dry soil, gm | 60.30 | 38.70 |
| Mass of water, gm | 10.90 | 2.10 |
| Mass of dry soil, gm | 27.40 | 5.40 |
| Water content, % | 39.78 | 38.89 |
| Average water content, % | 39.33 | |

| Depth :1.5m | | |
|---|---|---|
| Loction | Infront of Tiya School | |
| Determination No. | 1 | 2 |
| Container No. | 97 | 76 |
| Mass of container, gm | 33.10 | 32.70 |
| Mass of container +wet soil, gm | 82.80 | 54.60 |
| Mass of container +dry soil, gm | 73.20 | 50.30 |
| Mass of water, gm | 9.60 | 4.30 |
| Mass of dry soil, gm | 40.10 | 17.60 |
| Water content, % | 23.94 | 24.43 |
| Average water content, % | 24.19 | |

| Depth :3.0m | | |
|---|---|---|
| Determination No. | 1 | 2 |
| Container No. | 161 | 81 |
| Mass of container, gm | 33.10 | 33.20 |
| Mass of container +wet soil, gm | 73.90 | 61.00 |
| Mass of container +dry soil, gm | 63.90 | 54.10 |
| Mass of water, gm | 10.00 | 6.90 |
| Mass of dry soil, gm | 30.80 | 20.90 |
| Water content, % | 32.47 | 33.01 |
| Average water content, % | 32.74 | |

| Location | Meserete Kirestos | |
|---|---|---|
| Depth | 1.5m | |
| Determination No. | 1 | 2 |
| Container No. | 141 | 91 |
| Mass of container, gm | 33.40 | 33.20 |
| Mass of container +wet soil, gm | 71.60 | 76.30 |
| Mass of container +dry soil, gm | 63.50 | 67.40 |
| Mass of water, gm | 8.10 | 8.90 |
| Mass of dry soil, gm | 30.10 | 34.20 |
| Water content, % | 26.91 | 26.02 |
| Average water content, % | 26.47 | |

| Depth :3.0m | | |
|---|---|---|
| Determination No. | 1 | 2 |
| Container No. | 179 | 117 |
| Mass of container, gm | 33.20 | 33.40 |
| Mass of container +wet soil, gm | 80.60 | 58.20 |
| Mass of container +dry soil, gm | 66.00 | 50.60 |
| Mass of water, gm | 14.60 | 7.60 |
| Mass of dry soil, gm | 32.80 | 17.20 |
| Water content, % | 44.51 | 44.19 |
| Average water content, % | 44.35 | |

| Location | NOC | |
|---|---|---|
| Depth | 1.5m | |
| Determination No. | 1 | 2 |
| Container No. | 194 | 167 |
| Mass of container, gm | 33.40 | 32.60 |
| Mass of container +wet soil, gm | 82.10 | 59.30 |
| Mass of container +dry soil, gm | 70.70 | 53.10 |
| Mass of water, gm | 11.40 | 6.20 |
| Mass of dry soil, gm | 37.30 | 20.50 |
| Water content, % | 30.56 | 30.24 |
| Average water content, % | 30.40 | |

| Depth :3.0m | | |
|---|---|---|
| Determination No. | 1 | 2 |
| Container No. | 180 | 140 |
| Mass of container, gm | 32.90 | 33.00 |
| Mass of container +wet soil, gm | 68.00 | 75.80 |
| Mass of container +dry soil, gm | 59.20 | 65.20 |
| Mass of water, gm | 8.80 | 10.60 |
| Mass of dry soil, gm | 26.30 | 32.20 |
| Water content, % | 33.46 | 32.92 |
| Average water content, % | 33.19 | |

| Depth :1.5m | | |
|---|---|---|
| Location | Around Tiya Stele (1) | |
| Determination No. | 1 | 2 |
| Container No. | 124 | 161 |
| Mass of container, gm | 32.8 | 33.1 |
| Mass of container +wet soil, gm | 74.8 | 71.2 |
| Mass of container +dry soil, gm | 63.2 | 60.5 |
| Mass of water, gm | 11.6 | 10.7 |
| Mass of dry soil, gm | 30.4 | 27.4 |
| Water content, % | 38.16 | 39.05 |
| Average water content, % | 38.60 | |

| Depth :3.0m | | |
|---|---|---|
| Determination No. | 1 | 2 |
| Container No. | 180 | 149 |
| Mass of container, gm | 32.90 | 33.2 |
| Mass of container +wet soil, gm | 65.60 | 61.00 |
| Mass of container +dry soil, gm | 57.00 | 53.60 |
| Mass of water, gm | 8.60 | 7.40 |
| Mass of dry soil, gm | 24.10 | 20.40 |
| Water content, % | 35.68 | 36.27 |
| Average water content, % | 35.98 | |

| **Location** | Entrance to Amawete | | | | |
|---|---|---|---|---|---|
| **Depth** | 1.5m | | **Depth :3.0m** | | |
| Determination No. | 1 | 2 | Determination No. | 1 | 2 |
| Container No. | 154 | 183 | Container No. | 128 | 37 |
| Mass of container, gm | 33.5 | 32.9 | Mass of container, gm | 32.90 | 33.70 |
| Mass of container +wet soil, gm | 70.7 | 69.3 | Mass of container +wet soil, gm | 75.00 | 78.20 |
| Mass of container +dry soil, gm | 58.7 | 57.6 | Mass of container +dry soil, gm | 63.50 | 66.20 |
| Mass of water, gm | 12 | 11.7 | Mass of water, gm | 11.50 | 12.00 |
| Mass of dry soil, gm | 25.2 | 24.7 | Mass of dry soil, gm | 30.60 | 32.50 |
| Water content, % | 47.62 | 47.37 | Water content, % | 37.58 | 36.92 |
| Average water content, % | 47.49 | | Average water content, % | 37.25 | |

| **Location** | World vision | | | | |
|---|---|---|---|---|---|
| **Depth** | 1.5m | | **Depth :3.0m** | | |
| Determination No. | 1 | 2 | Determination No. | 1 | 2 |
| Container No. | 94 | 104 | Container No. | 195 | 185 |
| Mass of container, gm | 33.60 | 32.80 | Mass of container, gm | 33.20 | 33.70 |
| Mass of container +wet soil, gm | 59.50 | 67.20 | Mass of container +wet soil, gm | 54.70 | 65.70 |
| Mass of container +dry soil, gm | 53.70 | 59.60 | Mass of container +dry soil, gm | 47.60 | 55.20 |
| Mass of water, gm | 5.80 | 7.60 | Mass of water, gm | 7.10 | 10.50 |
| Mass of dry soil, gm | 20.10 | 26.80 | Mass of dry soil, gm | 14.40 | 21.50 |
| Water content, % | 28.86 | 28.36 | Water content, % | 49.31 | 48.84 |
| Average water content, % | 28.61 | | Average water content, % | 49.07 | |

| | | | | | |
|---|---|---|---|---|---|
| ***Location*** | Sutan Market | | | | |
| ***Depth*** | 1.5m | | ***Depth :3.0m*** | | |
| Determination No. | 1 | 2 | Determination No. | 1 | 2 |
| Container No. | 85 | 115 | Container No. | 157 | 179 |
| Mass of container, gm | 33.3 | 33.6 | Mass of container, gm | 33.5 | 33.2 |
| Mass of container +wet soil, gm | 67.60 | 69.70 | Mass of container +wet soil, gm | 88.10 | 75.30 |
| Mass of container +dry soil, gm | 59.10 | 60.80 | Mass of container +dry soil, gm | 73.30 | 63.80 |
| Mass of water, gm | 8.50 | 8.90 | Mass of water, gm | 14.80 | 11.50 |
| Mass of dry soil, gm | 25.80 | 27.20 | Mass of dry soil, gm | 39.80 | 30.60 |
| Water content, % | 32.95 | 32.72 | Water content, % | 37.19 | 37.58 |
| Average water content, % | 32.83 | | Average water content, % | 37.38 | |

| | | |
|---|---|---|
| ***Location*** | **Mariam Church** | |
| ***Depth*** | **1.5m** | |
| Determination No. | 1 | 2 |
| Container No. | 152 | 127 |
| Mass of container, gm | 32.90 | 33.20 |
| Mass of container +wet soil, gm | 66.70 | 72.30 |
| Mass of container +dry soil, gm | 59.40 | 64.00 |
| Mass of water, gm | 7.30 | 8.30 |
| Mass of dry soil, gm | 26.50 | 30.80 |
| Water content, % | 27.55 | 26.95 |
| Average water content, % | 27.25 | |

**Appendix E**

## Free swell test results

**Location** **Around Tiya Market** **Depth** **0.7m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 19.5 | 19 | 19.25 | 92.5 |

**Location** **Around Tiya Market** **Depth** **1.6m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 18 | 18.5 | 18.25 | 82.5 |

**Location** **(2)Around tiya stele** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 19.5 | 20 | 19.75 | 97.5 |

**Location** **(2)Around Tiya stele** **Depth** **3m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 20 | 20.5 | 20.25 | 102.5 |

**Location** **Infront of Tiya School** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 15 | 15.5 | 15.25 | 52.5 |

**Location** **Infront of Tiya School** **Depth** **3.0m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 19 | 20 | 19.5 | 95 |

**Location** **Meserete Kiristos Church** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 16.9 | 17 | 16.95 | 69.5 |

**Location** **Meserete Kirsitos Church** **Depth** **3m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 16 | 16 | 16 | 60 |

