JIMMA UNIVERSITY

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SCHOOL OF GRADUATE STUDIES

GEOTECHNICAL ENGINEERING STREAM

Study on Some of the Engineering Properties of Soils Found in Gilgel-Beles Town

By:

Tolossa Jote

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering (Geotechnical Engineering)

March, 2019

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Main advisor: - **Tadesse Abebe (Ass. Professor)**

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APPROVAL PAGE SHEET

The undersigned certify that they have read this thesis entitled: - **Study on Some of the Engineering Properties of Soils found in Gilgel-Beles –Town, Ethiopia** and here by recommend for acceptance by Jimma University in partial fulfilment of the requirement for the degree of Master of Science in Geotechnical Engineering.

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Signature Date

DECLARATION

I, the undersigned, declare that the work in the thesis entitled "**Investigation on some of the Engineering Properties of Soil Found in Gilgel-Beles –Town**" has been performed by me in the Department of Civil Engineering, Institute of Technology, under the supervision of my research advisor Tadesse Abebe (Ass. Professor). The information derived from literature has been duly acknowledged in the text and list of references provided. No part of this project was previously presented for another degree at any university.

Name: Tolossa Jote Denbi

Signature: ______________

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ACRONYMS

USCS	Unified Soil Classification System
AASHTO	American Association of State Highway and Transportation Officials
PL	Plastic Limit
LL	Liquid Limit
W%	Water Content in (%)
Ws	Dry weight of solids in (gr)
W_w	Weight of water in (gr)
W_{pw}	Weight of bottle filled with water in (gr)
W_{pws}	Weight of bottle r filled with water and soil in (gr)
γ_d	Dry unit weight of the soil sample
Gs	Specific gravity
γ_{bulk}	Bulk unit weight of the soil sample
γ_w	Unit weight of water
TP	Test Pit
ASTM	American Society for testing Materials
q_u	Unconfined compressive strength (kpa)
P	Compressive Force (KN)
A	Cross- sectional area (m2)
A_c	Corrected cross-sectional area (m2)
A_o	Original cross sectional area (m2)
ε	Axial strain (mm/mm), ΔL/Lo,
C_c	Compression index
C_v	Coefficient of vertical consolidation
OCR	Over consolidation ratio

ABSTRACT

In civil engineering works, "soil" is used in any kind of civil engineering structure, either as foundation material to support the load exerted by structures, or as construction materials. From this point of view, the geotechnical engineers are mainly interested in the engineering behaviour of soils and classify the soils on the basis of their properties.

The construction of civil engineering structures is developing fast in Gilgel-Beles Town like other main towns of Ethiopia. In the construction industry, engineering characteristics of soils play a significant task as input data in preliminary design, designing and construction. However, engineering properties such as index properties and consolidation characteristics of the Gilgel-Beles soil is not studied well yet. Therefore, investigating the engineering properties and identifying the characteristic of the soil is very important for construction works as well as for further studies in the future as an input.

The objective of this research was to investigate some of engineering properties of soils found in Gilgel-Beles town. To achieve the objective, disturbed and undisturbed samples from different parts of the city were collected. To determine the properties of soil the test was conducted by using ASTM standard test procedure.

Based on the laboratory test results the properties of soils of the study area were specific gravities range from 2.6 to 2.72, clay fraction 23-54.6%, silt fraction 14.9-50.5%, sand fraction 20.82-39.1% and gravel fraction 0-1.4%, liquid limit 30 – 52.5%, plastic limit, 24.9 – 40.5% and plastic index 5 – 19.5%.

According to USCS classification system of plasticity chart, most of the soil of the study area falls below A-Line in ML region, and TP-3, TP-5 and TP-7 in MH region, which have high plasticity (LL>50%) and the classification soils found in Gilgel-Beles town were ML, MH and CL. And also, according to AASTHO soil classification, the study area soils were dominantly categorized in A-7-5 and A-7-6 which is poor for sub-grade materials. Based on the compaction test, maximum dry density (MDD) ranges from1.57 to 1.81 g/cm3 with optimum moisture content from 17 to 35.38 %.

Unconfined compressive strength of the soil at the study area ranges from 85.28 to 179kN/m2 and un-drained shear strength 42.64 to 89.5kN/m2 According to the relation between consistency and unconfined compression strength of clays, the unconfined compressive strength of the study area is included in medium consistency. From the one-dimensional consolidation test result, the over-consolidation ratios of the soils are more than one, so the soil in the study area is over consolidated in the past with maximum effective stress.

Key words: *Investigating, Engineering Properties of Soils, Gilgel-Beles –Town*

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1. INTRODUCTION

1.1 General

In civil engineering works, "soil" is used in any kind of civil engineering works, either as foundation material to support the load exerted by structures, or as construction material. From this point of view, the geotechnical engineers are mainly interested in the engineering behaviour of soils and classify the soils on the basis of their properties. Thus, during the planning, design, and construction, of foundations, embankments, tunnel and earth-retaining structures geotechnical engineers must study the properties of soils, such as origin, grain-size distribution, permeability, compressibility, shear strength and load-bearing capacity. Soil investigation is an essential part of the design and construction of a proposed structural system. Usually soil investigations are conducted only on a fraction of a proposed site because it would be high expensive to conduct an extensive investigation of a whole site. One then makes estimates and judgments based on information from a limited set of observations, and from field and laboratory test data that will have profound effects on the performance and costs of structures constructed at a site. Investigation of the sub-surface conditions at a site is prerequisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies of the proposed project. Public building officials may require soil data together with the recommendations of the geotechnical consultant prior to issuing a building permit, particularly if there is a chance that the project will endanger the public health or safety or degrade the environment. The aim of investigation is to provide maximum information that is useful in the design and construction of the project at a minimum cost. Therefore, to obtain information on type, characteristics and distributions of a soil, geotechnical investigations should be done on soil and rock underlying and sometimes adjacent to a site of proposed structures.

For developing countries like Ethiopia, which is developing at high growth rate the construction industry is also growing rapidly. Detailed geotechnical investigation on the engineering property of soil is very essential. Therefore, a central aim of this study is to investigating the engineering properties of soils found in the Gilgel-Beles -town by conducting different types of laboratory tests and providing necessary data that can be used in designing civil engineering structures [4].

1.2 Statement of the Problem

The construction of civil engineering structures is developing fast in Gilgel-Beles Town like other main towns of Ethiopia. For those civil engineering construction works, engineering characteristics of soils play a significant task as input data in preliminary design and in designing. These made, the testing of soil is mandatory, to determine its geotechnical properties, to check the suitability as a construction and foundation material. Furthermore, Gilgel-Beles town is the transit way from Assosa to Grand Ethiopian Renaissance Dam, and simultaneously a famous investment zone which is found in Benshangul Gumuz regional government and the area need construction of buildings and roads. For those civil engineering construction works, engineering characteristics of soils play a significant task as input data in preliminary design and in designing. Several governmental institutions and private business centres are established in the town and around it. Therefore, a detailed and comprehensive geotechnical investigation is an essential requirement in designing of those civil engineering structures, which requires adequate knowledge of sub surface bearing capacity conditions at the sites of the proposed structures [24]. However, engineering properties such as index properties and consolidation characteristics of the Gilgel-Beles soil is not studied well yet. Therefore, investigating the engineering properties, identifying the characteristic of the soil and preparing soil map of the city is very important for construction works as well as for further studies in the future as an input [13]. This research is therefore directed to investigating the index property, consolidation characteristic, and identifying the characteristics of the soil at the study area.

1.3 Research questions

Research questions are important components of research that indicates some important problems to be addressed throughout the research. This includes the followings.

- ✓ How could be determine the index properties of soils at the study area?
- ✓ How can be determining the One-dimensional consolidation characteristic of soils?
- ✓ How can be determining the unconfined compression parameters?

Objectives

1.4.1 General objective

The overall aim of this thesis is to investigate some the engineering properties of soils found in Gilgel-Beles town.

1.4.2 Specific objective

- ✓ To investigate the index properties of soils in the study area.
- ✓ To classify of soil by USCS and AASHTO.
- ✓ To determine the unconfined compression parameters.
- ✓ To know the One-dimensional consolidation characteristic of soils.
- ✓ To compare the findings with other similar studies.

1.5 Scope of the Study

The scope of the study is focused on investigation of index properties of soils, modified compaction test, unconfined compression test and one-dimensional consolidation characteristic of the soil. The depth of investigation in this research is limited to the maximum depth of three meters since it is difficult to excavate and sampling manually beyond this depth. Consolidation test is done only for two samples. The permeability coefficient of the soil in the research area is calculated from consolidation test results.

1.6 Structure of the thesis

This thesis is organized in to five Chapters. Topics under first Chapter comprise general, objective, scope of the study and structure of the thesis. The second Chapter deals with literature review. The third Chapter deals with the study area, borehole locations, topography, drainage conditions, climate (rainfall and temperature), materials and research methodology. The fourth Chapter deals with laboratory tests result. Finally, conclusions and recommendations are presented in Chapter five.

2. LITERATURE REVIEW

2.1 General

Every civil engineering work involves the determination of soil type and its associated engineering application. 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 [13]. Physical soil properties include particle size and distribution, specific gravity, and water content. Index parameters of soils include liquid limit, plastic limit, shrinkage limit, and activity. Such parameters are useful to classify soils and provide correlations with engineering soil properties [20]. 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.

2.2 Soil Formation and Soil Deposit

Soil is formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition. The properties of the soil materials depend upon the properties of the rocks from which they are derived [24]. A brief discussion of the parent rocks is, therefore, quite essential in order to understand the properties of soil materials [12]. The main factors affecting the formations of soil are: Parent materials such as: 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, cat ion exchange capacity, profile drainage, moisture retaining capacity and organic content [10].

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 [27].

2.2.3 Climate

Climate is the principal factor governing the rate and type of soil formation. The two important components of climate are the amount and distribution of precipitation, and temperature. The temperature variable is adequately represented by mean annual 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^{o}c rise of temperature [16]. 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; chemical activities of solutions in the system.

2.3 General Types of Soils

According to their grain size, soil particles are classified as gravel, sand, silt and clay. Grains having diameters in the range of 4.75 to 76.2 mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75 mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eyes is about 0.075 mm. Soil grains ranging from 0.075 to 0.002 mm are termed as silt and those that are finer than 0.002 mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials [24].

Table 2.1 Particle Size Range

Particle Name	Size Range
Gravel	4.75 – 76.2mm
Sand	< 4.75mm
Silt	0.075 – 0.002mm
Clay	< 0.002mm

2.4 Soil Particle Size and Shape

Irrespective of the origin of soil, the sizes of particles in general, that make up soil, vary over a wide range. Soils are generally called gravel, sand, silt, or clay, depending on the predominant size of particles within the soil. 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.
Grains finer than 0.075mm, constitutes the finer fractions of soils. The shape of grains smaller than 1μ can be determined by means of an electron microscope. The molecular structure of soil particles can be investigated by means of X-ray analysis. The shape of particles present in a soil mass is equally as important as the particle size distribution because it has significant influence on the physical properties of a given soil. However, not much attention is paid to particle shape because it is more difficult to measure. The individual grains of gravel and sand may be angular, sub-angular, sub-rounded, rounded or well-rounded. Silt and clay constitute the finer fractions of the soil. Silt and clay constitute the finer fractions of the soil. The particles may be angular, flake-shaped or sometimes needle-like [30].

2.5 Index Properties of Soils

2.5.1 Moisture Content

Moisture content of a soil material is, the ratio between the mass of water in the sample and the mass of solid material, which expressed in percentage. For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its properties. In fine grained soils, the effect of water content on shear strength is highly significant. The water content of a material is used in expressing the phase relationship of air, water and solids in a given volume of material. The water content of a soil along with its liquid and plastic limits is used to express its relative consistency termed as liquidity index. Consistency is a term used to indicate the degree of firmness of cohesive soils. The consistency of natural cohesive soil deposits is expressed qualitatively by such terms as very soft, soft, stiff, very stiff and hard. Water content alone, therefore, is not an adequate index of consistency for engineering and many other purposes [14].

The conventional test for the determination of moisture content is based on the loss of water when a soil is dried to a constant mass at a temperature between 105 and 110 ºC.

2.5.2 Atterberg Limits

A fine-grained soil can exist in solid, semisolid, plastic, viscous or fluid state depending on its water content. The Swedish soil scientist Albert Atterberg originally defined seven “limits of consistency” to classify fine-grained soils, in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. [14]. Wide varieties of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the USCS or AASHTO system.

2.5.3 Specific Gravity

Soil is a three-phase system comprising solid, liquid and gas. Many soil parameters like unit weight void ratio, porosity and water content relates the proportion of these phases with each other or to the total soil mass/volume but specific gravity of a soil is a property of soil solids only. Specific gravity of a soil is, the ratio of the mass in air of a given volume of soil solid to the mass in air of an equal volume of distilled water at stated temperature [14].

2.5.4 Grain –Size Distribution

Soil consists mostly of different sized soil particles as major constituent ingredient. The determination of the fractions of the particles will help to identify the soil type as well as to estimate many other engineering properties such as strength and permeability and also to identify whether the soil is suitable for construct projects such as highways, dams or as a backfill or for filter design. Two methods are mostly used to determine grain size distribution are Sieve analysis for coarse grained portion of the soil (size coarser than 0.075mm) and Hydrometer analysis for fine grained portions (size finer than 0.075mm). For soil sample that contains a measurable portion of their grains both coarser and finer than 0.075mm size combined analysis is required [14].

2.6 Consolidation Test

Consolidation: - time dependent process of volume change in soil as water is squeezed from the pores. According Terzaghi (1943), “consolidation is a decrease of water content of a saturated soil without replacement of water by air.”

2.6.1 Theories of Compression and Consolidation

Any structure built on the ground causes increase of pressure on the underlying soil layers, and the compression of the soil mass leads to the decrease in the volume of the mass which result in the settlement of the structures, built on it.

Hence there must be adjusting to the new pressure by vertical deformation. The vertical compression of the soil mass under increased pressures is due to the following components.

I) An escape of water and air from the voids

II) Rearrangements of soil particles

III) Deformation of soil grains

2.6.2 Theory of one-dimensional Consolidation

The theory for the time rate of one-dimensional consolidation was first proposed by Terzaghi. Soil is laterally confined and the consolidation takes place only in the axial direction and drainage of water also occurs only in vertical direction. The standard one-dimensional consolidation test is usually carried out on saturated specimen using an Odometer [12]. In this test a small representative sample of the soil is carefully trimmed and fitted into a rigid metal ring. The soil sample is mounted on a porous stone base and a similar stone placed on the top to permit water, which is squeezed out of the sample to escape freely at the top and bottom. Prior to loading, the height of the sample should be accurately measured. The consolidation test apparatus is designed to permit the sample to be submerged in water during the test to simulate the position below a water table of the prototype soil sample from which the test sample was taken.

Loads are applied in steps in such a way that the successive load intensity (P) is twice the preceding one. The dial readings are taken at elapsed time of 0, 0.25, 0.5, 1, 2, 4, 8, 15, 30, minute……24hours. After the greatest load required for the test has been applied to the soil sample, the load is removed in decrements to provide data plotting the expansion curve of the soil in order to learn its elastic properties and permanent deformation.

The consolidation parameters of a soil which are the compression index, Cc, and the coefficient of consolidation, Cv, will be determined from the test. The compression index relates to how much settlement will take place, the coefficient of consolidation relates to how long it will take for an amount of settlement to take place. The results of the odometer test are usually presented in the form of an e-p, e-logp, and dial reading-time plots [12].

2.6.3 Compression Index

Compression index, Cc, is equal to the slope of the linear portion of the void ratio versus log pressure plot. This is useful for determination of the settlement of the filed.

$$C_c = log(\frac{\frac{\Delta e}{P+P_o}}{P_o}) \qquad (2.1)$$

Coefficient of consolidation, Cv, is the rate of consolidation of a soil which determined by Casagrandes semi logarithmic plot method is:

$$C_v = \frac{(0.196).H^2}{t_{50}}\left[\frac{cm^2}{s}\right] \qquad (2.2)$$

2.6.4 Pre-Consolidation Pressure

A soil may have been pre-consolidation during past by the weight of an ice which has melted away, or by other geologic overburden or any structural loads which no longer exist. For example, thick layers of overburden soil may have been eroded or excavated away or heavy structures may have been torn down. The relative amount of pre-consolidation is usually reported as the over consolidation ratio (OCR) defined as:

$$OCR = \frac{P_c}{P_o} \qquad (2.3)$$

3. STUDY AREA AND RESEARCH METHODOLOGY

3.1 Study Area Description

Gilgel-Beles town is the administrative city of Metekel Zone which found in Benshangul Gumuz regional Government, in Western Ethiopia. The geographical coordinate of the town is $11^0$00'0.00''N latitude and $36^0$00'0.00''E longitude. It is Located at a distance of 676km from West of Addis Ababa and at 396km from North of Assosa. It is bordered on the West by Sudan, on the North and East by the Amhara Region and south and southwest by Kamashi. According to the 2007 Census conducted by the central Statistical Agency of Ethiopia this zone has a total population of 276,367. The topography of the zone presents undulating hills slightly sloping down to low land Plateaus having an altitude range from 600-2800 meter above sea level. The surrounding of Metekel zone has a wide climatic range varied from hot to warm moist lowlands and hot to warm sub humid lowlands [31]. Gilgel-Beles town is predominantly covered with yellowish, black and gray soils. The yellowish, colored soils are found on rolling topography with higher elevation and well drainage condition. The black and gray soils, which cover the central and large part of the town, are found on flat topography of the town with lower elevation and unfavourable drainage condition.

