



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
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**INVESTIGATION INTO SOME OF THE ENGINEERING PROPERTIES OF
SOILS FOUND IN WORABE TOWN, ETHIOPIA**

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**“A thesis submitted to the school of graduate studies of Addis Ababa
University in partial fulfillment of the requirements for the degree of Master
of Science in civil engineering (Geotechniques)”**

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Table of contents

Contents	Pages
Acknowledgements.....	I
Table of contents.....	II
Symbols and Abbreviations.....	V
List of Tables.....	VI
List of Figures	VII
Abstract	VIII
1. Introduction	1
1.1. Background.....	1
1.2. Objective of the study	2
1.3. Methodology.....	2
1.4. Organization of the thesis work	3
2. Literature Review.....	4
2.1. General.....	4
2.2. Soil formation and soil deposits.....	5
2.2.1. Parent materials.....	6
2.2.2. Topography and Drainage	6
2.2.3. Climate	6
2.3. General Types of Soils	6
2.3.1. Soil particle size and shape	7
2.3.2. Soil mineralogical composition	7
2.4. Laboratory tests	7
2.4.1. Atterberg limits	8
2.4.2. Specific gravity	9
2.4.3. Particle-size distribution.....	10
2.4.4. Free Swell	11
2.5. Classification of the soils	12
2.5.1. General.....	12

2.5.3. Classification of soils based on AASHTO Classification system	13
2.5.4. Classification of soils based on Unified Soil Classification System (USCS)	13
2.6. Unconfined Compression Strength (UCS) test	15
2.7. Direct shear test	16
2.8. Triaxial Shear test	16
2.9. Consolidation test	17
3. Description of the study area	19
3.1. General	19
3.2. Hydrogeology	19
3.2.1. Climate	19
3.2.2. Geology	20
4. In-Situ Properties and Laboratory Tests Results	21
4.1. In-situ properties	21
4.1.1. Identification of Soil in the Study Area	21
4.2. Index properties	23
4.2.1. General	23
4.2.2. Natural Moisture Content	23
4.2.3. Specific Gravity	24
4.2.4. Grain-Size Distribution of soil	26
4.2.5. Atterberg Limits	28
4.2.6. Activity of Clay	29
4.2.7. Free Swell	30
4.3. Classification of the soils	32
4.3.1. General	32
4.3.2. Classifications of soils based on AASHTO Classification system	32
4.3.3. Classification of soils based on Unified Soil Classification System (USCS)	34
4.4. Unconfined Compression Strength (UCS) test	36
4.5. Consolidation	36
4.5.1. General	36
5. Discussions of the laboratory test results and Comparisons with previously done researches	38
5.1. Preliminary Soil Map of Worabe Town	38

5.2. Index property test results in different parts of the country.....	45
6. Conclusions and recommendations	47
6.1. Conclusion	47
6.2. Recommendation	48
7.0. References.....	49
Appendix-A.....	51

Symbols and Abbreviations

AASHTO	-	American Association of State Highway and Transportation Officials
ASTM	-	American Society for Testing Materials standard
C_c	-	Compression index
CH	-	Highly plastic clay
CL	-	Low plastic clay
C_r	-	Recompression index
C_v	-	Coefficient of consolidation
e	-	Void ratio
E_s	-	Modulus of compressibility
K	-	Modulus of Permeability
LL	-	Liquid limit
L_I	-	Liquidity Index
MH	-	Inorganic Elastic silt
ML	-	Inorganic Silt
NMC	-	Natural moisture content
OMC	-	Optimum moisture content
OCR	-	Over-consolidation ratio
P_c	-	Pre-consolidation pressure
P_o	-	Over burden pressure
PI (I_p)	-	Plastic Index
PL	-	Plastic limit
TP	-	Test pit
USCS	-	Unified Soil Classification System
γ_d	-	Dry unit weight
γ_w	-	Wet unit weight

List of Tables	Page
Table 3.1 Mean monthly rainfalls and mean monthly temperatures for Butajira (1986–2003).....	19
Table 3.2 Global coordinates of sampling areas.....	22
Table 4.1 Natural moisture content of samples.....	24
Table 4.2 Specific Gravity of the Soil of the Study Area	25
Table 4.3 Summary of grain size analysis result	26
Table 4.4 Summary of Atterberg Limit Results.....	29
Table 4.5 Plasticity Index and Activity	30
Table 4.6 Result of Free Swell Tests.....	30
Table 4.7 Classifications of soils based on AASHTO Classification system.....	33
Table 4.8 Classifications of soils based on USC Classification system.....	34
Table 4.9 Summary of UCS test results.....	36
Table 4.10 Summary of the consolidation test results.....	37
Table 5.1 Engineering properties of Group I soils.....	39
Table 5.2 Engineering properties of Group II soils.....	40
Table 5.3 Engineering properties of Group III soils.....	41
Table 5.4 Engineering properties of Group IV soils.....	42
Table 5.5 Laboratory test results of previous research studies around some towns of Ethiopia.....	46

List of Figures	Page
Fig.3.1 Location Map of Study Area from Map of Ethiopia.....	20
Fig.3.2 Location Map of Study area from SNNPR Region.....	20
Fig.4.1 Location of Test pits shown on map of Worabe town.....	21
Fig.4.2 Pictures of soils taken for the investigation.....	22
Fig.4.3 Grain size distribution curve for samples from TP 1 to TP6.....	27
Fig.4.4 Grain size distribution curve for samples from TP 7 to TP11.....	28
Fig.4.5 Plasticity chart of soil in the study area according to AASHTO classification system.....	32
Fig.4.6 Plasticity chart of the study area according to Unified Soil Classification System.....	35
Fig.5.1 Preliminary soil map of Worabe town at a depth of 1.5m.....	43
Fig.5.2 Preliminary soil map of Worabe town at a depth of 3.0m.....	44

Abstract

The main objective of the study is to investigate some of the engineering properties of soil found in Worabe town. To achieve the objective eleven different test pits have been taken and both disturbed and undisturbed samples are collected at a depth of 1.5m and 3m from each test pits.

After collecting all samples, the following laboratory tests are conducted; specific gravity, grain size analysis, Atterberg limits, free Swell, unconfined compression strength (UCS) and one dimensional consolidation.

According to this study, Worabe town soils are grouped in to four types of soils. Group I (expansive soils), group II (non-expansive soils), group III (marginal soils) and group IV (sandy soils).

The grain size analysis test results for group I, group II and group III soils showed that the dominant proportion of soil particles in the research area are clay and silt. For group I soils, the value of clay content ranging from 34.3% – 65.9% and silt fraction ranging from 17.3% - 39.4%. For group II soils, the value of clay content ranging from 37.1% –43.0% and silt fraction ranging from 38.5% - 54.2%. For group III soils, the value of clay content ranging from 36.9% –72.7% and silt fraction ranging from 20.6% - 53.0%.

The Atterberg limit test results for group I soils showed that liquid limit ranging from 67.3% – 131.3%, plastic limit ranging from 19.1% – 49.3% and plastic index ranging from 36.0% – 82.0%. For group II soils liquid limit ranging from 54.1% – 70.8%, plastic limit ranging from 24.8% – 43.4% and plastic index ranging from 15% – 34.3%. For group III soils liquid limit ranging from 49.5% – 125.2%, plastic limit ranging from 15.0% – 37.1% and plastic index ranging from 33.7% – 90%.

The specific gravity in the study area ranges from 2.65 to 2.85. For group I soils specific gravity ranging from 2.65 to 2.81, for group II soils specific gravity ranging from 2.67 to 2.75, for group III soils specific gravity ranging from 2.68 to 2.85 and for group IV soils specific gravity ranging from 2.65 to 2.77.

The free swell test results on the samples collected show a value ranging from 30% – 145%. The free swell test results for group I soils showed a value ranging from 103% – 145%, for group II soils a value ranging from 30%-45%, for group III a value ranging from 55%-95% and for group IV a value ranging from 31%-58%.

The values of unconfined compressive strength (UCS) in the study area ranging from 89kPa to 188kPa for natural moisture content ranging from 22.6% to 57.5%. The values of unconfined compressive strength (UCS) test for group I soils ranging from 126.2kPa to 178.4kPa and for group III soils a value ranging from 113.4kPa to 144.9kPa.

The classification of the soil is done according to American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS). According to the AASHTO Classification System, Worabe town soil consists of clay and sandy soils with designation A-7-6, A-7-5 and A-3. Unified Soil Classification System, the soil is mainly categorized as CH, MH, SM, SL and CL. But many areas are covered by highly plastic clay (CH). The result of one-dimensional consolidation tests show that the area under investigation is over consolidated in its natural state and the compression index ranges from 0.359 to 0.622.

1. Introduction

1.1. Background

Worabe (allegedly from the Silti word for "Hyena") is a town in south-central Ethiopia. The town is located in the Gurage Zone of the Southern Nations, Nationalities and Peoples Region (SNNPR). The geographical coordinates of the town are 8°1'N and 38°20'E with an average elevation of 2113 meters above sea level.

Many problems are caused on structures constructed on expansive soils as these soils undergo higher volume changes due to the variation of moisture content. Expansive soil, which is recognized by its considerable volume change upon exposure to moisture variation, has caused a number of problems on most structures. The problems are either due to misunderstanding of the behavior of the soil or lack of information on the engineering properties of the soil. The behavior of expansive soils varies from place to place depending upon the type of parent material, climate and topography. Therefore, due to the fact that the engineering properties of expansive soil of Ethiopia are different from the same soil in other locality, researches on the engineering properties of expansive soils of Ethiopia has been done. The main purpose of this work is to study the index and engineering properties of the soil found in Worabe town. Most of the zone is fairly level and found in northern part of SNNPR and located south east of Alaba special woreda, south west Hadiya, Oromia and in northern, north western and north eastern Gurage zone. Worabe town is the administrative center of the zone which is found 173 kms from Addis Ababa, Ethiopia.

Engineering properties such as index properties and consolidation characteristics of the Worabe soil is not studied well yet. Therefore, investigating the engineering properties, identifying the characteristic of the soil and preparing soil map of the town is very important for construction works as well as for further studies in the future.

1.2. Objective of the study

General objective

The general objectives of the research work are

- i. To investigate the engineering properties of Worabe town.
- ii. To investigate and characterize index and swelling properties of expansive soils in Worabe town and an attempt will be made to give an overview of spatial distribution of other soils found in Worabe town by preparing soil map of the town.

Specific objective

The general objective is obtained by performing the following specific cases

- i. Determining the grain size distribution and specific gravity of expansive soils.
- ii. Conducting Atterberg limit and Indices.
- iii. Determining free swell and swelling potential of the expansive soils.
- iv. Undertaking classification of the soils.
- v. Preparing soil map of the town.

1.3. Methodology

Eleven representative areas are selected by visual classification of the soil. From the selected areas, representative disturbed and undisturbed soil samples were collected from test pits by excavating manually to an average depth of 1.5m and 3m. Then these samples were taken to the laboratory and the following routine tests are performed

- Specific gravity test
- Moisture content test
- Consistency (Atterberg) limit test
- Grain size distribution test
- Free swell test
- UCS (unconfined compressive strength test)
- One dimensional consolidation test
- The tests were done according to ASTM standard.

1.4. Organization of the thesis work

The thesis consists of six chapters. The first chapter is introductory part which incorporates background of the study, objective and methodology of the work. The second chapter reviews the related literature on soil in general and expansive soil, soil properties, geotechnical investigation, characterization and classification of soil in particular. The third chapter deals with site descriptions; climate, and geology location of the town. The fourth chapter discusses the in-situ properties and laboratory test results. Chapter five describes the preliminary soil map of Worabe town and comparison of test results with the previously done work researches. The conclusion and recommendations are made in the last chapter of the report.

2. Literature Review

2.1. General

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

The variety of soils is very wide and it is probably true to say that no two sites have identical soil conditions.

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

Soil is a heterogeneous material. The properties and characteristics of soils vary from place to place laterally or vertically. 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. The properties of soils which are not of primary interest to the geotechnical engineer but which are indicative of the engineering properties are called index properties [1]. According to Punimia, the index properties of soils are water content, specific gravity, particle size distribution, consistency limits, in-situ density, free- swell and density index.

In nature, soils occur in a large variety. However, soils exhibiting similar behavior can be grouped together to form a particular group. Engineers are continually searching for simplified tests that will increase their knowledge of soils beyond that which can be gained from visual examination

without having to resort to the expense, detail, and precision required with engineering properties tests. These simplified tests provide indirect information about the engineering properties of soils and are, therefore, called index tests.

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

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 and biological decomposition. The properties of the soil materials depend upon the properties of the rocks from which they are derived.

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.

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. The main factors affecting the formations of soil are: Parent materials i.e. geology of the area, topography and drainage, climate and vegetation cover.

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.

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.

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.

According to Van's Hoff's principle the velocity of a chemical reaction increases by a factor of 2 or 3 for every 10 °c rise of temperature [6].

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.

2.3. General Types of Soils

According USCS classification based on 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 0.075mm. 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.

2.3.1. 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 quartz. Some sands contain a fairly high percentage of mica flakes that give them the property of elasticity. 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. 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.

2.3.2. Soil mineralogical composition

Mineral particles are inorganic materials derived from rocks and minerals. They are extremely variable in size and composition.

Primary minerals: present in original rock from which soil is formed. These occur predominantly in sand and silt fractions, and are weathering resistant (quartz, feldspars).

Secondary minerals: formed by decomposition of primary minerals, and their subsequent weathering and re-composition into new ones (clay minerals). Humus or organic matter (decomposed organic materials).

Generally the behaviors of soils are strongly dependent on the above factors.

2.4. 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 others measure "index properties" which provide useful information about the soil without directly measuring the property desired.

2.4.1. Atterberg limits

Albert Atterberg (1911), a Swedish agricultural engineer, described a suite of tests that might be performed to determine the water contents at which the character of the mechanical behavior of a clay went through various transitions (Wood, 1990). It defines the boundaries of several states of consistency for plastic soils. The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. The boundaries are called the plastic limit and the liquid limit, and the difference between them is called the plasticity index. The shrinkage limit is also a part of the Atterberg limits (Arora et al, 2007).

The results of this test can be used to help predict other engineering properties. Water content greatly affects the engineering behavior of fine-grained soils. In the order of increasing moisture content (see Figure below), a dry soil will exist into four distinct states: from solid state, to semisolid state, to plastic state, and to liquid state. The water contents at the boundary of these states are known as Atterberg limits. Between the solid and semisolid states is shrinkage limit, between semisolid and plastic states is plastic limit, and between plastic and liquid states are liquid (Arora et al, 2007).

Atterberg limits, then, are water contents at critical stages of soil behavior. They, together with natural water content, are essential descriptions of fine grained soils.

Liquid limit is the water content of soil in which soil grains are separated by water just enough for the soil mass to loss shear strength. A little higher than this water content will tend the soil to flow like viscous fluid while a little lower will cause the soil to behave as plastic (Arora et al, 2007).

Plastic limit on the other hand is the water content in which the soil will pass from plastic state to semi-solid state. Soil can no longer behave as plastic; any change in shape will cause the soil to show visible cracks. Shrinkage limit is the water content in which the soil no longer changes in volume regardless of further drying. It is the lowest water content possible for the soil to be completely saturated. Any lower than the shrinkage limit will cause the water to be partially saturated. This is the point in which soil will pass from semi-solid to solid state (Arora et al, 2007).

Arora also states that Plasticity index, PI is the range of water content over which the soil remains in the plastic state. It is the numerical difference between the liquid limit and plastic limit.

Liquidity index: the liquidity index of a soil indicates the nearness of its water content to its liquid limit. When the soil is at its liquid limit, its liquidity index is 100% and it behaves as a liquid. When the soil is at the plastic limit, its liquidity index is zero, negative values of the liquidity index indicate a water content smaller than the plastic limit. The soil is then in a hard (deshicated) state (Arora et al, 2007). It expressed as a percentage, of the natural water content of a soil minus its plastic limit, to its plasticity index:

$$IL = \frac{w-wp}{Ip} * 100$$

Where w= water content of soil in natural condition.

Liquidity index \geq 100%..... Soft soil

Liquidity index = 0%..... Stiff soil

Liquidity index $<$ 0%..... Very stiff soil

2.4.2. Specific gravity

The term specific gravity of soil actually refers to the specific gravity of the solid matter of the soil, which is designated Gs. The specific gravity of solids is normally only applied to that fraction of a soil that passes the No. 4 sieve. Generally, geotechnical engineers need the soil's specific gravity to perform additional testing of that soil. 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 (Das, 2007).

The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.90.

Sand particles composed of quartz have a specific gravity ranging from 2.64 to 2.66.

Inorganic clays generally range from 2.70 to 2.90.

Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) have specific gravities below 2.60. Some range as low as 2.00.

2.4.3. Particle-size distribution

In any soil mass, the sizes of the grains vary greatly. To classify a soil property grain size distribution is required. The grain size distribution of coarse grained soil is generally determined by means of sieve analysis. For a fine grained soil, the grain size distribution can be obtained by means of hydrometer analysis (Murthy, 2003).

In general, a soil sample may contain both coarse grained particles as well as fine particles and hence both sieve and hydrometer analysis may be necessary. The sieve analysis is, however, is the true representative of grain size distribution, since the test is not affected by temperature.

The complete sieve analysis can be divided into two parts- the coarse analysis and fine analysis. An oven dried sample of soil is separated into two fractions by sieving I through a 4.75mm sieve. The portion retained on it is termed as the gravel fraction and is kept for the coarse analysis, while the portion passing through it is subjected to fine sieve analysis. The following sets of sieves are used for coarse sieve analysis: ASTM 75, 50, 38, 25, 19, 12.5, 9.5 and 4.75mm. The sieves used for fine sieve analysis are: 2mm, 1mm, 0.6, 0.425, 0.3, 0.15 and 0.075mm ASTM sieves (Punmia, 2006).

Sieving is performed by arranging the various sieves one over the other in the order of their mesh openings. The larger aperture sieve being kept at the top and the smallest aperture sieve at the bottom. The receiver is kept at the top of the whole assembly. The soil sample is put on the top sieve, and the whole assembly is fitted on a sieve shaking machine. At least 10min. of shaking is desirable for soils with small particles. The portion of the soil sample retained on each sieve is calculated on the basis of the total mass of soil sample taken and from these results, percentage passing through each sieve is calculated (Punmia , 2006).

Sieve analysis is a simple but proven method of separating bulk materials of all kinds into size fractions and to ascertain the particle size and distribution through weighing the single fractions. Usually, sieving processes are carried out on dry material. However, when dry sieving cannot produce an adequate degree of separation between the individual fractions and even sieving aids cannot improve the quality, wet sieving is called for (Punmia ,2006).

The objective of the wet sieve test is to separate finer materials which are sticks to the larger particles and to obtain basic index information about the soil which can be used to estimate strength and permeability. It is the primary form of classification for granular soils (Das, 2007).

Hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the No. 200 (0.075 mm) sieve to around 0.01 mm. The method is based on Stokes' Law, according to which the velocity at which grains settle out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grain. However in the usual analysis it is assumed that the soil particles are spherical and have the same specific gravity (Average specific gravity), with this assumption, the coarser particles settle more quickly than the finer ones (Punmia et al, 2006).

The result of particle size analysis are plotted to get a particle size distribution curve with the percentage finer as the abscissa, the diameter being plotted on a logarithmic scale. A particle size distribution curve give as an idea about the type and gradation of the soil. A curve situated higher up or to the left represents a relatively fine grained soil while a curve situated to the right represents a coarse grained soil (Punmia et al, 2006).

2.4.4. Free Swell

The free swell test is one of the most commonly used simple tests in the field of geotechnical engineering for getting an estimate of soil swelling potential and to identify whether it is expansive or not. Free swell also termed as free swell index. It is the increase in volume of soil without any external constraint when subjected to submergence in water.

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:

$$\text{Free Swell}(\%) = \frac{V - V_0}{V_0}$$

Where V = the soil volume after swelling, cm^3

V_0 = The volume of dry soil, cm^3

Expansive Soils	>100% Free Swell
Marginal	50-100% Free Swell
Non expansive soil	<50% Free Swell

2.5. CLASSIFICATION OF THE SOILS

2.5.1. General

The systems that are quite popular amongst engineers are the AASHTO Soil Classification System and the Unified Soil Classification System (USCS).

A soil classification is a systematic method of categorizing soils into various groups and subgroups according to their probable engineering behavior without detailed descriptions.

It has been stated earlier that soil can be described as gravel, sand, silt and clay according to grain size. Most of the natural soils consist of a mixture of organic material in the partly or fully decomposed state. The proportions of the constituents in a mixture vary considerably and there is no generally recognized definition concerning the percentage of, for instance, clay particles that a soil must have to be classified as clay, etc.

When a soil consists of the various constituents in different proportions, the mixture is then given the name of the constituents that appear to have significant influence on its behavior, and then other constituents are indicated by adjectives. Thus sandy clay has most of the properties of clay but contains a significant amount of sand.

The individual constituents of a soil mixture can be separated and identified as gravel, sand, silt and clay on the basis of mechanical analysis. The clay mineral that is present in a clay soil is sometimes a matter of engineering importance. According to the mineral present, the clay soil can be classified as Kaolinite, Montmorillonite or Illite. The minerals present in clay can be identified by either X-ray diffraction or differential thermal analysis. Buildings, bridges, dams etc. are built on natural soils (undisturbed soils), whereas earthen dams for reservoirs, embankments for roads and railway lines, foundation bases for pavements of roads and airports are made out of remolded

soils. Sites for structures on natural soils for embankments will have to be chosen first on the basis of preliminary examinations of the soil that can be carried out in the field. An engineer should therefore be conversant with the field tests that would identify the various constituents of a soil mixture.

The behavior of a soil mass under load depends upon many factors such as the properties of the various constituents present in the mass, the density, the degree of saturation, the environmental conditions etc. If soils are grouped on the basis of certain definite principles and rated according to their performance, the properties of a given soil can be understood to a certain extent, on the basis of some simple tests.

Many systems are in use that is based on grain size distribution and limits of soil.

2.5.3. Classification of soils based on AASHTO Classification system

There are seven groups of inorganic soils, A-1 to A-7 with 12 subgroups in all. The system is based on Particle-Size Distribution, Liquid Limit and Plasticity Index.

The AASHTO system uses similar techniques as that of USCS 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 this Classification system (Table 4.10, Fig 4.5) the usual types of significant constituent material is clayey soil A-7-5 and A-7-6.

2.5.4. Classification of soils based on Unified Soil Classification System (USCS)

USCS (Unified Soil Classification System) - classifies soils using grain-size, liquid limit, and plasticity index. The boundary between coarse and fine soils is taken to be 50% fines (i.e. particles smaller than 0.075 mm, No. 200 sieve). The liquid and plastic limits are used to classify fine-grained soils, employing the plasticity chart shown in Figure below (alternative).

The axes of the plasticity chart are plasticity index and liquid limit; therefore, the plasticity characteristics of a particular soil can be represented by a point on the chart. Classification letters

are allotted to the soil according to the zone within which the point lies. The chart is divided into two ranges of liquid limit, low (L) and high (H). The A-line may be mathematically represented by:

$$PL=0.73(LL-20)$$

Applies these measurements to a chart and determine group symbol. The following group symbols are used in USCS:

G Gravel	W Well graded
S Sand	P Poorly graded
M Silt	L Low liquid limit compressibility; lean (clay)
C Clay	Low liquid limit; (silts); plasticity
O Organic	H High liquid limit, compressibility; fat (clays)
PT Peat	High liquid limit; elastic (silts)

SILT (M) plots below the A-line and CLAY (C) above the A-line on the plasticity chart, i.e. silts exhibit plastic properties over a lower range of water content than clays having the same liquid limit. The letter denoting the dominant size fraction is placed first in the group symbol. Organic silts and clays (with a low to moderate organic content) have their own group symbol (O). Highly organic soils (e.g. peat) are defined by PT. A group symbol may consist of two or more letters, for example:

SW – well-graded SAND

CL – Inorganic CLAY of low plasticity

Coarse-grained soils with fines between 5% and 12% must be classified using dual symbols (i.e. describing both the grading of the coarse fraction (W or P) and the type of fines (M or C).

Similarly, fine-grained soils which plot in the shaded zone in Fig. 4.7 are described using dual symbols (CL + ML).

In the laboratory, the grain-size curve and the Atterberg limits can be used. The peaty soils are readily identified by color, odor, spongy feel and fibrous texture. This system requires liquid limit and plasticity index values of Atterberg limit test. According to the Atterberg limit test the soils classification are presented in the form of plasticity chart.

2.6. Unconfined Compression Strength (UCS) test

The Unconfined Compression Test (UCS) is a special case of the Unconsolidated Undrained Triaxial compression Test. In this case, no confining pressure is applied to the specimen. The UCS test is one of the easiest and simplest tests for a quick estimate of the shear strength of cohesive soils. The test provides an immediate approximate value of the compressive strength of the soil, either in the undisturbed or the remolded condition. It is also widely used to determine the consistency of saturated clays and other cohesive soils.

To perform an Unconfined Compression Strength test, the sample is extruded from the sampling tube. A cylindrical sample of soil is trimmed such that the ends are reasonably smooth and the length-to-diameter ratio is on the order of two. The soil sample is placed in a loading frame on a metal plate; by turning a crank, the operator raises the level of the bottom plate. The top of the soil sample is restrained by the top plate, which is attached to a calibrated proving ring. As the bottom plate is raised, an axial load is applied to the sample. The operator turns the crank at a specified rate so that there is constant strain rate. The load is gradually increased to shear the sample, and readings are taken periodically of the force applied to the sample and the resulting deformation.