**Location** **NOC** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 16 | 15 | 15.5 | 55 |

**Location** **NOC** **Depth** **3m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 19 | 18.5 | 18.75 | 87.5 |

**Location** **(1)Around Tiya stele** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 16 | 18 | 17 | 70 |

**Location** **(1)Around Tiya stele** **Depth** **3.0m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 19 | 21 | 20 | 100 |

**Location** **Entrance to Amawete** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 17 | 16.5 | 16.75 | 67.5 |

**Location** **Entrance to Amawete** **Depth** **3.0m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 13.3 | 13.5 | 13.4 | 34 |

**Location** **World Vision** **Depth** **1.50m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 18.5 | 19 | 18.75 | 87.5 |

**Location** **World Vision** **Depth** **3.0m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 15.1 | 14 | 14.55 | 45.5 |

**Location** **Sutan Market** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 19 | 18.9 | 18.95 | 89.5 |

**Location** **Sutan Market** **Depth** **3.0m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 18.9 | 18.5 | 18.7 | 87 |

**Location** **St.Mariam Church** **Depth** **1.5m**

| Initial volume(cc) | Final volume | | Average volume(cc) | Free swell (%) |
|---|---|---|---|---|
| | Sample 1(cc) | Sample 2 (cc) | | |
| 10 | 18.5 | 18 | 18.25 | 82.5 |

# Appendix F

## Grain size analysis results

**Location** **Around Tiya market**

**Depth** **0.7m**

### Grain Size Analysis(At 0.7m)

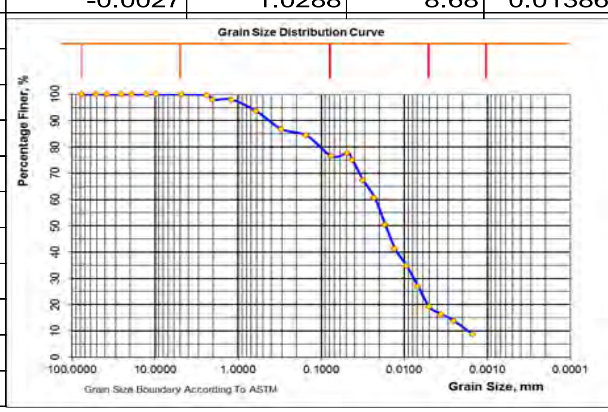
Total mass of sample, gm **500**

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 1.4 | 0.3 | 0.3 | 99.7 |
| No 10 | 2 | 1.1 | 0.22 | 0.5 | 99.5 |
| No 20 | 0.85 | 8.4 | 1.7 | 2.2 | 97.8 |
| No 40 | 0.425 | 13.0 | 2.6 | 4.8 | 95.2 |
| No 60 | 0.25 | 9.9 | 2.0 | 6.8 | 93.2 |
| No 100 | 0.15 | 8.1 | 1.6 | 8.4 | 91.6 |
| No 200 | 0.075 | 9.2 | 1.8 | 10.2 | 89.8 |
| pan | ------- | 448.9 | 89.8 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.59 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0315 | -0.0027 | 1.0288 | 8.68 | 0.01386 | 0.0472 | 93.83 | 84.24 |
| 1 | 1.0310 | | | | | 0.0411 | 92.20 | 82.77 |
| 2 | 1.0305 | | | | | 0.0293 | 90.57 | 81.31 |
| 4 | 1.0300 | | | | | 0.0209 | 88.94 | 79.85 |
| 8 | 1.0285 | | | | | 0.0151 | 84.05 | 75.46 |
| 15 | 1.0260 | | | | | 0.0114 | 75.91 | 68.15 |
| 30 | 1.0240 | | | | | 0.0083 | 69.39 | 62.30 |
| 60 | 1.0220 | | | | | 0.0060 | 62.88 | 56.45 |
| 120 | 1.0210 | | | | | 0.0043 | 59.62 | 53.53 |
| 240 | 1.0205 | | | | | 0.0030 | 57.99 | 52.06 |
| 480 | 1.0180 | | | | | 0.0022 | 49.85 | 44.75 |
| 1440 | 1.0162 | | | | | 0.0013 | 43.98 | 39.49 |



| | |
|---|---|
| Location | Around Tiya Market |
| Depth | 1.6m |

## Grain Size Analysis(At 1.6m)

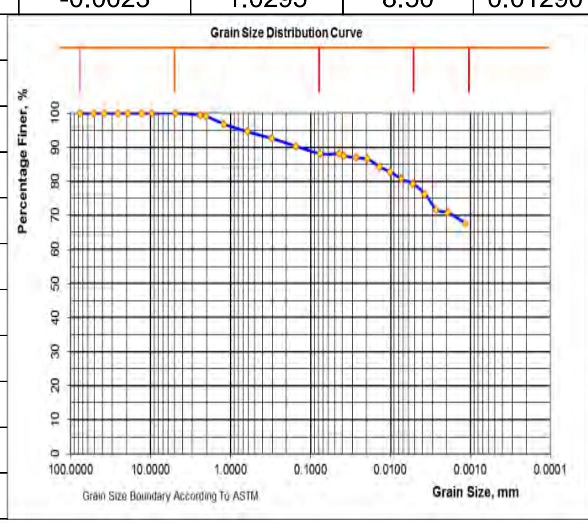
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 2.9 | 0.6 | 0.6 | 99.4 |
| No 10 | 2 | 1.7 | 0.3 | 0.9 | 99.1 |
| No 20 | 0.85 | 11.7 | 2.3 | 3.3 | 96.7 |
| No 40 | 0.425 | 11.4 | 2.3 | 5.5 | 94.5 |
| No 60 | 0.25 | 9.6 | 1.9 | 7.5 | 92.5 |
| No 100 | 0.15 | 11.5 | 2.3 | 9.8 | 90.2 |
| No 200 | 0.075 | 10.7 | 2.1 | 11.9 | 88.1 |
| pan | ------- | 440.5 | 88.1 | 100 | 0 |

Hydrometer Analysis

Gravity of soil = 2.44 Test Temperature, deg.c 22

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0318 | -0.0023 | 1.0295 | 8.50 | 0.01290 | 0.0434 | 99.97 | 88.08 |
| 1 | 1.0316 | | | | | 0.0377 | 99.29 | 87.48 |
| 2 | 1.0314 | | | | | 0.0268 | 98.62 | 86.88 |
| 4 | 1.0313 | | | | | 0.0190 | 98.11 | 86.43 |
| 8 | 1.0305 | | | | | 0.0136 | 95.57 | 84.19 |
| 15 | 1.0300 | | | | | 0.0100 | 93.87 | 82.70 |
| 30 | 1.0295 | | | | | 0.0072 | 91.50 | 80.61 |
| 60 | 1.0290 | | | | | 0.0051 | 89.81 | 79.12 |
| 120 | 1.0280 | | | | | 0.0037 | 86.42 | 76.13 |
| 240 | 1.0265 | | | | | 0.0027 | 81.33 | 71.65 |
| 480 | 1.0260 | | | | | 0.0019 | 80.32 | 70.76 |
| 1440 | 1.0255 | | | | | 0.0011 | 76.59 | 67.47 |



**Location** (2)around Tiya stele

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

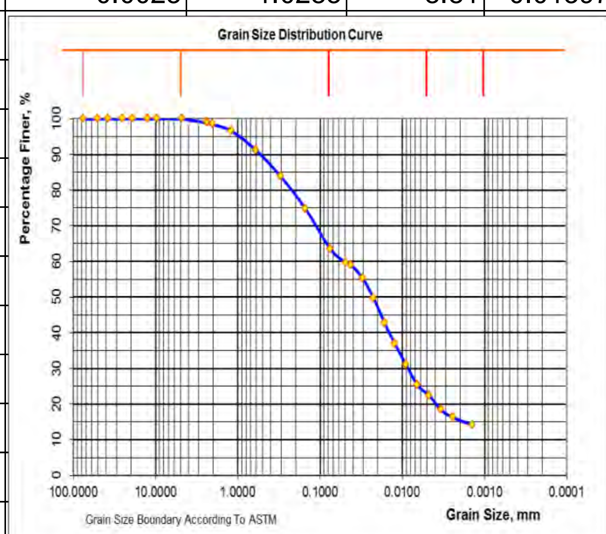
Total mass of sample, gm 500

| Sieve No | Sieve opening(mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.4 | 0.1 | 0.1 | 99.9 |
| No 8 | 2.36 | 5.6 | 1.1 | 1.2 | 98.8 |
| No 10 | 2 | 2.0 | 0.4 | 1.6 | 98.4 |
| No 20 | 0.85 | 9.6 | 1.9 | 3.5 | 96.5 |
| No 40 | 0.425 | 26.8 | 5.4 | 8.9 | 91.1 |
| No 60 | 0.3 | 37.0 | 7.4 | 16.3 | 83.7 |
| No 100 | 0.15 | 45.5 | 9.1 | 25.4 | 74.6 |
| No 200 | 0.075 | 55.9 | 11.2 | 36.6 | 63.4 |
| pan | ------- | 317.2 | 63.4 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.52 Test Temperature, 22