The sampling location is selected so that it can be well represent soils found in Gilgel-Beles town. Selection of these sampling locations also considers visual soil classification, economic importance of sampling area, non-uniformity of the sample locations and coverage of the section. This study will cover only Gilgel-Beles town by considering representative areas for sample collection process. The location of the research area, i.e. Gilgel-Beles town, on the map of Benshangul Gumuz regional Government is shown in figure 3.1.

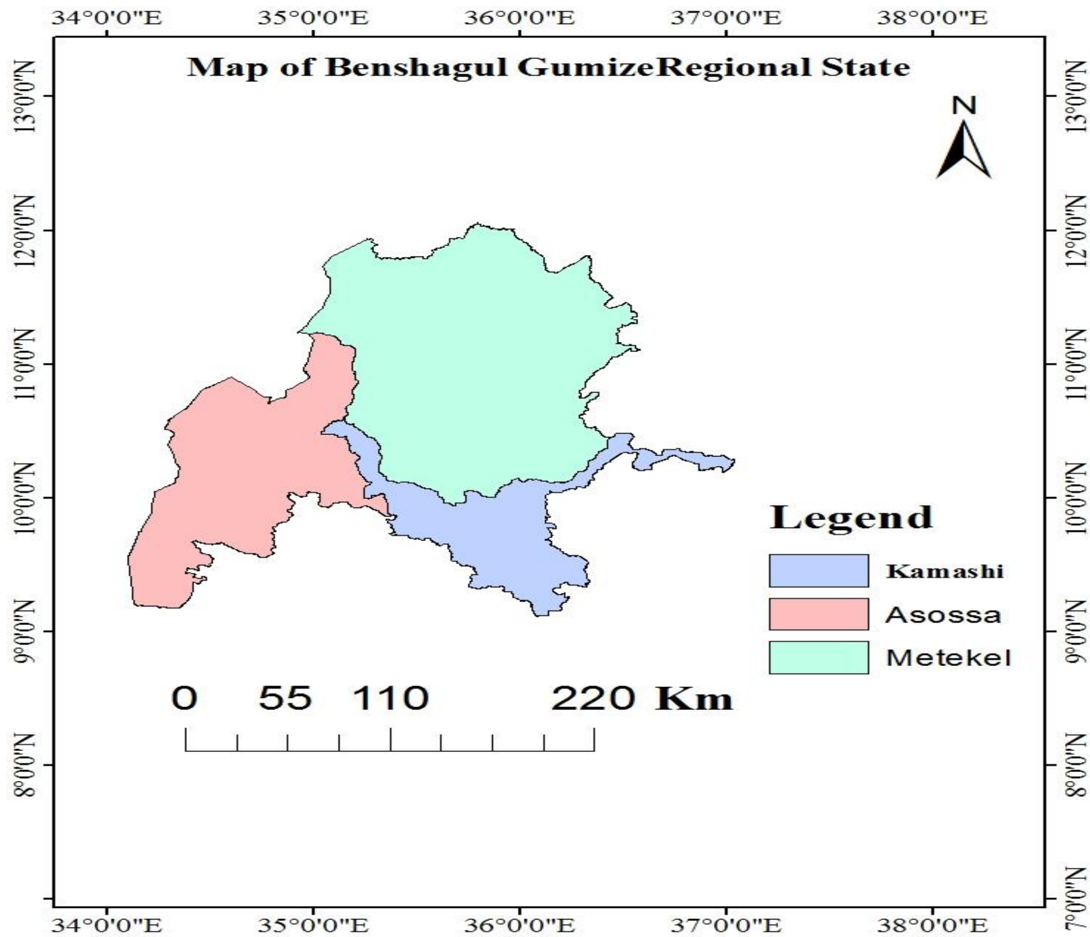

Figure 3. 1 The location of the study area

(Source: administrative map of Benshangul Gumuz regional state)

3.2 Topography and Drainage Conditions

The topography of the zone presents undulating hills slightly sloping down to low land Plateaus having an altitude range from 600-2800 meter above sea level. The surrounding of Metekel zone has a wide climatic range varied from hot to warm moist lowlands and hot to warm sub humid lowlands [31].

3.3 Climate Condition

As data on the climatic condition of Gilgel-Beles town is available, in winter there is much less rainfall than in summer. The average annual temperature is 23.0°c and the average annual rainfall is 1674mm. The precipitation varies 415mm between the driest month and wettest month. Average temperature varies during the year by 3.7°c.

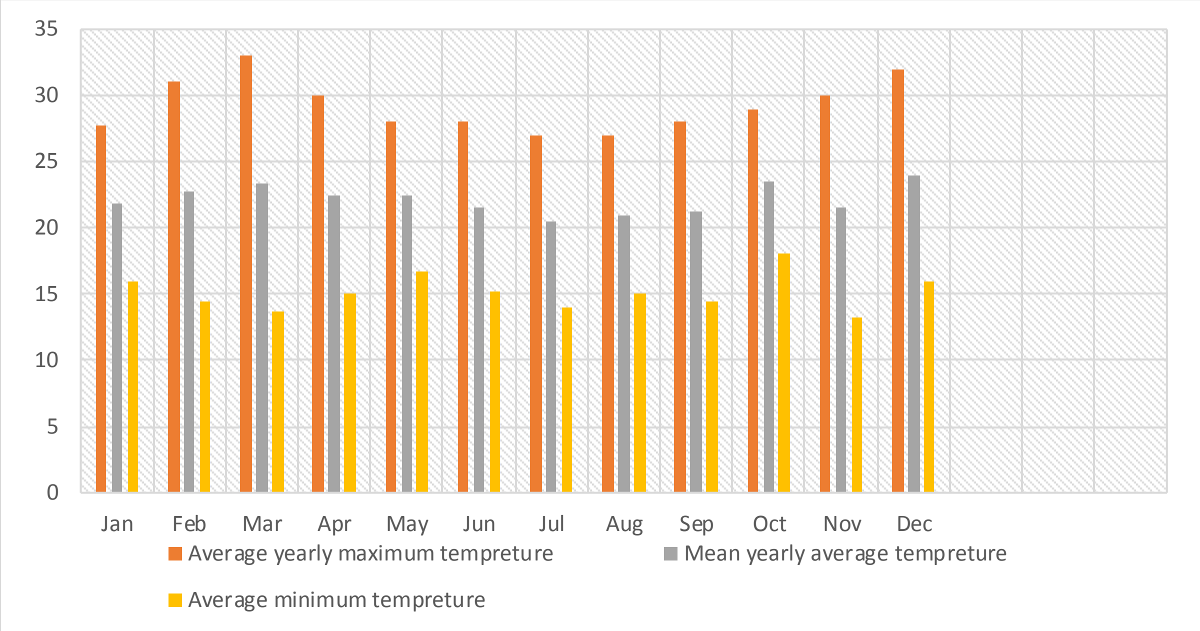

Figure 3. 2 Average annual Maximum and Minimum and mean annual average temperature (1995-20010 E.C).

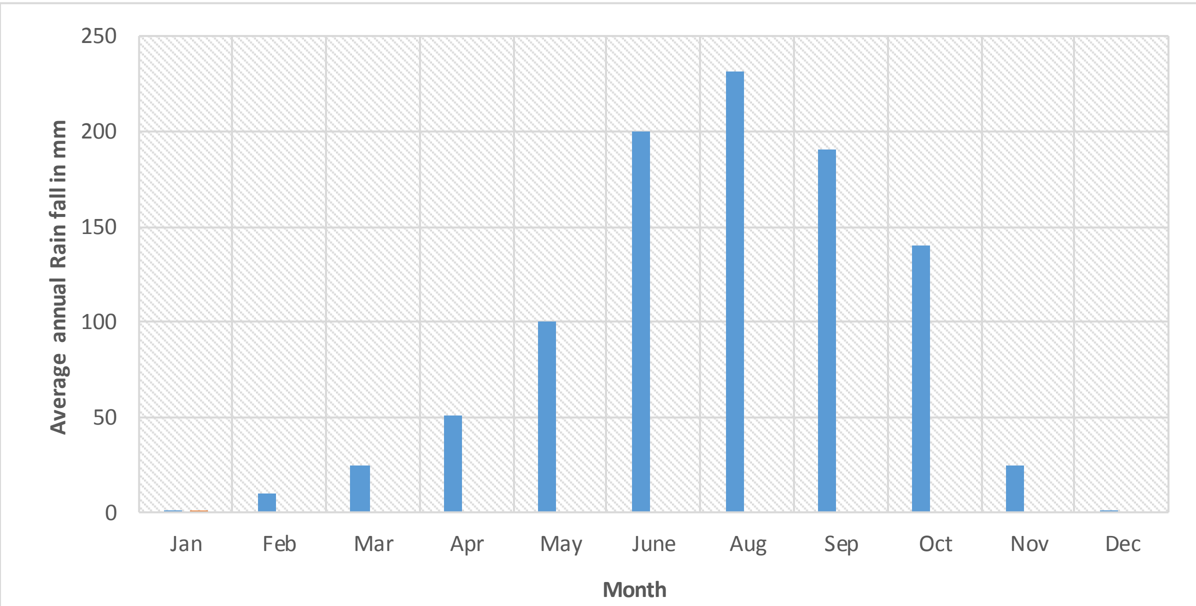

Figure 3. 3 Average annual rain falls of Gilgel-Beles (1995-20010 E.C

(Source: Ethiopian Metrological Agency)

3.4 Soil Characteristics

Soil development and the nature of the soils in the area are mainly controlled by geology, topography and drainage. In well drained table land areas, the predominant soil type is colour from yellowish to gray clay soils; there are also red and dark colour soils. In flat lying location, massive dark silty clay soils (alluvial origin) formation have colour ranging from gray to dark black. Even though most of the town is covered with soils colour from dark to gray clay soils, there are also red and yellow colour soils.

3.5 Study Design and Sampling Methods

The soil specimens for this study were collected from Gilgel-Beles town. Prior to sampling, identification of sampling area has been done by walk-over and visual site investigation to consider the different soil types and to take sample evenly in the whole town. Accordingly, ten sampling areas were selected from different locations of the town which are supposed to represent all types of the soils found in the town from preliminary site investigation. From the selected areas representative disturbed and undisturbed soil samples were collected from open pits by direct excavation manually at the average depths of 1.5m and 3m. Then these samples were taken to the laboratory by taking care for the undisturbed samples. All of the test pits were excavated up to depth of 3m except TP-2. Each tests listed below were done for all samples taken at a depth of one point five and three meters and one-dimensional consolidation test was done only for TP-3 and TP-5. Then, from the samples collected the following laboratory tests were done.

- ✓ Natural moisture content
- ✓ Specific gravity test
- ✓ Grain size analysis
- ✓ Atterberg limit tests
- ✓ Modified Compaction Test
- ✓ Unconfined Compression Test
- ✓ One-dimensional consolidation test

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

Table 3. 1 Sampling depth and location of sampling area

Test pit	Pit location	Sampling depth(m)	Visual Observed color
TP – 1	Adebaby	1.5	Red color
		3	Yellow color
TP – 2	Meniray	1.5	Gray color
		2.8	Gray color
TP – 3	Mariam	1.5	Black color
		3	Gray color
TP – 4	Hidsa sefer	1.5	Gray color
		3	Yellow color
TP – 5	02 kebele	1.5	Black color
		3	Gray color
TP – 6	Memeran college	1.5	Red color
		3	Yellow color
TP -7	Meseke adebabay	1.5	Black color
		3	Gray color
TP – 8	Tena tabya	1.5	Gray color
		3	Red color
TP -9	Mazoreya	1.5	Red color
		3	Yellow color
TP – 10	Chagni mwucha	1.5	Red color
		3	Red color

Table 3. 2 Global coordinates of sampling areas

Test Pit	Location	Northing	Easting	Elevation (m)
TP – 1	Adebaby	$11^0$09.7555	$036^0$20.5565	1031
TP – 2	Meniray	$11^0$09.6916	$036^0$20.5340	1049
TP – 3	Mariam	$11^0$10.1514	$036^0$20.1266	1031
TP – 4	Hidsa sefer	$11^0$10.2015	$036^0$20.1075	1032
TP – 5	02 kebele	$11^0$09.3428	$036^0$20.4122	1034
TP – 6	Memeran college	$11^0$09.8794	$036^0$20.3592	1023
TP – 7	Meseke adebabay	$11^0$09.6287	$036^0$20.5887	1023
TP – 8	Tena tabya	$11^0$09.4499	$036^0$20.7076	1047
TP – 9	Mazoreya	$11^0$09.4499	$036^0$20.707	1037
TP – 10	Chagni mwucha	$11^0$09.4806	$036^0$20.6883	1039

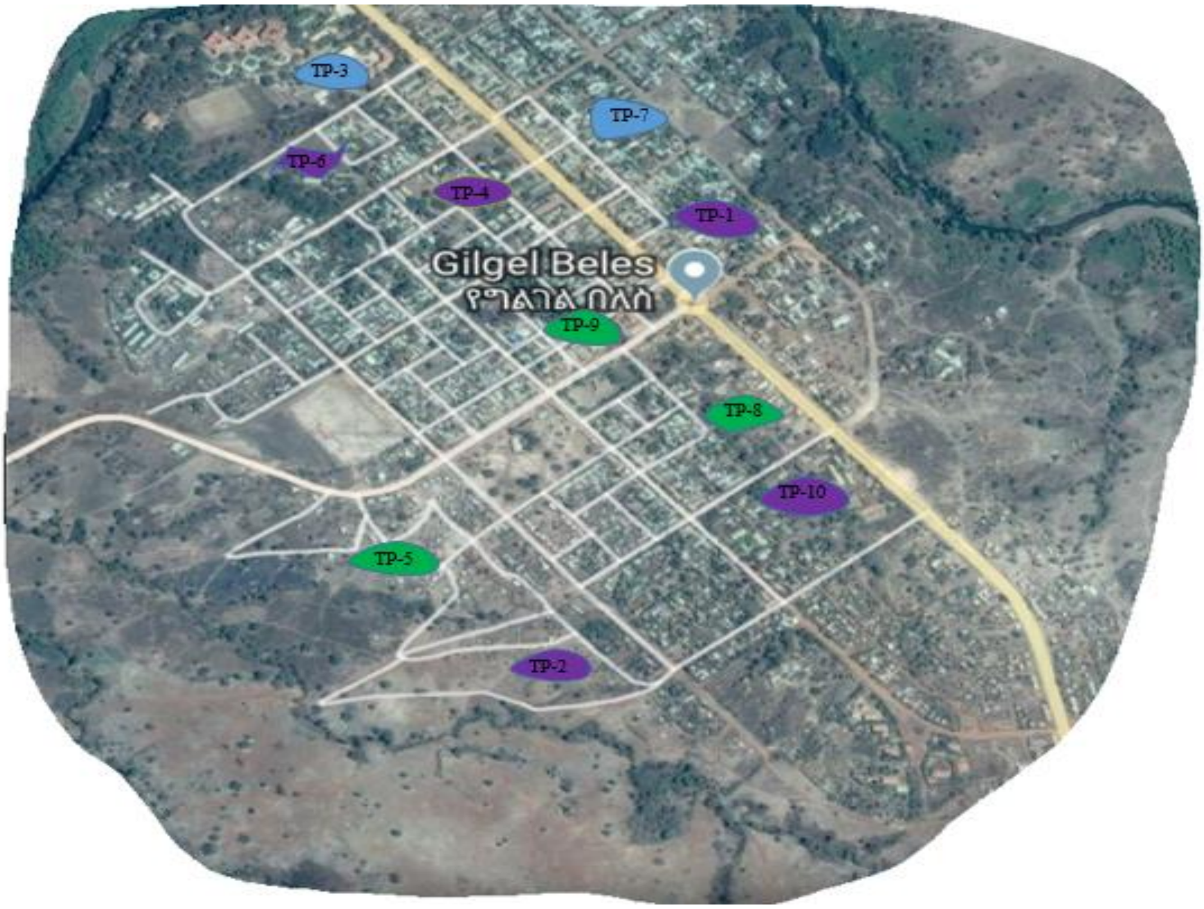

Figure 3. 4 Test pit locations on map of Gilgel-Beles town (Source: Google Map)

3.6 Index properties

3.6.1 General

Every civil engineering work involves the determination of soil type and its associated engineering application, which are more commonly related to bearing capacity, compressibility of soil and seepage through the soil. The possible solution to these problems is arrived at based on the study of the properties of the soil [7].