The loading is continued until the soil develops an obvious shearing plane or the deformations become excessive. The measured data are used to determine the strength of the soil specimen and the stress-strain characteristics. Finally, the sample is oven dried to determine its water content. The maximum load per unit area is defined as the unconfined compressive strength, q_u

For soils, the undrained shear strength (S_u) is necessary for the determination of the bearing capacity of foundations, dams, etc. The undrained shear strength (S_u) of clays is commonly determined from an Unconfined Compression Test. The undrained shear strength (S_u) of a cohesive soil is equal to one-half the Unconfined Compressive Strength (q_u) when the soil is under the $\phi=0$ condition (ϕ = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents undrained conditions, when the undrained shear strength is basically equal to the cohesion (c).

2.7. Direct shear test

Direct shear test is the earliest methods used to determine the shear strength parameters for both fine and coarse grained soils either in undisturbed or remolded state (Chen, 2000). The test is performed according to ASTM D 3080.

The advantages of the direct shear test over other shear tests are the simplicity of setup and equipment used, and the ability to test under differing saturation, drainage, and consolidation conditions. These advantages have to be weighed against the difficulty of measuring pore-water pressure when testing in undrained conditions, and possible spuriously high results from forcing the failure plane to occur in a specific location (Murthy et al, 2003).

2.8. Triaxial Shear test

The triaxial test is one of the most versatile and widely performed geotechnical laboratory tests, allowing the shear strength and stiffness of soil and rock to be determined for use in geotechnical design.

The advantages of the triaxial shear test over the direct shear test are (Chen et al, 2000, p. 60):

1. The stress is uniformly distributed on the failure plane.
2. Soil is free to fail on the weakest surface.
3. Water can be drained from the soil during the test to simulate actual conditions in the field.
4. A small diameter sample can be used and the sample preparation is easy.

Triaxial shear test apparatus is costly. For most foundation investigations, the uses of triaxial shear tests are not justified. The bearing pressure values can be obtained from the interpretation of the results of the unconfined compression test. Only in major projects such as earth dam construction, where the values of angle of internal friction and cohesion are critical, the triaxial shear test be conducted (Chen, 2000, p. 60).

Primary parameters obtained from the test may include the angle of shearing resistance ϕ , cohesion c , and undrained shear strength s_u , although other parameters such as the shear stiffness G , compression index C_c , and permeability k may also be determined (Arora, 2004).

There are three primary triaxial tests conducted in the laboratory, each allowing the soil response for differing engineering applications to be observed (Arora, 2004). These are:

- Unconsolidated Undrained test (UU)
- Consolidated Undrained test (CU)
- Consolidated Drained test (CD)

2.9. Consolidation test

A consolidation test, also called an odometer test, is a measurement of how soils compress when saturated with water and exposed to varying amounts of load, or varying weights of the soil. Saturated conditions exist when water is added until no more can be absorbed by the soil.

The test uses a saturated soil sample placed in a metal ring open at the top and bottom. Samples are compressed between two porous stones with increasing weights, with the height of the sample measured as the weight changes. Porous stones allow water to pass through them while maintaining strength to resist the testing load. Water is added to the soil during the test to maintain a fully saturated soil (Das, 2007).

As the soil is placed under a load, the water is forced out of voids or gaps in the soil structure. The consolidation test measures how the soil compacts as the water is forced out. This test is important because building foundations may not be deep enough to reach bedrock, or rock layers may not be present where construction will take place (Das, 2007).

Based on the laboratory tests, a graph can be plotted showing the variation of the void ratio e at the end of consolidation against the corresponding vertical effective stress σ' . (On semi logarithmic graph, e is plotted on the arithmetic scale and σ' on the log scale). From the $e - \log \sigma'$ curve, three parameters necessary for calculating settlement in the field can be determined (Arora, 2004):

- The Preconsolidation pressure, P_c , is the maximum past effective overburden pressure to which the soil specimen has been subjected. It can be determined by using a simple graphical procedure proposed by Casagande (1936).

Natural soil deposits can be normally consolidated or over consolidated (preconsolidated). If the present effective overburden pressure $P = P_o$ is equal to the preconsolidated pressure P_c the soil is normally consolidated. However, if $P_o > P_c$, the soil is over consolidated.

A normally consolidated soil is one which had not been subjected to a pressure greater than the present existing pressure. A soil is said to be over-consolidated if it had been subjected in the past to a pressure in excess of the present pressure.

The maximum pressure to which an over-consolidated soil had been subjected in the past divided by the present pressure is known as the over consolidation ratio (O.C.R).

- ii)* Compression Index, C_c – is equal to the slope of the linear portion of the void ratio versus $\log \sigma$ plot. It is extremely important to determine the settlement in the field.

The value of C_c normally varies between 0.30 for highly plastic clays and 0.075 for low plastic clays.

- iii)* The swelling index, C_s – is the slope of unloading portion in the $e - \log \sigma$ curve. The determination of this parameter is important in the estimation settlement of over consolidated clays.

3. Description of the study area

3.1.GENERAL

Worabe town is the administrative center of the zone which is found 173 km from Addis Ababa. The town is located in the Gurage zone of the southern nations, nationalities and peoples region (SNNPR). The geographical location of Worabe town is 8°1'N and 38°20'E with an elevation of 2113 meters above sea level.

3.2. HYDROGEOLOGY

3.2.1. CLIMATE

The temperature and the rainfall conditions of the study area generally vary with elevation. No climatic data is available for Worabe town. For this reason, the climatic data of stations which are not far distant and not much different in elevation may serve as approximations for the situation at the study sites. The data for Butajira is used to show the climatic conditions in Worabe town.

The mean monthly rainfall data for the area shows that summer experiences greater amount of rainfall. The annual average rainfall over the 15-year period for Butajira is 1200.5 mm. Like many area in the country, November, December, January and February are months with the lowest amounts of moisture. The annual average temperature for Butajira is 18.8°C, and all the mean monthly temperatures are not much different.

The Mean monthly rainfall and mean monthly temperatures for Butajira (1986–2003) are shown in the Table3.1.

Table3.1. Mean monthly rainfall and mean monthly temperatures for Butajira (1986–2003)

Month	Butajira	
	Mean monthly rainfall (mm)	Mean monthly temp (°C)
January	32.1	18.7
February	80.6	19.2
March	152.1	19.6
April	143.8	19.5
May	104.0	19.6
June	145.6	18.7
July	171.6	17.4
August	161.5	18.1
September	117.5	18.9
October	48.0	19.1
November	11.6	19.2
December	19.1	17.6

3.2.2. Geology

Worabe town is located near Central Main Ethiopian Rift of Ethiopia. The Average elevation of the region is over 2113m above sea level. Fig 3.1-Fig 3.2 shows the location map of Worabe.

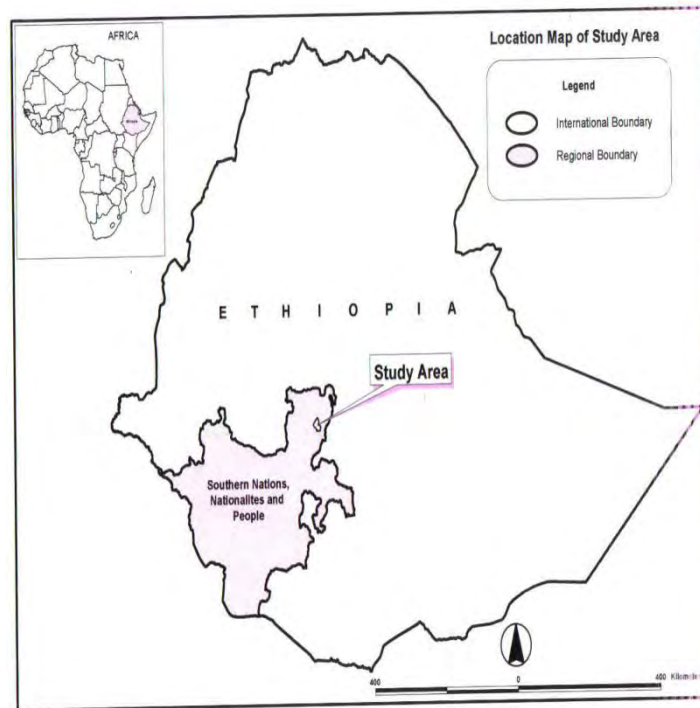


Figure 3.1 Location Map of Worabe town from map of Ethiopia



Figure 3.2 Location Map of Worabe town from SNNP region

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 in order to consider the different soil types and to take representative samples evenly. Accordingly, eleven sampling areas (Fig. 4.1) were selected from different locations of the town. Pits were excavated to a maximum depth of three meters. Both disturbed and undisturbed soil samples were collected. In the field visual soil description was made and samples were collected for laboratory testing.

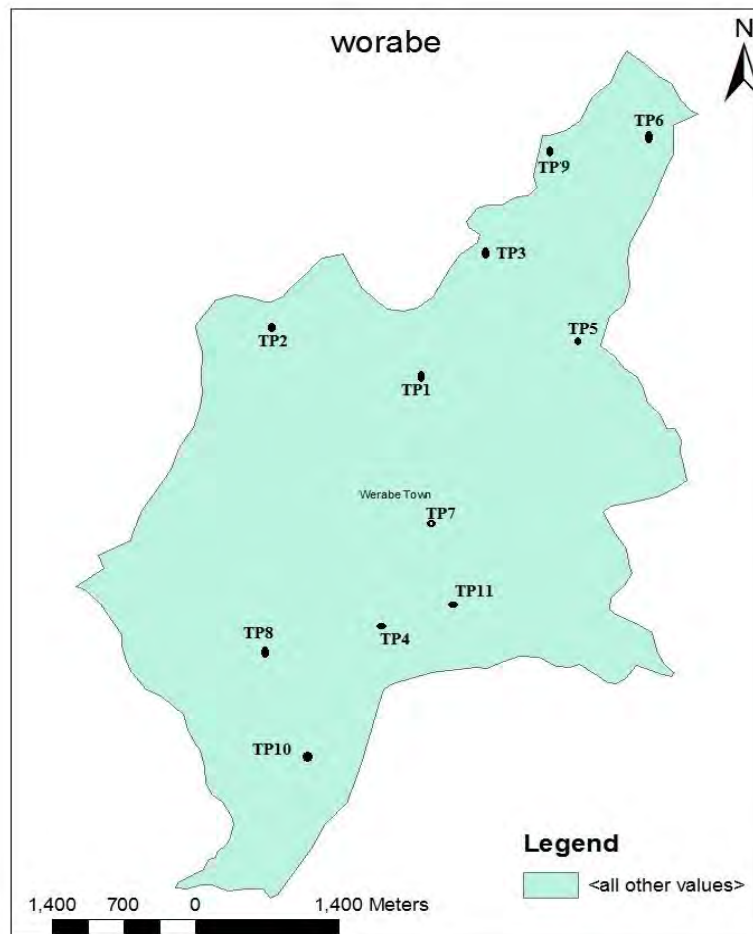


Fig. 4.1 Location of Test pits shown on map of Worabe town.

The global coordinates of sampling location are shown in Table 3.2.

Table 3.2. Global coordinates of sampling areas

Test Pit	Location	Northing	Easting	Elevation (m)
TP-1	Near Riyad Hotel	07°51'N	38°11'E	2082
TP-2	Near Worabe Prison	07°51'N	38°10'E	2107
TP-3	Near Ja'afar Mosque	07°51'N	38°11'E	2085
TP-4	Worabe Stadium	07°50'N	38°11'E	2098
TP-5	Worabe Municipality	07°50'N	38°11'E	2076
TP-6	Way to Dalocha	07°52.192'N	38°12.218'E	2094
TP-7	Umer Mosque (Limaza)	07°50.715'N	38°11.218'E	2088
TP-8	worabe Referral Hospital	07°50.046'N	38°10.846'E	2098
TP-9	Dijo Ber	07°52.217'N	38°11.871'E	2085
Tp10	Around Duna Mosque	07°49.862'N	38°10.760'E	2103
Tp11	Duna primary School	07°50.211'N	38°11.294'E	2091

The test pits are varied in colors and physical properties along the depth in visual inspection. Samples taken for the investigation are shown in fig 4.2.



Fig. 4.2. Some Pictures of soil taken for the investigation.

4.2. INDEX PROPERTIES

4.2.1. General

All bulk soils, as used in soil engineering, are composed of solids plus air or water or both air and water. The properties of soils are complex and variable. Every civil engineering work involves the determination of soil type and its 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 [6].

Basic soil properties and parameters can be subdivided into physical, index, and engineering categories. Physical soil properties include particle size and distribution, specific gravity, and water content. Index parameters of cohesive soils include liquid limit, plastic limit, shrinkage limit, and activity. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties [11].

4.2.2. Natural Moisture Content

The samples are collected at two different seasons. Samples from test pit one to test pit five are collected at a month of January and the remaining samples are collected during October.

The results of the Natural Moisture Content in the study area range from 22.6% to 57.5%.

Table 4.1. Shows the natural moisture content of all samples.

Table 4.1: Natural moisture content of samples

Designation	Depth(m)	Natural Moisture Content (%)
TP1	1.5	29.07
	3	49.13
TP2	1.5	30.66
	3	22.56
TP3	1.5	42.52
	3	49.10
TP4	1.5	46.58
	3	49.01
TP5	1.5	51.88
	3	39.63
TP6	1.5	26.39
	3	30.09
TP7	1.5	33.79
	3	37.59
TP8	1.5	25.28
	3	49.96
TP9	1.5	48.34
	3	37.94
TP10	1.5	50.68
	3	55.24
TP11	1.5	57.51
	3	27.64

4.2.3. Specific Gravity

Specific gravity is a measure of the actual particles which make up the soil mass and is defined as the ratio between the mass of dry solids and the mass of distilled water displaced by the dry soil particles. It is rarely possible to use specific gravity as an index for soil classification. But knowledge of the specific gravity is essential in relation to other soil tests, especially for

calculating porosity and void ratio, and particularly important when compaction and consolidation properties are considered.

For the study area the specific gravity of the samples is determined using ASTM D 854-00 (ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer) and the results are given in Table 4.2. In the study area the specific gravity of soil ranges from 2.65 to 2.85.

Table 4.2 Specific gravity of the soil of the Study Area

Serial No	Designation	Depth(m)	Specific Gravity
1	TP1	1.5	2.75
2		3	2.68
3	TP2	1.5	2.79
4		3	2.72
5	TP3	1.5	2.78
6		3	2.67
7	TP4	1.5	2.84
8		3	2.70
9	TP5	1.5	2.82
10		3	2.81
11	TP6	1.5	2.65
12		3	2.71
13	TP7	1.5	2.79
14		3	2.81
15	TP8	1.5	2.75
16		3	2.77
17	TP9	1.5	2.85
18		3	2.65
19	TP10	1.5	2.85
20		3	2.81
21	TP11	1.5	2.73
22		3	2.65

4.2.4. Grain-Size Distribution of soil

4.2.4.1. General

The objective of a particle size analysis is to group these particles in to separate ranges of sizes, and so determine the relative proportions, by dry weight, of each size range.

Gradation of soils in the study area varies considerably (Table 4.3, Figure 4.3 and Figure 4.4).

From the grain size analysis result, clay content ranges from 36.94% to 72.73% and silt fraction ranges between 27.9% and 54.21%.

Table 4.3. Summary of grain size analysis test result

Depth	1.5m				3.0m			
Designation	Percent amount of particle Size				Percent amount of particle Size			
	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Tp1	0.1	18.4	38.5	43.0	0.0	7.3	26.0	66.7
Tp2	0.0	6.6	20.6	72.7	0.7	66.7	27.1	5.5
Tp3	0.5	11.8	30.1	57.6	0.4	20.7	41.6	37.4
Tp4	0.5	4.3	29.4	65.9	0.0	8.6	54.2	37.1
Tp5	5.0	9.4	37.1	48.5	0.1	4.5	53.0	42.4
Tp6	0.2	9.8	39.2	50.8	0.8	14.7	45.7	38.9
Tp7	2.1	34.0	39.4	24.5	0.1	28.0	27.9	44.0
Tp8	0.2	17.7	21.9	60.2	0.7	57.1	19.3	22.8
Tp9	1.5	36.4	25.2	36.9	0.9	52.4	21.4	25.3
Tp10	0.7	21.0	24.5	53.8	0.1	38.8	26.9	34.3
Tp11	0.0	61.1	22.4	16.6	0.6	46.5	17.3	35.6

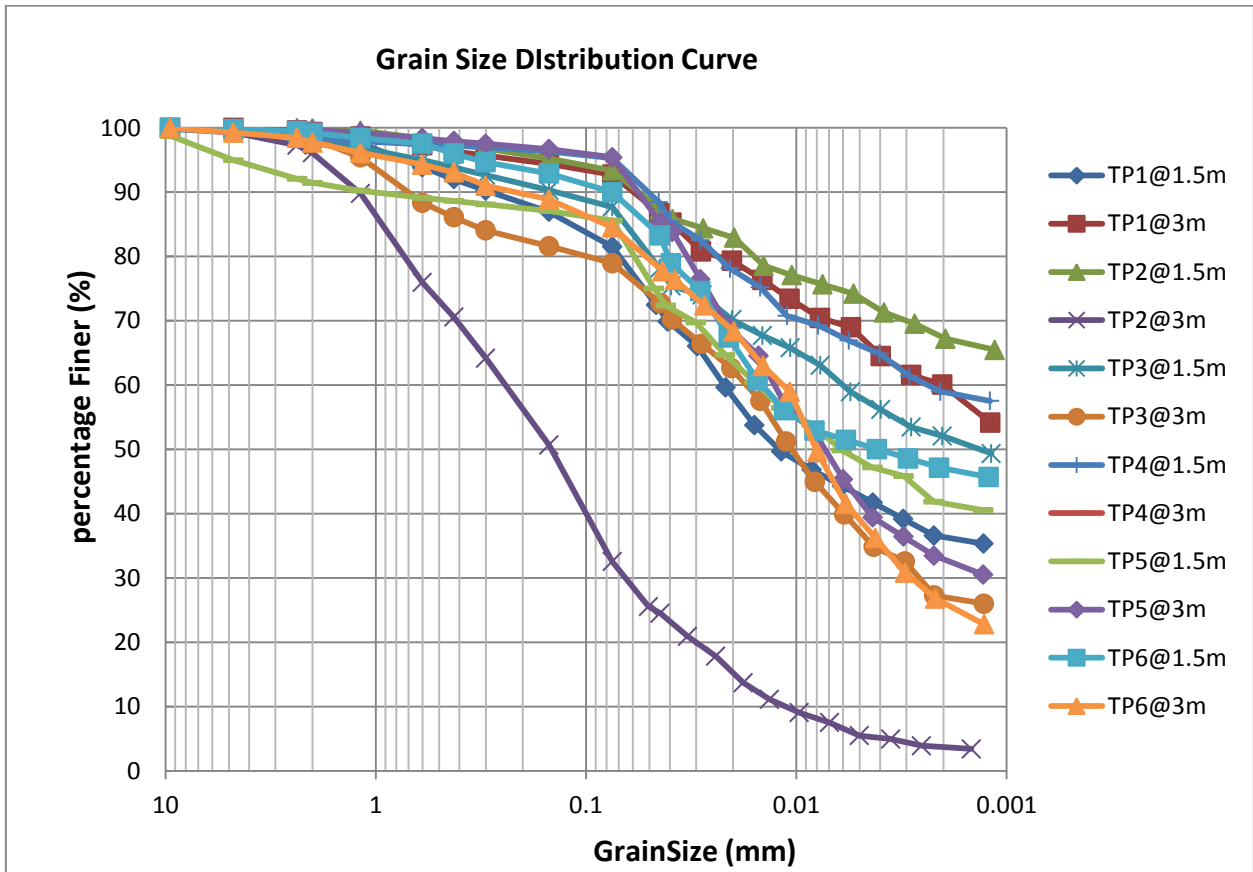


Fig 4.3 Grain size distribution curve for samples from TP1 to TP6

The grain size distribution curve for samples which are taken from TP1 to TP6 (Fig 4.3) indicates that the majority of the soils are clay and silt except samples taken from near Worabe Prison (TP2 at a depth of 3m) which is sand that consists of 0.7% gravel, 27.1% silt, 5.5% clay and 66.7% sand.

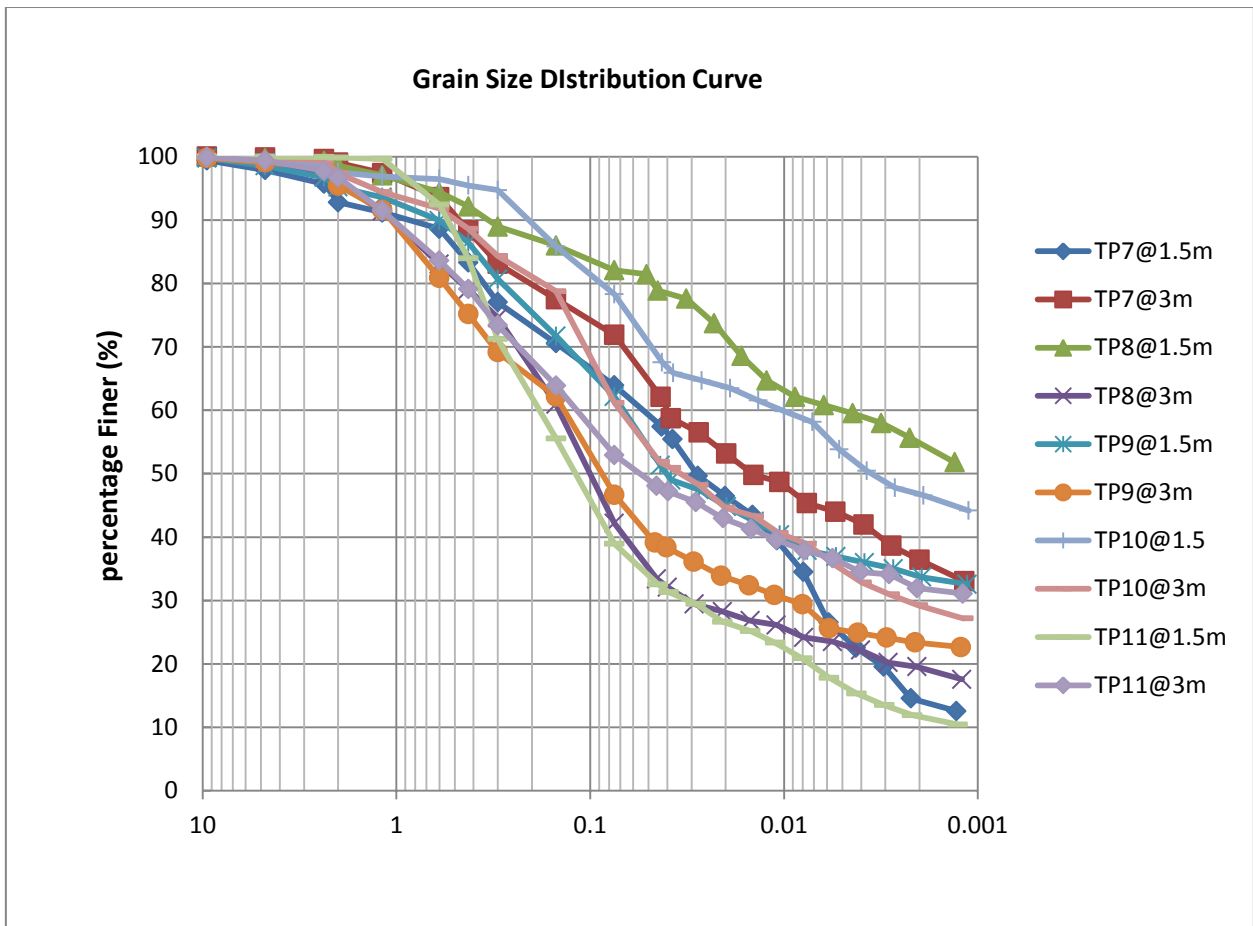


Fig 4.4 Grain size distribution cure for samples from TP 7 to TP11

4.2.5. Atterberg Limits

4.2.5.1. General

The Atterberg limits define the boundaries of several states of consistency for plastic soils. The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. The boundaries are called the plastic limit and the liquid limit, and the difference between them is called the plasticity index. The shrinkage limit is also a part of the Atterberg limits.

The Atterberg Limits Worabe soils are summarized in Table 4.4. From this we can observe that Liquid Limit ranges from 49.5%–131%, Plastic Limit ranges from 15%–49.3% and Plastic Index from 15%–90%.

Table4.4. Summary of Atterberg Limit Results

Depth	1.5m			3.0m		
Designation	Atterberg Limits					
	LL(%)	PL(%)	PI(%)	LL(%)	PL(%)	PI(%)
Tp1	59.1	24.8	34.3	116.5	34.5	82.0
Tp2	125.2	35.2	90.0	NA	NA	NA
Tp3	103.8	31.8	72.0	70.8	43.4	27.4
Tp4	131.3	49.3	82.0	54.1	39.1	15.0
Tp5	99.5	39.5	60.0	71.1	37.1	34.0
Tp6	68.9	28.9	40.0	68.6	34.9	33.7
Tp7	68.8	35.8	33.0	81.0	28.9	52.1
Tp8	68.5	23.2	45.3	NA	NA	NA
Tp9	49.5	15.0	34.5	NA	NA	NA
Tp10	103.1	32.3	70.8	69.0	25.4	43.6
Tp11	NA	NA	NA	67.3	19.1	48.2

4.2.6. Activity of Clay

Plasticity index and activity is shown in Table4.5. According to Table 4.5, Samples collected from test pit seven (TP7) at a depth of 1.5m is highly active clays and soil samples which are taken from TP4 at a depth of three meter are inactive clays. Samples from the remaining test pits are either active clays or normal clays except from test pit 2 and test pit 8 at a depth of 3m and at test pit 11 at a depth of 1.5m which are sands.