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0306 | -0.0023 | 1.0283 | 8.81 | 0.01397 | 0.0479 | 93.84 | 59.53 |
| 1 | 1.0303 | | | | | 0.0417 | 92.84 | 58.90 |
| 2 | 1.0285 | | | | | 0.0302 | 86.87 | 55.11 |
| 4 | 1.0258 | | | | | 0.0222 | 77.92 | 49.43 |
| 8 | 1.0225 | | | | | 0.0163 | 66.98 | 42.49 |
| 15 | 1.0198 | | | | | 0.0123 | 58.03 | 36.81 |
| 30 | 1.0170 | | | | | 0.0090 | 48.74 | 30.92 |
| 60 | 1.0143 | | | | | 0.0065 | 39.79 | 25.24 |
| 120 | 1.0129 | | | | | 0.0047 | 35.15 | 22.30 |
| 240 | 1.0110 | | | | | 0.0034 | 28.85 | 18.30 |
| 480 | 1.0100 | | | | | 0.0024 | 25.53 | 16.20 |
| 1440 | 1.0090 | | | | | 0.0014 | 22.22 | 14.09 |



**Location** (2)Around Tiya stele

**Depth** 3m

## Grain Size Analysis(At 3m)

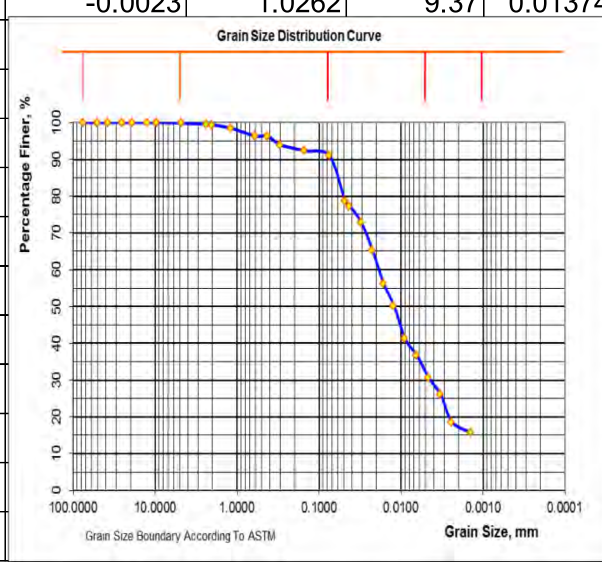
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained (g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.7 | 0.1 | 0.1 | 99.9 |
| No 8 | 2.36 | 1.6 | 0.3 | 0.5 | 99.5 |
| No 10 | 2 | 0.7 | 0.1 | 0.6 | 99.4 |
| No 20 | 0.85 | 4.7 | 0.9 | 1.5 | 98.5 |
| No 40 | 0.425 | 10.6 | 2.1 | 3.7 | 96.3 |
| No 60 | 0.25 | 11.7 | 2.3 | 6.0 | 94.0 |
| No 100 | 0.15 | 8.2 | 1.6 | 7.6 | 92.4 |
| No 200 | 0.075 | 6.9 | 1.4 | 9.0 | 91.0 |
| pan | ------- | 454.9 | 91.0 | 100.0 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.53 Test Temperature, 22

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0285 | -0.0023 | 1.0262 | 9.37 | 0.01374 | 0.0486 | 86.65 | 78.83 |
| 1 | 1.0280 | | | | | 0.0424 | 84.99 | 77.33 |
| 2 | 1.0265 | | | | | 0.0306 | 80.03 | 72.81 |
| 4 | 1.0240 | | | | | 0.0223 | 71.77 | 65.29 |
| 8 | 1.0210 | | | | | 0.0164 | 61.84 | 56.27 |
| 15 | 1.0190 | | | | | 0.0122 | 55.23 | 50.25 |
| 30 | 1.0160 | | | | | 0.0089 | 45.31 | 41.22 |
| 60 | 1.0145 | | | | | 0.0064 | 40.35 | 36.71 |
| 120 | 1.0125 | | | | | 0.0046 | 33.73 | 30.69 |
| 240 | 1.0110 | | | | | 0.0033 | 28.77 | 26.18 |
| 480 | 1.0085 | | | | | 0.0024 | 20.50 | 18.66 |
| 1440 | 1.0075 | | | | | 0.0014 | 17.20 | 15.65 |



**Location** Infront of Tiya school

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

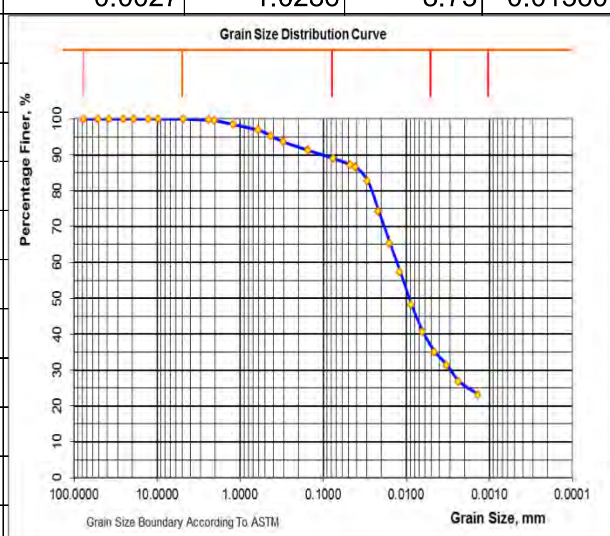
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.2 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 1.4 | 0.3 | 0.3 | 99.7 |
| No 10 | 2 | 0.7 | 0.1 | 0.5 | 99.5 |
| No 20 | 0.85 | 5.7 | 1.1 | 1.6 | 98.4 |
| No 40 | 0.425 | 7.8 | 1.6 | 4.7 | 95.3 |
| No 60 | 0.25 | 8.5 | 1.7 | 6.4 | 93.6 |
| No 100 | 0.15 | 11.8 | 2.4 | 8.8 | 91.2 |
| No 200 | 0.075 | 11.3 | 2.3 | 11.0 | 89.0 |
| pan | ------- | 444.8 | 89.0 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.46 Test Temperature, 22

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0313 | -0.0027 | 1.0286 | 8.73 | 0.01360 | 0.0464 | 96.38 | 87.24 |
| 1 | 1.0311 | | | | | 0.0403 | 95.70 | 86.63 |
| 2 | 1.0298 | | | | | 0.0291 | 91.32 | 82.67 |
| 4 | 1.0270 | | | | | 0.0214 | 81.89 | 74.12 |
| 8 | 1.0241 | | | | | 0.0157 | 72.12 | 65.28 |
| 15 | 1.0215 | | | | | 0.0118 | 63.35 | 57.35 |
| 30 | 1.0185 | | | | | 0.0086 | 53.24 | 48.20 |
| 60 | 1.0160 | | | | | 0.0063 | 44.82 | 40.57 |
| 120 | 1.0142 | | | | | 0.0045 | 38.75 | 35.08 |
| 240 | 1.0130 | | | | | 0.0032 | 34.71 | 31.42 |
| 480 | 1.0115 | | | | | 0.0023 | 29.65 | 26.84 |
| 1440 | 1.0103 | | | | | 0.0014 | 25.61 | 23.18 |



**Location** Infront of Tiya school

**Depth** 3.0m

## Grain Size Analysis(At 3.0m)

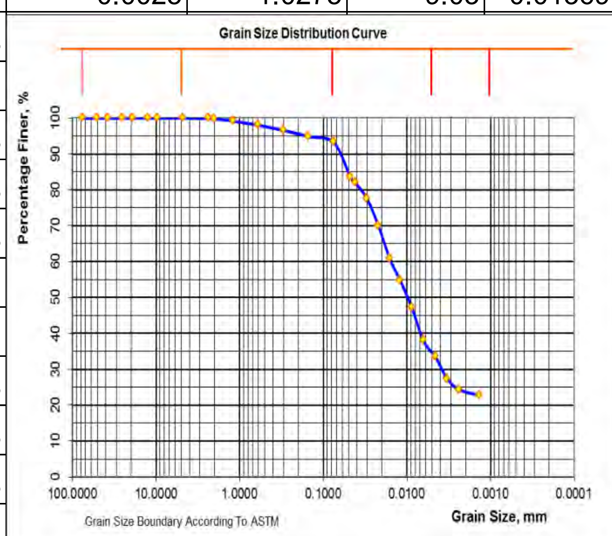
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.7 | 0.1 | 0.1 | 99.9 |
| No 10 | 2 | 0.4 | 0.08 | 0.2 | 99.8 |
| No 20 | 0.85 | 3.4 | 0.7 | 0.9 | 99.1 |
| No 40 | 0.425 | 5.5 | 1.1 | 2.0 | 98.0 |
| No 60 | 0.25 | 7.3 | 1.5 | 3.5 | 96.5 |
| No 100 | 0.15 | 8.4 | 1.7 | 5.1 | 94.9 |
| No 200 | 0.075 | 8.5 | 1.7 | 6.8 | 93.2 |
| pan | ------- | 465.8 | 93.2 | 100.0 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.59 Test Temperature, 21

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0300 | -0.0025 | 1.0275 | 9.03 | 0.01369 | 0.0475 | 89.59 | 83.46 |
| 1 | 1.0295 | | | | | 0.0414 | 87.96 | 81.95 |
| 2 | 1.0280 | | | | | 0.0299 | 83.08 | 77.39 |
| 4 | 1.0255 | | | | | 0.0219 | 74.93 | 69.81 |
| 8 | 1.0225 | | | | | 0.0161 | 65.16 | 60.70 |
| 15 | 1.0205 | | | | | 0.0120 | 58.64 | 54.63 |
| 30 | 1.0180 | | | | | 0.0087 | 50.50 | 47.04 |
| 60 | 1.0150 | | | | | 0.0064 | 40.72 | 37.94 |
| 120 | 1.0135 | | | | | 0.0046 | 35.84 | 33.39 |
| 240 | 1.0115 | | | | | 0.0033 | 29.32 | 27.32 |
| 480 | 1.0105 | | | | | 0.0024 | 26.06 | 24.28 |
| 1440 | 1.0100 | | | | | 0.0014 | 24.43 | 22.76 |