3.6.2 Natural Moisture Content

Natural moisture content of a soil material is the quantitative measure of the wetness of a soil mass at its natural state. It expresses the relationship between the weights of water in a given volume of material to the weight of the solids contained in the same volume. It is the most significant index properties of the soil which is determined in the laboratory by using undisturbed sample.

It is used in establishing a correlation between soil behavior and its properties. The water content of a soil along with its liquid and plastic limits is used to express its relative consistency termed as liquidity index [28]. This test is done by referring ASTM D2216 standard. A test specimen is first weighed in its natural state is then dried in oven at a temperature of 105°C to a constant mass for 24 hrs. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

$W\% = \frac{Ww}{Ws} * 100$.. (3.1)

3.6.3 Specific Gravity

Specific gravity is a measure of the actual particles which make up the soil mass. It is the ratio of the mass of unit volume of the soil particles to the mass of the same volume of gas-free distilled water they displace at a stated temperature. Knowledge of the particle density is essential in relation to other soil tests. It is used when calculating porosity and voids ratio and is particularly important when compaction and consolidation properties are being investigated. Most of the values may be estimated within a range of 2.6 to 2.7 for soil types of silty sands and 2.68 to 2.8 for inorganic clays [2].

3.6.4 Grain Size Determination

General

Soil consists mostly of different sized soil particles as major constituent ingredient. The determination of the fractions of the particles will help to identify the soil type as well as to estimate many other engineering properties such as strength and permeability and also to identify whether the soil is suitable for construction projects such as highways, dams or as a backfill. This test method covers both coarser and finer size analysis is required to determination the quantitative distribution of particle sizes in soils. The grain size distribution of coarse-grained (size greater than 0.075mm) soil is generally determined by means of sieve analysis, whereas for a fine-grained soil (size finer than 0.075mm), the grain size distribution can be obtained by means of by a sedimentation process, using a hydrometer analysis. If the soil contains a substantial quantity (say, more than 5%) of fine particles, a wet sieve analysis is required [28].

Test procedure and results

The procedure followed to run this test is according to ASTM standard with designations D422 and D1140. According to ASTM D422 the distribution of particles, finer than 75µm can be done by hydrometer test. In this test, wet preparations of soil sample for particle size analysis were used [2]. The material is washed until the wash water becomes clear. The material retained on the 75µmsieve is collected and dried in an oven for 24 hours. It is then sieved through the set of fine sieves of the size 4.75mm, 2mm, 1mm, 600µm, 425µm, 212µm, 150µm and 75µm. The material retained on each sieve is collected and weighted. The sample of soil passing No. 200 was transferred to large dish and soaked until the water becomes clean, then the clean water was decanted. After the sample has dried in the hydrometer test 50grams of soil was taken and soaked for 24 hours by adding dispersing agent. The detail tests are presented in Appendix.

3.7 Atterberg Limits

Atterberg limits very important index properties of fine-grained soils at which the soil changes from one state to the other at some particular water content. Atterberg defined four possible states of consistency for soils: liquid, plastic, semi-solid and solid. The Liquid Limit is arbitrarily the water content, in percentage, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The Plastic Limit is the lowest moisture content of a soil that will permit a sample to be rolled into threads of 3 mm diameter without the threads breaking [28].

3.8 Modified Compaction test

General

Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy. Compaction increases the strength characteristics of soils, which increase the bearing capacity of foundations, slope stability and physical properties of soil appropriate for structures constructed over them [30]. Soil specimen is oven dried and passing 4.75mm sieve size. The degree of compaction of a soil is measured in terms of its dry unit weight. When water is added to the soil during compaction, it acts as a softening agent on the soil particles and slip over each other and move into a densely packed position. The dry unit weight after compaction first increases as the moisture content increases, reworking and increasing amounts of water and subsequent expulsion of air and closing of the voids tend to produce a semi flocculated structure with increasing density until a peak is attained. When keep on increasing the water content higher than optimum water contents in the soil sample to be compacted, compaction results in a relatively dispersed soil structure that is lower dry density than soil compacted with optimum water content. The optimum water content is the water content that results in the greatest density for a specified comp-active effort [1].

The Modified Proctor Test is identical to the Standard Proctor Test, except it employs, a 44.5N hammer falling a distance of 0.457meters, and uses five equal layers of soil instead of three. There are two types of compaction moulds used for testing. The smaller type is 0.102meters in diameter and has a volume of about 944 cm3, and the larger type is 0.152meters in diameter and has a volume of about 2123 cm3. If the larger mould is used each soil layer must receive 56 blows instead of 25[13]. Generally, coarse grained soils can be compacted to a higher dry density than fine gained soils for the same compaction effort. When some fines are added to the coarse-grained soils to fill the voids, the maximum dry density further increases, but it the amount of fines is too much, more than required to fill the voids, it results in reduction of dry density; well graded soils can attain higher dry density than poorly graded soils [26].

$$\Upsilon d = \frac{Gs * \Upsilon w}{GsW + 1} = \frac{\Upsilon_b}{1 + w} \qquad (3.2)$$

3.9 Shear Strength of Soil

The shear strength of a soil is its maximum resistance to shear stresses just before the failure. It’s the principal engineering property which controls the stability of a soil mass under loads. It governs the bearing capacity of soils, the stability of slopes in soils, the earth pressure against retaining structure and many other problems. The most common laboratory methods employed to obtain shear strength parameters are direct shear test, triaxial compression test and unconfined compression test. For this thesis unconfined compression test is conducted.

3.9.1 The Unconfined Compression Test

The unconfined compression test is a special type of a triaxial compression test in which the all-round pressure is zero. The axial load is increased rapidly until the soil sample fails, that is, it cannot support any additional load. The objective of the unconfined compression test is to determine the UU (unconsolidated, undrained) strength of a cohesive soil. The strength of a soil determined by compression testing varies with ratios of length to diameter of 2 to 2.5 and similarly, rates of strain are 0.5 to 2.0% per minute are satisfactory [18]. During the test, $\sigma 1$ was plotted versus $\varepsilon 1$ to identify qu. For stiff clays, qu is defined as the peak of the $\sigma 1$ – $\varepsilon 1$ curve. The shear strength is defined as half the compression strength, where the equation is given as:

$$qu = \frac{\mathrm{P}}{\mathrm{A}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . 3.3$$

Then the shear strength of saturated clay is calculated as:

$$S = Cu = \frac{\mathrm{qu}}{2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.4$$

The corrected averages cross - sectional area is calculated by:

$$A = \frac{\mathrm{Ao}}{1 - \epsilon} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . 3.5$$

The results from unconfined compression tests can be used to determine the stress–strain characteristics under fast (undrained) loading conditions.

Table 3. 3 Consistency and unconfined compression strength of clays [10]

Consistency	qu (KN/m2)
Very soft	0 - 24
Soft	24 - 48
Medium	48 - 96
Stiff	96 - 192
Very stiff	192 - 383
Hard	>383

3.10 Consolidation test

3.10.1 Test Procedure

The standard test method used for One-Dimensional Consolidation is based on ASTM D 2435[14]. The standard one-dimensional consolidation test is usually carried out on saturated specimen using an Odometer [30]. In this test soil is laterally confined and the consolidation takes place only in the axial direction and drainage of water also occurs only in vertical direction. The small representative sample of the soil is carefully trimmed and fitted into a rigid metal ring. The soil sample is mounted on a porous stone base and a similar stone placed on the top to permit water, which is squeezed out of the sample to escape freely at the top and bottom. Prior to loading, the height of the sample should be accurately measured. Then a setting load of 7 kPa was applied until the soil saturated fully.

Loads are applied in steps in such a way that the successive load intensity (P) is twice the preceding one (50, 100, 200, 400, 800, 1600kPa). The dial readings are taken at elapsed time of 0, 0.25, 0.5, 1, 2, 4, 8, 15, 30, minute………24hours. After the greatest load required for the test has been applied to the soil sample, the load is removed in decrements to provide data plotting the expansion curve of the soil in order to learn its elastic properties and permanent deformation.

3.10.2 Pre-consolidation pressure

A soil may have been pre-consolidated during the geologic past by the weight of an ice which has melted away, or by other geologic overburden or and structural loads which no longer exist. For example, thick layers of overburden soil may have been eroded or excavated away. The practical significance of the pre-consolidation load appears in calculating settlements of structures [25]. From a few graphical methods for determining the pre-consolidation pressure based on laboratory test data. The earliest and the most widely used method was the one proposed by Casagrande (1936). The relative amount of pre-consolidation is usually reported as the over consolidation ratio (OCR), defined as:

$$OCR = \frac{P_c}{P_o} \quad (3.3)$$

Where, P_c= pre-consolidation pressure, Po = over-burden pressure

4. RESULTS AND DISCUSSIONS

4.0. In-situ Properties

4.1 Natural Moisture Content Test Results

Natural Moisture content is expressing the relationship between the weight of water in a given volume of material to the weight of the solids contained in the same volume. It is the most significant index properties of the soil which is determined in the laboratory by using undisturbed Sample. The water content is calculated using the mass of water and the mass of the dry specimen.

$$W = \frac{Ww}{Ws} * 100 \qquad (4.1)$$

Table 4. 1 Natural moisture content for test pit (TP-1)

TP-1@1.5m			
Container No	A	B	C
Container mass(g)	17.5	17.5	18
Mass of container +wet soil(g)	84.8	90.1	75
Mass of container + dry soil(g)	73.6	78	65
Mass of dry soil(g)	56.4	61.9	51
Mass of water(g)	11.2	12.1	10
Natural moisture content (%)	19.86	19.55	19.61
Average = 19.68			
TP-1@3m			
Container No	Hcs	29	101
Container mass(g)	17.18	17.48	17.89
Mass of container +wet soil(g)	85.55	89.96	74.9
Mass of container + dry soil(g)	73.5	77.5	65
Mass of dry soil(g)	56.32	60.02	47.11
Mass of water(g)	12.05	12.46	9.9
Natural moisture content (%)	21.40	20.76	21.01
Average = 21.06			

In similarly the natural moisture content of each sample is summarized in Table4.1 below and the detailed test results are given in Appendix.

Table 4. 2 Natural moisture content of samples

Test Pit	Sampling Depth(m)	Natural Moisture content (%)
TP – 1	1.5	19.68
	3	21.06
TP -2	1.5	33.4
	2.8	30.18
TP – 3	1.5	59.87
	3	47.3
TP – 4	1.5	27.488
	3	22.97
TP – 5	1.5	37.513
	3	28.89
TP – 6	1.5	25.55
	3	21.5
TP – 7	1.5	33.88
	3	27.23
TP – 8	1.5	34.12
	3	31.70
TP – 9	1.5	21
	3	19
TP – 10	1.5	32.45
	3	25.56

From the test result natural moisture content of soils of the study area ranges from 19.68 %- 59.87%. The values of natural moisture content of TP-3, TP-5 and TP-7 is high than the other test pits.

4.2 Specific Gravity Test Results

For the study area the specific gravity of the samples is determined using ASTM D 854 Standard Test for Specific Gravity of Soil Solids by density Bottle method.

Specific gravity calculation for test pit (TP-1) is:

$$Specific\ gravity, Gs = \frac{Ws}{Ws+(Wbw-Wbws)} \qquad (4.2)$$

Table 4. 3 The test results for Specific Gravity (G_s) for TP-1

TP-1@1.5m			
Specimen number	1	2	3
Bottle number	1	2	3
Mos = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	85.18	84	84.88
Mbw = mass of bottle + water(g)	79	77.75	78.65
Mbw – Mbdw	-6.18	-6.25	-6.23
Ms +(Mbw - Mbdw)	3.82	3.75	3.77
At temperature of 20^{o}c			
Gs	2.62	2.67	2.65
Gs (average) = 2.65			
TP-1@3m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	85.54	84.22	85.35
Mbw = mass of bottle + water(g)	79.28	77.95	79
Mbw - Mbdw =	-6.26	-6.27	-6.35
Ms +(Mbw - Mbdw)	3.74	3.73	3.65
At temperature of 20^{o}c			
Gs	2.67	2.68	2.74
Gs (average) = 2.70			

In similarly the Specific gravity of each sample is summarized in Table 4.4 below and the detailed test results are given in Appendix.

Table 4. 4: Summery of Specific gravity of soil in the study area

Test Pit	Sampling Depth(m)	Specific gravity (Gs)	Water used for testing
TP – 1	1.5	2.63	Distilled water
	3	2.7	Distilled water
TP -2	1.5	2.64	″
	2.8	2.65	″
TP – 3	1.5	2.67	″
	3	2.68	″
TP – 4	1.5	2.64	″
	3	2.66	″
TP – 5	1.5	2.68	″
	3	2.7	″
TP – 6	1.5	2.65	″

	3	2.66	″
TP – 7	1.5	2.67	″
	3	2.68	″
TP – 8	1.5	2.65	″
	3	2.7	″
TP – 9	1.5	2.69	″
	3	2.72	″
TP – 10	1.5	2.62	″
	3	2.6	″

From the test result the specific gravities of the soils of the study area range from 2.6 to 2.72, which is within a limited range of sand to silty clay.

4.3 Grain Size Determination Test Results

Table 4. 5: Grain size analysis test result for TP-1

Pit	Sieve Size (opening) (mm)	Mass retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage finer particle (%)
1 @3m	9.5	0	0	0	100
	4.75	0	0	0	100
	2	4	0.8	0.8	99.2
	0.85	25	5	5.8	94.2
	0.425	34	6.8	12.6	87.4
	0.3	40	8	20.6	79.4
	0.15	45	9	29.6	70.4
	0.075	98	19.6	49.2	50.8

Hydrometer analysis result for TP-1@3m depth

Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth) from table 1(Cm)	K(cor. fac.Gs) from tabel-2	D (mm)	C_t from tabel-3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percent age of finer %	% Adjusted Finer
1	21	28	11.7	0.013	0.044	0.2	0.989	21.2	41.93	21.30
2	21	26	12	0.013	0.032	0.2	0.989	19.2	37.97	19.29
5	21	20	13	0.013	0.021	0.2	0.989	13.2	26.11	13.26
15	21	17	13.5	0.013	0.012	0.2	0.989	10.2	20.17	10.25
30	21	16	13.7	0.013	0.009	0.2	0.989	9.2	18.19	9.24
60	22	15	13.8	0.013	0.006	0.4	0.989	8.4	16.61	8.44
120	22	14	14	0.013	0.004	0.4	0.989	7.4	14.63	7.43

240	22	13	14.2	0.013	0.003	0.4	0.989	6.4	12.66	6.43
480	22	13	14.2	0.013	0.002	0.4	0.989	6.4	12.66	6.43
1440	22	13	14.2	0.013	0.001	0.4	0.989	6.4	12.66	6.43

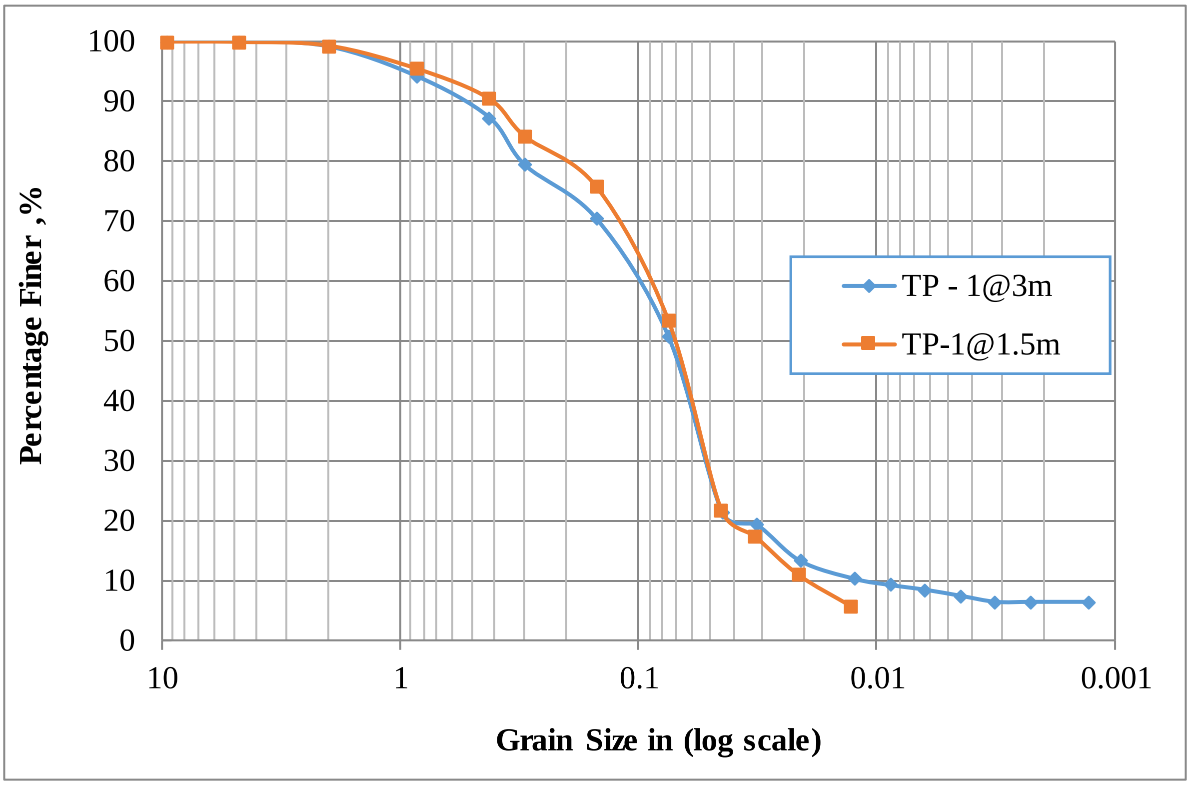

Figure 4. 1: Grain size distribution curve of soil sample for TP-1

The summary of the wet sieve and hydrometer analysis result is shown in the following table 4.6 and figure 4.2 and 4.3 below. The detailed test results are given in Appendix

Table 4. 6: Summary of grain size analysis test result of the study area.