Table 4.5: Plasticity index and Activity

Designation	Depth	PI (%)	Clay particles, < 0.002, %	Activity, A	Degree of Activity
Tp1	1.5	34.3	26.61	1.29	Active Clays
	3	82.0	60.08	1.36	Active Clays
Tp2	1.5	90.0	67.2	1.34	Active Clays
	3	NA	3.98	NA	NA
Tp3	1.5	72.0	52.08	1.38	Active Clays
	3	27.4	27	1.01	Normal Clays
Tp4	1.5	82.0	59	1.39	Active Clays
	3	15.0	28	0.54	Inactive Clays
Tp5	1.5	60.0	41.5	1.45	Active Clays
	3	34.0	33	1.03	Normal Clays
Tp6	1.5	40.0	47.1	0.85	Normal Clays
	3	33.7	26.3	1.28	Active Clays
Tp7	1.5	36.0	14	2.57	Highly active Clays
	3	52.1	36.4	1.43	Active Clays
Tp8	1.5	45.3	55	0.82	Normal Clays
	3	NA	19.5	NA	NA
Tp9	1.5	34.5	33.6	1.03	Normal Clays
	3	NA	23.38	NA	NA
Tp10	1.5	70.8	46.6	1.52	Active Clays
	3	43.6	29.25	1.49	Active Clays
Tp11	1.5	NA	12.2	NA	NA
	3	48.2	31.9	1.51	Active Clays

4.2.7. Free Swell

From the test result one can see that the free swell of the soil under investigation ranges from 30% to 145%. Those soils having a free swell less than 50% are considered as non-expansive and soils having a free swell between 50% and 100% are marginal and those having more than 100% are Expansive soils. Hence most of the soils found in Worabe town are Expansive Soils. Three samples are below 50%, seven samples are between 50% to 100% and eight samples are above 100%. The result of free swell values of the study area is shown in Table 4.6.

Table 4.6 Result of Free Swell Tests.

Designation	Depth(m)	FREE SWELL(%)
TP1	1.5	30
	3	95
TP2	1.5	85
	3	NA
TP3	1.5	94
	3	45
TP4	1.5	145
	3	35
TP5	1.5	120
	3	65
TP6	1.5	103
	3	65
TP7	1.5	109
	3	115
TP8	1.5	95
	3	NA
TP9	1.5	55
	3	NA
TP10	1.5	118
	3	125
TP11	1.5	NA
	3	105

4.3. CLASSIFICATION OF THE SOILS

4.3.1. General

The systems that are quite popular amongst engineers are the AASHTO Soil Classification System and the Unified Soil Classification System (USCS).

4.3.2. Classifications of soils based on AASHTO Classification system

The AASHTO classification system is generally used by highway engineers for classification of sub-grade soils for pavement design and it classifies soils based on grain size distribution test, liquid limit test and plastic limit test. Based on these tests results soils of Worabe town are grouped under A-7-5 and A-7 -6 as it can be seen in Fig 4.5. Thus, these are not suitable for using as a sub grade material.

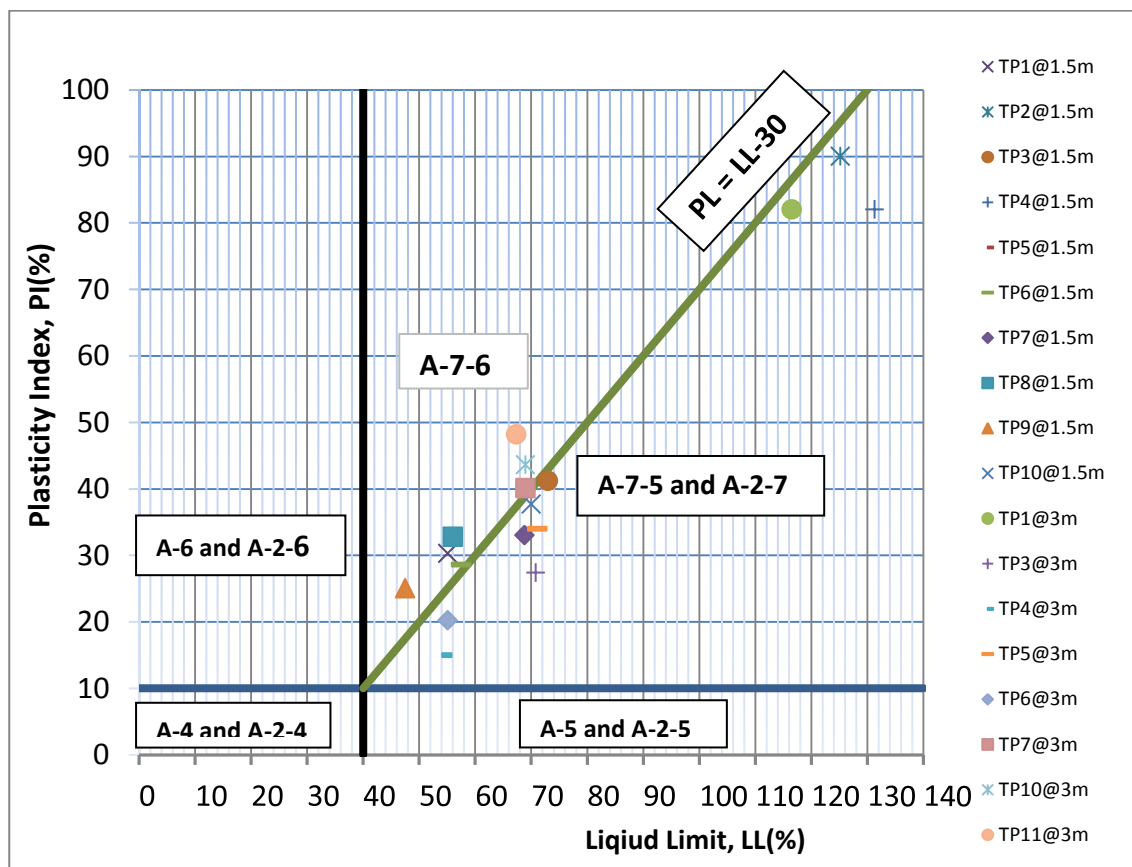


Fig. 4.5 Plasticity chart of soil in the study area according to AASHTO classification system

Classification of soils based on AASHTO classification is given in Table 4.7.

Table 4.7 Classifications of soils based on AASHTO Classification system

Serial No	Test pit Designation	LL (%)	PI (%)	Group Classification	Usual types of significant constituent materials	General rating as sub-grade materials
1	TP1@ 1.5m	59.1	34.29	A-7-6	Clay soils	poor
2	TP1@ 3.0m	116.5	82	A-7-5	Clay soils	poor
3	TP2@ 1.5m	125.2	90	A-7-5	Clay soils	poor
4	TP2@ 3.0m	NA	NA	A-3	Sand	Good
5	TP3@ 1.5m	103.8	72	A-7-5	Clay soils	poor
6	TP3@ 3.0m	70.8	27.4	A-7-5	Clay soils	poor
7	TP4@ 1.5m	131.3	82	A-7-5	Clay soils	poor
8	TP4@ 3.0m	54.1	15	A-7-5	Clay soils	poor
9	TP5@ 1.5m	99.5	60	A-7-5	Clay soils	poor
10	TP5@ 3.0m	71.1	34	A-7-5	Clay soils	poor
11	TP6@ 1.5m	68.9	40	A-7-6	Clay soils	poor
12	TP6@ 3.0m	68.6	33.75	A-7-5	Clay soils	poor
13	TP7@ 1.5m	71.8	36	A-7-5	Clay soils	poor
14	TP7@ 3.0m	81	52.08	A-7-6	Clay soils	poor
15	TP8@ 1.5m	68.5	45.3	A-7-6	Clay soils	poor
16	TP8@ 3.0m	NA	NA	A-3	Sand	Good
17	TP9@ 1.5m	49.5	34.5	A-7-6	Clay soils	poor
18	TP9@ 3.0m	NA	NA	A-3	Sand	Good
19	TP10@ 1.5m	103.1	70.81	A-7-5	Clay soils	poor
20	TP10@ 3.0m	69	43.6	A-7-6	Clay soils	poor
21	TP11@1.5m	NA	NA	A-3	Sand	Good
22	TP11@3m	67.3	48.2	A-7-6	Clay soils	poor

4.3.3. Classification of soils based on Unified Soil Classification System (USCS)

According to USC classification scheme 77.3% of Worabe Soil falls in CH and MH, of which about 54.5% of the soils are CH. From the plot of plasticity chart in Figure 4.6 and the classification of soils on Table 4.8 most of the soils found in Worabe town is highly plastic inorganic clay and inorganic silt (CH and MH).

Table 4.8 Classifications of soils based on USC Classification system

Serial No	Test pit Designation	LL (%)	PI (%)	Group Classification
1	TP1@ 1.5m	59.1	34.3	CH
2	TP1@ 3.0m	116.5	82	CH
3	TP2@ 1.5m	125.2	90	CH
4	TP2@ 3.0m	NA	NA	SM
5	TP3@ 1.5m	103.8	72	CH
6	TP3@ 3.0m	70.8	27.4	MH
7	TP4@ 1.5m	131.3	82	CH
8	TP4@ 3.0m	54.1	15	MH
9	TP5@ 1.5m	99.5	60	CH
10	TP5@ 3.0m	71.1	34	MH
11	TP6@ 1.5m	68.9	40	CH
12	TP6@ 3.0m	68.6	33.7	MH
13	TP7@ 1.5m	71.8	36	MH
14	TP7@ 3.0m	81	52.1	CH
15	TP8@ 1.5m	68.5	45.3	CH
16	TP8@ 3.0m	NA	NA	SC
17	TP9@ 1.5m	49.5	34.5	CL
18	TP9@ 3.0m	NA	NA	SC
19	TP10@ 1.5m	103.1	70.8	CH
20	TP10@ 3.0m	69	43.6	CH
21	TP11@1.5m	NA	NA	SM
22	TP11@3m	67.3	48.2	CH

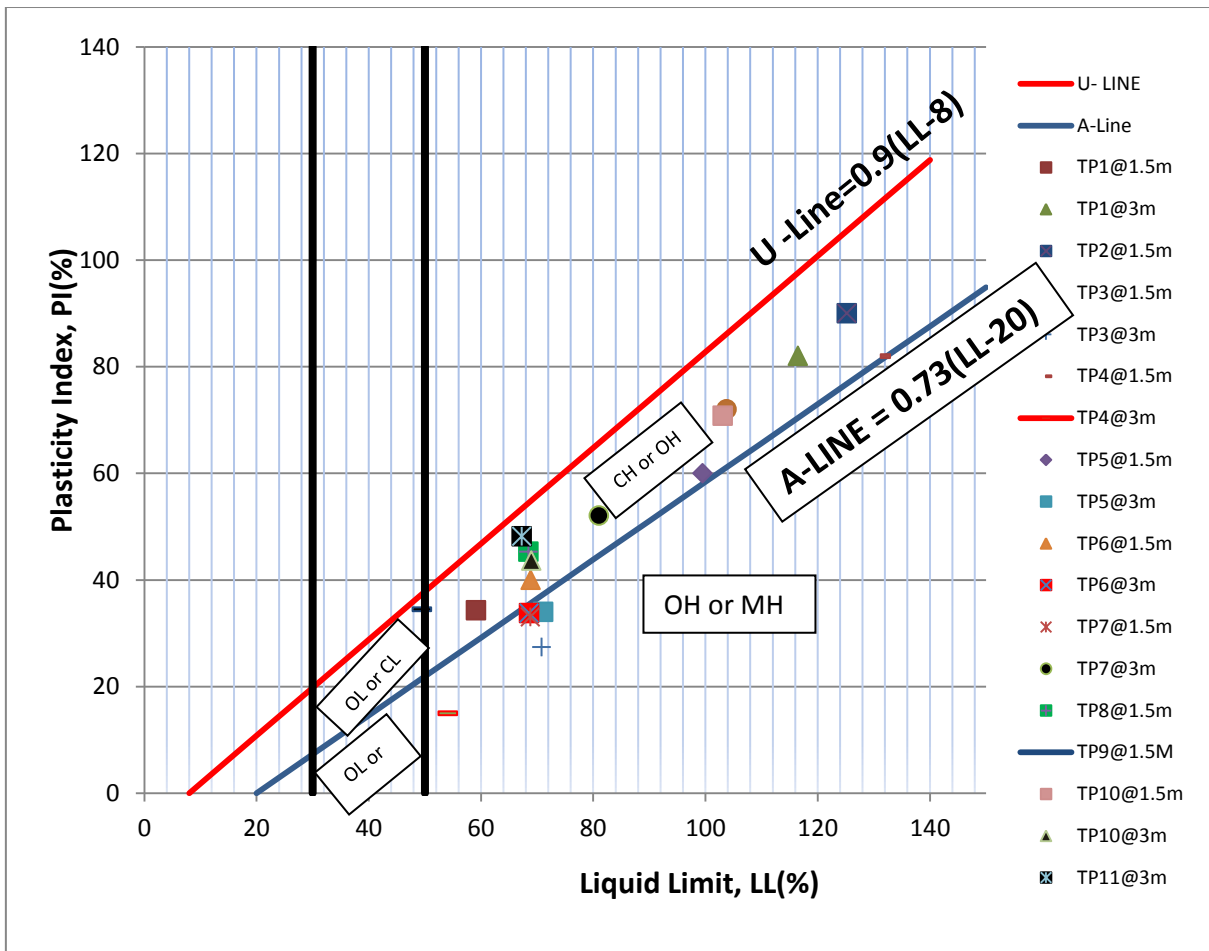


Fig 4.6 Plasticity chart of the study area according to Unified Soil Classification System

4.4. UNCONFINED COMPRESSION STRENGTH (UCS) TEST

In this study the UCS tests were carried out on five representative undisturbed samples obtained by tube sampling, from the field. The results of UCS tests are shown in Table 4.9.

Table 4.9 Summary of UCS test results

Test Pit Designation	Depth(m)	Moisture Content (%)	Unconfined Compressive Strength, C_u (kPa)	Undrained Shear Strength, S_u (kPa)
TP4	1.5	46.58	178.4	89.2
TP7	3	37.59	126.2	63.1
TP4	3	49.01	89.3	44.6
TP9	1.5	48.34	113.4	56.7
TP6	3	30.09	144.9	72.5

4.5. CONSOLIDATION

4.5.1. General

A consolidation test, also called an Oedometer test, is a measurement of how soils compress when saturated with water and exposed to varying amounts of load, or varying weights of the soil. Saturated conditions exist when water is added until no more can be absorbed by the soil.

A representative consolidation tests were run on samples of three undisturbed samples on different test pits.

The pre-consolidation pressures for the samples have been determined by Casagrande method.

The summary of consolidation results are shown in Table 4.10

Table 4.10 Summary of consolidation tests

Deignation	Test Pit Location	Description	Compression Index	Swelling Pressure, kPa	Preconsolidation Pressure, kPa	Unit Weight, kN/m ³	Overburden pressure, P _o (kPa)	O.C.R
TP4@3m	Near Worabe stadium	Non expansive, MH	0.622	-	190	17.2	51.6	3.68
TP10@3m	Around Duna Mesjid	Expansive, CH	0.567	200	300	17.2	51.6	5.81
TP11@3m	Duna primary School	Expansive, CH	0.359	400	215	12.2	36.6	5.87432

Consolidation tests are conducted after soil is classified. The test results show that expansive CH soils (TP10) had been subjected to 300kPa pressure in the past; non-expansive MH soil had been subjected to 190kPa pressure and expansive CH (TP11) soil had been subjected to 215kPa pressure. In the study area the present effective overburden pressure is greater than the pre-consolidation pressure in all cases. This indicates that the soils in the study areas are over-consolidated.

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

5.1. Preliminary Soil Map of Worabe Town

Generally, based on the results, found in the study, Worabe town soils are grouped in to four types of soils. Group I (expansive soils), Group II (non-expansive soils), Group III (marginal soils) and Group IV (sandy soils). Each Group is discussed below.

Group I: Expansive Soils

The majority of the soils found in Worabe town are expansive Soils. Soils found near Worabe Stadium (TP4), near Worabe Municipality (TP5), around Dalocha Junction (TP6), Near Umer Mosque (TP7) and Around Duna Mosque (TP10) at a depth of 1.5 meters and around Duna primary school (TP11), around Umer Mosque (TP7) and around Duna Mosque (TP10) at a depth of 3meters are expansive soils with free swell values of more than 100%. The black cotton soil found around Worabe referral Hospital (TP8) at a depth of 1.5m is also an expansive soil but has a free swell value of less than 100% which is 95%.

According to Unified soil classification, Group I soils fall under CH (highly plastic clay) except at Umer Mosque (TP7) which falls under MH (Highly Plastic Silt).

According to AASHTO soil classification, Group I soils fall under A-7-5 and A-7-6.

These soils are black in color except soils which are found around Umer Mosque (TP7) at a depth of 1.5m and 3m which are brownish and gray color respectively.

The properties of Group 1 soils are summarized in table 5. 1

Table 5.1 Engineering properties of Group I soils

Engineering Properties		Depth (m)	
		1.5	3
Specific gravity		2.65-2.85	2.65-2.81
Free Swell (%)		103-145	105-125
Atterberg Limits	Liquid Limit (%)	68.5-131.3	67.3-81.0
	Plastic Limit (%)	23.2-49.3	19.1-28.9
	Plastic Index (%)	36.0-82.0	43.6-52.1
Grain size distribution	Gravel (%)	0.2-5	0.1-0.6
	Sand (%)	4.3-34	28-46.5
	Silt (%)	21.9-39.2	17.3-27.9
	Clay (%)	24.5-65.9	34.3-44.0
Soil Classification	AASHTO	A-7-5 and A-7-6	A-7-6
	USCS	CH and MH	CH
UCS (kPa)		178.4	126.2
Swelling pressure (kPa)		-	198-400
Preconsolidation (kPa)		-	215-260
Compression Index		-	0.36-0.57

Group II: Non Expansive Soils

Soils found near Jaafer Mosque (TP3) and around Worabe Stadium (TP4), at a depth of 3 meters and soils that are found near Riyadh Hotel (TP1) at a depth of 1.5m are non-expansive soils with a free swell values less than 50%.

According to Unified soil classification, Group II soils fall under highly plastic silt (MH) and highly plastic clay (CH).

According to AASHTO soil classification, Group II soils fall under A-7-5 and A-7-6

These soils are red clay soils. Their property is shown in table 5.2.

Table 5.2 Engineering properties of Group II soils

Engineering Properties		Depth (m)	
		1.5	3
Specific gravity		2.75	2.67-2.70
Free Swell (%)		30	35-45
Atterberg Limits	Liquid Limit (%)	59.1	54.1-70.8
	Plastic Limit (%)	24.8	39.1-43.4
	Plastic Index (%)	34.3	15-27.4
Grain size distribution	Gravel (%)	0.1	0-0.4
	Sand (%)	18.4	8.6-20.7
	Silt (%)	38.5	41.6-54.2
	Clay (%)	43	37.1-37.4
Soil Classification	AASHTO	A-7-6	A-7-5
	USCS	CH	MH
UCS (kPa)		-	89.3
Swelling pressure (kPa)		-	-
Preconsolidation (kPa)		-	195
Compression Index		-	0.622

Group III: Marginal Soils

Soils found near Worabe prison (TP2), near Jaafer Mosque (TP3) and near Dijo-Ber (TP9) at a depth of 1.5m have a free swell between 50% and 100%. Soils which are found near Riyadh Hotel (TP1), near Worabe Municipality (TP5) and way to Dalocha (TP6) at a depth of 3m have also a free swell value between 50% and 100%.

According to Unified soil classification, Group III soils fall under highly plastic silt (MH), highly plastic clay (CH) and Low plastic clay (CL).

According to AASHTO soil classification, Group III soils fall under A-7-5 and A-7-6.

Their property is shown in table 5.3.

Table 5.3 Engineering properties of Group III soils

Engineering Properties		Depth (m)	
		1.5	3
Specific gravity		2.79-2.85	2.68-2.81
Free Swell (%)		55-94	65-95
Atterberg Limits	Liquid Limit (%)	49.5-125.2	68.6-116.5
	Plastic Limit (%)	15-35.2	34.5-37.1
	Plastic Index (%)	34.5-90	33.7-82
Grain size distribution	Gravel (%)	0-1.5	0-0.8
	Sand (%)	6.6-36.4	4.5-14.7
	Silt (%)	20.6-30.1	26-53
	Clay (%)	36.9-72.7	38.9-66.7
Soil Classification	AASHTO	A-7-6 and A-7-5	A-7-5
	USCS	CH and CL	MH and CH
UCS (kPa)		113.4	144.9

Group IV: Sandy Soils

These soils are found around Worabe prison (TP2), Worabe referral hospital (TP8) and at Dijo Ber (TP9) at a depth of 3meters and around Duna primary school (TP11) at a depth of 1.5meter.

According to Unified soil classification, Group IV soils fall under Silty Sand(SM) and Clayey sand (SC).

According to AASHTO soil classification, Group IV soils fall under A-3 which is Fine sand.

The properties of GroupIV soils are summarized in Table 5.4.

Table 5.4 Engineering properties of Group IV soils

Engineering Properties		Depth (m)	
		1.5	3
Specific gravity		2.73	2.65-2.77
Free Swell (%)		58	31-41
Atterberg Limits	Liquid Limit (%)	NA	NA
	Plastic Limit (%)	NA	NA
	Plastic Index (%)	NA	NA
Grain size distribution	Gravel (%)	0	0.7-0.9
	Sand (%)	61.1	52.4-66.7
	Silt (%)	22.4	19.3-27.1
	Clay (%)	16.6	5.5-25.3
Soil Classification	AASHTO	A-3	A-3
	USCS	SM	SC, SM

A Preliminary Soil map of the town is prepared at a depth of 1.5m and 3m. The map is done by extrapolating an average outward radius of half kilometer from known test pits. The radius is decided by visual inspection for the preliminary map at a depth of 1.5m. Figure 5.1 and 5.2 shows the preliminary soil map of Worabe Town. The map shows the location and type of soils on some radius away from known test pits.

Test Pits are plotted using GPS data collected during pit excavation.