**Location** meserete kiristos

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

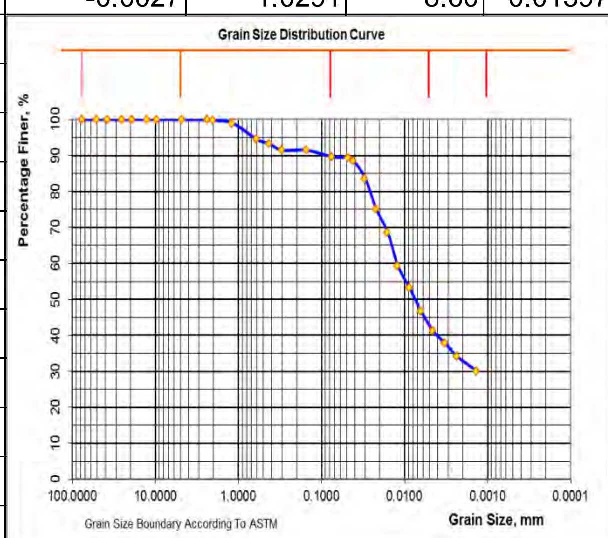
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.6 | 0.1 | 0.1 | 99.9 |
| No 10 | 2 | 0.6 | 0.1 | 0.2 | 99.8 |
| No 20 | 0.85 | 3.9 | 0.8 | 1.0 | 99.0 |
| No 40 | 0.425 | 6.0 | 1.2 | 6.7 | 93.3 |
| No 60 | 0.25 | 9.0 | 1.8 | 8.5 | 91.5 |
| No 100 | 0.15 | 0.0 | 0.0 | 8.5 | 91.5 |
| No 200 | 0.075 | 9.1 | 1.8 | 10.4 | 89.6 |
| pan | ------- | 448.2 | 89.6 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.51 Test Temperature, 22

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0318 | -0.0027 | 1.0291 | 8.60 | 0.01397 | 0.0473 | 96.74 | 89.45 |
| 1 | 1.0315 | | | | | 0.0412 | 95.75 | 88.53 |
| 2 | 1.0299 | | | | | 0.0298 | 90.43 | 83.61 |
| 4 | 1.0271 | | | | | 0.0219 | 81.12 | 75.00 |
| 8 | 1.0250 | | | | | 0.0159 | 74.14 | 68.55 |
| 15 | 1.0220 | | | | | 0.0121 | 64.16 | 59.33 |
| 30 | 1.0200 | | | | | 0.0087 | 57.51 | 53.18 |
| 60 | 1.0179 | | | | | 0.0063 | 50.53 | 46.72 |
| 120 | 1.0161 | | | | | 0.0046 | 44.55 | 41.19 |
| 240 | 1.0150 | | | | | 0.0033 | 40.89 | 37.81 |
| 480 | 1.0138 | | | | | 0.0023 | 36.90 | 34.12 |
| 1440 | 1.0125 | | | | | 0.0014 | 32.58 | 30.12 |



**Location** meserete kiristos

**Depth** 3m

## Grain Size Analysis(At 3m)

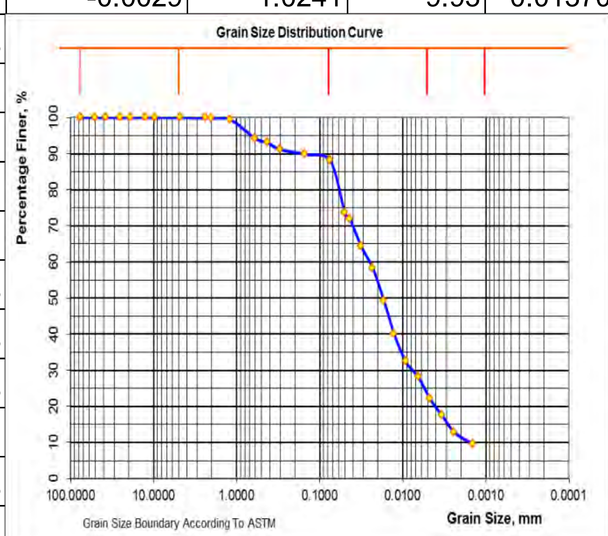
Total mass of sample, gm 500

| Sieve No | Sieve opening(mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.5 | 0.1 | 0.1 | 99.9 |
| No 10 | 2 | 0.3 | 0.1 | 0.2 | 99.8 |
| No 20 | 0.85 | 2.5 | 0.5 | 0.7 | 99.3 |
| No 40 | 0.425 | 6.1 | 1.2 | 7.0 | 93.0 |
| No 60 | 0.25 | 9.2 | 1.8 | 8.8 | 91.2 |
| No 100 | 0.15 | 6.7 | 1.3 | 10.2 | 89.8 |
| No 200 | 0.075 | 9.3 | 1.9 | 12.0 | 88.0 |
| pan | ------- | 439.8 | 88.0 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.57 Test Temperature, 22

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0270 | -0.0029 | 1.0241 | 9.93 | 0.01370 | 0.0498 | 78.90 | 73.44 |
| 1 | 1.0265 | | | | | 0.0434 | 77.26 | 71.92 |
| 2 | 1.0240 | | | | | 0.0317 | 69.08 | 64.30 |
| 4 | 1.0220 | | | | | 0.0230 | 62.53 | 58.20 |
| 8 | 1.0190 | | | | | 0.0168 | 52.71 | 49.06 |
| 15 | 1.0160 | | | | | 0.0127 | 42.89 | 39.92 |
| 30 | 1.0135 | | | | | 0.0092 | 34.70 | 32.30 |
| 60 | 1.0115 | | | | | 0.0065 | 30.12 | 28.04 |
| 120 | 1.0095 | | | | | 0.0047 | 23.57 | 21.94 |
| 240 | 1.0080 | | | | | 0.0034 | 18.66 | 17.37 |
| 480 | 1.0065 | | | | | 0.0024 | 13.75 | 12.80 |
| 1440 | 1.0060 | | | | | 0.0014 | 10.15 | 9.45 |



**Location** Noc

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

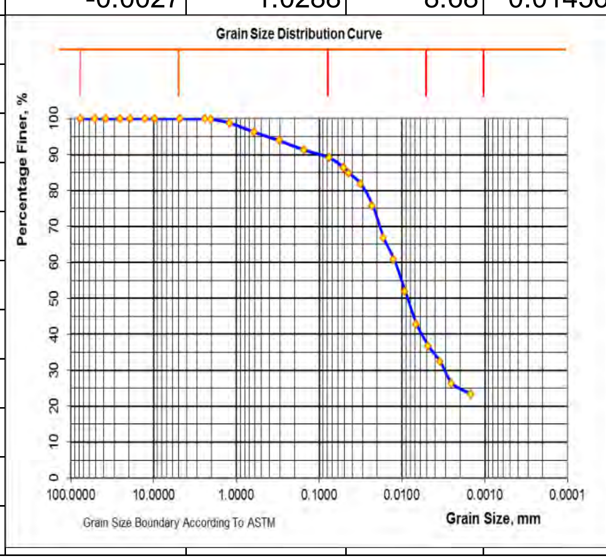
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.5 | 0.1 | 0.1 | 99.9 |
| No 10 | 2 | 0.3 | 0.06 | 0.2 | 99.8 |
| No 20 | 0.85 | 5.7 | 1.1 | 1.3 | 98.7 |
| No 40 | 0.425 | 12.5 | 2.5 | 3.8 | 96.2 |
| No 60 | 0.25 | 12.0 | 2.4 | 6.2 | 93.8 |
| No 100 | 0.15 | 12.8 | 2.6 | 8.8 | 91.2 |
| No 200 | 0.075 | 10.8 | 2.2 | 10.9 | 89.1 |
| pan | ------- | 445.4 | 89.1 | 100 | 0 |

Hydrometer Analysis

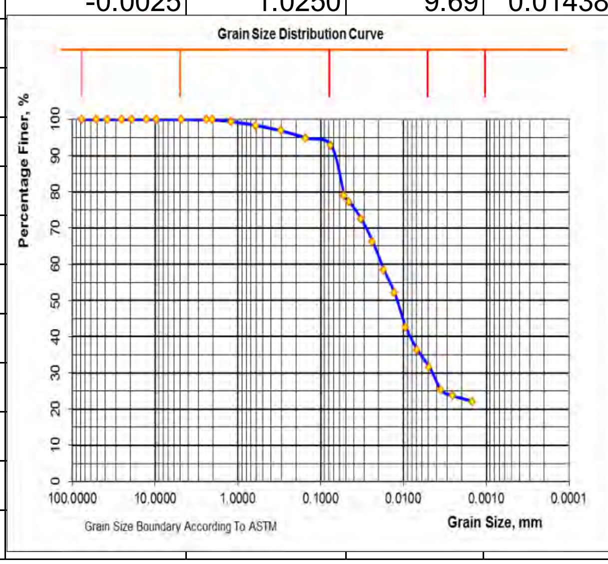
Specific Gravity of soil = 2.47 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0315 | -0.0027 | 1.0288 | 8.68 | 0.01456 | 0.0495 | 96.78 | 86.21 |
| 1 | 1.0310 | | | | | 0.0432 | 95.10 | 84.72 |
| 2 | 1.0300 | | | | | 0.0310 | 91.74 | 81.72 |
| 4 | 1.0280 | | | | | 0.0226 | 85.02 | 75.74 |
| 8 | 1.0250 | | | | | 0.0166 | 74.94 | 66.76 |
| 15 | 1.0230 | | | | | 0.0124 | 68.22 | 60.77 |
| 30 | 1.0200 | | | | | 0.0091 | 58.14 | 51.79 |
| 60 | 1.0170 | | | | | 0.0067 | 48.06 | 42.81 |
| 120 | 1.0150 | | | | | 0.0048 | 41.33 | 36.82 |
| 240 | 1.0135 | | | | | 0.0034 | 36.29 | 32.33 |
| 480 | 1.0115 | | | | | 0.0025 | 29.57 | 26.34 |
| 1440 | 1.0105 | | | | | 0.0014 | 26.21 | 23.35 |