Designation	Depth(m)	Percentage amount of particle size			
		Gravel	Sand	Silt	Clay
TP-1-1	1.5	0.68	37.86	41.2	20.5
TP-1-2	3	0.8	36.4	47.3	6.43
TP-2-1	1.5	1.4	39.1	28.9	30.6
TP-2-2	2.8	0.68	35.82	26.6	36.9
TP-3-1	1.5	0.64	30.62	14.9	53.8
TP-3-2	3	0.67	24.16	24.5	50.7
TP-4-1	1.5	0.76	33.72	24.8	40.8
TP-4-2	3	0.04	38.24	50.2	12.3
TP-5-1	1.5	0.5	22.76	22.17	54.6
TP-5-2	3	0.82	36.06	14.22	49.7
TP-6-1	1.5	0.44	26.6	50.5	23

TP-6-2	3	0	28.7	30.3	41
TP-7-1	1.5	0.3	27.38	26.9	45.5
TP-7-2	3	0.2	27.52	24.9	47
TP-8-1	1.5	0.4	29.48	32.3	37.4
TP-8-2	3	0.8	29.5	38.5	40
TP-9-1	1.5	0.9	20.82	37.7	41.1
TP-9-2	3	0.3	24.28	41.5	34.3
TP-10-1	1.5	0	25.08	33.1	42
TP-10-2	3	0	26.98	41.3	31.1

The grain size distribution curve for the different soil samples are shown in the following figures. The grain size distribution curve is included in Appendix.

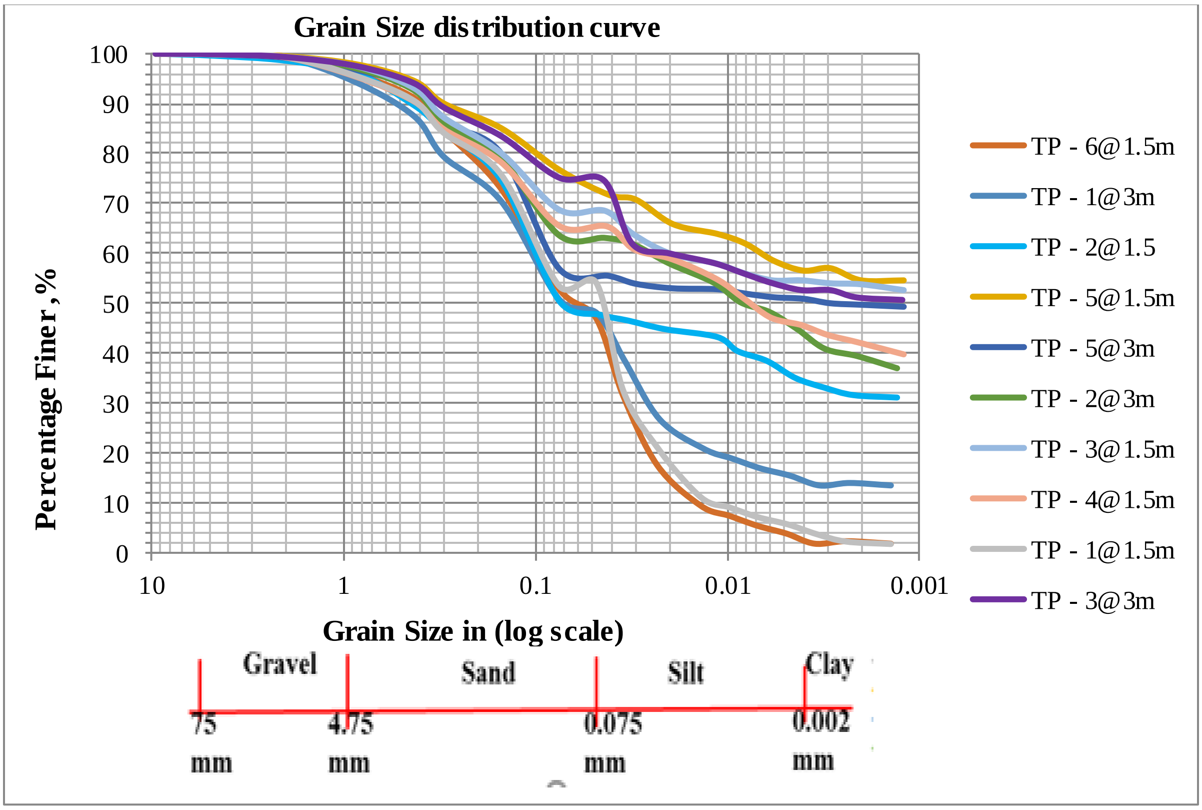

Figure 4. 2: Grain size distribution curve of soil sample for test pit (1-6)

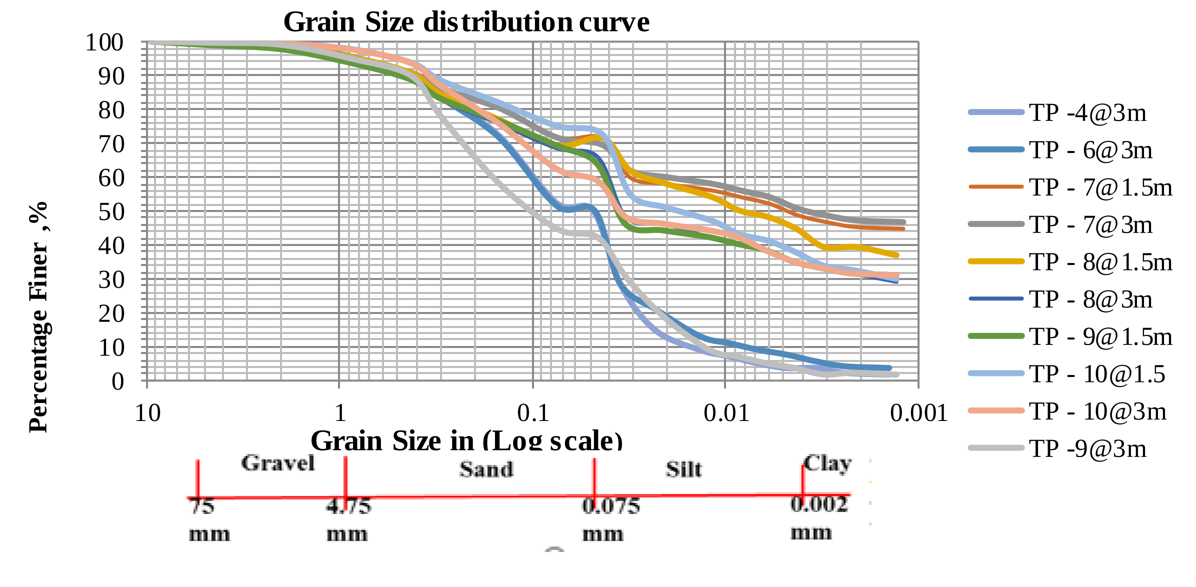

Figure 4. 3 : Grain size distribution curve of soil sample for test pit (4-10)

From the table and graph above we can observe the following results; The results of grain size analysis showed that soils of Gilgel-Beles town have clay fraction ranging from 23-54.6%, silt fraction from 14.9-50.5%, sand from 20.82-39.1% and gravel from 0-1.4%.

This show that the soils for almost all samples are fine grained soil with consists of sand in nature.

4.4 Atterberg Limits Test Results

Atterberg Limits were determined for oven - dry sample by putting the sample in an oven for 24 hours at a temperature of 110 °c ± 5°. Casagrand's apparatus was used for the determination of liquid limit. The portions of the samples passing the No. 40 (0.425mm) sieve were used for the preparation of the sample for this test. The atterberg Limits for test pit-one at three meters was determined below [3].

Table 4. 7: Liquid limit and Plastic limit test results for TP-1 at 3m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	A1	A2	A3	A4	11	12	13
Mc	17	17	12	12	17	12	12
Mcws	48	49	42	42	20	14	14.6
Mcds	41	40	32	31	19.4	13.6	14
Mds	24	23	20	19	2.4	1.6	2
Mw	7	9	10	11	0.6	0.4	0.6
W%	48.17	50	53.3	65	38.5	38	37
No blows	31	26	20	17	Ave = 40.5		

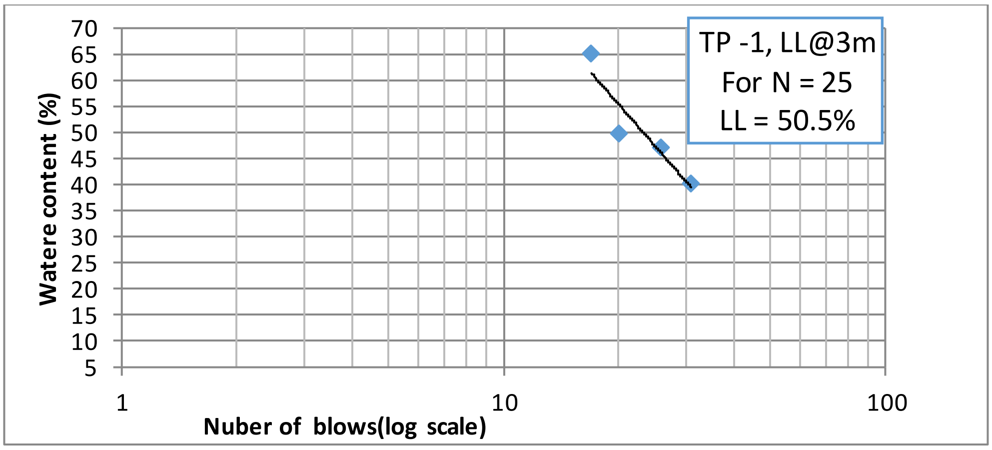

Figure 4. 4 : liquid limit for test pit (TP-1) at 3m

Plasticity index, $PI = LL - PL$... (4.3)

The test results of Atterberg limit for soil in Gilgel Beles town are summarized in Table 4.8 below. The detailed test results are given in Appendix.

Table 4. 8: Summery of atterberg Limit Result of the study area

Test pit	Sample Depth(m)	Liquid Limit LL (%)	Plastic Limit (%)	Plasticity Index (%)
TP – 1	1.5	40	35	5
	3	50.5	38	11.5
TP – 2	1.5	46	30	16
	2.8	42	29.7	12.3
TP – 3	1.5	51	31.47	19.5
	3	50	33	17
TP – 4	1.5	35.3	26	10.7
	3	40	26	14
TP – 5	1.5	50	32	18
	3	50.4	38.5	11
TP – 6	1.5	40	29	11
	3	40	25.6	14.4
TP – 7	1.5	52.5	34.45	18
	3	40	28	12
TP - 8	1.5	43	30.9	13
	3	46	30.2	15.8
TP - 9	1.5	50	34.3	15.7
	3	45	30.5	14.5
TP – 10	1.5	41	33	8
	3	30	26	4

From this test result the liquid limit of the study area lies in the ranges of 30 – 50%, except the liquid at TP-3, TP-5, and TP-7 which lies in the range of high plasticity (LL>50%), plastic limit ranges from 24.9 – 40.5% and plastic index from 5 – 19.5%.

4.5. Activity number (A)

The Activity number is given by the following equation.

$$Activity(A) = \frac{plasticity\ index, PI}{precent\ of\ finer\ than\ 2\ micron} \quad \text{.......} \quad (4.4)$$

Depending upon activity, the soils are classified into three types.

Table 4. 9: Classification of soils based on activity [1]

Activity	Degree of activity
<0.75	Inactive clay
0.75-1.25	Normal clay
>1.25	Active clay

Table 4. 10: The activity numbers of the study area

Test Pit	Depth(m)	Plastic Index (PI)	Percentage of clay	Activity (A)
TP -1	1.5	5	20.5	0.24
	3	11.5	6.43	0.85
TP -2	1.5	16	30.6	0.56
	2.8	12.3	36.9	0.33
TP -3	1.5	19.5	53.8	0.36
	3	17	50.7	0.33
TP -4	1.5	10.7	40.8	0.26
	3	14	13.5	1.04
TP -5	1.5	18	54.5	0.33
	3	11	49.7	0.22
TP -6	1.5	11	23	0.47
	3	14.4	41	0.340
TP -7	1.5	18	45.5	0.39
	3	12	47	0.25
TP -8	1.5	13	37.4	0.35
	3	15.8	40	0.953
TP -9	1.5	15.7	41.1	0.38
	3	14.5	34	0.43
TP -10	1.5	8	42	0.20
	3	4	31.1	0.13

Accordingly, Skempton's colloidal activity values the clay found in the investigated soils are inactive clay except test pit-1 at 3m and test pit-4 at 3m which are normal clay.

4.6 Soil classification

4.6.1 Unified system of soil classification

This classification uses the symbols (GW, GP, GM, GC, SW, SP, SM, SC, ML, CL, OL, MH, CH, and OH) based on the indicated percentages passing the No.200 and No.4 sieves, and the atterberg limit values [21]. The Plasticity Chart is presented in Figure 4.5 and 4.6.