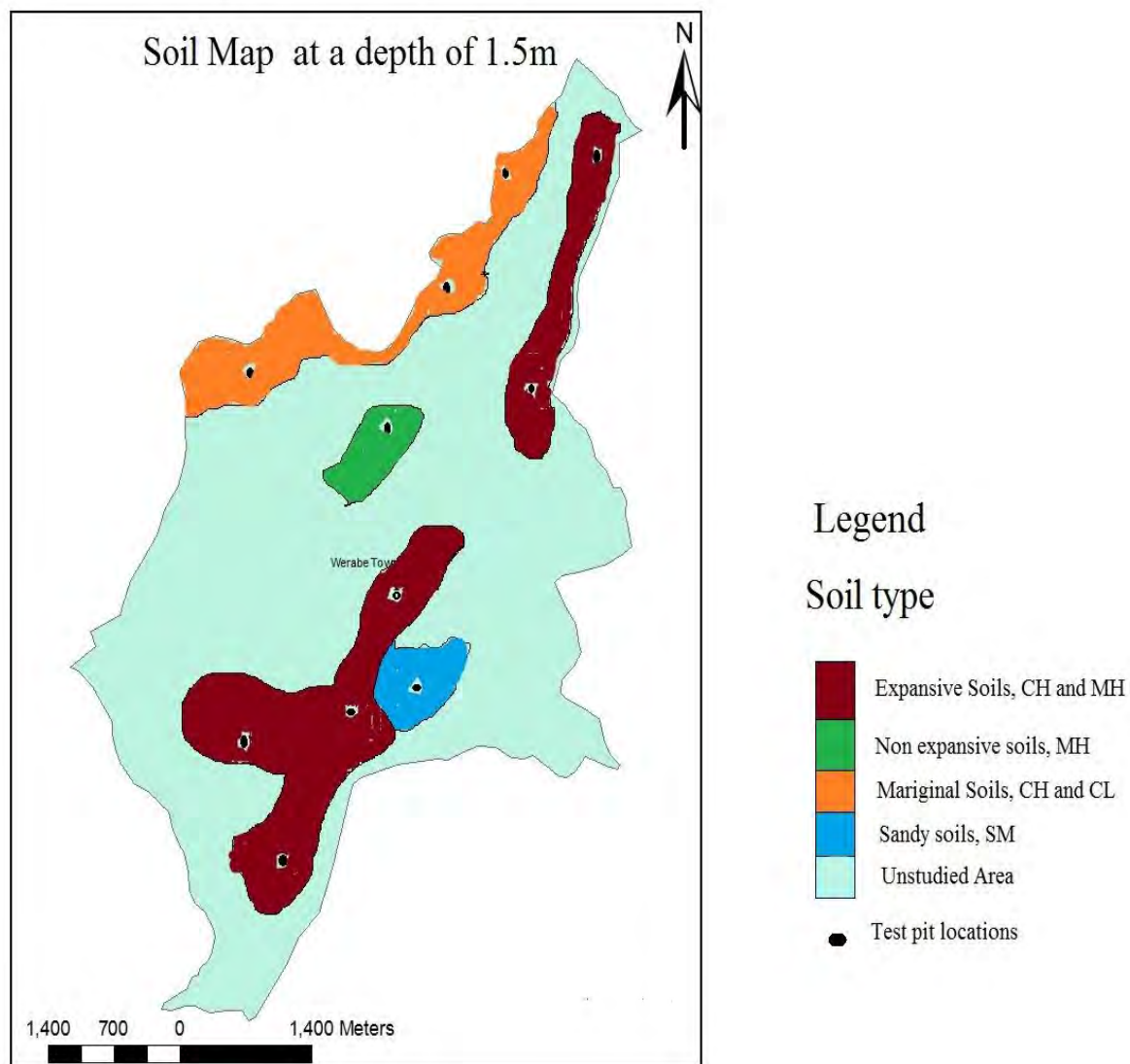


Fig.5.1.preliminary Soil map of Worabe town at a depth of 1.5m

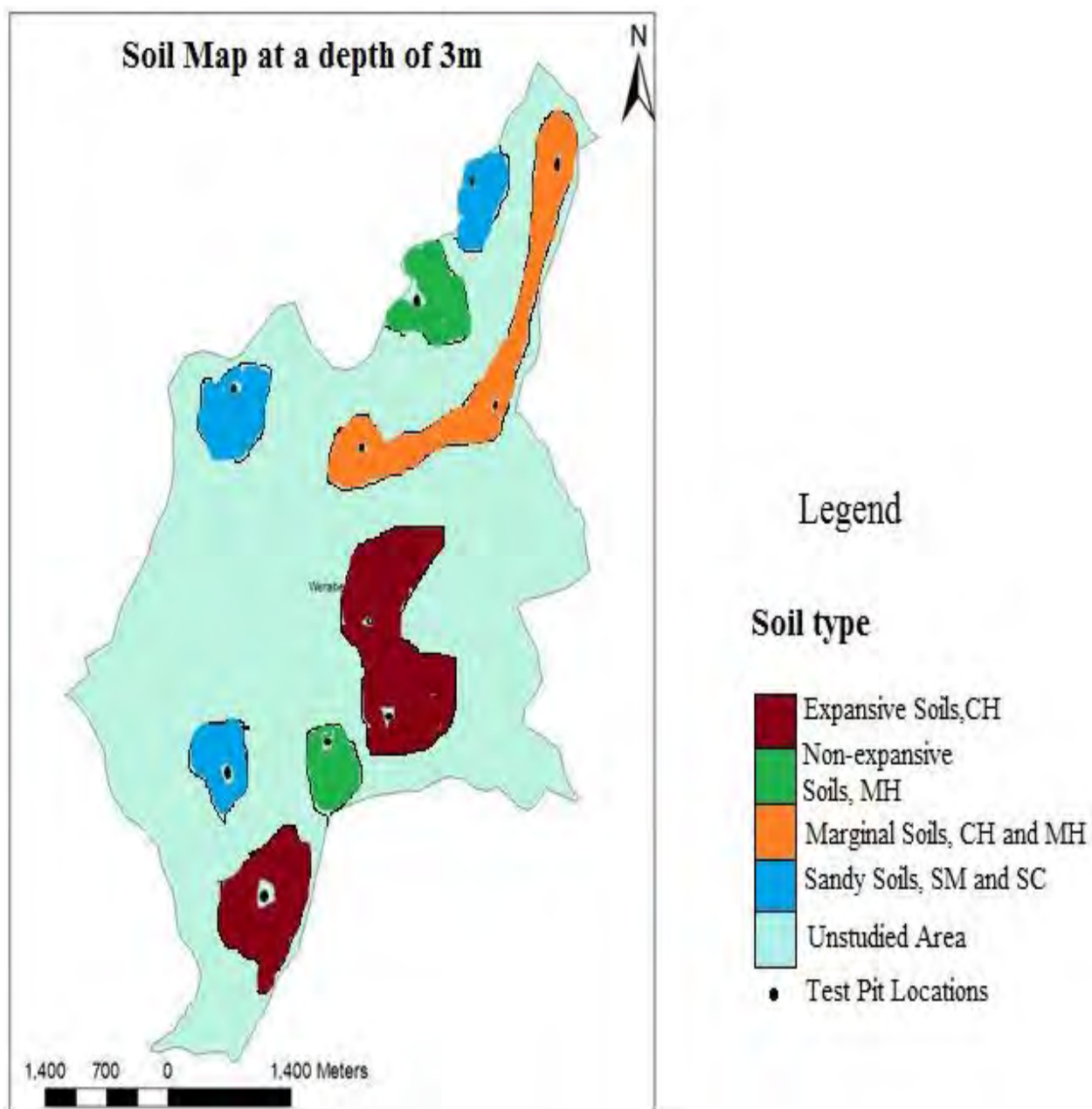


Fig 5.2. Preliminary Soil map of Worabe town at a depth of 3m.

5.2. INDEX PROPERTY TEST RESULTS IN DIFFERENT PARTS OF THE COUNTRY.

The laboratory test results of this investigation can be compared with the other research data as shown in the Table 5.5.

The Specific Gravity lies in the range between 2.65 to 2.85, Clay Content lies in the range 34.3% – 72.7%, free swell ranges between 30% - 145% and these values are similar to the results obtained by previous study carried out in Addis Ababa and other parts of the country.

The plasticity index range in this study is a little bit higher than other studies.

Table 5.5, shows the laboratory test results of previous research studies some parts of Ethiopia.

Table 5.5.Laboratory test results of previous research studies around some towns of Ethiopia

	Morin & Parry	Previous Research (Haile Mariam,1992)	Previous Research (Hanna T. 2008)	Previous Research (Samuel,1989)			Previous Research (Selamawit M, 2015)	Current Research
Soil type	Red clay	Red clay	Lateritic	Red clay			Black expansive soils	Black expansive soils
Location	Ethiopia	Addis Ababa	Wolayita-Sodo	Addis Ababa			Sebeta	Worabe
				Kolfe	Semen Gebeya	Rufael		
Clay Content (%)	34-76	48-73	48 - 70	58-70	53-68	50-70	33 – 72	34.3 – 72.7
Activity	-	-	-	-	-	-	0.35-1.25	0.54 -2.54
Liquid Limit (%)	44-66	54-81	-	61-75	57-76	56-75	38 -97	49.5 -131
Plasticity Index (%)	14-30	21-30	19 - 30	30-43	33-47	29-41	11 - 55	15-90
Shrinkage limit (%)	-	14-22	11 - 22	15-21	14-25	14-20	-	-
Free swell (%)	-	10.0-40.0	28 - 38	15-45	15-50	30-40	40 - 135	30-140
Specific gravity	2.61-2.90	2.61-2.79	2.61-2.97	2.66-2.73	2.70-2.77	2.66-2.74	2.65 – 2.86	2.65- 2.85
From plasticity chart	-	-	MH	CH	CH	CH	CH,CL& MH	MH, CH, CL,SM & SL

6. Conclusions and recommendations

6.1. CONCLUSION

1. Worabe town soils are grouped in to four types of soils. Expansive soils, non-expansive soils, marginal soils and sandy soils. Since expansive soils are poor and unsuitable as a construction material and as a subgrade material, proper measures should be done before construction. Thickness of Worabe expansive soils ranges from few centimeters to as much as 3m.
2. The grain size analysis test results showed that the dominant proportion of soil particle in the research area is Highly Plastic Clay, which have clay content ranging from 34.3% – 72.7% and silt fraction 39.4% – 54.21 %.
3. From the index property test results, specific gravity of the study area is ranging between 2.65 and 2.85.
4. The free swell value of the study area ranges from 30% to 140%.
5. From consistency limit test results the liquid limit of the area ranges 49.5% – 131%, plastic limit ranges from 14.5% – 49.3% and plastic index from 15% – 90%.
6. The values of unconfined compressive strength from UCS Test range from 89.3kPa to 178.4kPa.
7. From the one-dimensional consolidation test result, compression index, C_c , ranges from 0.359-0.622. The values of C_c indicate that the soil can easily be deformed and will have larger settlement
8. The consolidation test result shows that the soil exists naturally in a condition of over-consolidated, which has $O.C.R > 1$, therefore the soil had been subjected in the past to a pressure in excess of the present pressure.

6.2. RECOMMENDATION

In this research, the samples of soil were collected only from eleven test pits. Technically it is not possible to prepare soil map with only eleven test pits. Therefore it is recommended that further studies must be done in detail to prepare an accurate soil map of the town.

Since expansive soils dominant in Worabe town, careful site investigations, special foundation design procedures and proper post construction landscaping and maintenance are required to prevent or minimize damage in expansive soil areas.

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Appendix-A

(Laboratory Tests)

Specific Gravity Test**Sample description : TP1**

specimen number	1.5m		3m	
pycnometer bottle number	1	3	1	2
Wp = Mass of empty, clean pycnometer (grams)	45.8	49.4	49.6	45.2
Wps = Mass empty pycnometer + dry soil (grams)	71.1	74.2	62.1	58.4
WB = Mass of pycnometer + dry soil + water (grams)	160.8	164.4	156.6	152.5
WA = Mass of pycnometer + water (grams)	144.8	148.5	148.8	144.2
W0 = weight of sample of oven-dry soil, g	25.3	24.8	12.5	13.2
Specific Gravity (Gs)	2.72	2.79	2.66	2.69
Average specific Gravrity(Gs)	2.75		2.68	

Sample description : TP2

specimen number	1.5m		3m	
pycnometer bottle number	1	2	3	2
Wp = Mass of empty, clean pycnometer (grams)	45.8	45.2	49.4	45.2
Wps = Mass empty pycnometer + dry soil (grams)	72	71.2	74.6	71.6
WB = Mass of pycnometer + dry soil + water (grams)	161.6	160.9	164.4	160.9
WA = Mass of pycnometer + water (grams)	144.8	144.2	148.5	144.2
W0 = weight of sample of oven-dry soil, g	26.2	26	25.2	26.4
Specific Gravity (Gs)	2.79	2.80	2.71	2.72
Average specific Gravrity(Gs)	2.79		2.72	

Sample description : TP3

specimen number	1.5m		3m	
pycnometer bottle number	1	2	1	2
Wp = Mass of empty, clean pycnometer (grams)	45.8	45.2	45.8	45.2
Wps = Mass empty pycnometer + dry soil (grams)	72.3	70.9	71.3	69.3
WB = Mass of pycnometer + dry soil + water (grams)	161.8	160.6	160.8	159.2
WA = Mass of pycnometer + water (grams)	144.8	144.2	144.8	144.2
W0 = weight of sample of oven-dry soil, g	26.5	25.7	25.5	24.1
Specific Gravity (Gs)	2.79	2.76	2.68	2.65
Average specific Gravrity(Gs)	2.78		2.67	

Sample description : TP4

specimen number	1.5m		3m	
pycnometer bottle number	1	3	1	2
Wp = Mass of empty, clean pycnometer (grams)	45.8	49.4	45.8	45.2
Wps = Mass empty pycnometer + dry soil (grams)	71.9	75.8	71.5	70.8
WB = Mass of pycnometer + dry soil + water (grams)	161.7	165.6	161	160.3
WA = Mass of pycnometer + water (grams)	144.8	148.5	144.8	144.2
W0 = weight of sample of oven-dry soil, g	26.1	26.4	25.7	25.6
Specific Gravity (Gs)	2.84	2.84	2.71	2.69
Average specific Gravrity(Gs)	2.84		2.70	

Sample description : TP5

specimen number	1.5m		3m	
pycnometer bottle number	2	3	3	2
Wp = Mass of empty, clean pycnometer (grams)	45.2	49.4	49.4	45.2
Wps = Mass empty pycnometer + dry soil (grams)	71.4	75.4	73.5	70
WB = Mass of pycnometer + dry soil + water (grams)	161.1	165.3	164	160.2
WA = Mass of pycnometer + water (grams)	144.2	148.5	148.5	144.2
W0 = weight of sample of oven-dry soil, g	26.2	26	24.1	24.8
Specific Gravity (Gs)	2.82	2.83	2.80	2.82
Average specific Gravrity(Gs)	2.82		2.81	

Sample description : TP6

specimen number	1.5m		3m	
pycnometer bottle number	1	3	1	2
Wp = Mass of empty, clean pycnometer (grams)	45.8	49.4	45.8	45.2
Wps = Mass empty pycnometer + dry soil (grams)	70.5	75	70	69.5
WB = Mass of pycnometer + dry soil + water (grams)	160.3	164.3	160.1	160
WA = Mass of pycnometer + water (grams)	144.8	148.5	144.8	144
W0 = weight of sample of oven-dry soil, g	24.7	25.6	24.2	24.3
Specific Gravity (Gs)	2.68	2.61	2.72	2.7
Average specific Gravrity(Gs)	2.65		2.71	

Sample description : TP7

specimen number	1.5m		3m	
	1	2	3	2
pycnometer bottle number				
Wp = Mass of empty, clean pycnometer (grams)	45.9	45.6	49.7	45.8
Wps = Mass empty pycnometer + dry soil (grams)	71	71.2	74.2	71
WB = Mass of pycnometer + dry soil + water (grams)	160.9	160.5	164.3	160.4
WA = Mass of pycnometer + water (grams)	144.7	144.2	148.5	144.2
W0 = weight of sample of oven-dry soil, g	25.1	25.6	24.5	25.2
Specific Gravity (Gs)	2.82	2.75	2.82	2.8
Average specific Gravirty(Gs)	2.79		2.81	

Sample description : TP8

specimen number	1.5m		3m	
	1	2	3	2
pycnometer bottle number				
Wp = Mass of empty, clean pycnometer (grams)	45.9	45.6	49.7	45.6
Wps = Mass empty pycnometer + dry soil (grams)	71	70.6	74.6	70.5
WB = Mass of pycnometer + dry soil + water (grams)	160.7	160.1	164.5	160
WA = Mass of pycnometer + water (grams)	144.7	144.2	148.5	144
W0 = weight of sample of oven-dry soil, g	25.1	25	24.9	24.9
Specific Gravity (Gs)	2.76	2.75	2.80	2.74
Average specific Gravirty(Gs)	2.75		2.77	

Sample description : TP9

specimen number	1.5m		3m	
	2	1	2	3
pycnometer bottle number				
Wp = Mass of empty, clean pycnometer (grams)	45.6	45.9	45.2	49.7
Wps = Mass empty pycnometer + dry soil (grams)	70.7	71	70.2	74.6
WB = Mass of pycnometer + dry soil + water (grams)	160.5	161	159.7	163.9
WA = Mass of pycnometer + water (grams)	144.2	144.7	144.2	148.5
W0 = weight of sample of oven-dry soil, g	25.1	25.1	25	24.9
Specific Gravity (Gs)	2.85	2.85	2.63	2.62
Average specific Gravirty(Gs)	2.85		2.65	

Sample description : TP10

specimen number	1.5m		3m	
	3	2	1	2
pycnometer bottle number	3	2	1	2
Wp = Mass of empty, clean pycnometer (grams)	49.7	45.6	45.9	45.6
Wps = Mass empty pycnometer + dry soil (grams)	74.7	70.7	71.1	70.7
WB = Mass of pycnometer + dry soil + water (grams)	164.7	160.5	161	160
WA = Mass of pycnometer + water (grams)	148.5	144.2	144.7	144
W0 = weight of sample of oven-dry soil, g	25	25.1	25.2	25.1
Specific Gravity (Gs)	2.84	2.85	2.83	2.79
Average specific Gravirty(Gs)	2.85		2.81	

Sample description : TP11

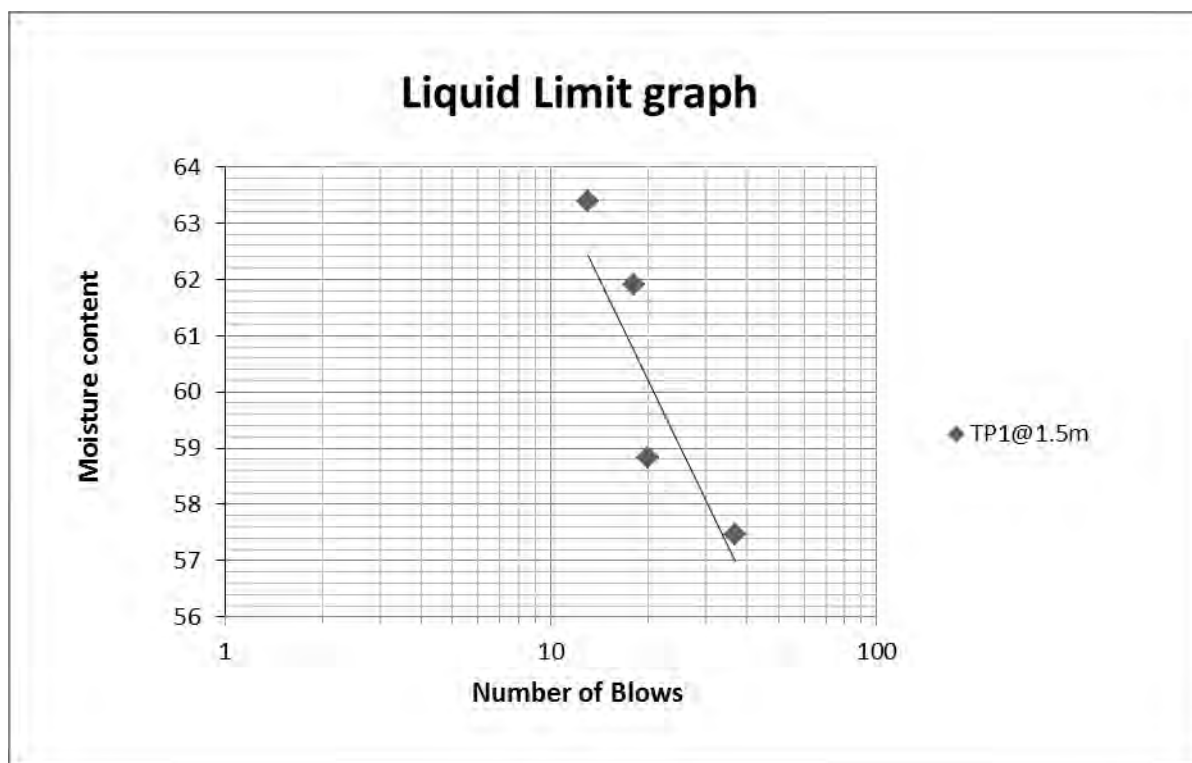
specimen number	1.5m		3m	
	1	2	3	2
pycnometer bottle number	1	2	3	2
Wp = Mass of empty, clean pycnometer (grams)	45.9	45.6	49.7	45.6
Wps = Mass empty pycnometer + dry soil (grams)	71	70.8	74.6	70.6
WB = Mass of pycnometer + dry soil + water (grams)	160.7	160.1	164.1	159.7
WA = Mass of pycnometer + water (grams)	144.7	144.2	148.5	144.2
W0 = weight of sample of oven-dry soil, g	25.1	25.2	24.9	25
Specific Gravity (Gs)	2.76	2.71	2.68	2.63
Average specific Gravirty(Gs)	2.73		2.65	

ATTERBERG LIMITS DATA SHEETS**SAMPLE DESCRIPTION: TP1 @ 1.5m depth(near Riyad Hotel)****Liquid Limit****Determination**

Sample no.	1	2	3	4
Can number	D26	C28	1A	TA2
Mc = Mass of empty, clean can (grams)	15.7	14	15.3	15.3
Mcms = Mass of can and moist soil (grams)	26.71	23.29	26.9	31.66
Mcds = Mass of can and dry soil (grams)	22.5	19.9	22.4	25.6
Ms = Mass of soil solids (grams)	6.8	5.9	7.1	10.3
Mw = Mass of pore water (grams)	4.21	3.39	4.5	6.06
w = Water content, w%	61.91	57.46	63.38	58.83
No. of drops (N)	18	37	13	20

PLASTIC LIMIT**DETERMINATION**

Sample no.	1	2	3
Can number	SB	C3	Z1
Mc = Mass of empty, clean can (grams)	15.4	15.5	21.9
Mcms = Mass of can and moist soil (grams)	21	20	25.4
Mcds = Mass of can and dry soil (grams)	19.9	19.1	24.7
Ms = Mass of soil solids (grams)	4.5	3.6	2.8
Mw = Mass of pore water (grams)	1.1	0.9	0.7
w = Water content, w%	24.44	25	25
plastic limit (PL) = Average of w %	24.81		



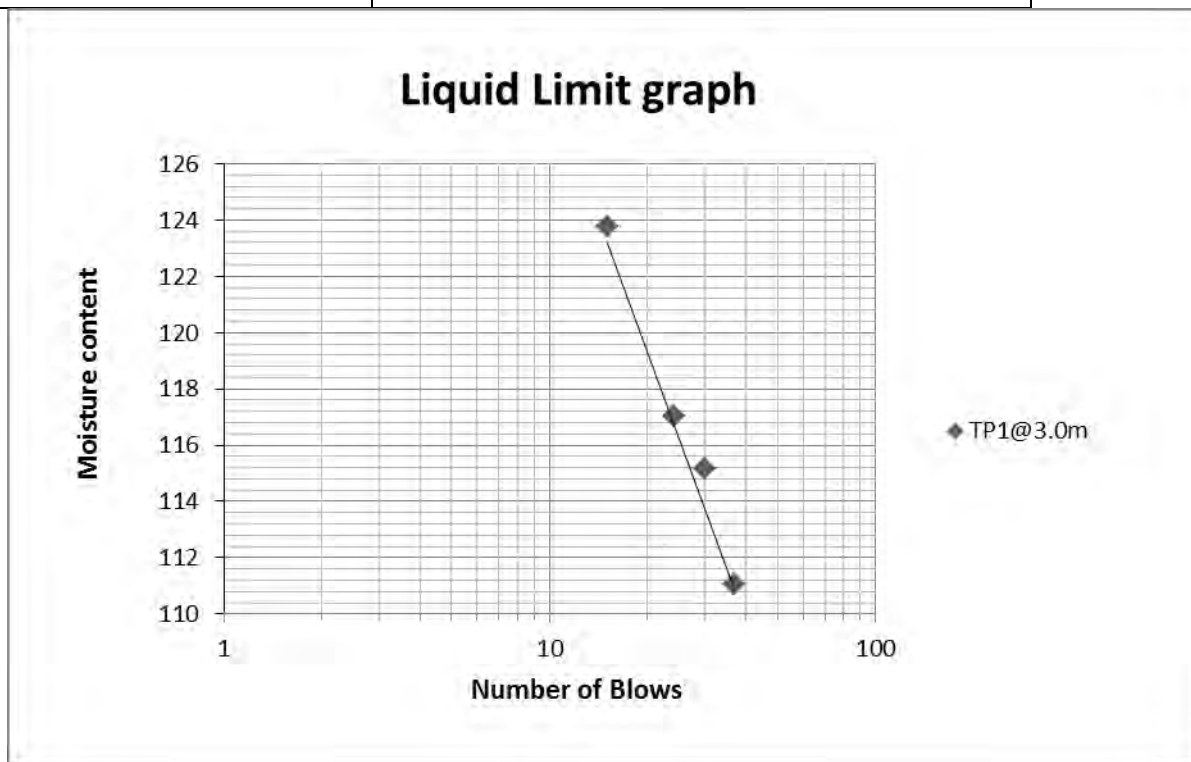
SAMPLE DESCRIPTION: TP1 @ 3.0m depth(near Riyad Hotel)

**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	TL4	E3	A19	TL9
Mc = Mass of empty, clean can (grams)	15.6	15.3	11.8	13.8
Mcms = Mass of can and moist soil (grams)	23.1	23.1	19.8	24.54
Mcds = Mass of can and dry soil (grams)	19.1	19	15.5	18.6
Ms = Mass of soil solids (grams)	3.5	3.7	3.7	4.8
Mw = Mass of pore water (grams)	4.03	4.11	4.33	5.94
w = Water content, w%	115.1	111.08	117.03	124
No. of drops (N)	30	37	24	15

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	A1	MA13	BA3
Mc = Mass of empty, clean can (grams)	19.6	14.1	15.5
Mcms = Mass of can and moist soil (grams)	25	19.2	20.2
Mcds = Mass of can and dry soil (grams)	23.6	17.9	19
Ms = Mass of soil solids (grams)	4	3.8	3.5
Mw = Mass of pore water (grams)	1.4	1.3	1.2
w = Water content, w%	35	34.21	34.29
plastic limit (PL) = Average of w %	34.5		



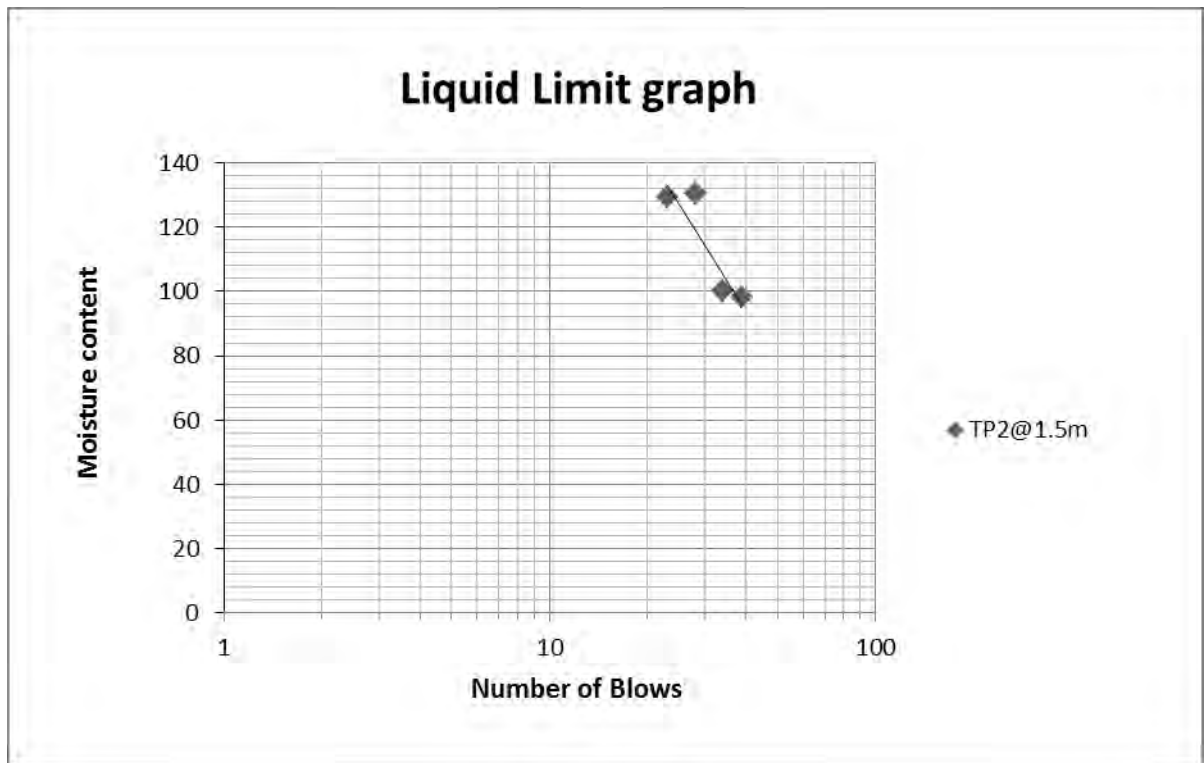
SAMPLE DESCRIPTION: TP2 @ 1.5m depth(near to prison)