| | | | | | |
|---|---|---|---|---|---|
| Location | | Noc | | | |
| Depth | | 3m | | | |
| | | Grain Size Analysis(At 3m) | | | |
| | | Total mass of sample, gm | | | 500 |
| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.4 | 0.1 | 0.1 | 99.9 |
| No 10 | 2 | 0.2 | 0.04 | 0.1 | 99.9 |
| No 20 | 0.85 | 2.6 | 0.5 | 0.6 | 99.4 |
| No 40 | 0.425 | 5.2 | 1.0 | 1.7 | 98.3 |
| No 60 | 0.25 | 7.3 | 1.5 | 3.1 | 96.9 |
| No 100 | 0.15 | 10.0 | 2.00 | 5.14 | 94.86 |
| No 200 | 0.075 | 10.2 | 2.04 | 7.18 | 92.82 |
| pan | ------- | 464.1 | 92.8 | 100 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hydrometer Analysis | | | | | | | | |
| Specific Gravity of soil = | | 2.43 | | Test Temperature, 21 | | | | |
| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
| 0.75 | 1.0275 | -0.0025 | 1.0250 | 9.69 | 0.01438 | 0.0517 | 84.97 | 78.86 |
| 1 | 1.0270 | | | | | 0.0451 | 83.27 | 77.29 |
| 2 | 1.0255 | | | | | 0.0325 | 78.17 | 72.56 |
| 4 | 1.0235 | | | | | 0.0236 | 71.37 | 66.25 |
| 8 | 1.0210 | | | | | 0.0172 | 62.87 | 58.36 |
| 15 | 1.0190 | | | | | 0.0128 | 56.08 | 52.05 |
| 30 | 1.0160 | | | | | 0.0094 | 45.88 | 42.59 |
| 60 | 1.0140 | | | | | 0.0068 | 39.08 | 36.28 |
| 120 | 1.0125 | | | | | 0.0049 | 33.99 | 31.55 |
| 240 | 1.0105 | | | | | 0.0035 | 27.19 | 25.24 |
| 480 | 1.0100 | | | | | 0.0025 | 25.49 | 23.66 |
| 1440 | 1.0095 | | | | | 0.0014 | 23.79 | 22.08 |



**Location** (1)Around Tiya stele dengai

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

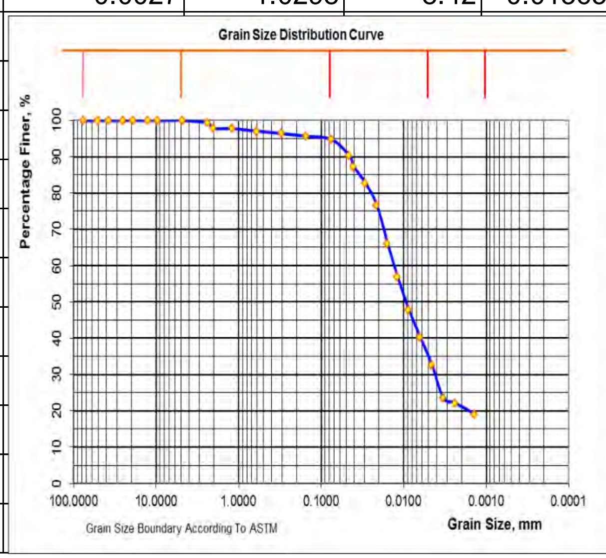
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 3.7 | 0.7 | 0.7 | 99.3 |
| No 10 | 2 | 7.6 | 1.52 | 2.3 | 97.7 |
| No 40 | 0.425 | 3.5 | 0.7 | 3.0 | 97.0 |
| No 60 | 0.25 | 3.2 | 0.6 | 3.6 | 96.4 |
| No 100 | 0.15 | 3.8 | 0.8 | 4.4 | 95.6 |
| No 200 | 0.075 | 4.5 | 0.9 | 5.3 | 94.7 |
| pan | ------- | 473.7 | 94.7 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.67 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0325 | -0.0027 | 1.0298 | 8.42 | 0.01365 | 0.0457 | 95.29 | 90.28 |
| 1 | 1.0315 | | | | | 0.0402 | 92.09 | 87.25 |
| 2 | 1.0300 | | | | | 0.0291 | 87.29 | 82.70 |
| 4 | 1.0280 | | | | | 0.0212 | 80.90 | 76.64 |
| 8 | 1.0245 | | | | | 0.0157 | 69.71 | 66.04 |
| 15 | 1.0215 | | | | | 0.0119 | 60.11 | 56.95 |
| 30 | 1.0185 | | | | | 0.0087 | 50.52 | 47.86 |
| 60 | 1.0160 | | | | | 0.0063 | 42.53 | 40.29 |
| 120 | 1.0135 | | | | | 0.0046 | 34.53 | 32.72 |
| 240 | 1.0105 | | | | | 0.0033 | 24.94 | 23.63 |
| 480 | 1.0100 | | | | | 0.0024 | 23.34 | 22.11 |
| 1440 | 1.0090 | | | | | 0.0014 | 20.14 | 19.09 |



**Location** (1) Around Tiya stele dengai

**Depth** 3m

## Grain Size Analysis(At 3m)

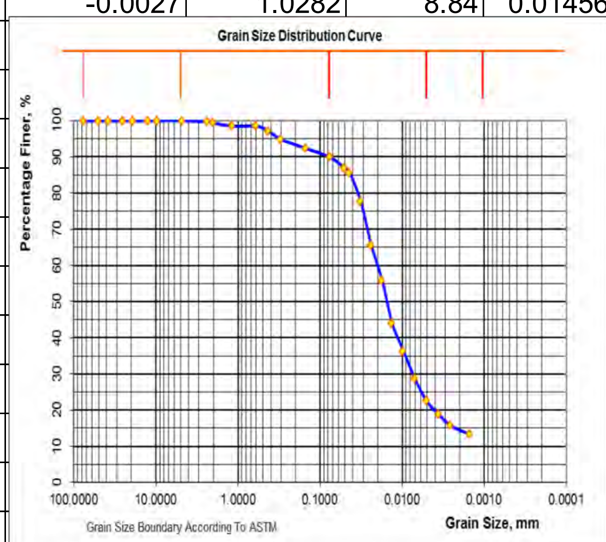
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 1.5 | 0.3 | 0.3 | 99.7 |
| No 10 | 2 | 0.7 | 0.1 | 0.6 | 99.4 |
| No 20 | 0.85 | 4.5 | 0.9 | 1.5 | 98.5 |
| No 40 | 0.425 | 6.9 | 1.4 | 2.9 | 97.1 |
| No 60 | 0.25 | 11.3 | 2.3 | 5.1 | 94.9 |
| No 100 | 0.15 | 12.4 | 2.5 | 7.6 | 92.4 |
| No 200 | 0.075 | 12.5 | 2.5 | 10.1 | 89.9 |
| pan | ------- | 450.2 | 90.0 | 100.2 | 0.0 |

Hydrometer Analysis

Specific Gravity of soil = 2.42 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0309 | -0.0027 | 1.0282 | 8.84 | 0.01456 | 0.0500 | 96.12 | 86.83 |
| 1 | 1.0305 | | | | | 0.0435 | 94.75 | 85.60 |
| 2 | 1.0279 | | | | | 0.0320 | 85.89 | 77.60 |
| 4 | 1.0240 | | | | | 0.0238 | 72.60 | 65.59 |
| 8 | 1.0208 | | | | | 0.0175 | 61.69 | 55.73 |
| 15 | 1.0170 | | | | | 0.0133 | 48.74 | 44.03 |
| 30 | 1.0145 | | | | | 0.0097 | 40.22 | 36.33 |
| 60 | 1.0120 | | | | | 0.0070 | 31.70 | 28.64 |
| 120 | 1.0100 | | | | | 0.0050 | 24.88 | 22.48 |
| 240 | 1.0088 | | | | | 0.0036 | 20.79 | 18.78 |
| 480 | 1.0078 | | | | | 0.0026 | 17.38 | 15.70 |
| 1440 | 1.0070 | | | | | 0.0015 | 14.66 | 13.24 |