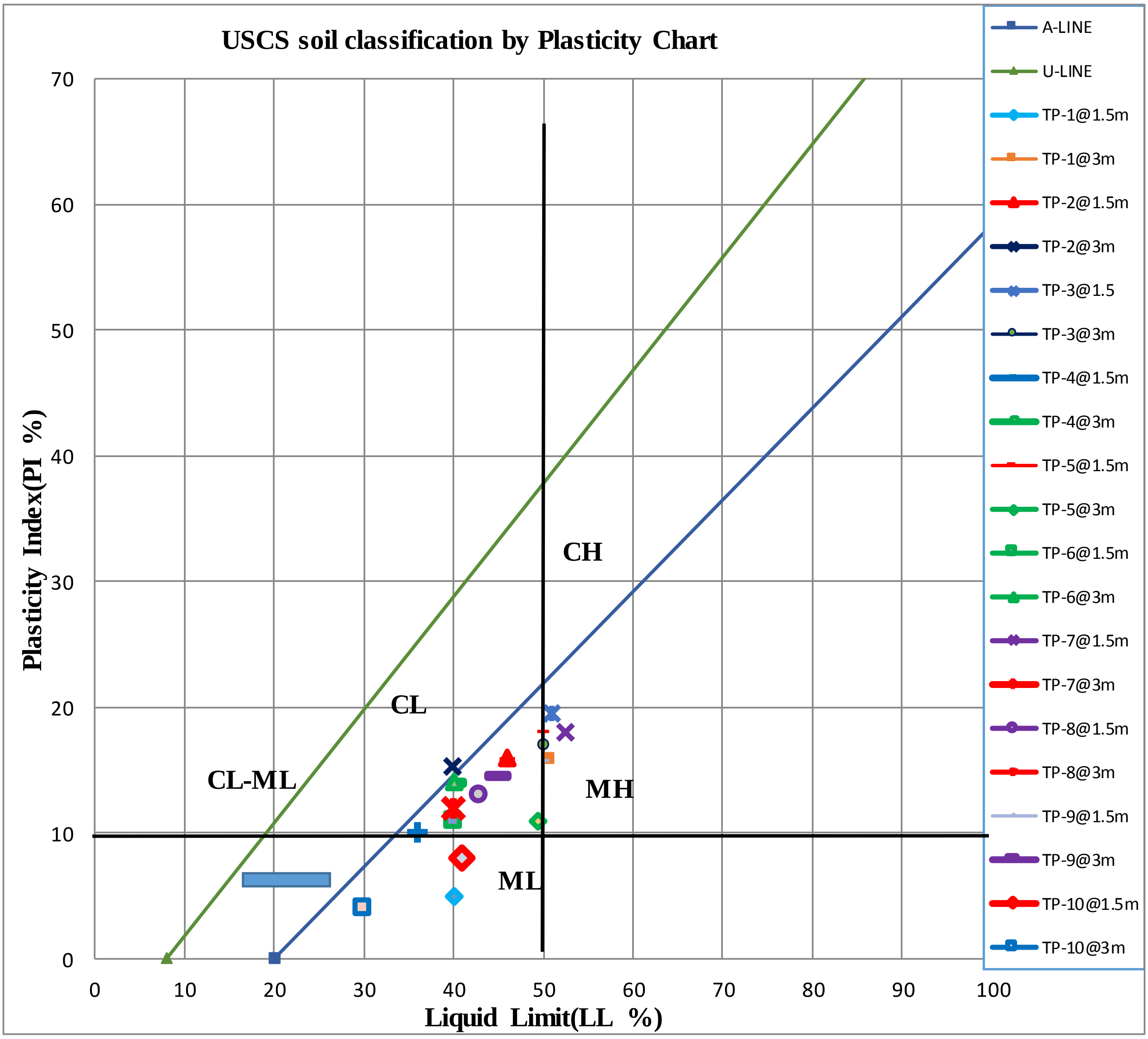

Figure 4. 5: Plasticity chart of the study area according to Unified Soil Classification System

Table 4. 11: Summary of soil classifications based on USCS

Test Pit	Dept h(m)	Percentage of amount of particle size				LL (%)	PI (%)	Activity (A)	Classification According to USCS
		Gravel (%)	Sand (%)	Silt (%)	Clay (%)				
TP-1	1.5	0.68	37.86	41.2	23.5	40	5	0.262	ML
	3	0.8	36.4	47.3	13.5	50.5	11.5	0.73	MH
TP-2	1.5	1.4	39.1	28.9	30.1	46	16	0.55	SM
	2.8	0.68	35.82	26.6	36.9	40	12.3	0.44	CL
TP-3	1.5	0.64	30.62	14.9	53.8	51	19.5	0.34	MH
	3	0.67	24.16	24.5	50.7	50.5	17	0.83	MH
TP-4	1.5	0.76	33.72	24.8	40.8	36	10.7	0.13	ML
	3	0.04	38.24	50.2	12.3	40	14	0.68	ML
TP-5	1.5	0.5	22.76	22.17	54.6	50	18	0.32	MH
	3	0.82	36.06	14.22	49.7	50.4	11	0.22	MH
TP-6	1.5	0.44	26.6	50.5	23	40	11	0.54	ML
	3	0	28.7	30.3	41	40	14.4	0.40	ML
TP-7	1.5	0.3	27.38	26.9	45.5	52.5	18	0.41	MH
	3	0.2	27.52	24.9	47	40	12	0.32	MH
TP-8	1.5	0.4	29.48	32.3	37.4	43	13	0.35	ML
	3	0.8	29.5	38.5	40	46	15.8	0.63	ML
TP-9	1.5	0.9	20.82	37.7	41.1	50	15.7	0.5	MH
	3	0.3	24.28	41.5	34.3	45	14.5	0.67	ML
TP-10	1.5	0	25.08	33.1	42	41	8	0.25	ML
	3	0	26.98	41.3	31.1	30	4	0.13	ML

According to USCS classification system of plasticity chart, most of the soil of the study area falls below A-Line in ML region, and TP-3, TP-5 and TP-7 in MH region, which have high plasticity (LL>50%). From the plot of plasticity chart in figure 4.5 and the classification soils on table 4.11 the soils found in Gilgel-Beles town are ML, MH and CL.

4.6.2 AASHTO Classification System

According to this system, soil is classified into seven major groups: A-1 through A-7. Soils classified under groups A-1, A-2, and A-3 are granular materials of which 35% or less of the particles pass through the No. 200 sieve. Soils of which more than 35% pass through the No. 200 sieve are classified under groups A-4, A-5, A-6, and A-7. The soil properties that are used for this classification system are; particle size distribution, Liquid limit and Plastic index. To check the quality of the soil, a group index is defined.

The smaller the value of the group index, the better is the soil in that category. A group index of zero indicates a good subgrade, whereas a group index of 20 or greater shows a very poor subgrade.

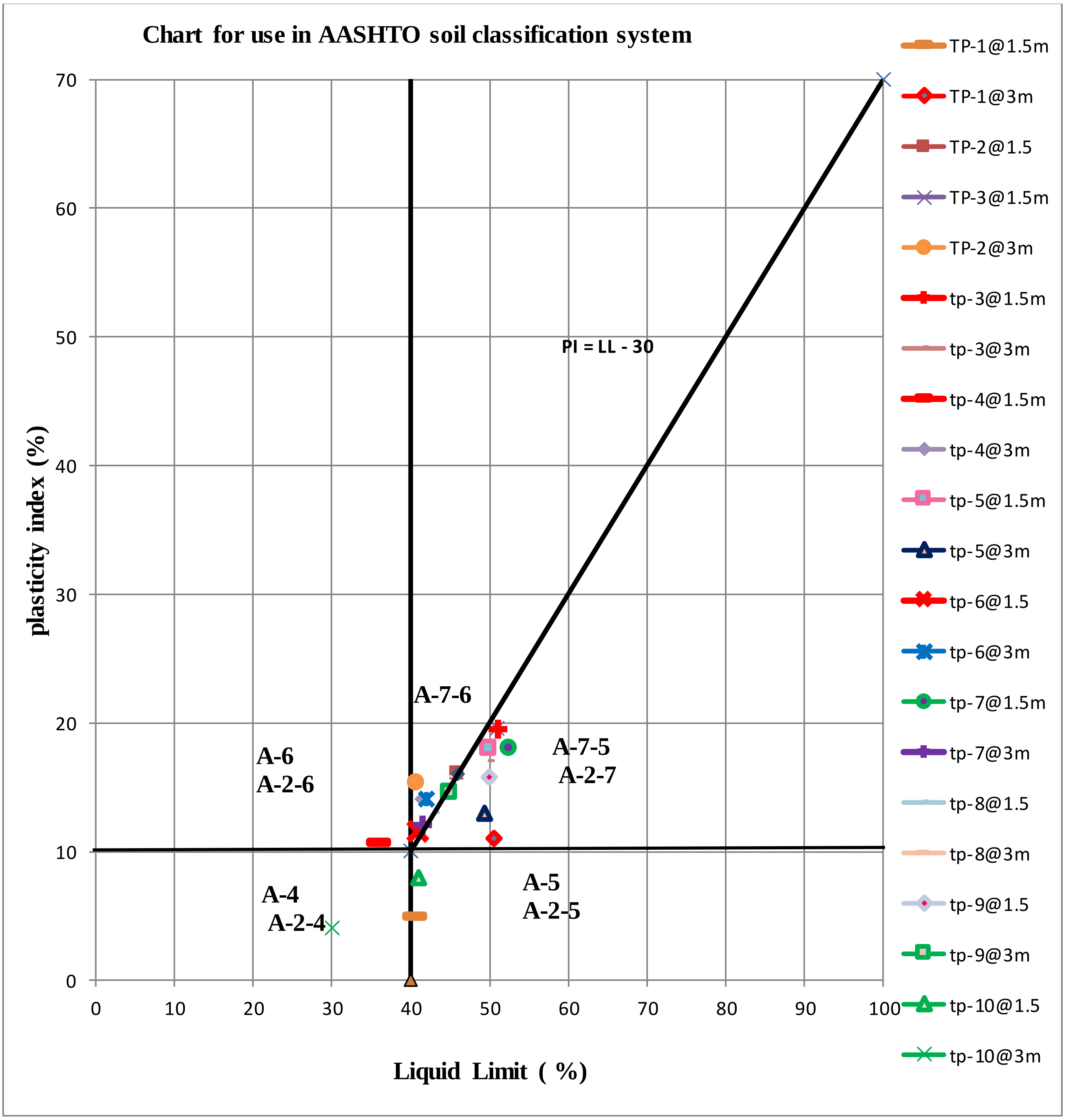

Figure 4. 6: Plasticity chart of the study area according to AASHTO Classification system

Table 4. 12: Classifications of soils base on AASHTO

Test Pit	Depth (m)	Percentage of amount of particle size				LL (%)	PI (%)	Classification according to AASHTO		General rating as sub-grade materials
		Gravel (%)	Sand (%)	Silt (%)	Clay (%)			GI	Group	
TP-1	1.5	0.68	37.86	41.2	23.5	40	5	6	A-2-4	Good
	3	0.8	36.4	47.3	13.5	50.5	11.5	4	A-2-7	Good
TP-2	1.5	1.4	39.1	28.9	30.1	46	16	9	A-2-7	Good
	2.8	0.68	35.82	26.6	36.9	39.8	12.3	6	A-7-6	Poor
TP-3	1.5	0.64	30.62	14.9	53.8	51	19.5	12	A-7-5	Poor
	3	0.67	24.16	24.5	50.7	50.5	17	19	A-7-5	Poor
TP-4	1.5	0.76	33.72	24.8	40.8	36	10.7	8	A-4	Fair
	3	0.04	38.24	50.2	12.3	40	14	15	A-2-6	Good
TP-5	1.5	0.5	22.76	22.17	54.6	50	18	13	A-7-5	Poor
	3	0.82	36.06	14.22	49.7	50.4	11	15	A-7-5	Poor
TP-6	1.5	0.44	26.6	50.5	23	40	11	10	A-2-6	Good
	3	0	28.7	30.3	41	40	14.4	11	A - 6	Good
TP-7	1.5	0.3	27.38	26.9	45.5	52.5	18	15	A-7-5	Poor
	3	0.2	27.52	24.9	47	40	12	14	A-7-6	Poor
TP-8	1.5	0.4	29.48	32.3	37.4	43	13	10	A-7-6	Poor
	3	0.8	29.5	38.5	40	46	15.8	14	A-7-6	Poor
TP-9	1.5	0.9	20.82	37.7	41.1	50	15.7	16	A-7-5	Poor
	3	0.3	24.28	41.5	34.3	45	14.5	14	A-7-6	Poor
TP-10	1.5	0	25.08	33.1	42	41	8	7.0	A-2-5	Good

According to AASTHO classification system, the test result summarized in Table 4.12 and Figure 4.6 show that the dominant soils under the study area are categorized in A-7-5 and A-7-6 which is poor for sub-grade materials.

4.7 Modified Compaction Test Result

The maximum dry density and optimum moisture content obtained are used to determine the strength to be attained during construction of road, foundation base, or retaining structures. For road construction the CBR value is obtained using the modified compaction test results and used to determine the thickness of the sub-grade layer of a road section.

Table 4. 13: The moisture content Vs dry density computation for test TP-1@1.5m

Modified method (ASTM D-1557) TP-1@1.5m Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mould, cm3 = 944					
Number of trial	1	2	3	4	5
Weight of mould	1707	1707	1707	1707	1707
Weight of mould + soil	3252	3405	3645	3501	3415
Volume of mould	944	944	944	944	944
Weight of soil	1545	1698	1938	1794	1708
Bulk density	1.64	1.80	2.05	1.90	1.81
Weight of can	17.9	16.6	17	16.9	18
Weight of can+ soil	108	108.6	106.4	107.9	109
Weight of can+ dry soil	95	93.3	88	83	82
Weight of soil	77.1	76.7	71	66.1	64
Weight of water	13	15.3	18.4	24.9	27
Water content (%)	16.86	19.95	25.92	37.67	42.19
Dry density	1.40	1.50	1.63	1.38	1.27
TP-1@3m					
Number of trial	1	2	3	4	5
Weight of mould	1707	1707	1707	1707	1707
Weight of mould+ soil	3302	3560	3771	3635	3545
Volume of mould	944	944	944	944	944
Weight of soil	1595	1853	2064	1928	1838
Bulk density	1.69	1.96	2.19	2.04	1.95
Weight of can	17	17.5	17.5	18	18
Weight of can+ soil	98.2	94.8	94.1	98.2	98.3
Weight of can+ dry soil	87	80	76	74	72
Weight of soil	70	62.5	58.5	56	54
Weight of water	11.2	14.8	18.1	24.2	26.3
Water content (%)	16.00	23.68	30.94	43.21	48.70
Dry density	1.46	1.59	1.67	1.43	1.31

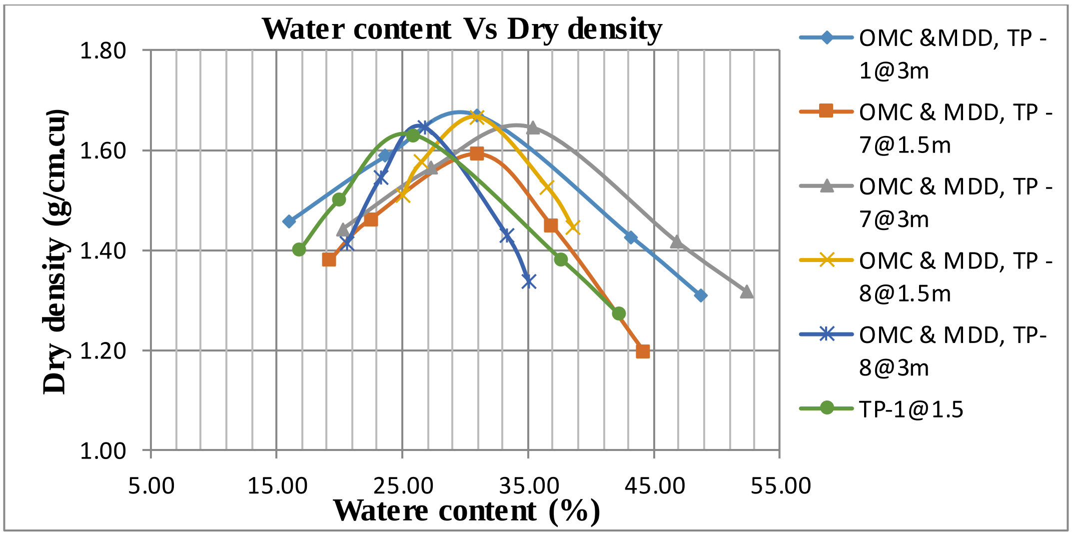

Figure 4. 7: Compaction curve for samples from test pit-(1, 7 and 8) at 1.5 and 3m depth

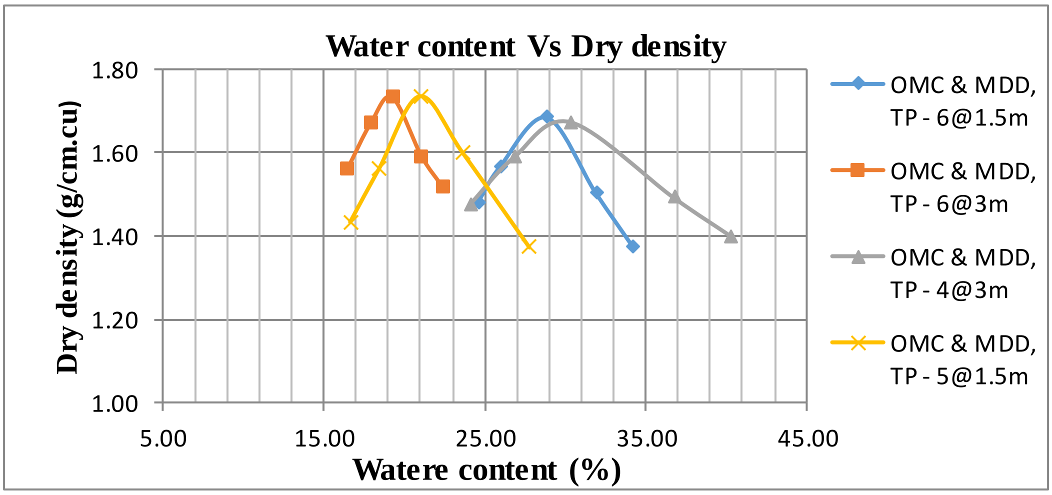

Figure 4. 8: Compaction curves for samples from test pit (1-4) @ 1.5m and 3m depth