**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	fre	mes	sam	ise
Mc = Mass of empty, clean can (grams)	15.9	16	15.9	15.8
Mcms = Mass of can and moist soil (grams)	28.3	27.7	37.1	35.1
Mcds = Mass of can and dry soil (grams)	22.1	21.9	25.1	24.2
Ms = Mass of soil solids (grams)	6.2	5.9	9.2	8.4
Mw = Mass of pore water (grams)	6.2	5.7899	11.99	10.85
w = Water content, w%	100	98.13	130.33	129.17
No. of drops (N)	34	39	28	23

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	MA13	HD2	ILD
Mc = Mass of empty, clean can (grams)	15.5	15.4	15.7
Mcms = Mass of can and moist soil (grams)	21.5	23.7	22.1
Mcds = Mass of can and dry soil (grams)	20	21.5	20.4
Ms = Mass of soil solids (grams)	4.5	6.1	4.7
Mw = Mass of pore water (grams)	1.5	2.2	1.7
w = Water content, w%	33.33	36.07	36.17
plastic limit (PL) = Average of w %	35.19		



SAMPLE DESCRIPTION: TP2 @ 3.0m depth(near to prison)

NOT POSSIBLE

Liquid Limit Determination

Sample no.	1	2	3	4
Can number				
Mc = Mass of empty, clean can (grams)				
Mcms = Mass of can and moist soil (grams)				
Mcds = Mass of can and dry soil (grams)				
Ms = Mass of soil solids (grams)				
Mw = Mass of pore water (grams)				
w = Water content, w%				
No. of drops (N)				

NOT POSSIBLE

PLASTIC LIMIT DETERMINATION

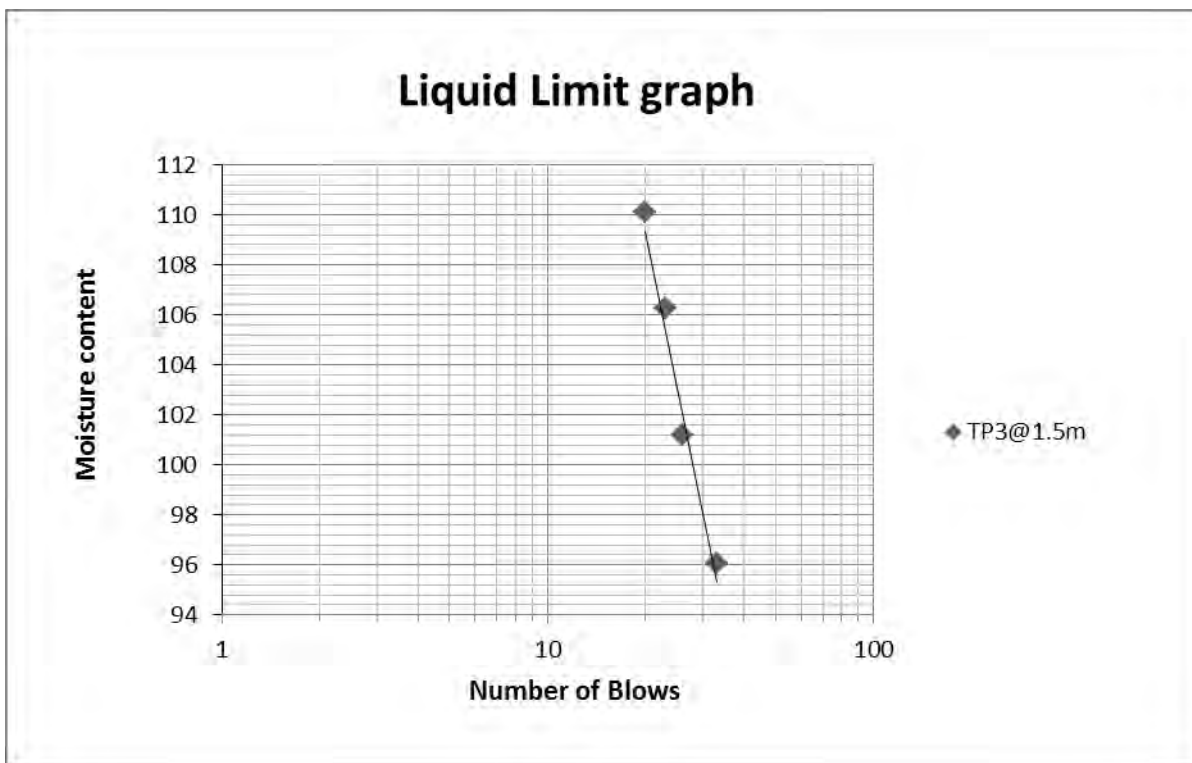
Sample no.	1	2	3
Can number			
Mc = Mass of empty, clean can (grams)			
Mcms = Mass of can and moist soil (grams)			
Mcds = Mass of can and dry soil (grams)			
Ms = Mass of soil solids (grams)			
Mw = Mass of pore water (grams)			
w = Water content, w%			
plastic limit (PL) = Average of w %			

SAMPLE DESCRIPTION: TP3 @ 1.5m depth(JAFER MOSQUE)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	D26	FaB	P2S	C21
Mc = Mass of empty, clean can (grams)	15.8	15.5	15.6	14.2
Mcms = Mass of can and moist soil (grams)	44.0	29.0	30.5	35
Mcds = Mass of can and dry soil (grams)	30.2	22.2	22.8	24.1
Ms = Mass of soil solids (grams)	14.4	6.7	7.2	9.9
Mw = Mass of pore water (grams)	13.83	6.78	7.65	10.9
w = Water content, w%	96.04	101.20	106.25	110.10
No. of drops (N)	33	26	23	20

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	BA3	2C7	CP3
Mc = Mass of empty, clean can (grams)	15.6	15.7	15.2
Mcms = Mass of can and moist soil (grams)	21.9	25.6	21.8
Mcds = Mass of can and dry soil (grams)	20.3	23.2	20.3
Ms = Mass of soil solids (grams)	4.7	7.5	5.1
Mw = Mass of pore water (grams)	1.6	2.4	1.5
w = Water content, w%	34.04	32	29.41
plastic limit (PL) = Average of w %	31.82		



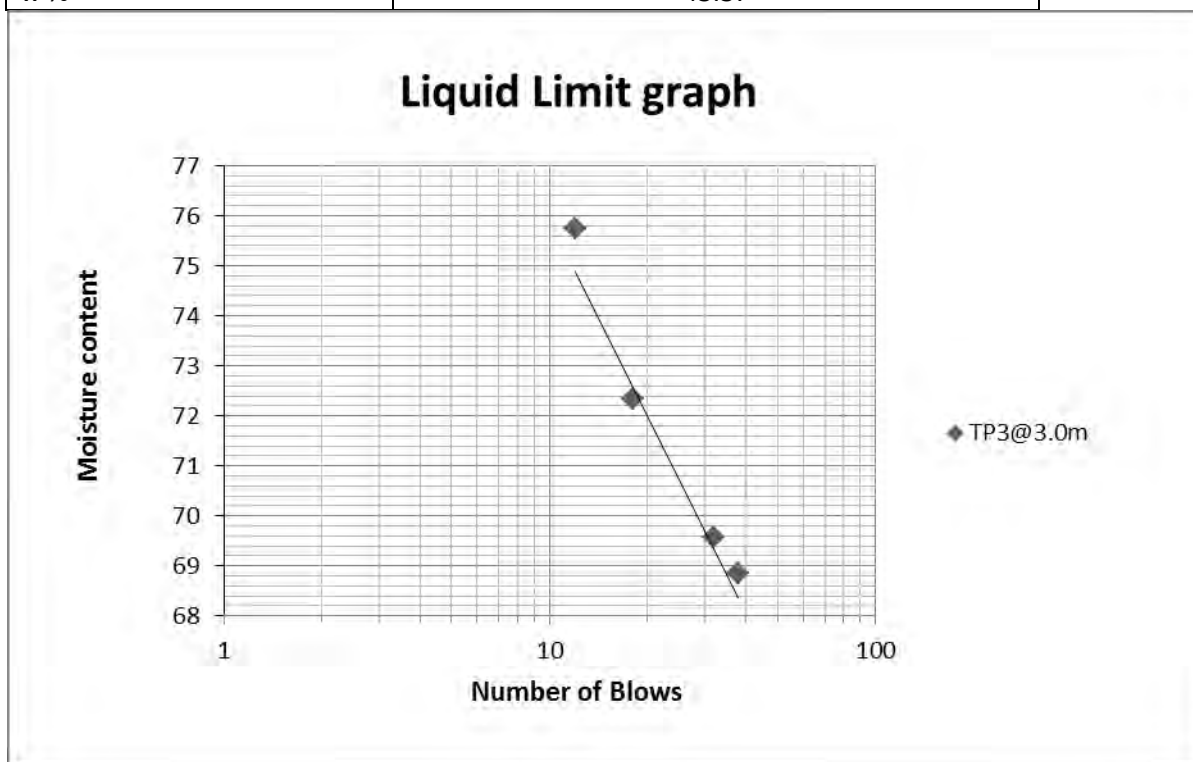
SAMPLE DESCRIPTION: TP3 @ 3.0m depth (JAFER MOSQUE)

Liquid Limit Determination

Sample no.	1	2	3	4	
Can number	DAS12	C2	TL4	J43	
Mc = Mass of empty, clean can (grams)	15	15.6	13.8	15.8	15.3
Mcms = Mass of can and moist soil (grams)	25.3	23.7	25.5	27.4	28.6
Mcds = Mass of can and dry soil (grams)	21.1	20.3	20.7	22.4	22.9
Ms = Mass of soil solids (grams)	6.1	4.7	6.9	6.6	7.6
Mw = Mass of pore water (grams)	4.2	3.4	4.8	5	5.7
w = Water content, w%	68.85	72.34	69.57	75.76	75
No. of drops (N)	38	18	32	12	15

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	CP3	BA3	H10D
Mc = Mass of empty, clean can (grams)	15.2	15.6	15.5
Mcms = Mass of can and moist soil (grams)	19	21.9	21.5
Mcds = Mass of can and dry soil (grams)	17.9	19.9	19.7
Ms = Mass of soil solids (grams)	2.7	4.3	4.2
Mw = Mass of pore water (grams)	1.1	2	1.8
w = Water content, w%	40.74	46.51	42.86
plastic limit (PL) = Average of w %	43.37		

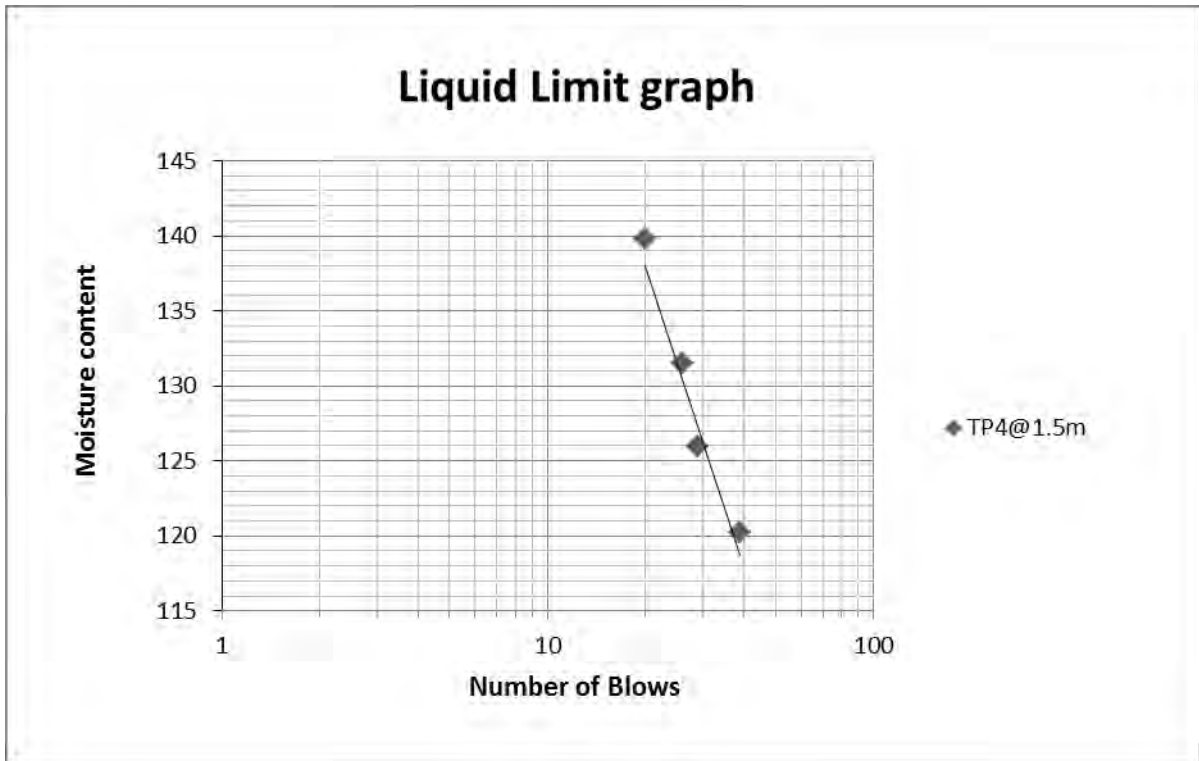


SAMPLE DESCRIPTION: TP4 @ 1.5m depth(STADIUM)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	TL6	C3	1A	BA3
Mc = Mass of empty, clean can (grams)	15.9	16.3	16.3	16
Mcms = Mass of can and moist soil (grams)	31.2	27.2	25.0	24.5
Mcds = Mass of can and dry soil (grams)	22.3	21.0	20.2	19.9
Ms = Mass of soil solids (grams)	6.4	4.7	3.85	3.86
Mw = Mass of pore water (grams)	8.945	6.18	4.85	4.64
w = Water content, w%	139.77	131.49	125.97	120.2
No. of drops (N)	20	26	29	39

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	DAS2	FET	E3
Mc = Mass of empty, clean can (grams)	15.8	15.8	15.7
Mcms = Mass of can and moist soil (grams)	23.5	21.6	23.5
Mcds = Mass of can and dry soil (grams)	21	19.6	21
Ms = Mass of soil solids (grams)	5.2	3.8	5.3
Mw = Mass of pore water (grams)	2.5	2	2.5
w = Water content, w%	48.08	52.63	47.17
plastic limit (PL) = Average of w %	49.29		



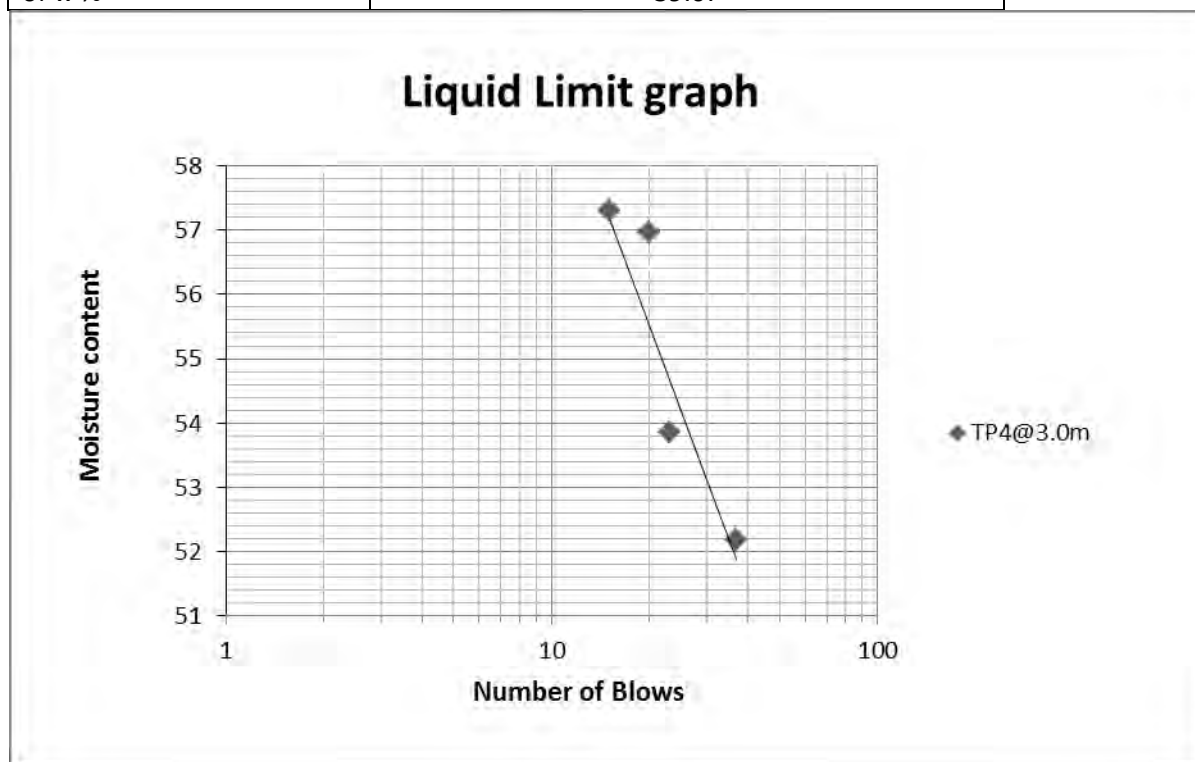
SAMPLE DESCRIPTION: TP4 @ 3.0m depth(STADIUM)

Liquid Limit Determination

Sample no.	1	2	3	4	
Can number	A20	T3	P1	T1	
Mc = Mass of empty, clean can (grams)	15.7	15.6	15.6	15.6	15.7
Mcms = Mass of can and moist soil (grams)	28.1	29.6	29.6	27.6	29.3
Mcds = Mass of can and dry soil (grams)	23.6	24.8	24.5	23.4	24.4
Ms = Mass of soil solids (grams)	7.9	9.2	8.9	7.8	8.7
Mw = Mass of pore water (grams)	4.5	4.8	5.1	4.2	4.9
w = Water content, w%	56.96	52.17	57.30	53.85	56.32
No. of drops (N)	20	37	15	23	22

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	A19	A1B	D26
Mc = Mass of empty, clean can (grams)	11.7	20.7	15.7
Mcms = Mass of can and moist soil (grams)	18.3	28.8	20.5
Mcds = Mass of can and dry soil (grams)	16.4	26.5	19.2
Ms = Mass of soil solids (grams)	4.7	5.8	3.5
Mw = Mass of pore water (grams)	1.9	2.3	1.3
w = Water content, w%	40.43	39.66	37.14
plastic limit (PL) = Average of w %	39.07		

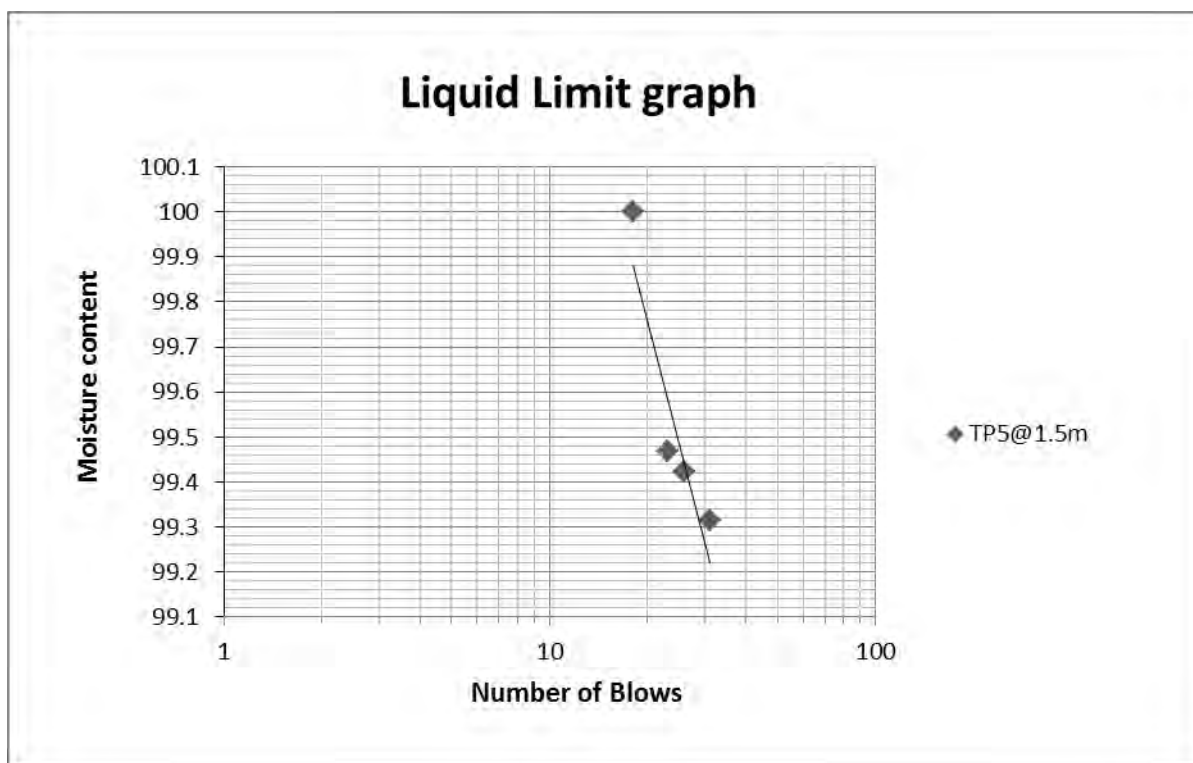


SAMPLE DESCRIPTION: TP5 @ 1.5m depth(NEAR MUNICIPALITY)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	A4	TA3	T2	E2
Mc = Mass of empty, clean can (grams)	15.6	15.8	15.5	15.4
Mcms = Mass of can and moist soil (grams)	26.0	30.4	32.7	30.4
McDs = Mass of can and dry soil (grams)	20.8	23.1	24.1	22.9
Ms = Mass of soil solids (grams)	5.2	7.3	8.6	7.5
Mw = Mass of pore water (grams)	5.17	7.25	8.6	7.46
w = Water content, w%	99.42	99.32	100	99.47
No. of drops (N)	26	31	18	23

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	ES	M2	M3
Mc = Mass of empty, clean can (grams)	15.7	15.8	15.4
Mcms = Mass of can and moist soil (grams)	21.4	21.3	20.8
McDs = Mass of can and dry soil (grams)	19.8	19.7	19.3
Ms = Mass of soil solids (grams)	4.1	3.9	3.9
Mw = Mass of pore water (grams)	1.6	1.6	1.5
w = Water content, w%	39.02	41.03	38.46
plastic limit (PL) = Average of w %	39.50		



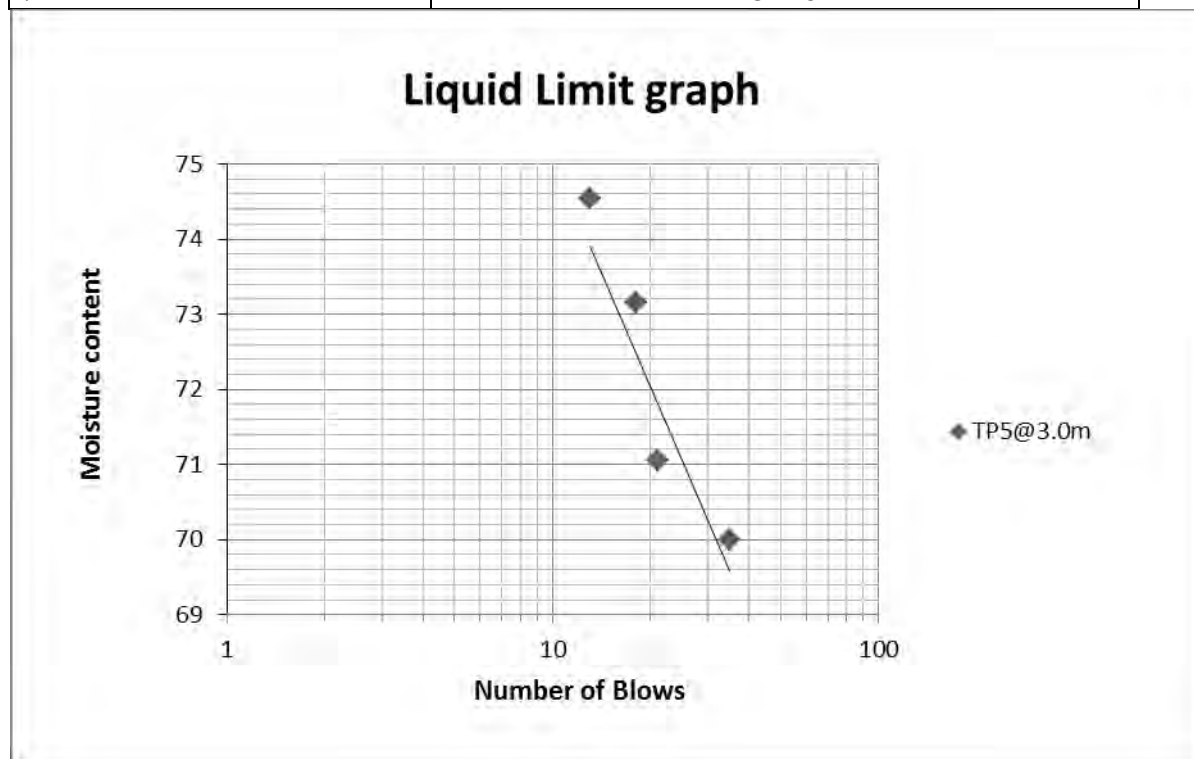
SAMPLE DESCRIPTION: TP5 @ 3.0m depth(NEAR MUNICIPALITY)