**Location** **Entrance to Amawete**

**Depth** **1.5m**

## Grain Size Analysis(At 1.5m)

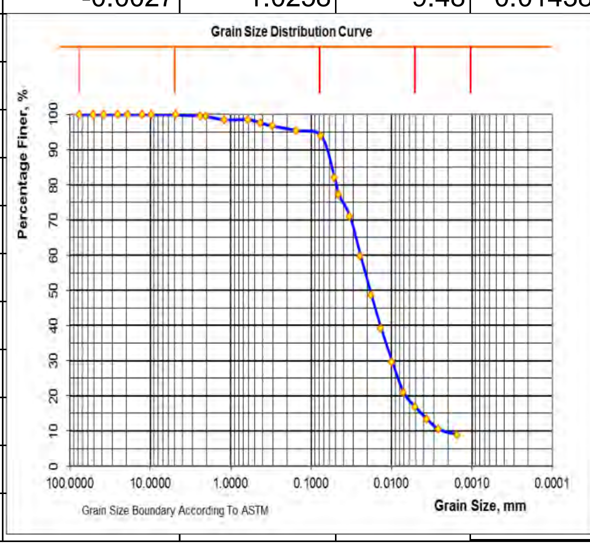
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.4 | 0.1 | 0.1 | 99.9 |
| No 8 | 2.36 | 1.5 | 0.3 | 0.4 | 99.6 |
| No 10 | 2 | 0.8 | 0.2 | 0.5 | 99.5 |
| No 20 | 0.85 | 4.7 | 0.9 | 1.5 | 98.5 |
| No 40 | 0.425 | 4.70 | 0.9 | 2.4 | 97.6 |
| No 60 | 0.25 | 4.2 | 0.8 | 3.3 | 96.7 |
| No 100 | 0.15 | 6.6 | 1.3 | 4.6 | 95.4 |
| No 200 | 0.075 | 7.3 | 1.5 | 6.0 | 94.0 |
| pan | ------- | 469.8 | 94.0 | 100 | 0.0 |

Hydrometer Analysis

Specific Gravity of soil = 2.46 Test Temperature, 21

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0285 | -0.0027 | 1.0258 | 9.48 | 0.01438 | 0.0511 | 86.94 | 82.02 |
| 1 | 1.0270 | | | | | 0.0452 | 81.89 | 77.25 |
| 2 | 1.0250 | | | | | 0.0328 | 75.15 | 70.89 |
| 4 | 1.0215 | | | | | 0.0242 | 63.35 | 59.77 |
| 8 | 1.0180 | | | | | 0.0178 | 51.56 | 48.64 |
| 15 | 1.0150 | | | | | 0.0134 | 41.45 | 39.10 |
| 30 | 1.0120 | | | | | 0.0098 | 31.34 | 29.57 |
| 60 | 1.0093 | | | | | 0.0071 | 22.24 | 20.98 |
| 120 | 1.0080 | | | | | 0.0051 | 17.86 | 16.85 |
| 240 | 1.0069 | | | | | 0.0036 | 14.15 | 13.35 |
| 480 | 1.0060 | | | | | 0.0026 | 11.12 | 10.49 |
| 1440 | 1.0055 | | | | | 0.0015 | 9.44 | 8.90 |



**Location** Entrance to Amawete

**Depth** 3m

## Grain Size Analysis(At 3m)

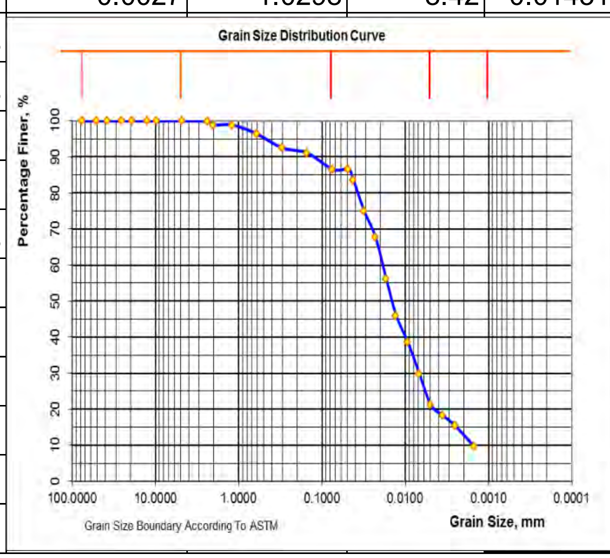
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.8 | 0.2 | 0.2 | 99.8 |
| No 10 | 2 | 4.8 | 1.0 | 1.1 | 98.9 |
| No 40 | 0.425 | 12.8 | 2.6 | 3.7 | 96.3 |
| No 60 | 0.25 | 19.1 | 3.8 | 7.5 | 92.5 |
| No 100 | 0.15 | 7.0 | 1.4 | 8.9 | 91.1 |
| No 200 | 0.075 | 22.7 | 4.5 | 13.4 | 86.6 |
| pan | ------- | 432.8 | 86.6 | 100.0 | 0.0 |

Hydrometer Analysis

Specific Gravity of soil = 2.53 Test Temperature, 21

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0325 | -0.0027 | 1.0298 | 8.42 | 0.01431 | 0.0479 | 98.55 | 86.55 |
| 1 | 1.0315 | | | | | 0.0422 | 95.25 | 83.65 |
| 2 | 1.0285 | | | | | 0.0311 | 85.33 | 74.93 |
| 4 | 1.0260 | | | | | 0.0228 | 77.06 | 67.67 |
| 8 | 1.0220 | | | | | 0.0169 | 63.83 | 56.05 |
| 15 | 1.0185 | | | | | 0.0129 | 52.25 | 45.89 |
| 30 | 1.0160 | | | | | 0.0093 | 43.99 | 38.63 |
| 60 | 1.0130 | | | | | 0.0068 | 34.06 | 29.92 |
| 120 | 1.0100 | | | | | 0.0050 | 24.14 | 21.20 |
| 240 | 1.0090 | | | | | 0.0035 | 20.84 | 18.30 |
| 480 | 1.0080 | | | | | 0.0025 | 17.53 | 15.39 |
| 1440 | 1.0060 | | | | | 0.0015 | 10.91 | 9.58 |



**Location** World Vision

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

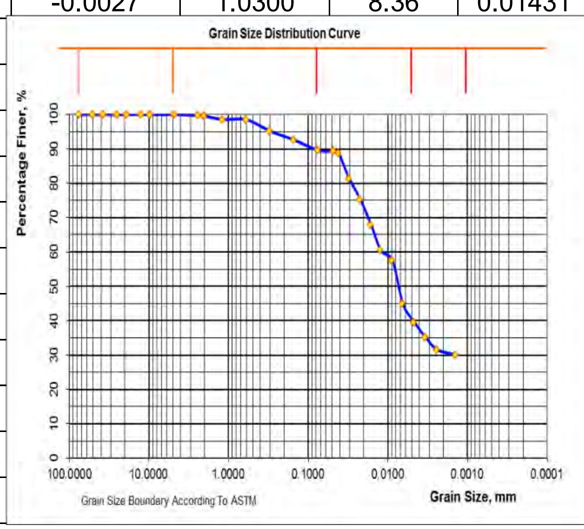
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 1.0 | 0.2 | 0.2 | 99.8 |
| No 10 | 2 | 0.3 | 0.1 | 0.3 | 99.7 |
| No 20 | 0.85 | 4.2 | 0.8 | 1.1 | 98.9 |
| No 40 | 0.425 | 6.1 | 1.2 | 2.3 | 97.7 |
| NO 60 | 0.25 | 7.2 | 1.4 | 3.8 | 96.2 |
| No 100 | 0.15 | 10.5 | 2.1 | 5.9 | 94.1 |
| No 200 | 0.075 | 12.0 | 2.4 | 8.3 | 91.7 |
| pan | ------- | 458.7 | 91.7 | 100.0 | 0.0 |

Hydrometer Analysis

Gravity of soil = 2.52 Test Temperature, deg.c 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0327 | -0.0027 | 1.0300 | 8.36 | 0.01431 | 0.0478 | 99.47 | 89.36 |
| 1 | 1.0325 | | | | | 0.0415 | 98.81 | 88.76 |
| 2 | 1.0300 | | | | | 0.0305 | 90.52 | 81.32 |
| 4 | 1.0280 | | | | | 0.0222 | 83.89 | 75.36 |
| 8 | 1.0255 | | | | | 0.0162 | 75.60 | 67.91 |
| 15 | 1.0230 | | | | | 0.0122 | 67.31 | 60.47 |
| 30 | 1.0220 | | | | | 0.0087 | 63.99 | 57.49 |
| 60 | 1.0178 | | | | | 0.0065 | 50.07 | 44.98 |
| 120 | 1.0160 | | | | | 0.0047 | 44.10 | 39.62 |
| 240 | 1.0145 | | | | | 0.0034 | 39.13 | 35.15 |
| 480 | 1.0133 | | | | | 0.0024 | 35.15 | 31.57 |
| 1440 | 1.0128 | | | | | 0.0014 | 33.49 | 30.08 |



**Location** **World Vision**

**Depth** **3m**

## Grain Size Analysis(At 3m)

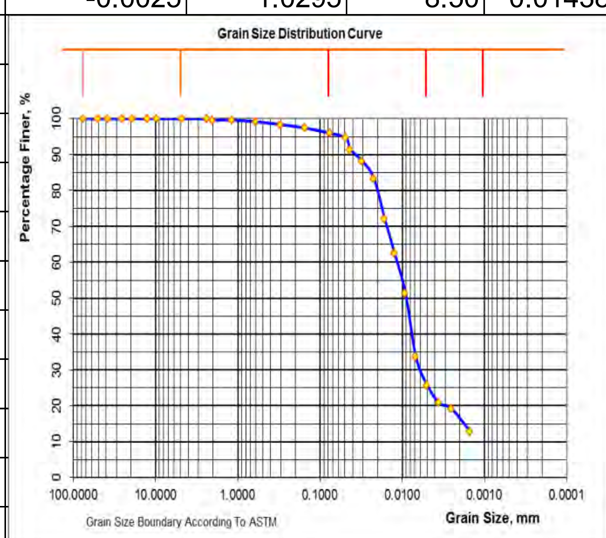
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 0.3 | 0.1 | 0.1 | 99.9 |
| No 10 | 2 | 1.6 | 0.32 | 0.4 | 99.6 |
| No 40 | 0.425 | 2.3 | 0.5 | 0.8 | 99.2 |
| No 60 | 0.25 | 3.9 | 0.8 | 1.6 | 98.4 |
| No 100 | 0.15 | 5.0 | 1.0 | 2.6 | 97.4 |
| No 200 | 0.075 | 7.2 | 1.4 | 4.1 | 95.9 |
| pan | ------- | 479.7 | 95.9 | 100 | 0 |