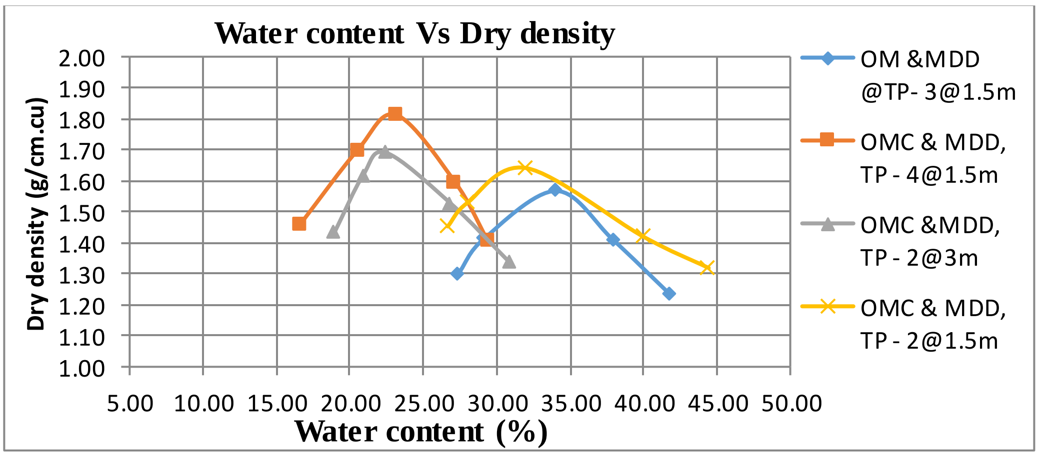

Figure 4. 9: Compaction curves for samples from test pit (4-6) @ 1.5 and 3m depth

Table 4. 14: Summary of Optimum moisture content and the maximum dry density

Serial No	Designation	Depth (m)	MDD (g/cm^3)	Wet density (gm/cm^3)	Bulk unit weight in (γ)KPa	OMC (%)
1	TP – 1	1.5	1.63	1.67	16.7	25.92
		3	1.67	1.71	17.1	30.94
2	TP – 2	1.5	1.63	1.68	16.8	32.75
		2.8	1.69	1.71	17.1	22.47
3	TP – 3	1.5	1.57	1.69	16.9	34.04
		3	1.76	1.72	17.2	17.93
4	TP – 4	1.5	1.81	1.83	18.3	23.16
		3	1.67	1.68	16.8	30.32
5	TP – 5	1.5	1.73	1.74	17.4	20.95
		3	1.71	1.76	17.6	25.23
6	TP -6	1.5	1.68	1.69	16.9	28.85
		3	1.73	1.75	17.5	19.26
7	TP – 7	1.5	1.58	1.66	16.6	30.94
		3	1.64	1.70	17.0	35.38
8	TP – 8	1.5	1.67	1.78	17.8	31.02
		3	1.65	1.81	18.1	26.77
9	TP – 9	1.5	1.62	1.67	16.7	26.76
		3	1.66	1.69	17	30.77
10	TP -10	1.5	1.62	1.69	16.9	22.38
		3	1.78	1.86	18.6	16.91

From the test results the maximum dry density (MDD) ranges from1.57 to 1.81 g/cm3 and the optimum moisture content ranges 17 to 35.38 %. High plasticity clays attain much less dry density than low plasticity clays for the same comp-active effort.

4.8 Shear Strength of Soil

The shear strength of a soil is its maximum resistance to shear stresses just before the failure. It's the principal engineering property which controls the stability of a soil mass under loads. It governs the bearing capacity of soils, the stability of slopes in soils, and the earth pressure against retaining structure and many other problems. The most common laboratory methods employed to obtain shear strength parameters are direct shear test, triaxial compression test and unconfined compression test. For this thesis unconfined compression test is conducted.

4.8.1 The Unconfined Compression Test Results

The undisturbed soil samples are used for these tests for test pits TP-3 at 3m, TP-5 at 3m and TP–7 at 3m. The detailed test results are presented in Appendix D.

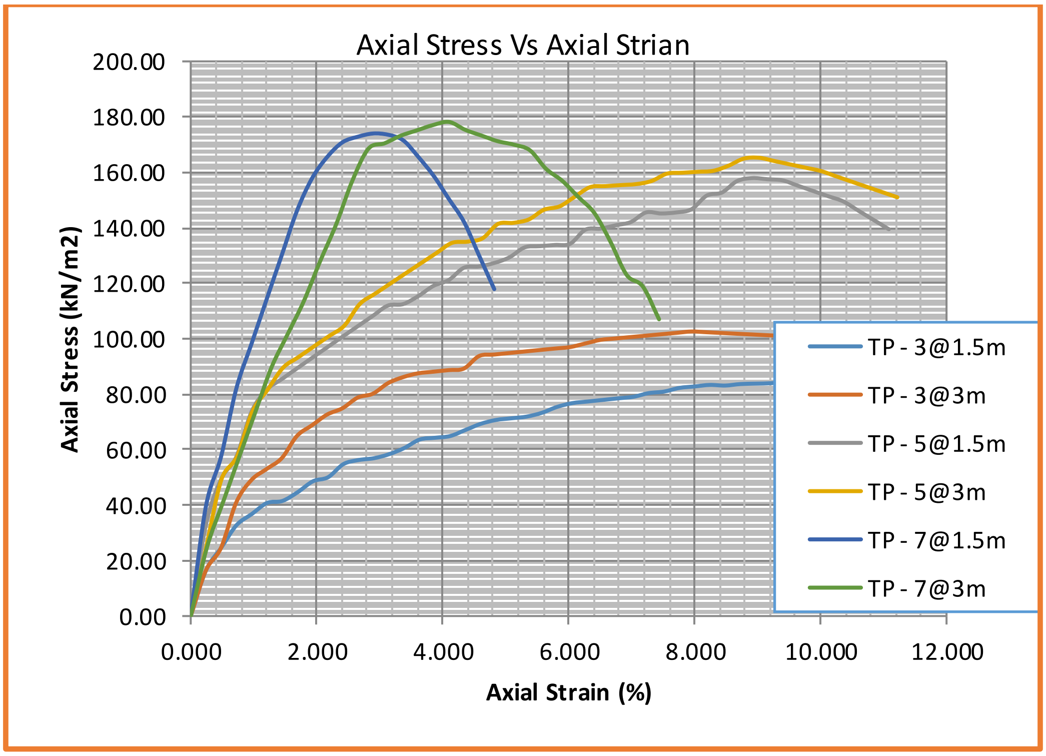

Figure 4. 10: Axial Stress Vs. Axial Strain of the study area

Table 4. 15 : Unconfined compressive strength, undrained shear strength and consistency of soils of the study area.

Test Pit	Depth (m)	Water content (%)	Unconfined compressive strength, qu (KN/m2)	Undrained shear strength, Su (kN/m2)	consistency
TP– 3	1.5	27.14	85.28	42.64	soft
	3	28.12	102.6	51.3	Medium
TP– 5	1.5	27.51	168.8	84.4	Medium
	3	28.12	167.4	83.7	Medium
TP– 7	1.5	27.84	179	89.5	Medium
	3	27.3	178	89	Medium

As summarized in table 4.15, above unconfined compressive strength of the soil at the study area ranges from85.28 to 179kN/m2 and undrained shear strength 42.64 to 89.5kN/m2. According to the relation between consistency and unconfined compression strength of clays, the unconfined compressive strength of the study area is included in medium consistency. From the test results the shear strength of clays is highly dependent on its consistency (i.e. natural water content). So in using this shear strength test result for design season where the site will have high water content should be taken into consideration.

4.9 Consolidation Test Results

General

Consolidation is time dependent process of volume change in soil as water is squeezed from the pores. According to Terzaghi (1943), "consolidation is a decreasing of water content of a saturated soil without replacement of water by air", whereas soil particles are packed more closely together over a period of time under the application of continued pressure. It is accompanied by drainage of water from the pore spaces between solid particles [24]. The compression of the soil mass due to the imposed stresses may be almost immediate or time dependent according to the permeability characteristics of the soil. Cohesion less soils which are highly permeable are compressed in a relatively short period of time as compared to cohesive soils which are less permeable.

4.9.1 Pre-consolidation pressure

The method involves locating the point of maximum curvature, on the laboratory e-log p curve of an undisturbed sample as shown in Fig 4.11 and 12. By drawing a tangent line to the curve and a horizontal line are also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure, Pc [22].

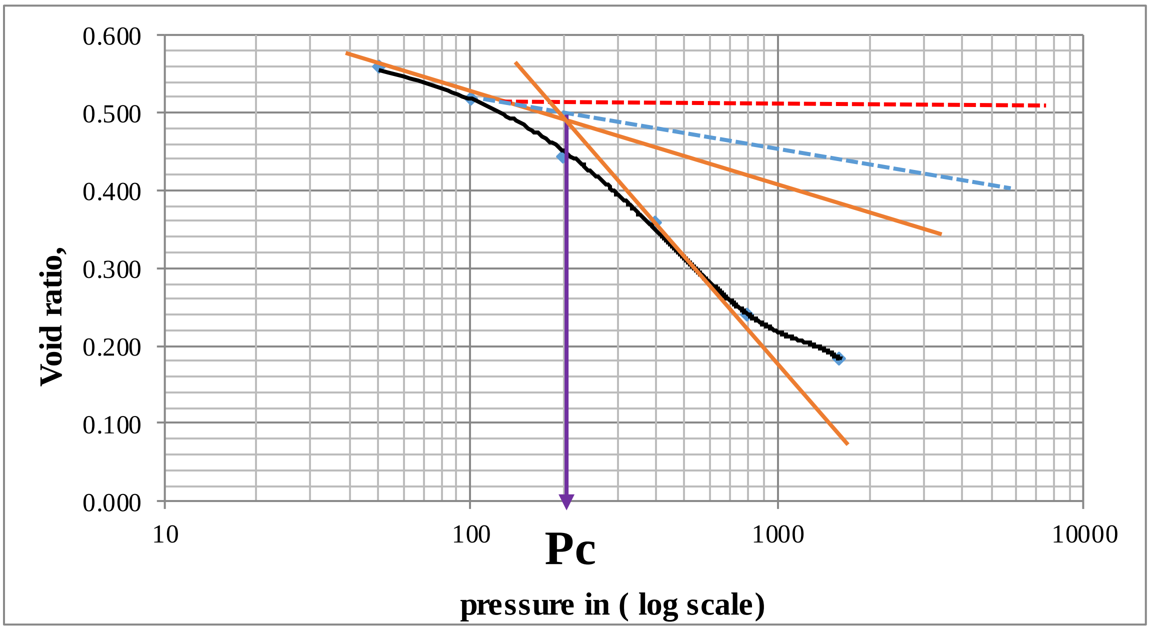

Figure 4. 11: Void ratio Vs log pressure of TP-3@3m to determine Pc by Casagrande method

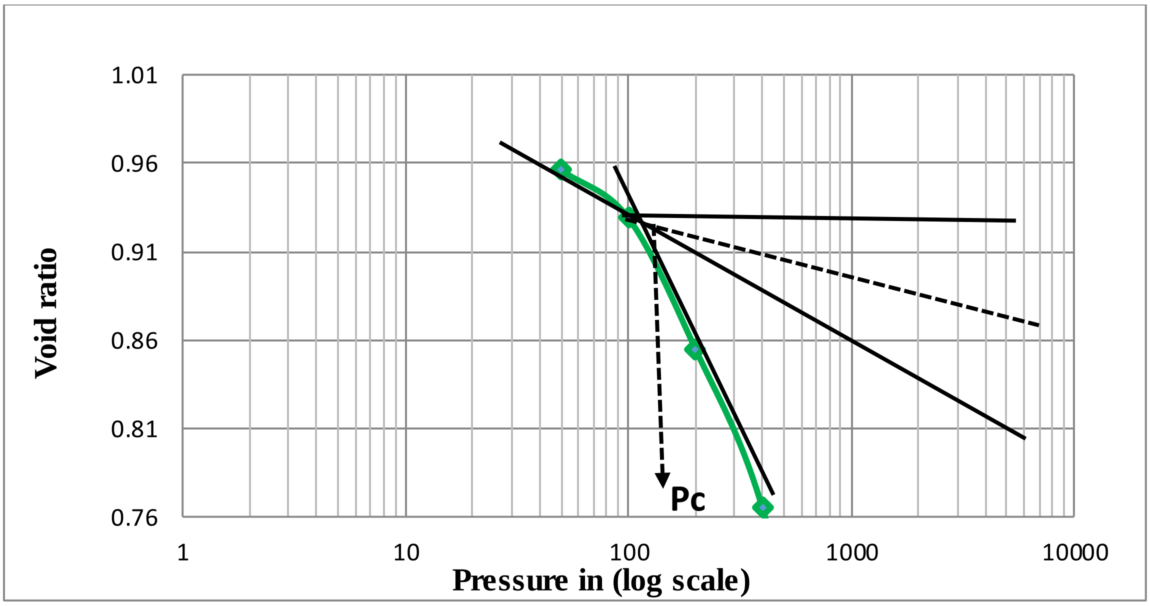

Figure 4. 12: Void ratio Vs log pressure of TP-5@3m to determine Pc by Casagrande method

4.9.2 Compression Index

Compression index, Cc, is equal to the slope of the linear portion of the void ratio versus log pressure plot. This is useful for determination of the settlement of the filed.

$$C_c = \frac{e1-e2}{logP2-logP1} \quad \text{.........} \quad (4.5)$$

Then calculation was repeated for different load increments using equation 4.5 and an average value of Cc for the desired load range is determined and the results are summarized using table 4.16

Table 4. 16: Summery of the consolidation test results

Test Pit	Depth (m)	Total Unit weight (γ)kPa	Pressure kPa	Pre-consolidation pressure, Pc (kPa)	Over-burden pressure, Po (kPa)	Compression Index, (Cc)	Over-consolidation ratio (OCR)
TP-3	3	17.1	50	230	51.3	0.29	4.48
			100				
			200				
			400				
			800				
			1600				
TP-5	3	17.5	50	150	52.5	0.404	2.86
			100				
			200				
			400				
			800				
			1600				

According to the two samples taken from the soil under investigation the over-consolidation ratios of the soils are more than one, so the soil in the study area is over consolidated in the past with maximum effective stress.

4.9.3 Coefficient of consolidation

Logarithm-of-time-fitting method

A straight line is drawn through the points representing the final readings which exhibit a straight line trend and constant slope. A second straight line is drawn tangent to the steepest part of the deformation-log time curve. The intersection represents the deformation, d100, and time, t100, corresponding to 100% primary consolidation. Compression in excess of the above estimated 100% primary consolidation is defined as secondary compression.

The deformation, d50, corresponding to 50% primary consolidation is equal to the average of the deformations corresponding to the 0 and 100% deformations. The time, t50, requid for 50% consolidation may be found graphically from the deformation-log time curve by observing the time that corresponds to 50% of primary consolidation on the curve.

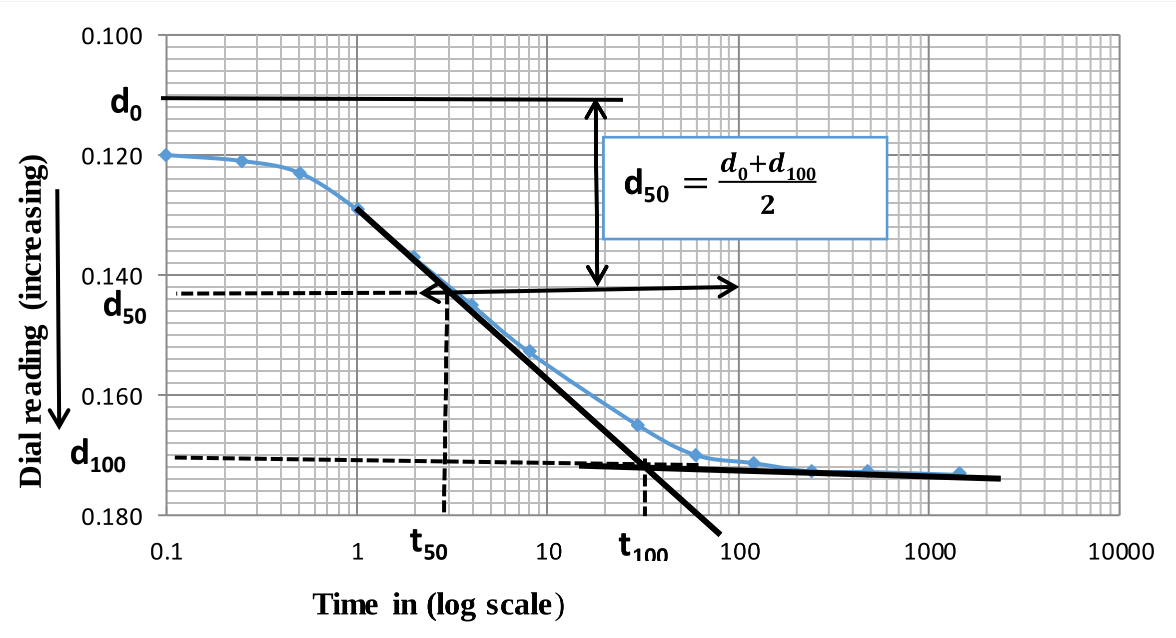

Figure 4. 13: Deformation dial reading Vs logarithm of time fitting graph for determining coefficient of consolidation of TP-5@3m.