Liquid Limit Determination

Sample no.	1	2	3	4
Can number	TA2	P2	A1	CP3
Mc = Mass of empty, clean can (grams)	15.4	15.6	20.6	15.2
Mcms = Mass of can and moist soil (grams)	34.1	25.2	30.8	34.7
Mcds = Mass of can and dry soil (grams)	26.2	21.1	26.6	26.6
Ms = Mass of soil solids (grams)	10.8	5.5	6	11.4
Mw = Mass of pore water (grams)	7.9	4.1	4.2	8.1
w = Water content, w%	73.15	74.55	70	71.05
No. of drops (N)	18	13	35	21

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	I3	SO	DAS8
Mc = Mass of empty, clean can (grams)	14.8	15.4	24.5
Mcms = Mass of can and moist soil (grams)	22.1	22.1	32.3
Mcds = Mass of can and dry soil (grams)	20.1	20.3	30.2
Ms = Mass of soil solids (grams)	5.3	4.9	5.7
Mw = Mass of pore water (grams)	2	1.8	2.1
w = Water content, w%	37.74	36.73	36.84
plastic limit (PL) = Average of w %	37.10		

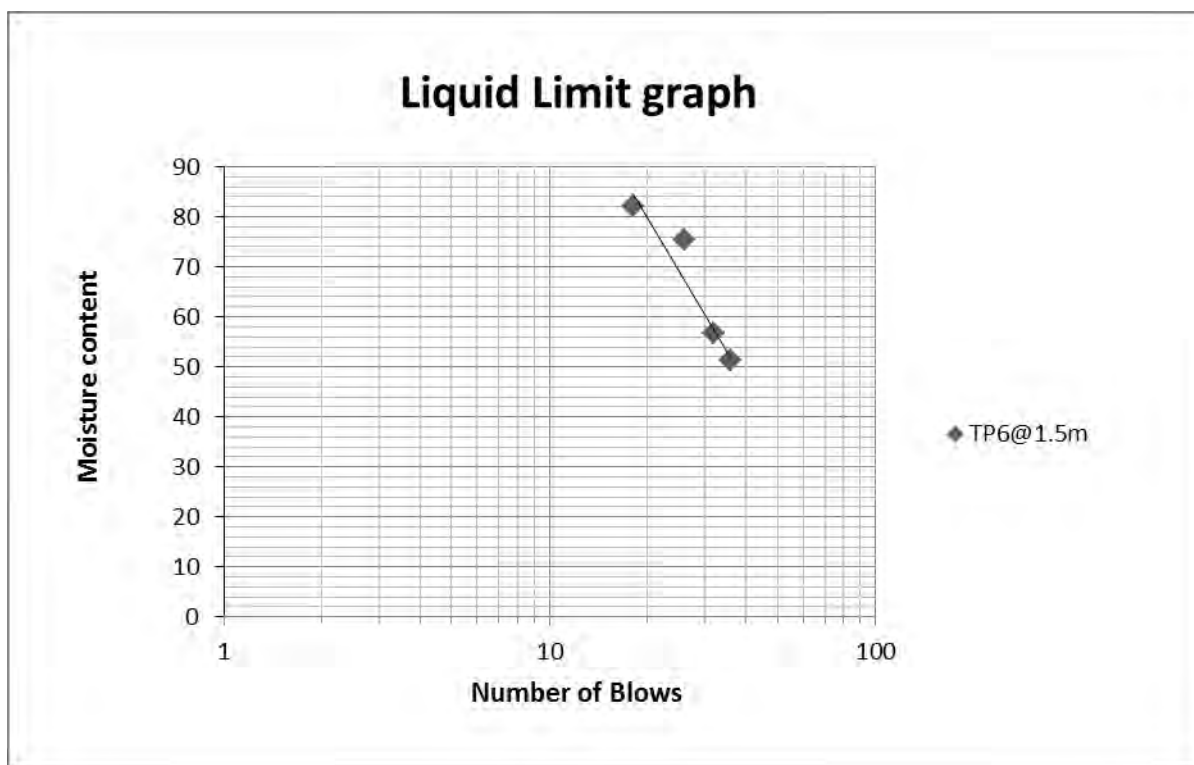


SAMPLE DESCRIPTION: TP6 @ 1.5m depth(TO Dalocha)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	cv1	fgr	vr	fetu
Mc = Mass of empty, clean can (grams)	15.8	14.2	16.1	15.4
Mcms = Mass of can and moist soil (grams)	26.7	23.5	27.8	31.7
Mcds = Mass of can and dry soil (grams)	23	19.5	22.5	25.8
Ms = Mass of soil solids (grams)	7.2	5.3	6.4	10.4
Mw = Mass of pore water (grams)	3.7	4	5.26	5.9
w = Water content, w%	51.39	75.47	82.19	56.73
No. of drops (N)	36	26	18	32

**PLASTIC LIMIT
DETERMINATION**

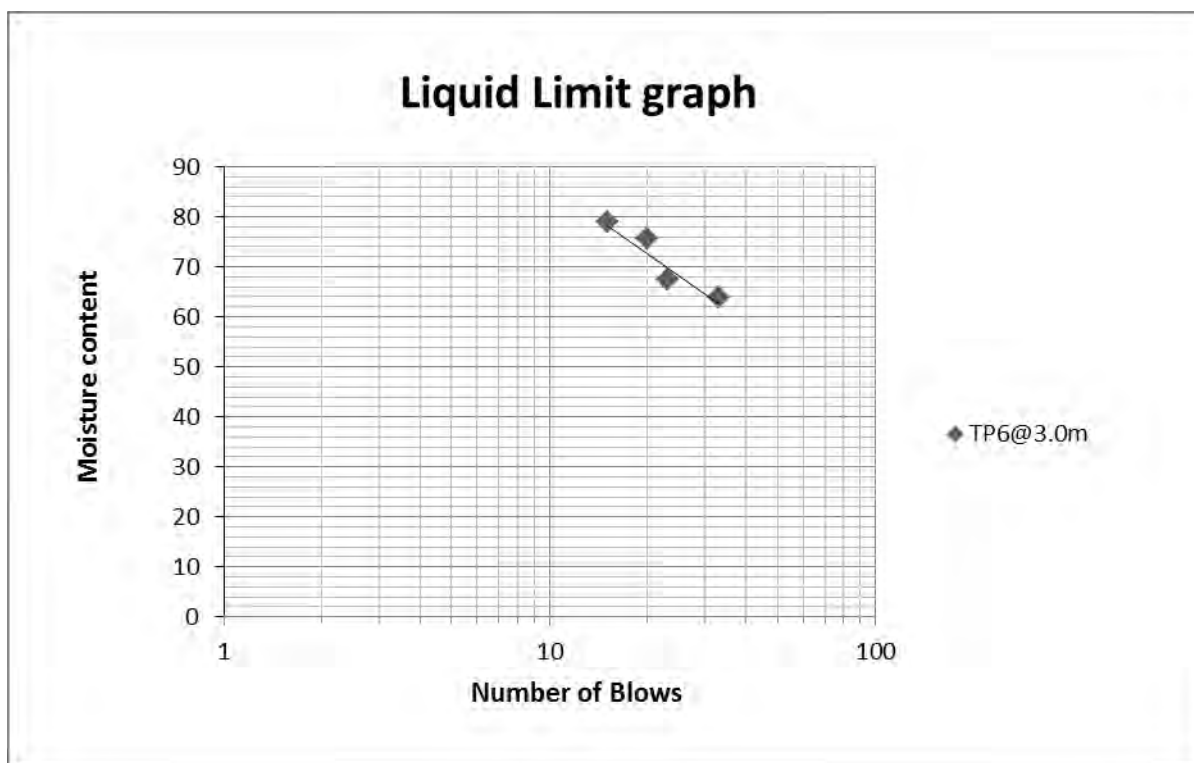
Sample no.	1	2	3
Can number	Sd	fc3	jZ1
Mc = Mass of empty, clean can (grams)	15.4	15.5	21.9
Mcms = Mass of can and moist soil (grams)	21.1	20.1	25.4
Mcds = Mass of can and dry soil (grams)	19.8	19.1	24.6
Ms = Mass of soil solids (grams)	4.4	3.6	2.7
Mw = Mass of pore water (grams)	1.3	1	0.8
w = Water content, w%	29.55	27.78	29.63
plastic limit (PL) = Average of w %	28.98		



SAMPLE DESCRIPTION: TP6 @ 3.0m depth(TO Dalocha)

Liquid Limit Determination

Sample no.	1	2	3	4
Can number	TL	vE3	A1	T9
Mc = Mass of empty, clean can (grams)	15.5	15.3	11.8	13.9
Mcms = Mass of can and moist soil (grams)	22.3	23	18	21.8
Mcds = Mass of can and dry soil (grams)	19.3	20	15.5	18.4
Ms = Mass of soil solids (grams)	3.8	4.7	3.7	4.5
Mw = Mass of pore water (grams)	3	3	2.5	3.4
w = Water content, w%	78.95	63.83	67.57	75.56
No. of drops (N)	15	33	23	20



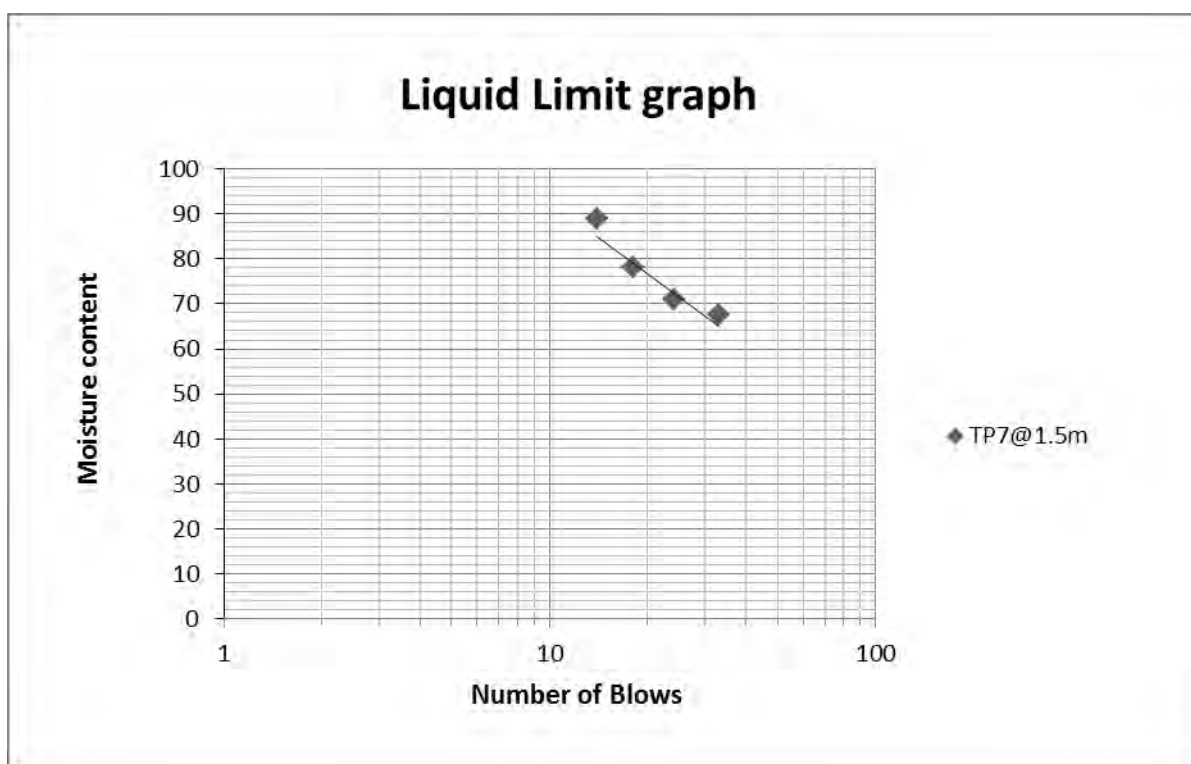
SAMPLE DESCRIPTION: TP7 @ 1.5m depth(Worabe Prison)

Liquid Limit Determination

Sample no.	1	2	3	4
Can number	Afd	kA3	NT2	HE2
Mc = Mass of empty, clean can (grams)	15.5	15.9	15.7	15.6
Mcms = Mass of can and moist soil (grams)	25.7	29.4	31.9	29.67
Mcds = Mass of can and dry soil (grams)	20.9	23.8	24.8	24
Ms = Mass of soil solids (grams)	5.4	7.9	9.1	8.4
Mw = Mass of pore water (grams)	4.8	5.6	7.1	5.2
w = Water content, w%	88.89	70.88	78.02	67.40
No. of drops (N)	14	24	18	33

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	FER	FAF	AF
Mc = Mass of empty, clean can (grams)	15.6	15.5	15.4
Mcms = Mass of can and moist soil (grams)	21.3	21.2	20.7
Mcds = Mass of can and dry soil (grams)	19.8	19.7	19.3
Ms = Mass of soil solids (grams)	4.2	4.2	3.9
Mw = Mass of pore water (grams)	1.5	1.5	1.4
w = Water content, w%	35.71	35.71	35.9
plastic limit (PL) = Average of w %	35.78		

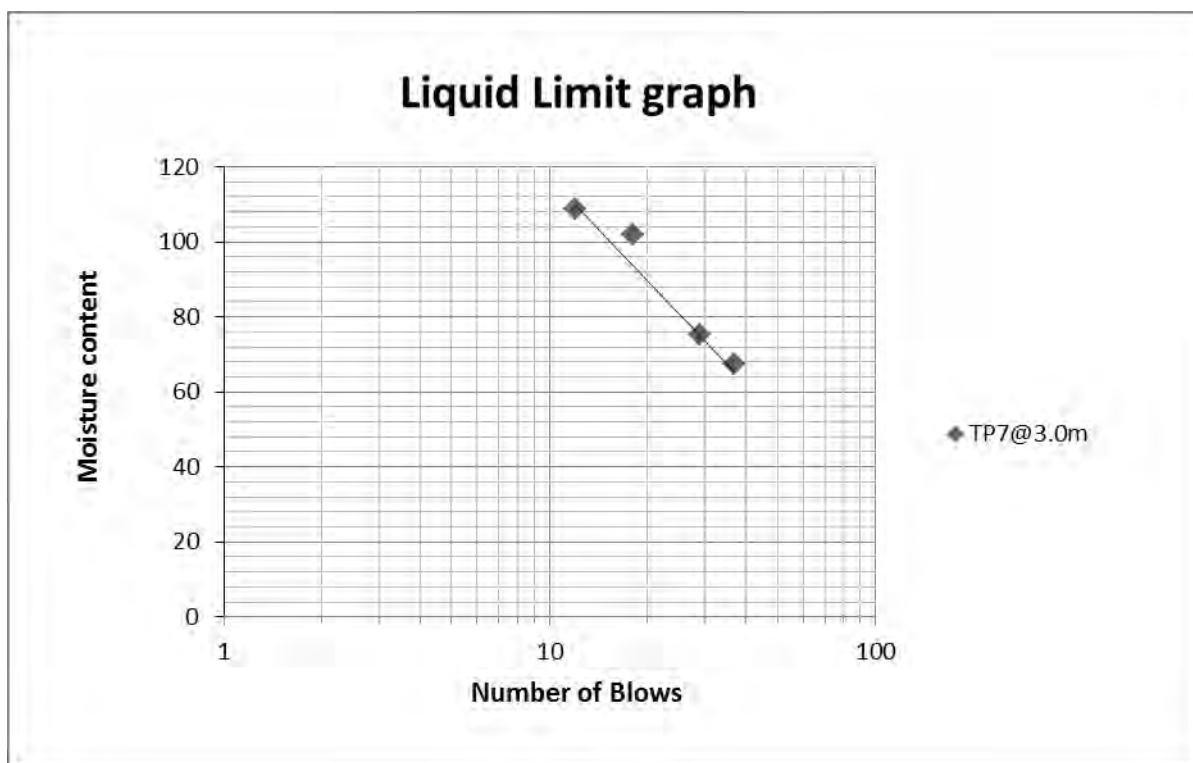


SAMPLE DESCRIPTION: TP7 @ 3.0m depth(Worabe Prison)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	BUD	GRT	VB	MJI
Mc = Mass of empty, clean can (grams)	15.8	16	15.9	15.5
Mcms = Mass of can and moist soil (grams)	35	26.1	30.5	33.74
McDs = Mass of can and dry soil (grams)	25	21	24.6	25.9
Ms = Mass of soil solids (grams)	9.2	5	8.7	10.4
Mw = Mass of pore water (grams)	10	5.1	5.85	7.836
w = Water content, w%	108.70	102.00	67.24	75.35
No. of drops (N)	12	18	37	29

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	ZX	KI	R43
Mc = Mass of empty, clean can (grams)	15.9	15.1	19.6
Mcms = Mass of can and moist soil (grams)	21.7	21.4	32.4
McDs = Mass of can and dry soil (grams)	20.4	20	29.5
Ms = Mass of soil solids (grams)	4.5	4.9	9.9
Mw = Mass of pore water (grams)	1.3	1.4	2.9
w = Water content, w%	28.89	28.57	29.29
plastic limit (PL) = Average of w %	28.92		



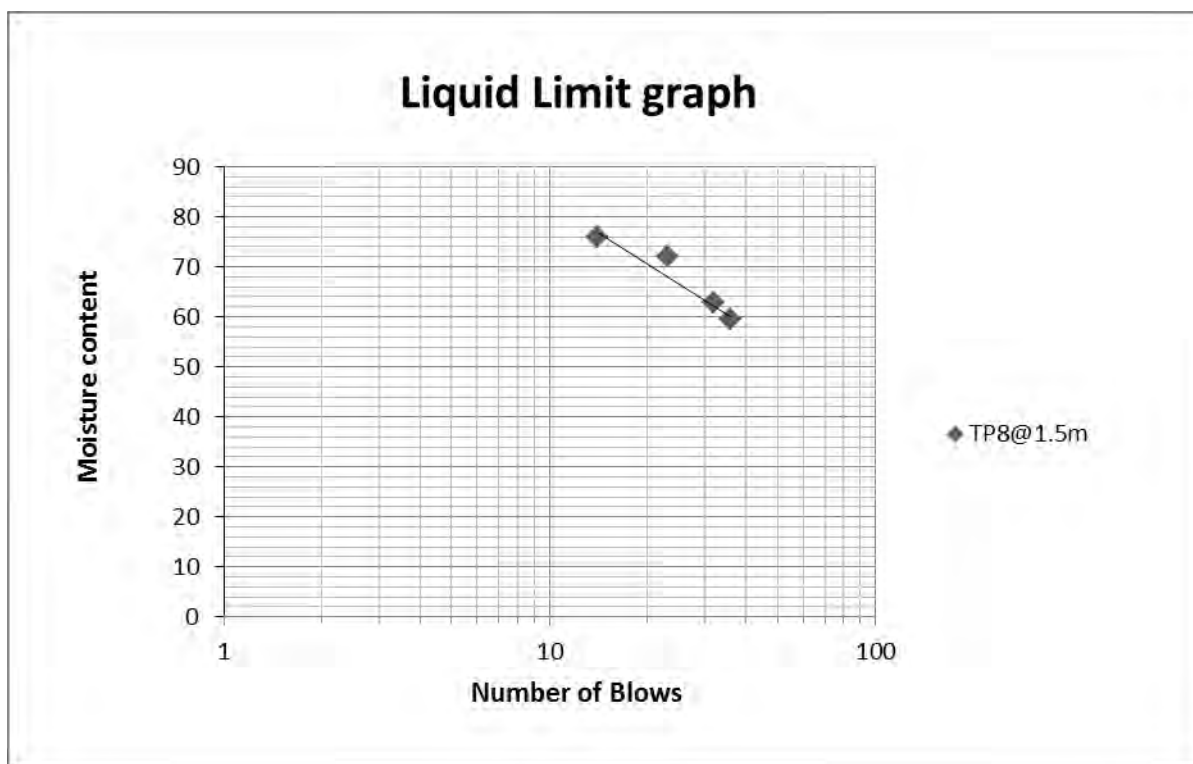
SAMPLE DESCRIPTION: TP8 @ 1.5m depth(Near Worabe Referral Hospital)

Liquid Limit Determination

Sample no.	1	2	3	4
Can number	FDE	FAFU	BG	5GT
Mc = Mass of empty, clean can (grams)	15.1	15.2	14.9	15.6
Mcms = Mass of can and moist soil (grams)	25.1	30.987	31.965	26.64
Mcds = Mass of can and dry soil (grams)	20.91	25.1	24.6	22.377
Ms = Mass of soil solids (grams)	5.81	9.9	9.7	6.777
Mw = Mass of pore water (grams)	4.19	5.887	7.365	4.263
w = Water content, w%	72.12	59.46	75.93	62.90
No. of drops (N)	23	36	14	32

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	CFT	FD	NH
Mc = Mass of empty, clean can (grams)	15.6	15.1	15.8
Mcms = Mass of can and moist soil (grams)	21	20.8	20.1
Mcds = Mass of can and dry soil (grams)	20	19.7	19.3
Ms = Mass of soil solids (grams)	4.4	4.6	3.5
Mw = Mass of pore water (grams)	1	1.1	0.8
w = Water content, w%	22.73	23.91	22.86
plastic limit (PL) = Average of w %	23.17		

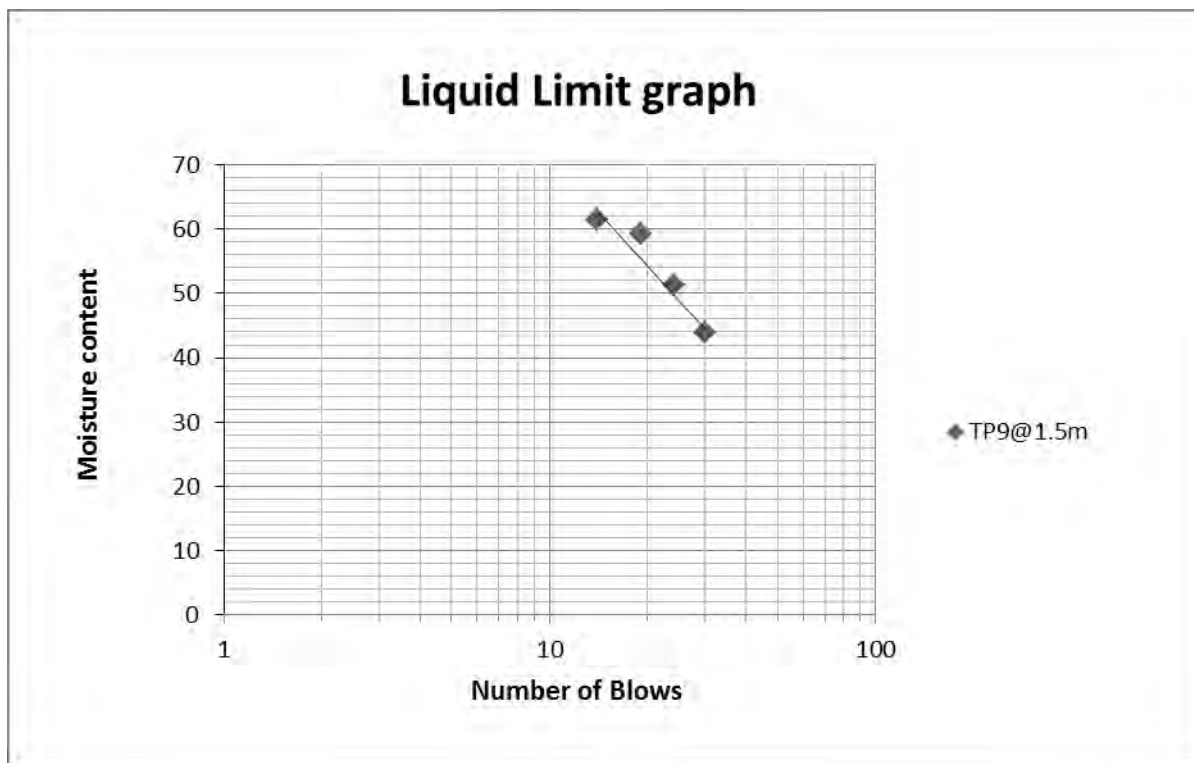


SAMPLE DESCRIPTION: TP9 @ 1.5m depth(Entoto mender)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	OZS	ETY	HYU	OP
Mc = Mass of empty, clean can (grams)	15.5	15.7	15.9	15.4
Mcms = Mass of can and moist soil (grams)	24.1	29.1	30	29.8
Mcds = Mass of can and dry soil (grams)	20.9	24	25.7	24.9
Ms = Mass of soil solids (grams)	5.4	8.3	9.8	9.5
Mw = Mass of pore water (grams)	3.2	5.1	4.3	4.88
w = Water content, w%	59.3	61.4	43.9	51.4
No. of drops (N)	19	14	30	24

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	NM	KL	OK
Mc = Mass of empty, clean can (grams)	15.1	14.9	15
Mcms = Mass of can and moist soil (grams)	20.5	20.4	20
Mcds = Mass of can and dry soil (grams)	19.8	19.71	19.318
Ms = Mass of soil solids (grams)	4.7	4.81	4.318
Mw = Mass of pore water (grams)	0.7	0.69	0.682
w = Water content, w%	14.89	14.35	15.79
plastic limit (PL) = Average of w %	15.01		