Hydrometer Analysis

Specific Gravity of soil = 2.49 Test Temperature, 21

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0320 | -0.0025 | 1.0295 | 8.50 | 0.01438 | 0.0484 | 98.60 | 94.59 |
| 1 | 1.0310 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0426 | 95.26 | 91.39 |
| 2 | 1.0300 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0305 | 91.91 | 88.18 |
| 4 | 1.0285 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0221 | 86.90 | 83.37 |
| 8 | 1.0250 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0164 | 75.20 | 72.15 |
| 15 | 1.0220 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0124 | 65.17 | 62.53 |
| 30 | 1.0185 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0091 | 53.48 | 51.31 |
| 60 | 1.0130 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0068 | 35.09 | 33.67 |
| 120 | 1.0105 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0049 | 26.74 | 25.65 |
| 240 | 1.0090 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0035 | 21.72 | 20.84 |
| 480 | 1.0085 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0025 | 20.05 | 19.24 |
| 1440 | 1.0065 | [illegible] | [illegible] | [illegible] | [illegible] | 0.0015 | 13.37 | 12.83 |



**Location** **Sutan market**

**Depth** **1.5m**

## Grain Size Analysis(At 1.5m)

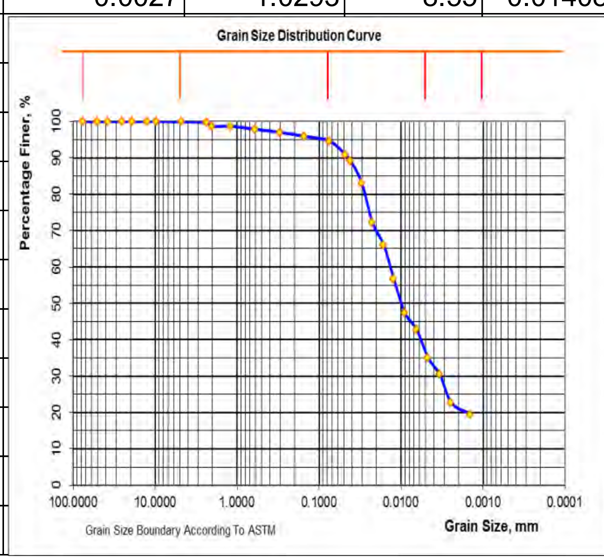
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.4 | 0.1 | 0.1 | 99.9 |
| No 8 | 2.36 | 1.4 | 0.3 | 0.4 | 99.6 |
| No 10 | 2 | 4.8 | 1.0 | 1.3 | 98.7 |
| No 40 | 0.425 | 4.2 | 0.8 | 2.2 | 97.8 |
| No 60 | 0.25 | 4.2 | 0.8 | 3.0 | 97.0 |
| No 100 | 0.15 | 5.5 | 1.1 | 4.1 | 95.9 |
| No 200 | 0.075 | 6.3 | 1.3 | 5.4 | 94.6 |
| pan | ------- | 473.2 | 94.6 | 100.0 | 0.0 |

Hydrometer Analysis

Specific Gravity of soil = 2.57 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0320 | -0.0027 | 1.0293 | 8.55 | 0.01408 | 0.0475 | 95.92 | 90.78 |
| 1 | 1.0315 | | | | | 0.0415 | 94.29 | 89.23 |
| 2 | 1.0295 | | | | | 0.0302 | 87.74 | 83.04 |
| 4 | 1.0260 | | | | | 0.0224 | 76.28 | 72.19 |
| 8 | 1.0240 | | | | | 0.0163 | 69.73 | 66.00 |
| 15 | 1.0210 | | | | | 0.0123 | 59.91 | 56.70 |
| 30 | 1.0180 | | | | | 0.0090 | 50.09 | 47.41 |
| 60 | 1.0165 | | | | | 0.0065 | 45.18 | 42.76 |
| 120 | 1.0140 | | | | | 0.0047 | 36.99 | 35.01 |
| 240 | 1.0125 | | | | | 0.0034 | 32.08 | 30.36 |
| 480 | 1.0100 | | | | | 0.0024 | 23.90 | 22.62 |
| 1440 | 1.0090 | | | | | 0.0014 | 20.63 | 19.52 |



**Location** Sutan market

**Depth** 3m

## Grain Size Analysis(At 3m)

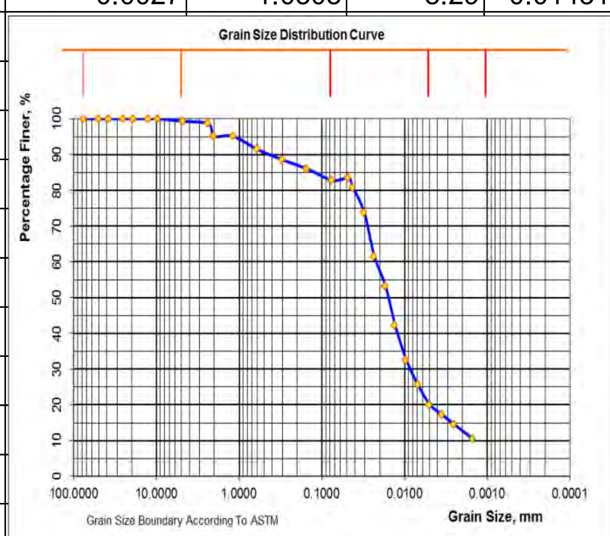
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Cum. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 3.3 | 0.7 | 0.7 | 99.3 |
| No 8 | 2.36 | 3.6 | 0.7 | 1.4 | 98.6 |
| No 10 | 2 | 17.3 | 3.5 | 4.8 | 95.2 |
| No40 | 0.425 | 18.7 | 3.7 | 8.6 | 91.4 |
| No 60 | 0.25 | 14.4 | 2.9 | 11.5 | 88.5 |
| No 100 | 0.15 | 12.8 | 2.6 | 14.0 | 86.0 |
| No 200 | 0.075 | 15.8 | 3.2 | 17.2 | 82.8 |
| pan | ------- | 414.1 | 82.8 | 100 | 0.0 |

Hydrometer Analysis

Specific Gravity of soil = 2.51 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0330 | -0.0027 | 1.0303 | 8.29 | 0.01431 | 0.0476 | 100.73 | 83.43 |
| 1 | 1.0320 | | | | | 0.0418 | 97.41 | 80.67 |
| 2 | 1.0295 | | | | | 0.0307 | 89.10 | 73.79 |
| 4 | 1.0250 | | | | | 0.0231 | 74.14 | 61.40 |
| 8 | 1.0220 | | | | | 0.0169 | 64.16 | 53.14 |
| 15 | 1.0180 | | | | | 0.0129 | 50.86 | 42.13 |
| 30 | 1.0145 | | | | | 0.0095 | 39.23 | 32.49 |
| 60 | 1.0120 | | | | | 0.0069 | 30.92 | 25.61 |
| 120 | 1.0100 | | | | | 0.0050 | 24.27 | 20.10 |
| 240 | 1.0090 | | | | | 0.0035 | 20.94 | 17.35 |
| 480 | 1.0080 | | | | | 0.0025 | 17.62 | 14.59 |
| 1440 | 1.0065 | | | | | 0.0015 | 12.63 | 10.46 |



**Location** St.mariam church

**Depth** 1.5m

## Grain Size Analysis(At 1.5m)

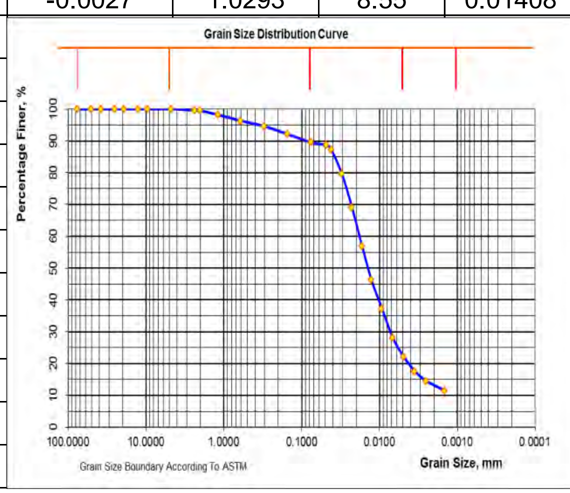
Total mass of sample, gm 500

| Sieve No | Sieve opening (mm) | Mass of of retained soil (g) | Percentage retained(g) | Comm. Percentage retained(%) | Percentage passing(%) |
|---|---|---|---|---|---|
| 3" | 75.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2" | 50.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.5" | 37.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1" | 25.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3/4" | 19.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1/2" | 12.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3.8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 4 | 4.75 | 0.0 | 0.0 | 0.0 | 100.0 |
| No 8 | 2.36 | 1.5 | 0.3 | 0.3 | 99.7 |
| No 10 | 2 | 0.6 | 0.1 | 0.4 | 99.6 |
| No 20 | 0.85 | 5.4 | 1.1 | 1.5 | 98.5 |
| No 40 | 0.425 | 7.8 | 1.6 | 3.1 | 96.9 |
| No 60 | 0.25 | 7.2 | 1.4 | 4.5 | 95.5 |
| No 100 | 0.15 | 10.3 | 2.1 | 6.6 | 93.4 |
| No 200 | 0.075 | 10.8 | 2.2 | 8.7 | 91.3 |
| pan | ------- | 456.4 | 91.3 | 100.0 | 0.0 |