It is also determined by Casagrandes semi logarithmic plot method as:

$C_v = \frac{(0.196).H^2}{t_{50}}$ .... (4.6)

Where H =drainage path, H_i = initial height of specimen

For specimens drained at both top and bottom, equals one–half the average height of the specimen during consolidation 50% at t_{50}: -

$$\mathbf{H} = \frac{Hav}{2} = \frac{Ho + Hf}{4} = \frac{Hi - d50}{2} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4.7)$$

Then calculation was repeated for different load increments using equation 4.6 and an average value of C_V for the desired load range is determined and the results are summarized using table 4.18.

Table 4. 17: Summary of consolidation test results TP-3 & TP-5 at 3m

Pressure (kpa)	Change in Thickness of Specimen, ΔH	Void Ratio [$\Delta e=\Delta H/H_s$]	Change in Void Ratio [$e=e_0-\Delta e$]	Compression index (CC)
50	0.673	0.067	0.559	**0.29**
100	1.095	0.109	0.517	
200	1.855	0.184	0.442	
400	2.705	0.269	0.357	
800	3.89	0.387	0.239	
1600	4.465	0.444	0.182	
800	4.44	0.441	0.185	0.02
400	4.42	0.439	0.187	
200	4.298	0.427	0.199	
100	4.238	0.421	0.205	
50	4.196	0.417	0.209	

Summary of consolidation test results TP-5 at 3m

Pressure (KPa)	Change in Thickness of Specimen, ΔH	Void Ratio [$\Delta e=\Delta H/Hs$]	Change in Void Ratio [$e=e_0-\Delta e$]	Compression index (CC)
50	0.673	0.067	0.956	0.40
100	1.095	0.109	0.929	
200	1.855	0.184	0.855	
400	2.705	0.269	0.765	
800	3.89	0.387	0.601	
1600	4.465	0.444	0.491	
800	4.44	0.441	0.492	0.0194
400	4.42	0.439	0.498	
200	4.298	0.427	0.503	
100	4.238	0.421	0.509	
50	4.196	0.417	0.512	

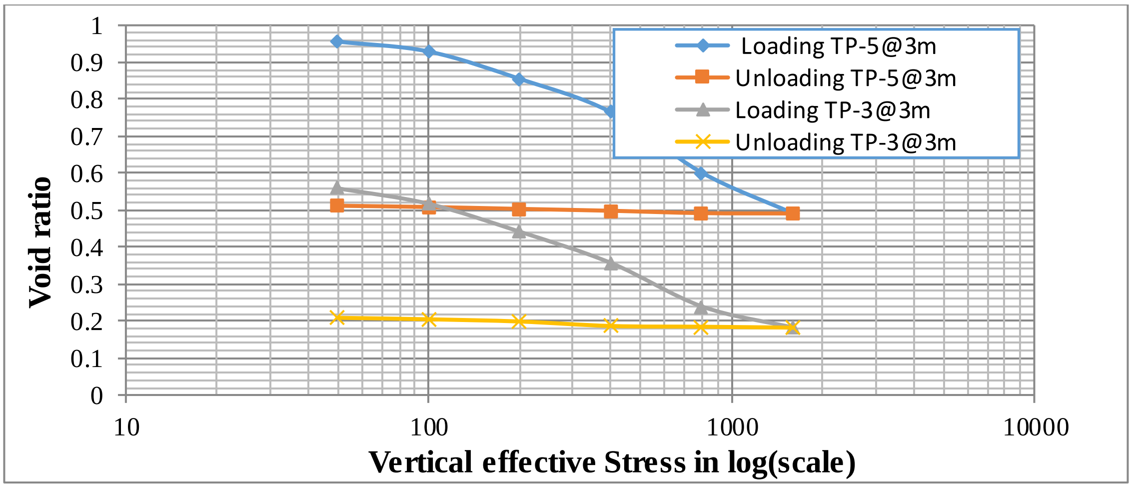

Figure 4. 14: Loading and unloading curve to calculate the coefficient of consolidation and the recompression index

From the one-dimensional consolidation test result, compression index (Cc) of the two test pits are 0.29 and 0.40, Swelling index (Cs) are 0.02 and 0.0194 and coefficient of consolidation, Cv, are 0.14 to 1.0 (x10^{-3}) cm^2/sec.

4.9.4 Coefficient of permeability

The flow of water through soils depends upon its permeability coefficient. Which means coarse sand and gravel are highly pervious and have correspondingly high permeability coefficients. The coefficient of permeability can be measured using field tests, or tests conducted in the laboratory. Sometimes it can be estimated from one dimensional consolidation test. Using coefficient of consolidation (CV), coefficient of permeability can be determined from the following relationship:

$$K = \frac{C_v a_v \cdot \gamma_w}{1+e} \quad \text{.......... (4.8)}$$

Where: C_v=coefficient of vertical consolidation

a_v= coefficient of compressibility= $\frac{\Delta e}{\Delta P}$

e = initial void ratio

γ_w=unit weight of water =9.81kN/m^3.

$$K = \frac{2.4*8.2*9.81}{1+0.182} = 1.6 *10^{-4}\text{cm/sec}$$

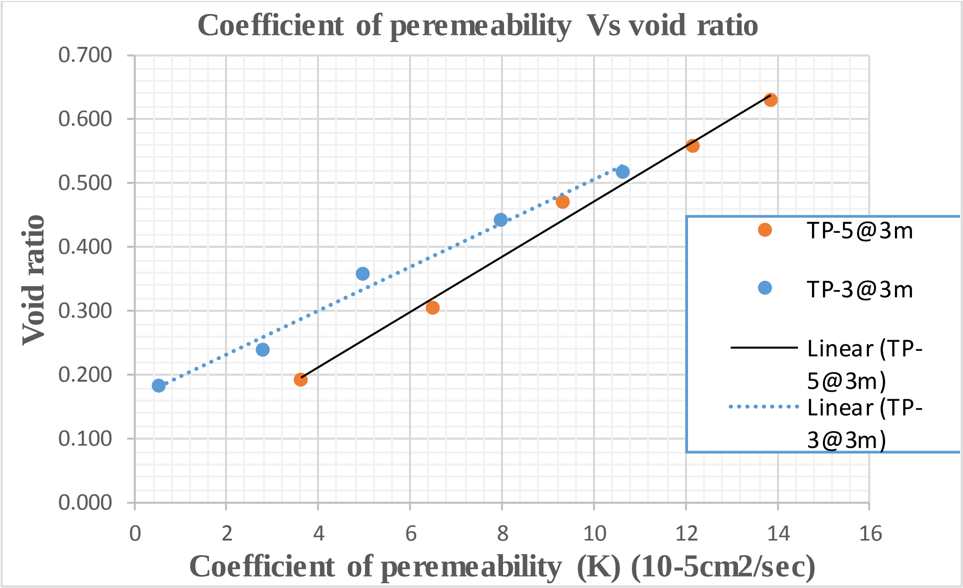

Figure 4. 15: Relationship between void ratio and coefficient of permeability of TP-3@3m and TP-5@3m depth.

Table 4. 18: Summary of coefficient of con consolidation, coefficient of compressibility and coefficient of permeability for test results.

Test pit	Depth(m)	Pressure (kPa)	Void ratio (e)	Coefficient of Consolidation, Cv(10^{-3}cm2/sec)	Coefficient of Compressibility, av(10^{-3}cm2/KN)	Coefficient of permeability, k (10^{-5}cm/sec)
TP-3-2	3	100	0.517	2.36727814	8.2	2.3
		200	0.442	0.352112529	7.4	1.297
		400	0.357	0.813170651	4.5	1.82
		800	0.239	0.265248779	4.1	0.541
		1600	0.182	0.844712997	1.41	0.59
TP-5-2		100	0.929	0.53	6.3	2.77
		200	0.855	0.33	7.3	1.999
		400	0.765	0.27	4.35	9.75
		800	0.601	0.18	4.1	6.12
		1600	0.491	0.14	0.3	0.35

The coefficient of permeability of soil under investigation which is calculated from the test results of consolidation shows that range of values of coefficient of permeability lies between (0.35-9.8) x10^{-5} cm/s under the increments of loading, which indicates that the soils are dense silty.

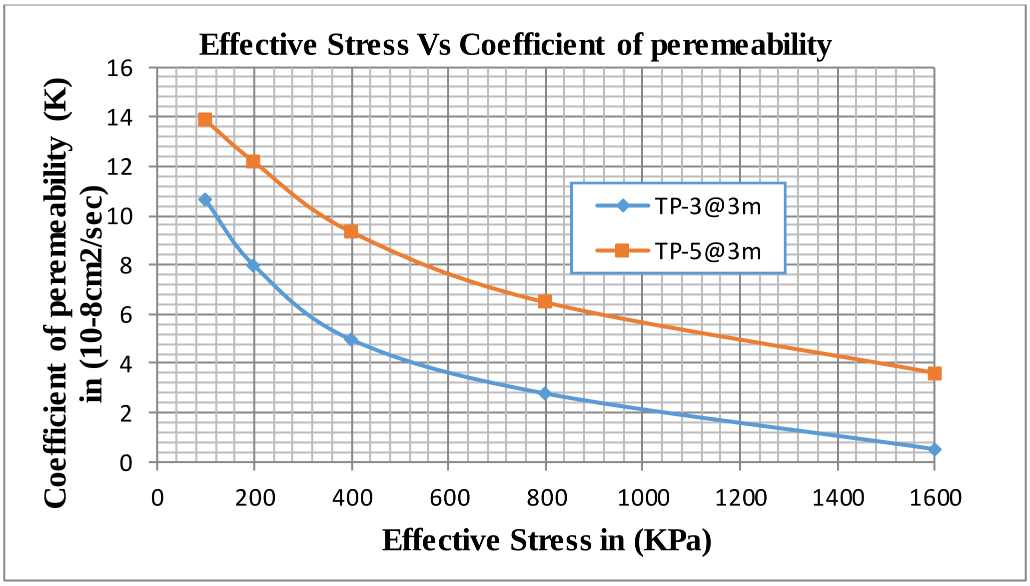

Figure 4. 16: Relationship between consolidation pressure and coefficient of permeability

From relationship between consolidation pressure and coefficient of permeability, the result shows that, consolidation pressure has a direct impact on permeability of soil and the value of 'k' decreases with increasing consolidation pressure.

4.10 Comparison of Test Results with Previous investigated research in different parts of the country.

Table 4. 19: Comparison of test results

	Previous Research[13]	Previous Research[31]	Previous Research[30]	Previous Research[3]	Current Research
Soil type	Silt &silt sand	silt	Red Clay	Silt	Silt soil &clayey sand
Location	Adama town	Kemise	Burayu	Dessie	Gilgele-beles
Clay content%	5.4 – 40.5	21.78-46.4	56-74	50.6-70.7	23-54.6
Liquid Limit %	29-73	36.8-67.5	66-72	61-88	30 - 52.5
Plastic Limit %	21-39	22.9-33.3	31-34	38-59	24.9 – 40.5
Plastic Index%	5-34	12.1-34.7	36-40	22-38	5 – 19.5
Activity	-----	0.47-0.86	<0.75	--	0.13-0.87
Specific Gravity	2.4- 2.7	2.63-2.74	2.70-2.82	2.65-2.83	2.59-2.72
AASHTO classification	-	A-6, A-7-5/6	-	A-7-5	A-2-4/5, A-2-6/7, A-4, A-6, A-7-5/6

As shown in the table 5.3 above the soils of Gilgele-Beles town when compared with the previously tested soils of Adama, show considerable similarities with Clay content and Kemise with activity and classification. More similarity between those three study areas is observed with respect to the index tests results. Generally, the soil of Gilgele-Beles town could be classified as silty and clayey sand soil with almost close characteristics with Adama and Kemise soils.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The outcomes would be applicable only for light structures which under lie their foundation up to depth of 3m.

From the test result the physical and index properties of the study area were concluded as ranges natural moisture content from 19.68 %- 59.87%, specific gravities from 2.6 to 2.72, clay fraction from 23-54.6%, silt fraction from 14.9-50.5%, sand from 20.82-39.1%, gravel from 0-1.4%, liquid limit from 30 – 52.5%, plastic limit from 24.9 – 40.5% and plastic index from 5 – 19.5%.

According to USCS classification system of plasticity chart, most of the soil of the study area falls below A-Line in ML region, and TP-3, TP-5 and TP-7 in MH region, which have high plasticity (LL>50%) and the classification soils found in Gilgel-Beles town are ML, MH and CL. And also, according to AASTHO classification system, the test result show that the dominant soils under the study area are categorized in A-7-5 and A-7-6 which is poor for sub-grade materials. The maximum dry density (MDD) ranges from1.57 to 1.81 g/cm3 with the optimum moisture content ranges 17 to 35.38 %.

Some engineering properties of the study area were; unconfined compressive strength from 85.28 to 179kN/m^2, un-drained shears strength 42.64 to 89.5kN/m^2 with in the range of medium consistency. And from the one-dimensional consolidation test result, the over-consolidation ratios of the soils are more than one, so the soil in the study area is over consolidated in the past with maximum effective stress. Compression index (Cc) of the two test pits are 0.29 and 0.40, Swelling index (CS) are 0.02 and 0.0194 and coefficient of consolidation, Cv, are 0.14 to 1.0 (x10^{-3}) cm2/sec. The coefficient of permeability which is calculated from the test results of consolidation lies between (0.35-9.8) x10^{-5} cm/s under the increments of loading.

5.2. Recommendations

1. Detailed in situ investigation and laboratory tests should be conduct in future, because soil properties at in situ stresses are critical.
2. In this research samples of soil were collected only from two test pits for one-dimensional consolidation, by increasing the number of sampling area and depth of sampling further investigation should be carried out to determine detail Engineering properties of the soil at the study area.

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APPENDIXS

Appendix A

Detail Test Result of Natural Moisture Content of the Study area

TP-1@1.5m			
Container No	A	B	C
Container mass(g)	17.5	17.5	18
Mass of container +wet soil(g)	84.8	90.1	75
Mass of container + dry soil(g)	73.6	78	65
Mass of dry soil(g)	56.4	61.9	51
Mass of water(g)	11.2	12.1	10
Natural moisture content (%)	19.86	19.55	19.61
Average = 19.68			
TP-1@3m			
Container No	Hcs	29	101
Container mass(g)	17.18	17.48	17.89
Mass of container +wet soil(g)	85.55	89.96	74.9
Mass of container + dry soil(g)	73.5	77.5	65
Mass of dry soil(g)	56.32	60.02	47.11
Mass of water(g)	12.05	12.46	9.9
Natural moisture content (%)	21.40	20.76	21.01
Average = 21.06			

TP-3@1.5m			
Container No	L3	L4	ATR
Container mass(g)	17.5	17	17.4
Mass of container +wet soil(g)	71.5	71	56.14
Mass of container + dry soil(g)	51	52	41
Mass of dry soil(g)	33.5	35	23.6
Mass of water(g)	20.5	19	15.14
Natural moisture content (%)	61.19	54.29	64.15
Average = 59.87742884			
TP-3@3m			
Container No	B3	B4	A4
Container mass(g)	17.5	17	17.4
Mass of container +wet soil(g)	73.5	82.4	58.9
Mass of container + dry soil(g)	53.1	62.1	47.1
Mass of dry soil(g)	35.6	45.1	29.7
Mass of water(g)	20.4	20.3	11.8
Average = 47.34836566			

TP-2@1.5m			
Container No	SB	Uc	FT
Container mass(g)	18	17.5	17.5
Mass of container +wet soil(g)	61.1	54.4	60.4
Mass of container + dry soil(g)	49.9	45.1	50.2
Mass of dry soil(g)	31.9	27.6	32.7
Mass of water(g)	11.2	9.3	10.2
Natural moisture content (%)	35.11	33.70	31.19
Average = 33.4			
TP-2@2.8m			
Container No	B	U	FTT
Container mass(g)	17.5	18.2	17.5
Mass of container +wet soil(g)	62.4	58.9	61.2
Mass of container + dry soil(g)	52.4	49.4	50.72
Mass of dry soil(g)	34.9	31.2	33.22
Mass of water(g)	10	9.5	10.48
Natural moisture content (%)	28.65	30.45	31.55
Average = 30.2			