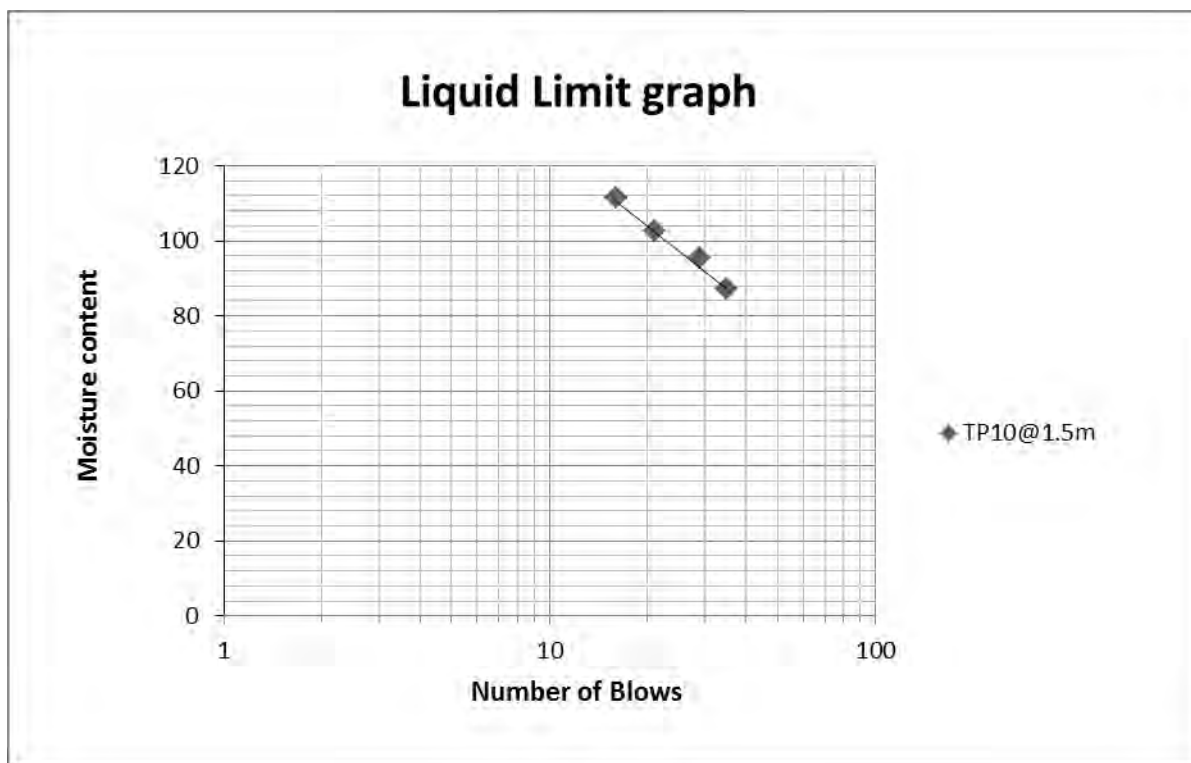
SAMPLE DESCRIPTION: TP10 @ 1.5m depth(Duna Mesjid)

Liquid Limit Determination

Sample no.	1	2	3	4
Can number	IBR	TOF	MEF	MUN
Mc = Mass of empty, clean can (grams)	15.8	15.1	15.7	15.4
Mcms = Mass of can and moist soil (grams)	24.6	29.3	31.4	33.0
Mcds = Mass of can and dry soil (grams)	20.3	22.1	23.1	24.8
Ms = Mass of soil solids (grams)	4.5	7	7.4	9.4
Mw = Mass of pore water (grams)	4.29	7.18	8.26	8.201
w = Water content, w%	95.33	102.57	111.62	87.25
No. of drops (N)	29	21	16	35

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	HAY	LEY	BERT
Mc = Mass of empty, clean can (grams)	15.1	15.5	15
Mcms = Mass of can and moist soil (grams)	20.4	21.3	20.7
Mcds = Mass of can and dry soil (grams)	19.1	19.9	19.3
Ms = Mass of soil solids (grams)	4	4.4	4.3
Mw = Mass of pore water (grams)	1.3	1.4	1.4
w = Water content, w%	32.5	31.82	32.56
plastic limit (PL) = Average of w %	32.29		

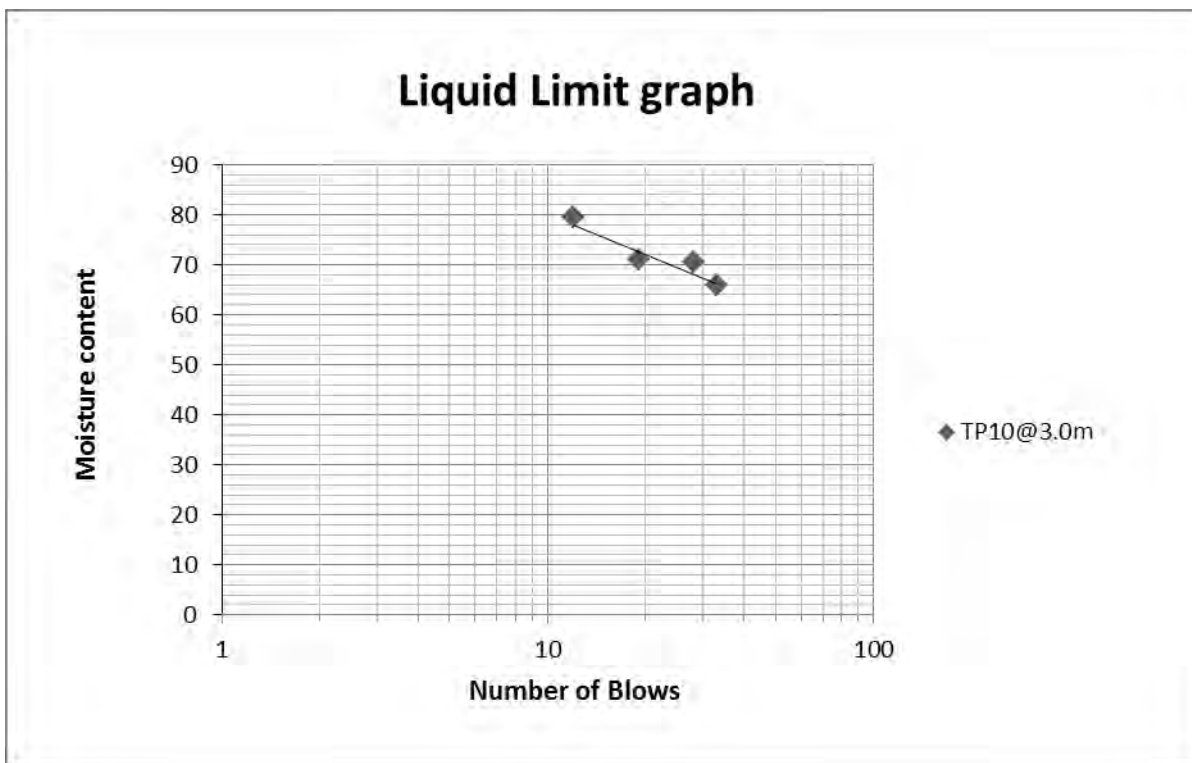


SAMPLE DESCRIPTION: TP10 @ 3.0m depth(Duna Mesjid)**Liquid Limit
Determination**

Sample no.	1	2	3	4
Can number	AYS	LIV	TRE	YHN
Mc = Mass of empty, clean can (grams)	15.8	15.6	15.7	15.2
Mcms = Mass of can and moist soil (grams)	34.1	26	30.8	34.7
Mcds = Mass of can and dry soil (grams)	26	21.7	24.8	26.6
Ms = Mass of soil solids (grams)	10.2	6.1	9.1	11.4
Mw = Mass of pore water (grams)	8.1	4.3	6	8.1
w = Water content, w%	79.41	70.49	65.93	71.05
No. of drops (N)	12	28	33	19

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	YON	SEL	RIH
Mc = Mass of empty, clean can (grams)	15.8	15.4	16.5
Mcms = Mass of can and moist soil (grams)	22.4	22.3	34.3
Mcds = Mass of can and dry soil (grams)	21.1	20.9	30.6
Ms = Mass of soil solids (grams)	5.3	5.5	14.1
Mw = Mass of pore water (grams)	1.3	1.4	3.7
w = Water content, w%	24.53	25.45	26.24
plastic limit (PL) = Average of w %	25.41		



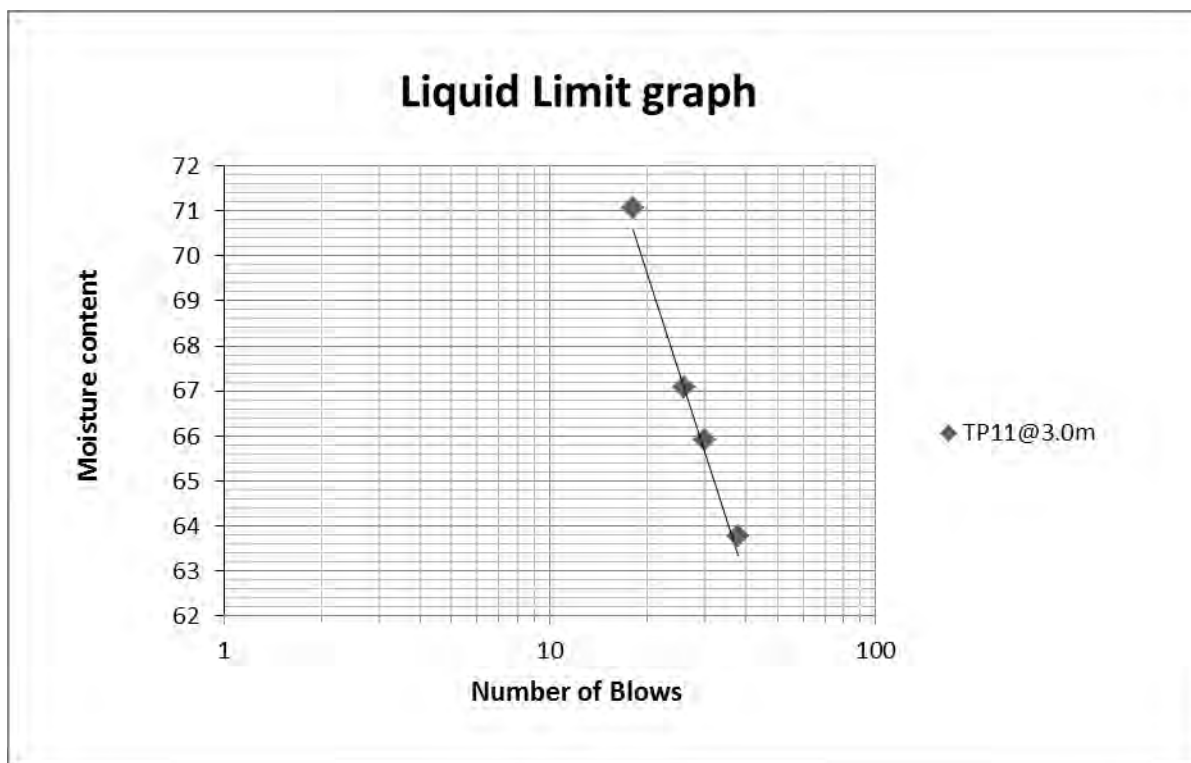
SAMPLE DESCRIPTION: TP11 @ 3.0m depth((JAFER MOSQUE)

Liquid Limit Determination

Sample no.	1	2	3	4
Can number	AGER	BER	WED	GTR
Mc = Mass of empty, clean can (grams)	15	15.6	13.8	15.2
Mcms = Mass of can and moist soil (grams)	26.3	22.9	27	33.2
Mcds = Mass of can and dry soil (grams)	21.9	20	21.7	26.6
Ms = Mass of soil solids (grams)	6.9	4.4	7.9	11.4
Mw = Mass of pore water (grams)	4.4	2.9	5.3	8.1
w = Water content, w%	63.77	65.91	67.09	71.05
No. of drops (N)	38	30	26	18

**PLASTIC LIMIT
DETERMINATION**

Sample no.	1	2	3
Can number	FIK	LIB	KAB
Mc = Mass of empty, clean can (grams)	15.8	15.9	15.5
Mcms = Mass of can and moist soil (grams)	21	20.7	21.1
Mcds = Mass of can and dry soil (grams)	20.2	19.9	20.2
Ms = Mass of soil solids (grams)	4.4	4	4.7
Mw = Mass of pore water (grams)	0.8	0.8	0.9
w = Water content, w%	18.18	20	19.15
plastic limit (PL) = Average of w %	19.11		



Free Swell Test

TP1@1.5m

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	11.00	15.0	13.0	30

TP6@1.5m

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	20.00	20.5	20.3	103

TP1@3m

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	21.00	18.00	19.5	95

TP6@3m

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	17.00	16.00	16.5	65

TP2@1.5

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	18.00	19.0	18.5	85

TP7@1.5

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	21.00	21.7	15.5	109

TP2@3m

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	13.00	14.0	13.5	35

TP7@3m

Initial	Final Volume		Average	Free
Volume	Sample No.1	Sample No.2	Final Volume	Swell Index
(cc)	(cc)	(cc)	(cc)	(%)
10.0	21.00	22.0	21.5	115

TP3@1.5m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	19.00	19.8	19.4	94	

TP8@1.5m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	19.00	20.0	19.5	95	

TP3@3m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	14.00	15.0	14.5	45	

TP8@3m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	13.00	13.2	13.1	31	

TP4@1.5m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	24.00	25.0	24.5	145	

TP9@1.5m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	15.00	16.0	15.5	55	

TP4@3m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	13.00	14.0	13.5	35	

TP9@3m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	14.00	14.2	14.1	41	

TP5@1.5m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	21.00	23.0	22.0	120	

TP10@1.5m

Initial Volume	Final Volume	Sample No.1	Sample No.2	Average Final Volume	Free Swell Index
(cc)	(cc)	(cc)	(cc)	(cc)	(%)
10.0	21.50	22.0	21.8	118	

[TP5@3m](#)

Initial	Final		Average	Free
Volume	Volume	Sample	Final	Swell
(cc)	(cc)	No.1	Volume	Index
10.0	17.00	16.0	16.5	65

[TP10@3m](#)

Initial	Final		Average	Free
Volume	Volume	Sample	Final	Swell
(cc)	(cc)	No.1	Volume	Index
10.0	23.00	22.0	22.5	125

[TP11@3m](#)

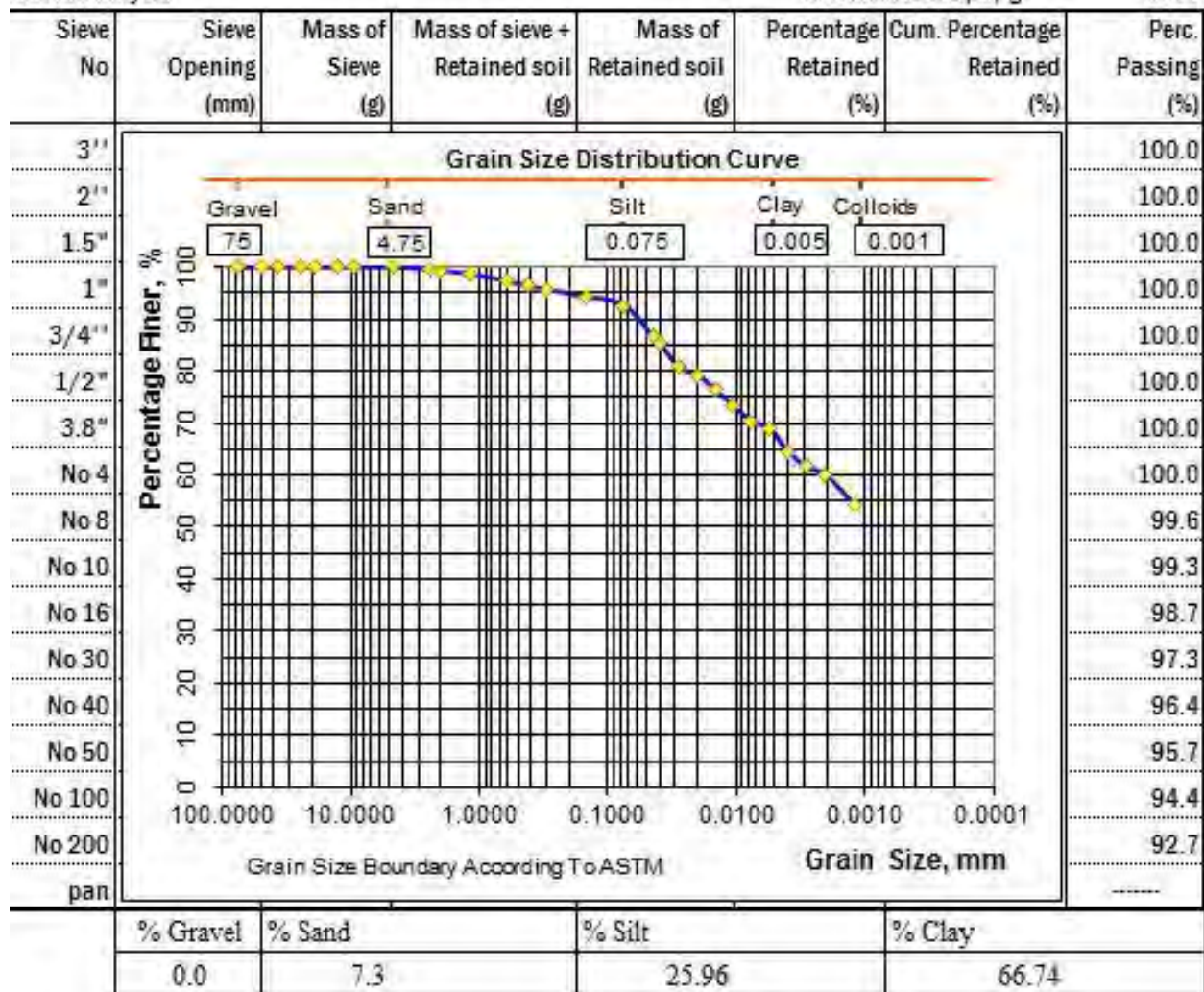
Initial	Final		Average	Free
Volume	Volume	Sample	Final	Swell
(cc)	(cc)	No.1	Volume	Index
10.0	21.00	20.0	20.5	105

[TP11@1.5m](#)

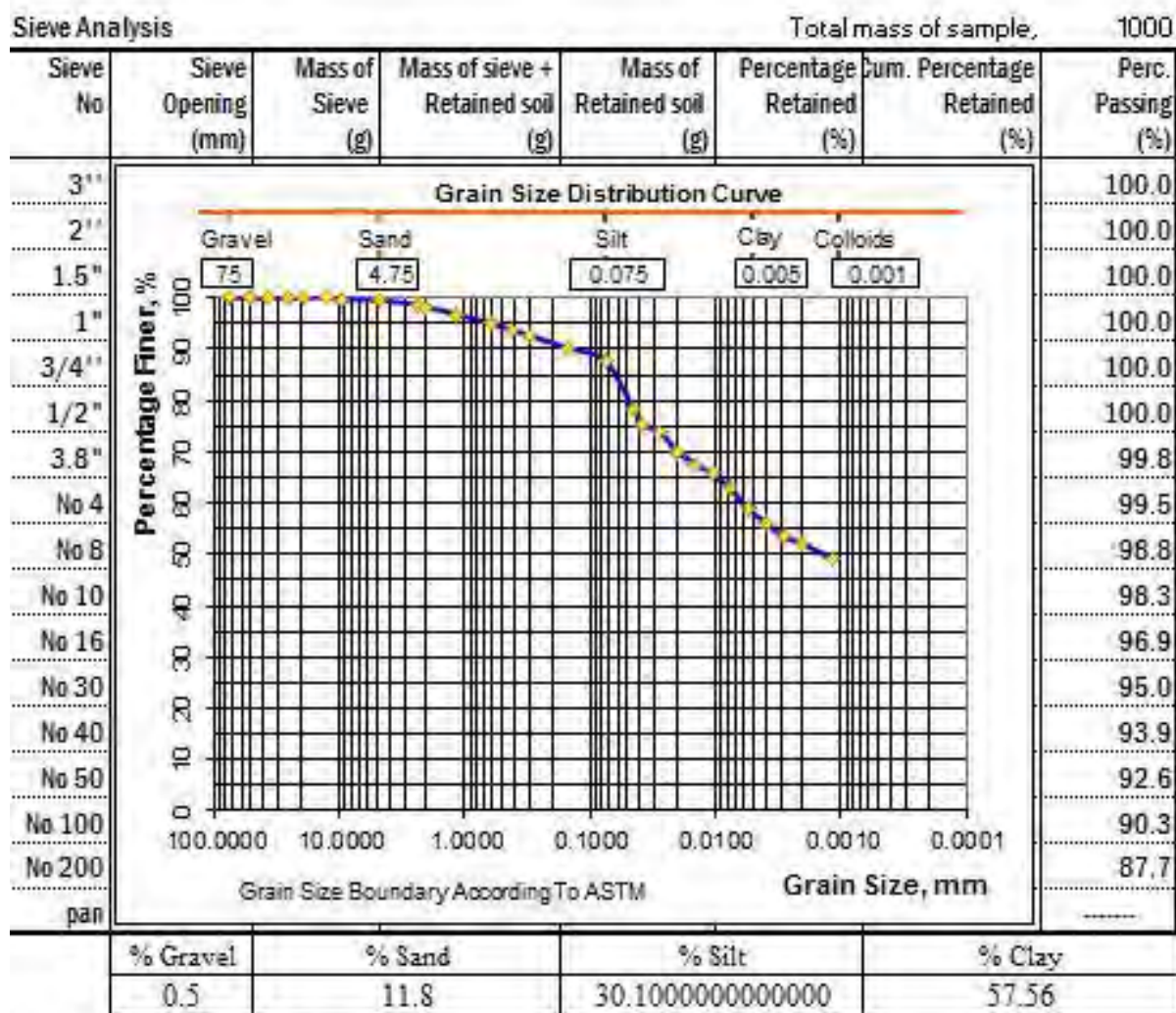
Initial	Final		Average	Free
Volume	Volume	Sample	Final	Swell
(cc)	(cc)	No.1	Volume	Index
10.0	15.60	16.0	15.8	58

Sample No : TP1 Sample Depth, m : 3.00

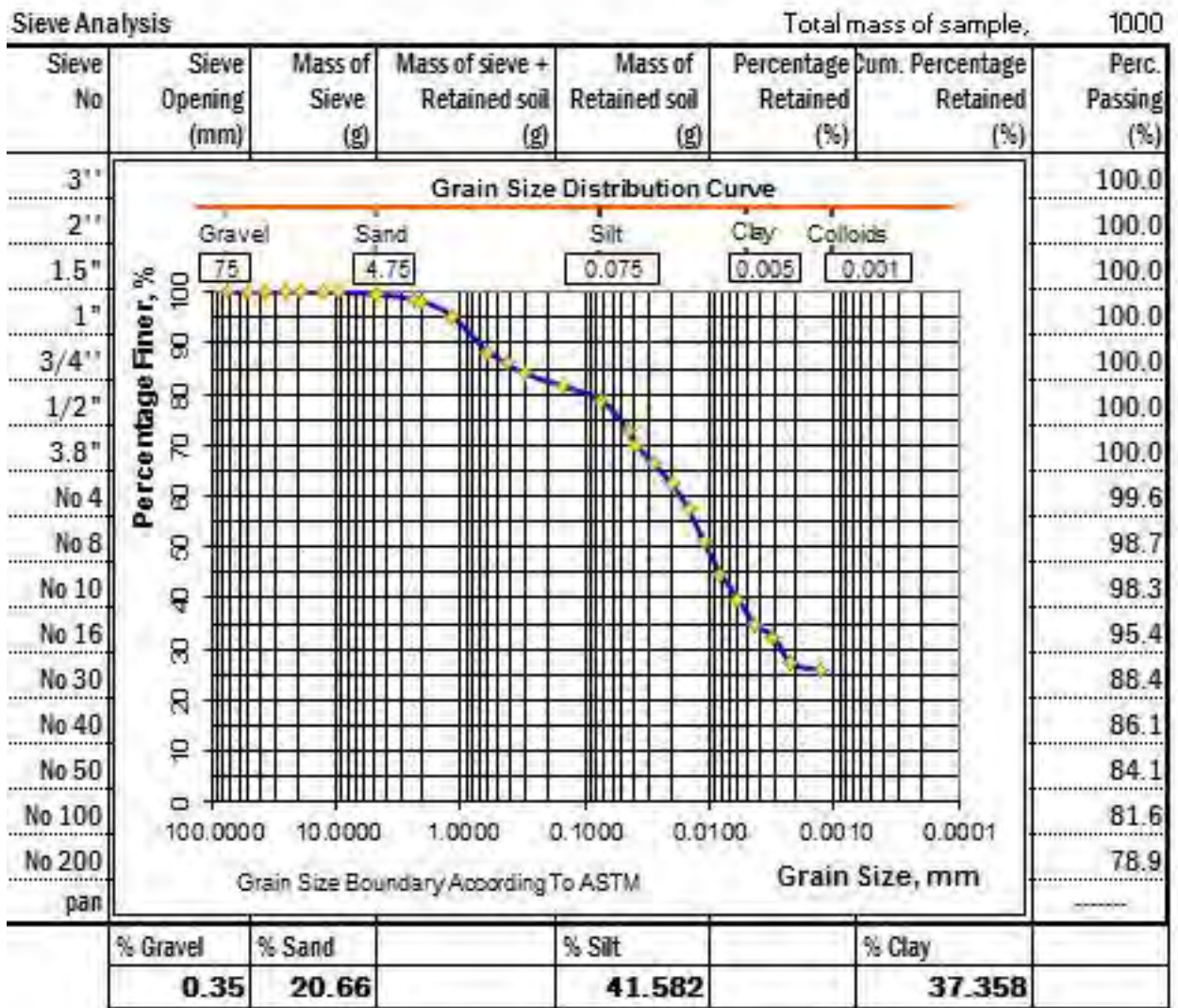
Sieve Analysis Total mass of sample, g 1000