Hydrometer Analysis

Specific Gravity of soil = 2.58 Test Temperature, 20

| Elapsed Time (min) | Actual Hydrometer Reading | Composite Correction | Corrected Hydrometer Reading | Effective Depth (cm) | Coefficient K | Grain Size (mm) | Perc. Finer (%) | Perc. Finer Combined (%) |
|---|---|---|---|---|---|---|---|---|
| 0.75 | 1.0320 | -0.0027 | 1.0293 | 8.55 | 0.01408 | 0.0475 | 95.69 | 88.62 |
| 1 | 1.0315 | | | | | 0.0415 | 94.06 | 87.11 |
| 2 | 1.0290 | | | | | 0.0304 | 85.89 | 79.54 |
| 4 | 1.0255 | | | | | 0.0226 | 74.46 | 68.96 |
| 8 | 1.0215 | | | | | 0.0168 | 61.40 | 56.86 |
| 15 | 1.0180 | | | | | 0.0127 | 49.97 | 46.27 |
| 30 | 1.0150 | | | | | 0.0093 | 40.17 | 37.20 |
| 60 | 1.0120 | | | | | 0.0068 | 30.37 | 28.13 |
| 120 | 1.0100 | | | | | 0.0049 | 23.84 | 22.08 |
| 240 | 1.0085 | | | | | 0.0035 | 18.94 | 17.54 |
| 480 | 1.0075 | | | | | 0.0025 | 15.68 | 14.52 |
| 1440 | 1.0065 | | | | | 0.0015 | 12.41 | 11.49 |



**Appendix G**

# Specific Gravity

**TP-1**
**Depth=0.7m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.00* | 145.3 |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.30* | *160.70* |
| Mass of soil(g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.58 | 2.60 |
| to | 23.00 | 23.20 |
| k | 0.9993689 | 0.9993048 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.58 | 2.60 |
| Average Specific Gravity $G_s$ = | 2.59 | |

**TP-1**
**Depth=1.6m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *150.50* | 143.8 |
| Mass of flask, soil and water (g) $M_{fs}$ | *165.30* | *158.50* |
| Mass of soil(g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.45 | 2.43 |
| to | 23.00 | 23.00 |
| k | 0.9993689 | 0.9993488 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.45 | 2.43 |
| Average Specific Gravity $G_s$ = | 2.44 | |

**TP-2**

**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *142.90* | 143.1 |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.00* | *158.20* |
| Mass ofsoil(g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.53 | 2.53 |
| to | 22.00 | 22.00 |
| k | 0.9995793 | 0.9995692 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.52 | 2.52 |
| Average Specific Gravity $G_s$ = | 2.52 | |

**TP-2**
**Depth=3m**

| | Sample 1 | Sample 2 | |
|---|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.70* | 153.8 | |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.85* | *168.90* | |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* | |
| Specific Gravity $G_{sat\ to}$ | 2.54 | 2.53 | |
| to | 22.00 | 22.30 | |
| k | 0.9995793 | 0.9995031 | |
| Specific Gravity $G_{s\ at\ 20}$ | 2.54 | 2.52 | |
| Average Specific Gravity $G_s$ = | 2.53 | | |

**TP-3**
**Depth=1.5m**

| | Sample 1 | Sample 2 | |
|---|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *153.80* | 146.7 | |
| Mass of flask, soil and water (g) $M_{fs}$ | *168.60* | *161.60* | |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* | |
| Specific Gravity $G_{sat\ to}$ | 2.45 | 2.48 | |
| to | 23.00 | 23.00 | |
| k | 0.9993689 | 0.9993488 | |
| Specific Gravity $G_{s\ at\ 20}$ | 2.45 | 2.47 | |
| Average Specific Gravity $G_s$ = | 2.46 | | |

**TP-3**
**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.00* | 145.3 |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.30* | *160.70* |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.58 | 2.60 |
| to | 22.50 | 22.80 |
| k | 0.9994741 | 0.9993929 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.58 | 2.60 |
| Average Specific Gravity $G_s$ = | 2.59 | |

## TP-4

**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *145.30* | 143 |
| Mass of flask, soil and water (g) $M_{fs}$ | *160.30* | *158.10* |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.50 | 2.53 |
| to | 23.00 | 23.00 |
| k | 0.9993689 | 0.9993488 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.50 | 2.52 |
| Average Specific Gravity $G_s$ = | 2.51 | |

## TP-4

**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.80* | 153.85 |
| Mass of flask, soil and water (g) $M_{fs}$ | *159.10* | *169.10* |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.58 | 2.56 |
| to | 23.20 | 23.20 |
| k | 0.9993268 | 0.9993048 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.58 | 2.56 |
| Average Specific Gravity $G_s$ = | 2.57 | |

## TP-5

**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *144.30* | 146.8 |
| Mass of flask, soil and water (g) $M_{fs}$ | *159.20* | *161.70* |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.48 | 2.48 |
| to | 22.00 | 22.00 |
| k | 0.9995793 | 0.9995692 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.47 | 2.47 |
| Average Specific Gravity $G_s$ = | 2.47 | |

## TP-5

**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *150.50* | 143.4 |
| Mass of flask, soil and water (g) $M_{fs}$ | *165.20* | *158.10* |
| Mass ofsoil(g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.43 | 2.43 |
| to | 23.20 | 23.40 |
| k | 0.9993268 | 0.9992607 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.43 | 2.43 |
| Average Specific Gravity $G_s$ = | 2.43 | |

## TP-6

**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.00* | 146.8 |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.65* | *162.40* |
| Mass of soil (g) Ms | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.67 | 2.66 |
| to | 21.00 | 21.00 |
| k | 0.9997896 | 0.9997896 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.67 | 2.66 |
| Average Specific Gravity $G_s$ = | 2.67 | |

## TP-6
**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *144.50* | 147.1 |
| Mass of flask, soil and water (g) $M_{fs}$ | *159.20* | *161.70* |
| Mass of soil (g) Ms | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.43 | 2.40 |
| to | 23.00 | 23.00 |
| k | 0.9993488 | 0.9993488 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.43 | 2.40 |
| Average Specific Gravity $G_s$ = | 2.42 | |

## TP-7
**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *145.20* | 144.00 |
| Mass of flask, soil and water (g) $M_{fs}$ | *160.00* | *158.90* |
| Mass of soil(g) Ms | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.45 | 2.48 |
| to | 22.00 | 23.00 |
| k | 0.9995793 | 0.9993488 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.45 | 2.47 |
| Average Specific Gravity $G_s$ = | 2.46 | |

## TP-7

**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.50* | 153.8 |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.60* | *168.95* |
| Mass of soil (g) Ms | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.53 | 2.54 |
| to | 21.00 | 21.00 |
| k | 0.9997896 | 0.9997896 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.52 | 2.54 |
| Average Specific Gravity $G_s$ = | 2.53 | |

## TP-8

**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *150.30* | 153.7 |
| Mass of flask, soil and water (g) $M_{fs}$ | *165.40* | *168.75* |
| Mass of soil(g) Ms | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.53 | 2.51 |
| to | 23.00 | 23.00 |
| k | 0.9993689 | 0.9993488 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.52 | 2.51 |
| Average Specific Gravity $G_s$ = | 2.52 | |

**TP-8**
**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *145.10* | 144.6 |
| Mass of flask, soil and water (g) $M_{fs}$ | *160.10* | *159.50* |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.50 | 2.48 |
| to | 22.00 | 22.00 |
| k | 0.9995793 | 0.9995692 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.50 | 2.47 |
| Average Specific Gravity $G_s$ = | 2.49 | |

**TP-9**
**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *143.90* | 150.3 |
| Mass of flask, soil and water (g) $M_{fs}$ | *159.15* | *165.60* |
| Mass of soil (g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.56 | 2.58 |
| to | 21.00 | 21.00 |
| k | 0.9997896 | 0.9997896 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.56 | 2.58 |
| Average Specific Gravity $G_s$ = | 2.57 | |

## TP-9
**Depth=3m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *145.30* | 144.7 |
| Mass of flask, soil and water (g) $M_{fs}$ | *160.40* | *159.70* |
| Mass of soil(g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.53 | 2.50 |
| to | 22.00 | 22.00 |
| k | 0.9995793 | 0.9995692 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.52 | 2.50 |
| Average Specific Gravity $G_s$ = | 2.51 | |

## TP-10
**Depth=1.5m**

| | Sample 1 | Sample 2 |
|---|---|---|
| Mass of flask and water (g) $M_{fw}$ | *142.90* | 143.1 |
| Mass of flask, soil and water (g) $M_{fs}$ | *158.20* | *158.40* |
| Mass of soil(g) $M_s$ | *25.00* | *25.00* |
| Specific Gravity $G_{sat\ to}$ | 2.58 | 2.58 |
| to | 22.00 | 22.00 |
| k | 0.9995793 | 0.9995692 |
| Specific Gravity $G_{s\ at\ 20}$ | 2.58 | 2.58 |
| Average Specific Gravity $G_s$ = | 2.58 | |

**INVESTIGATION ON SOME OF THE ENGINEERING CHARACTERISTICS OF SOILS IN TIYA TOWN, ETHIOPIA**