Sample No : TP3 Sample Depth, m : 1.50



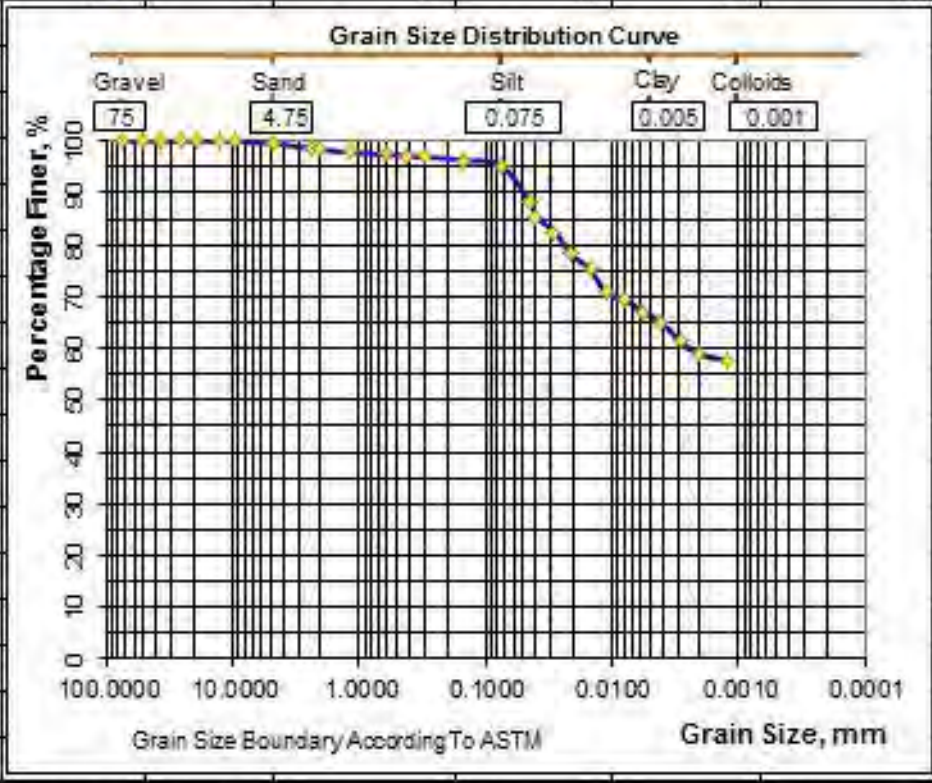
Sample No : TP3 Sample Depth, m : 3m



Sample No : TP4 Sample Depth, m : 1.50

Sieve Analysis Total mass of sample, 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"							100.0
2"							100.0
1.5"							100.0
1"							100.0
3/4"							100.0
1/2"							100.0
3.8"							100.0
No 4	75						99.6
No 8	4.75						98.6
No 10							98.4
No 16							97.9
No 30							97.4
No 40							97.2
No 50							97.0
No 100							96.3
No 200							95.3
pan							---
		% Gravel	% Sand		% Silt		% Clay
		0.45	4.27		29.3686		65.911401



Title Investigation in to some of engineering properties of soils found in Worabe town

Location:

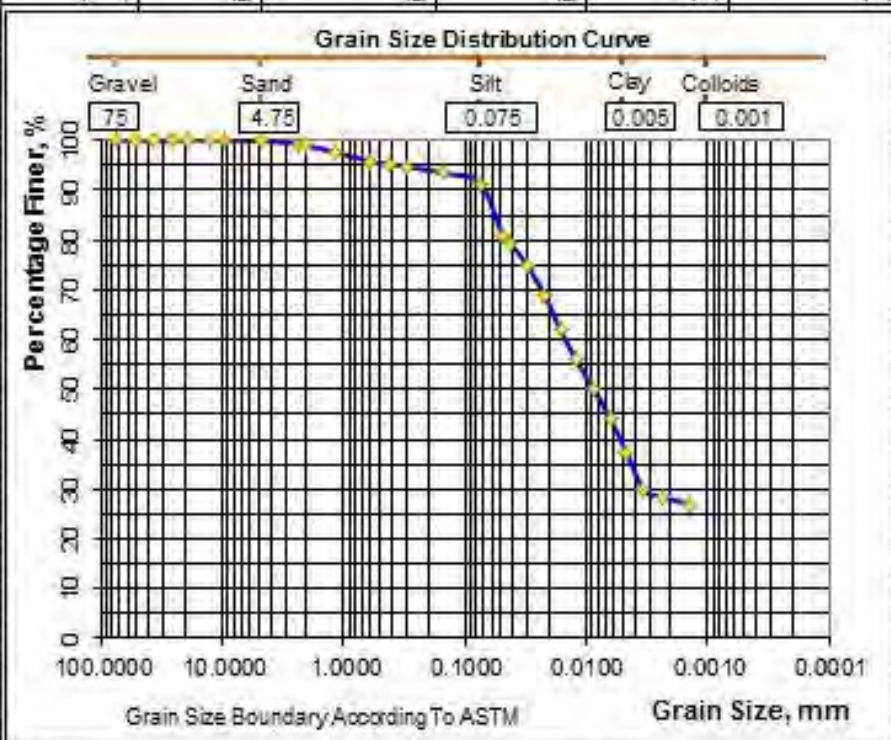
Sample No : TP4

Sample Depth, m : 3.00

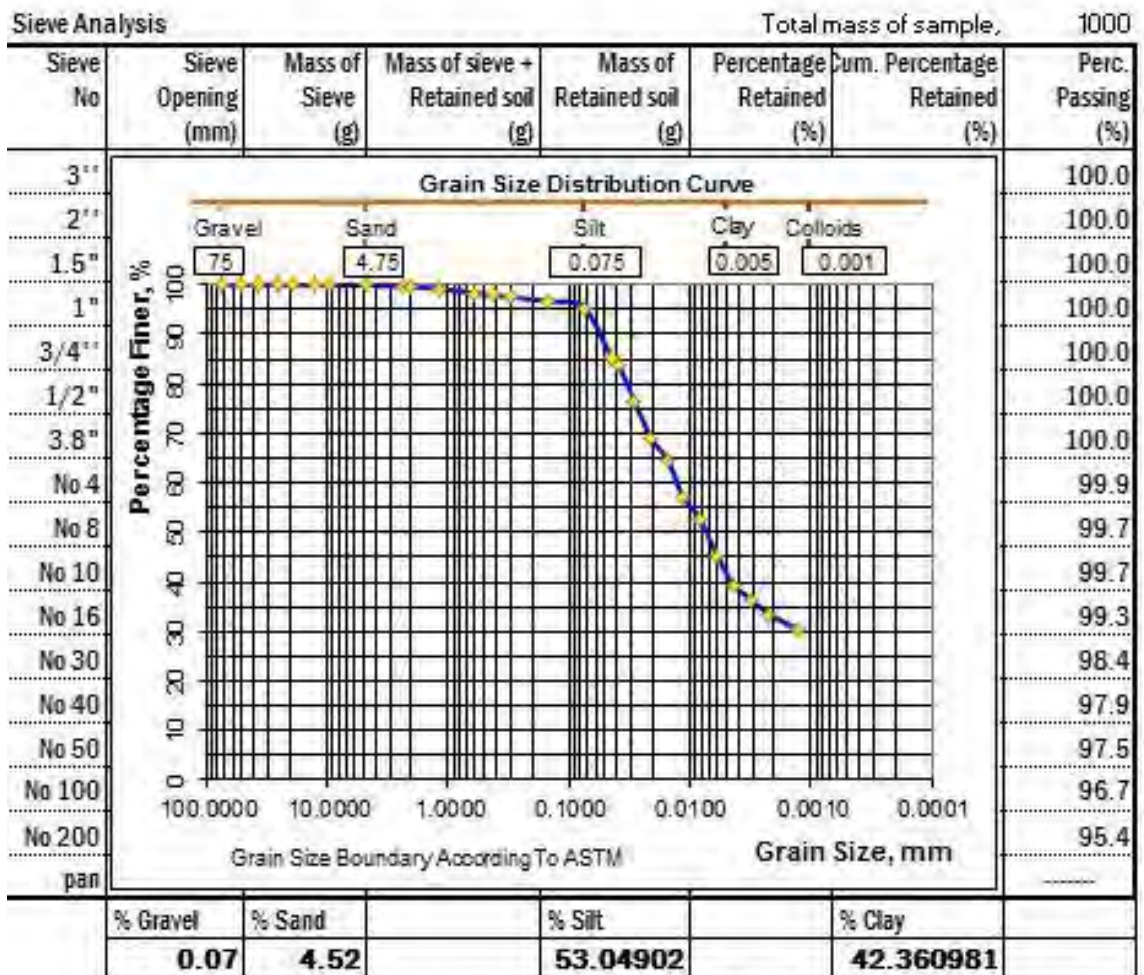
Sieve Analysis

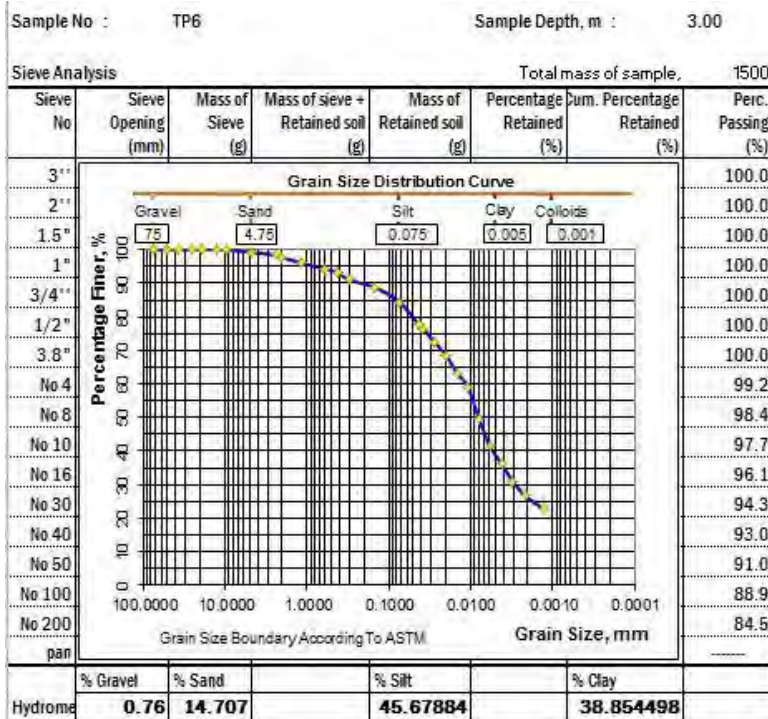
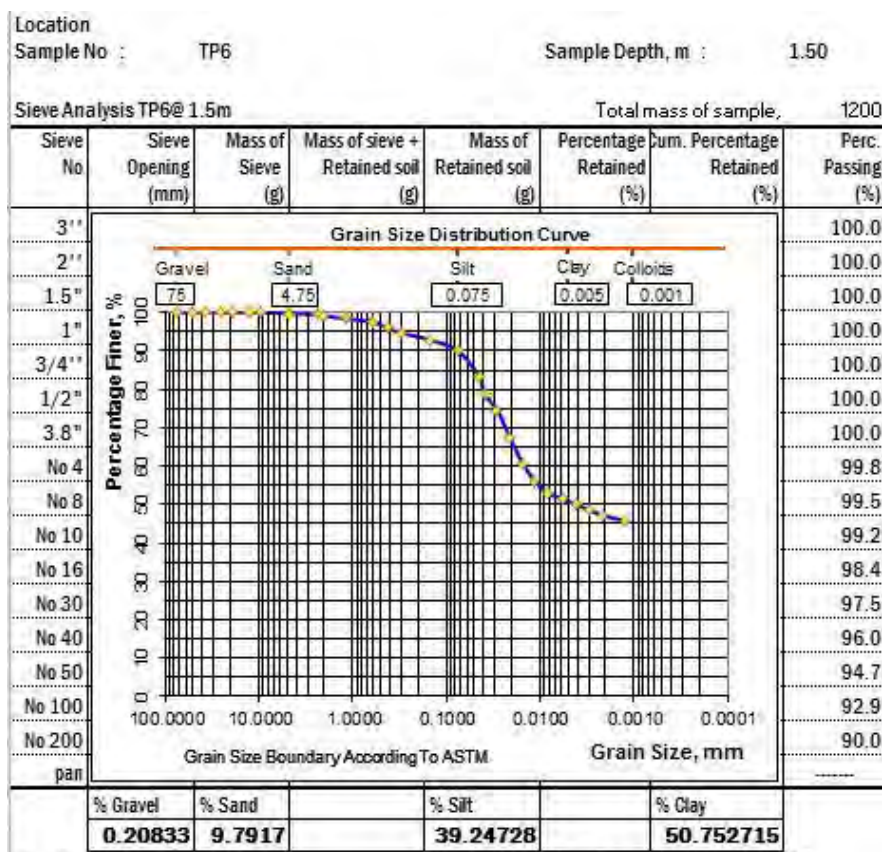
Total mass of sample, 1000

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"							100.0
2"							100.0
1.5"							100.0
1"							100.0
3/4"							100.0
1/2"							100.0
3/8"							100.0
No 4							100.0
No 8							99.4
No 10							99.0
No 16							97.7
No 30							95.8
No 40							95.3
No 50							94.7
No 100							93.5
No 200							91.4
pan							
		% Gravel			% Silt		
		0.04			54.2141	37.145901	
		% Sand			% Clay		
		8.6					



Sample No : TP5 Sample Depth, m : 3.00



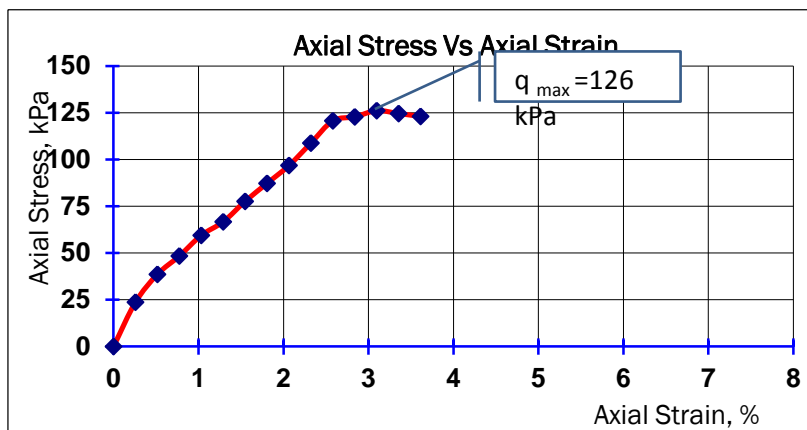


Unconfined Compression Strength Test

Test Pit No:	TP7	Cross- Sectional Area , m²	0.001134
Depth, m :	3.0m	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	Moisture content, %	46.58
Diameter of sample , mm	38	Wet unit weight, kN/m ³	16.36
Length of sample , mm	76	Dry Unit Weight, kN/m ³	11.16
mass, gm	146.6	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	19	0.0270	0.001137	23.73
0.40	0.52	31	0.0440	0.001140	38.61
0.60	0.77	39	0.0554	0.001143	48.45
0.80	1.03	48	0.0682	0.001146	59.48
1.00	1.29	54	0.0767	0.001149	66.74
1.20	1.55	63	0.0895	0.001152	77.66
1.40	1.81	71	0.1008	0.001155	87.29
1.60	2.06	79	0.1122	0.001158	96.87
1.80	2.32	89	0.1264	0.001161	108.85
2.00	2.58	99	0.1406	0.001164	120.76
2.20	2.84	101	0.1434	0.001167	122.87
2.40	3.10	104	0.1477	0.001170	126.18
2.60	3.35	103	0.1463	0.001173	124.64
2.80	3.61	102	0.1448	0.001177	123.10

Unconfined Compressive Strength , kPa = 126



Test Pit No: TP4 **Cross- Sectional Area ,**
m² **0.001134**

Depth, m : 1.50 **Ring Calibration Factor,**
kN/div **0.00142**

Sampling **Undisturbed** **Moisture content, %**
46.58

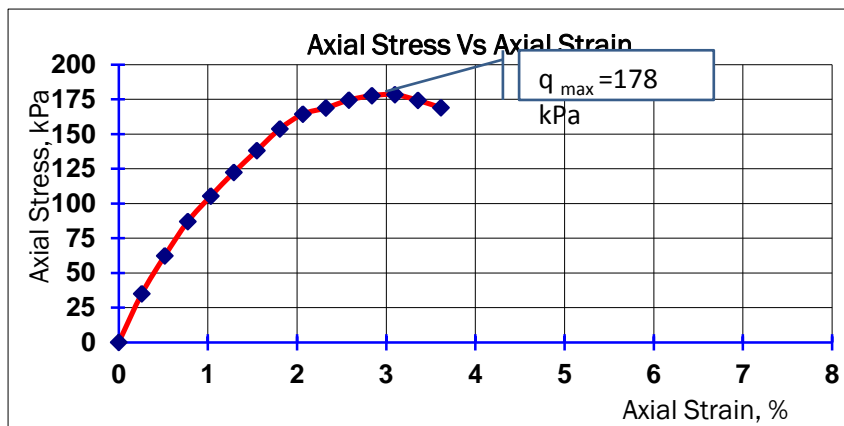
Diameter of sample , mm **38** **Wet unit weight, kN/m³**
16.36

Length of sample , mm **77.5** **Dry Unit Weight, kN/m³**
11.16

mass, gm **146.6** **Rate of Strain, mm/min**
1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	28	0.0398	0.001137	34.97
0.40	0.52	50	0.0710	0.001140	62.28
0.60	0.77	70	0.0994	0.001143	86.97
0.80	1.03	85	0.1207	0.001146	105.33
1.00	1.29	99	0.1406	0.001149	122.36
1.20	1.55	112	0.1590	0.001152	138.06
1.40	1.81	125	0.1775	0.001155	153.68
1.60	2.06	134	0.1903	0.001158	164.31
1.80	2.32	138	0.1960	0.001161	168.77
2.00	2.58	143	0.2031	0.001164	174.43
2.20	2.84	146	0.2073	0.001167	177.61
2.40	3.10	147	0.2087	0.001170	178.36
2.60	3.35	144	0.2045	0.001173	174.25
2.80	3.61	140	0.1988	0.001177	168.96

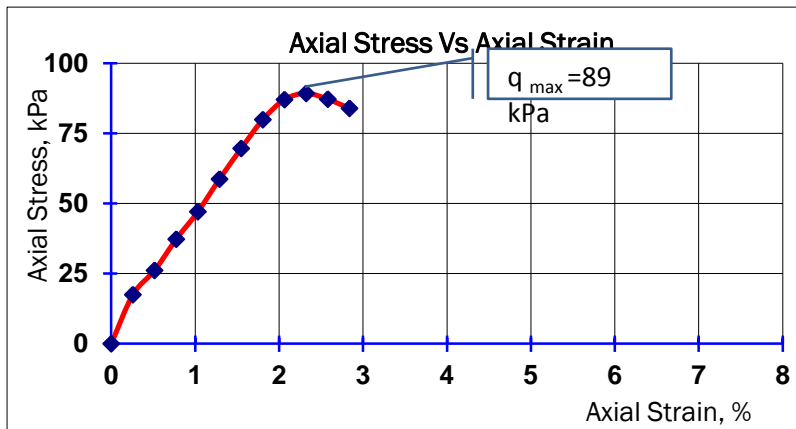
Unconfined Compressive Strength , kPa = 178



Test Pit No:	TP4	Cross- Sectional Area , m²	0.001134
Depth, m :	3.0m	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	46.58
Diameter of sample , mm	38	Moisture content, %	46.58
Length of sample , mm	81	Wet unit weight, kN/m ³	15.58
mass, gm	139.6	Dry Unit Weight, kN/m ³	10.63
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	14	0.0199	0.001137	17.48
0.40	0.52	21	0.0298	0.001140	26.16
0.60	0.77	30	0.0426	0.001143	37.27
0.80	1.03	38	0.0540	0.001146	47.09
1.00	1.29	47.5	0.0675	0.001149	58.71
1.20	1.55	56.5	0.0802	0.001152	69.65
1.40	1.81	65	0.0923	0.001155	79.91
1.60	2.06	71	0.1008	0.001158	87.06
1.80	2.32	73	0.1037	0.001161	89.28
2.00	2.58	71.5	0.1015	0.001164	87.21
2.20	2.84	69	0.0980	0.001167	83.94

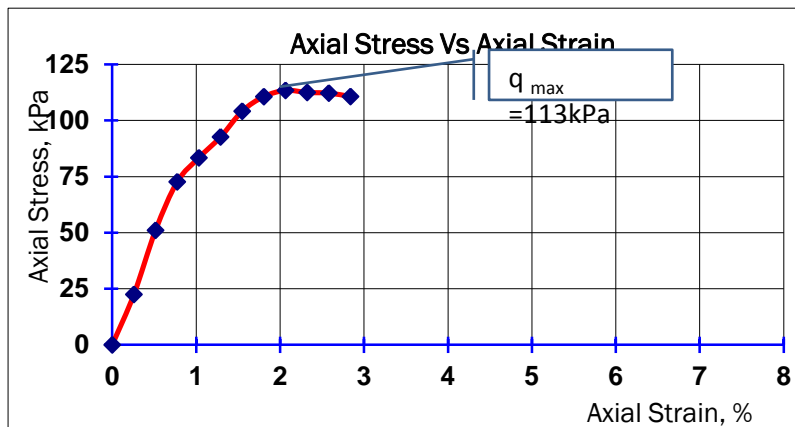
Unconfined Compressive Strength , kPa = **89**



Test Pit No:	TP9	Cross- Sectional Area , m²	0.001134
Depth, m :	1.5m	Ring Calibration Factor,	0.00142
Sampling	Undisturbed	kN/div	46.58
Diameter of sample , mm	38	Moisture content, %	46.58
Length of sample , mm	87.5	Wet unit weight, kN/m ³	16.35
mass, gm	146.5	Dry Unit Weight, kN/m ³	11.16
		Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	18	0.0256	0.001137	22.48
0.40	0.52	41	0.0582	0.001140	51.07
0.60	0.77	58.5	0.0831	0.001143	72.68
0.80	1.03	67.3	0.0956	0.001146	83.39
1.00	1.29	75	0.1065	0.001149	92.69
1.20	1.55	84.5	0.1200	0.001152	104.16
1.40	1.81	90	0.1278	0.001155	110.65
1.60	2.06	92.5	0.1314	0.001158	113.43
1.80	2.32	92	0.1306	0.001161	112.52
2.00	2.58	92	0.1306	0.001164	112.22
2.20	2.84	91	0.1292	0.001167	110.70

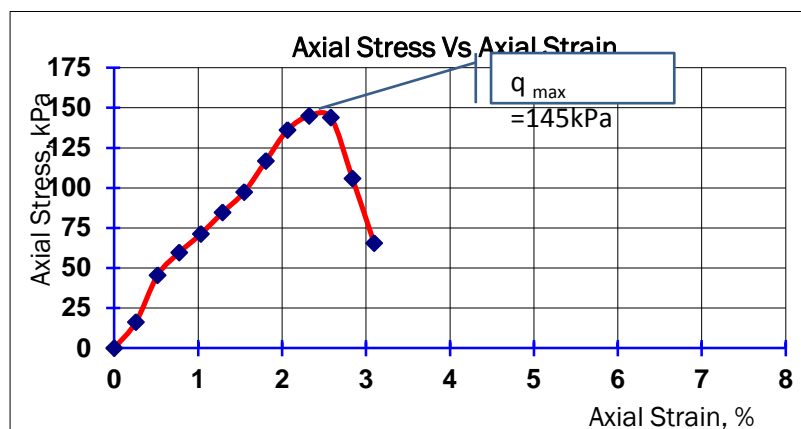
Unconfined Compressive Strength, kPa = **113**



Test Pit No: TP6 **Cross- Sectional Area , m²** 0.001134
Depth, m : 3.0m **Ring Calibration Factor,** 0.00142
Sampling Undisturbed **Moisture content, %** 46.58
Diameter of sample , mm 38 **Wet unit weight, kN/m³** 17.14
Length of sample , mm 77 **Dry Unit Weight, kN/m³** 11.70
mass, gm 153.6 **Rate of Strain, mm/min** 1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	13	0.0185	0.001137	16.24
0.40	0.52	36.5	0.0518	0.001140	45.46
0.60	0.77	48	0.0682	0.001143	59.63
0.80	1.03	57.5	0.0817	0.001146	71.25
1.00	1.29	68.5	0.0973	0.001149	84.66
1.20	1.55	79	0.1122	0.001152	97.38
1.40	1.81	95	0.1349	0.001155	116.80
1.60	2.06	111	0.1576	0.001158	136.11
1.80	2.32	118.5	0.1683	0.001161	144.93
2.00	2.58	118	0.1676	0.001164	143.93
2.20	2.84	87	0.1235	0.001167	105.84
2.40	3.10	54	0.0767	0.001170	65.52

Unconfined Compressive Strength , kPa = 145



DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Messele Haile and has not been presented as a thesis for a degree in any other university, and that all sources of materials used for this thesis have also been duly acknowledged.

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Addis Ababa University,
Addis Ababa.
Date of submission: October, 2015