TP-4@1.5m			
Container No	DN4	AT-1-1	W
Container mass(g)	17.48	17.56	17.94
Mass of container +wet soil(g)	70.13	78.95	68
Mass of container + dry soil(g)	58.92	65.25	57.46
Mass of dry soil(g)	41.44	47.69	39.52
Mass of water(g)	11.21	13.7	10.54
Natural moisture content (%)	27.0511583	28.72719648	26.67004049
Average = 27.48279842			
TP-4@3m			
Container No	DN4	AT-1	W-1
Container mass(g)	17.5	18.2	17.5
Mass of container +wet soil(g)	70.5	79.2	68
Mass of container + dry soil(g)	61.1	67.1	59
Mass of dry soil(g)	43	47.7	42
Mass of water(g)	9.4	12.1	9
Natural moisture content (%)	21.86046512	25.36687631	21.42857143
Average = 22.88530429			

TP-5@1.5m		
Container No	PP	MK
Container mass(g)	17.5	18.5
Mass of container +wet soil(g)	98.6	87.4
Mass of container + dry soil(g)	81.2	72.5
Mass of dry soil(g)	63.7	54
Mass of water(g)	17.4	14.9
Natural moisture content (%)	27.3155416	27.59259259
Average = 27.4540671		
TP-5@3m		
Container No	A	B
Container mass(g)	17.5	18.5
Mass of container +wet soil(g)	99.1	86.4
Mass of container + dry soil(g)	84.1	73.6
Mass of dry soil(g)	66.6	55.1
Mass of water(g)	15	12.8
Natural moisture content (%)	22.52252252	23.23049002
Average = 22.87650627		

TP-6@1.5m			
Container No	1	2	3
Container mass(g)	17.5	17.9	17.3
Mass of container +wet soil(g)	88.3	98.1	94.4
Mass of container + dry soil(g)	77.4	83.8	73.8
Mass of dry soil(g)	58.6	65.6	56.8
Mass of water(g)	10.9	14.3	20.6
Natural moisture content (%)	18.60068259	21.79878049	36.2676056
Average = 25.55568957			
TP-6@3m			
Container No	1	2	3
Container mass(g)	17.5	17.9	17.3
Mass of container +wet soil(g)	86.4	97.9	90.4
Mass of container + dry soil(g)	78	83.5	74.1
Mass of dry soil(g)	60.5	65.6	56.8
mass of water(g)	8.4	14.4	16.3
Natural moisture content (%)	13.88429752	21.95121951	28.6971831
Average = 21.51090004			

TP-7@1.5			
Container No	F	W	DN4
Container mass(g)	17	17.8	17.5
Mass of container +wet soil(g)	74.8	77.8	79.6
Mass of container + dry soil(g)	60	62.8	64.1
Mass of dry soil(g)	43	45	46.6
Mass of water(g)	14.8	15	15.5
Natural moisture content(%)	34.42	33.33	33.26
Average = 33.88			
TP-7@3m			
Container No	AA	BB	DN4
Container mass(g)	17.5	17.5	18.5
Mass of container +wet soil(g)	72.4	75.8	77.6
Mass of container + dry soil(g)	60.5	63.4	64.8
Mass of dry soil(g)	43	45.9	46.3
Mass of water(g)	11.9	12.4	12.8
Natural moisture content (%)	27.67	27.02	27.65
Average = 27.23			

TP-8@1.5		
Container No	H11	1A
Container mass(g)	17.5	17.5
Mass of container +wet soil(g)	81.9	82.5
Mass of container + dry soil(g)	66.5	65
Mass of dry soil(g)	49	47.5
Mass of water(g)	15.4	17.5
Natural moisture content (%)	31.42857143	36.84210526
Average = 34.13533835		
TP-8@3m		
Container No	11	1
Container mass(g)	17.5	18.5
Mass of conta +wet soil(g)	90.5	81.5
Mass of conta + dry soil(g)	73.57	66.47
Mass of dry soil(g)	56.07	47.97
Mass of water(g)	16.93	15.03
Natural moisture content (%)	30.19439986	31.33208255
Average = 31.70		

Appendix B

The detailed test results for Specific Gravity (G_s)

TP-1@1.5m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	85.18	84	84.88
Mbw = mass of bottle + water(g)	79	77.75	78.65
Mbw - Mbdw	-6.18	-6.25	-6.23
Ms +(Mbw - Mbdw)	3.82	3.75	3.77
Gs	2.62	2.67	2.65
Gs (average) = 2.65			
TP-1@3m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	85.54	84.22	85.35
Mbw = mass of bottle + water(g)	79.28	77.95	79
Mbw - Mbdw =	-6.26	-6.27	-6.35
Ms +(Mbw - Mbdw)	3.74	3.73	3.65
Gs	2.67	2.68	2.74
Gs (average) = 2.70			

TP-2@1.5m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	84.84	83.87	84.91
Mbw = mass of bottle + water(g)	78.65	77.65	78.7
Mbw - Mbdw =	-6.2	-6.2	-6.2
Ms +(Mbw - Mbdw)	3.81	3.78	3.79
Gs =	2.62	2.65	2.64
Gs (average) = 2.64			
TP-2@2.8m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10

Mb =mass of empty bottle (g)	28.69	27.89	28.02
Mbs = Mass empty bottle + dry soil(g)	39	39.5	38.27
Mbdw = mass bottle + dry soil + water(g)	85.64	85.17	85.58
Mbw = mass of bottle + water(g)	79.36	78.99	79.35
Mbw - Mbdw	-6.28	-6.18	-6.23
Ms +(Mbw - Mbdw)	3.72	3.82	3.77
Gs	2.69	2.62	2.65
Gs (average) =2.65			
TP-3@1.5m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.7	37.83	38.12
Mbdw = mass bottle + dry soil + water(g)	85.07	84.2	85.09
Mbw = mass of bottle + water(g)	78.86	77.95	78.8
Mbw - Mbdw =	-6.21	-6.25	-6.29
Ms +(Mbw - Mbdw)	3.79	3.75	3.71
Gs	2.64	2.67	2.70
Gs (average) = 2.67			
TP-3@3m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mps = Mass empty + dry soil(g)	38.7	37.83	38.12
Mbdw = mass bottle + dry soil + water(g)	85.3	84.13	85.35
Mbw = mass of bottle + water(g)	79	77.86	79.1
Mbw - Mbdw =	-6.3	-6.27	-6.25
Ms +(Mbw - Mbdw)	3.7	3.73	3.75
Gs	2.70	2.68	2.67
Gs (average) =2.68			
TP-4@1.5m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	84.84	83.87	84.91
Mbw = mass of bottle + water(g)	78.65	77.65	78.7
Mbw - Mbdw	-6.2	-6.2	-6.2
Ms +(Mbw - Mbdw)	3.81	3.78	3.79
Gs	2.62	2.65	2.64
Gs (average) =2.64			

TP-4@3m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty bottle + dry soil(g)	39.98	39.5	38.27
Mbdw = mass bottle + dry soil + water(g)	85.64	85.17	85.58
Mbw = mass of bottle + water(g)	79.44	78.85	79.35
Mbw - Mbdw =	-6.2	-6.32	-6.23
Ms +(Mbw - Mbdw)	3.8	3.68	3.77
Gs	2.63	2.72	2.65
Gsave	2.67		
TP-5@1.5m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty + dry soil(g)	39.98	39.5	38.27
Mbdw = mass bottle + dry soil + water(g)	85.68	85.17	85.58
Mbw = mass of bottle + water(g)	79.44	78.85	79.35
Mbw - Mbdw	-6.24	-6.32	-6.23
Ms +(Mbw - Mbdw)	3.76	3.68	3.77
Gs	2.66	2.72	2.65
Gs (average) =2.68			
TP-5@3m			
Specimen number	1	2	3
Bottle number	1	2	3
Ms = Mass of soil added(g)	10	10	10
Mb =mass of empty bottle (g)	28.69	27.82	28.02
Mbs = Mass empty + dry soil(g)	38.69	37.82	38.02
Mbdw = mass bottle + dry soil + water(g)	85.64	84.12	85.35
Mbw = mass of bottle + water(g)	79.28	77.95	79
Mbw - Mbdw =	-6.36	-6.17	-6.35
Ms +(Mbw - Mbdw)	3.64	3.83	3.65
Gs =	2.75	2.61	2.74
Gsave =	2.70		

Appendix C

Grain size analysis

The detailed grain size test results

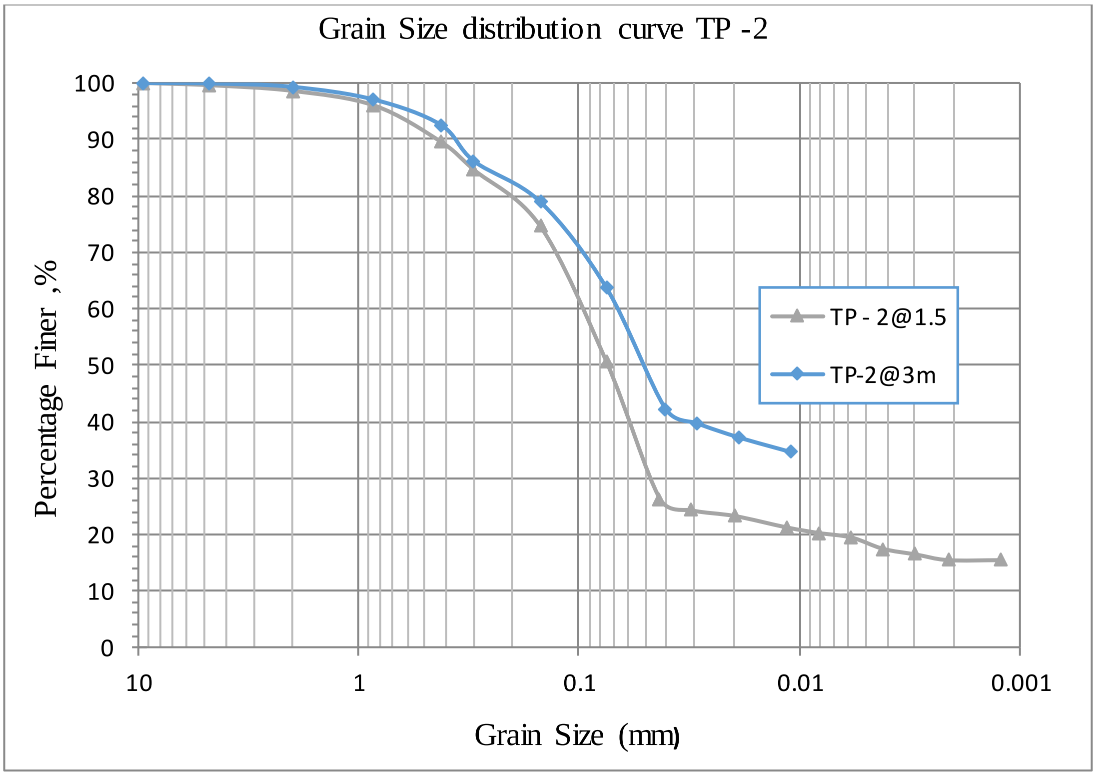
Wet sieve test result for TP-2@1.5m				
9.5	0	0	0	100
4.75	2	0.4	0.4	99.6
2	5	1	1.4	98.6
0.85	15	3	4.4	95.6
0.425	32	6.4	10.8	89.2
0.3	40	8	18.8	81.2
0.15	35	7	25.8	74.2
0.075	121.2	24.24	50.04	49.96

Hydrometer test result for TP-2@1.5m

Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth) from table 1(Cm)	K(cor. fac.Gs) from tabel-2	D (mm)	C_{tep} from tabel -3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percentage of finer %	% Adjusted Finer
1	21	33	10.9	0.013	0.043	0.2	1.002	26.2	52.52	26.26
2	21	31	11.2	0.013	0.031	0.2	1.002	24.2	48.51	24.25
5	21	30	11.4	0.013	0.019	0.2	1.002	23.2	46.50	23.25
15	21	28	11.7	0.013	0.012	0.2	1.002	21.2	42.49	21.25
30	21	27	11.9	0.013	0.008	0.2	1.002	20.2	40.49	20.25
60	22	26	12	0.013	0.006	0.4	1.002	19.4	38.89	19.44
120	22	24	12.4	0.013	0.004	0.4	1.002	17.4	34.88	17.44
240	22	23	12.5	0.013	0.003	0.4	1.002	16.4	32.87	16.44
480	22	22	12.7	0.013	0.002	0.4	1.002	15.4	30.87	15.43
1440	22	22	12.7	0.013	0.001	0.4	1.002	15.4	30.87	15.43

Hydrometer test result for TP-2@3m

Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth) from table 1(Cm)	K(cor. fac.Gs) from tabel-2	D (mm)	C_{tep} from tabel -3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percentage of finer %	% Adjusted Finer
1	21	40	9.7	0.013	0.040	0.2	0.9999	33.2	66.40	42.24
2	21	38	10.1	0.013	0.029	0.2	0.99993	31.2	62.40	39.70
5	21	36	10.4	0.013	0.018	0.2	0.99993	29.2	58.40	37.15
15	21	34	10.7	0.013	0.011	0.2	0.99993	27.2	54.40	34.61
30	21	32	11.1	0.013	0.007	0.2	0.99993	25.2	50.40	32.06
60	22	31	11.2	0.013	0.005	0.4	0.99993	24.4	48.80	31.04
120	22	29	11.5	0.013	0.004	0.4	0.99993	22.4	44.80	28.50
240	22	27	11.9	0.013	0.003	0.4	0.99993	20.4	40.80	25.96
480	22	26	12	0.013	0.002	0.4	0.99993	19.4	38.80	24.68
1440	22	25	12.2	0.013	0.001	0.4	0.99993	18.4	36.80	23.41

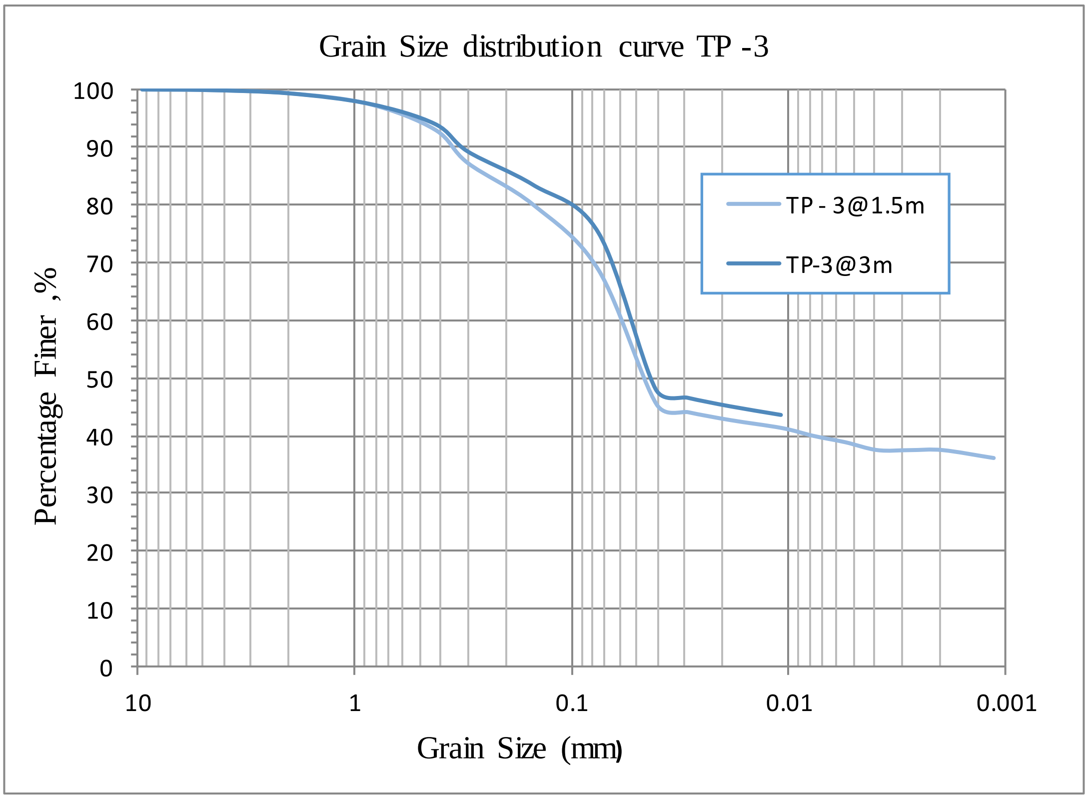


Wet sieve test result for TP-3@1.5m				
Sieve Size (opening)	Mass retained in g	Percentage retained	Cumulative percentage retained	Percentage finer particle
9.5	0	0	0	100
4.75	0.5	0.1	0.1	99.9
2	2.7	0.54	0.64	99.36
0.85	9.5	1.9	2.54	97.46
0.425	22.1	4.42	6.96	93.04
0.3	28.9	5.78	12.74	87.26
0.15	36.1	7.22	19.96	80.04
0.075	56.5	11.3	31.26	68.74

Hydrometer test result for TP-3@1.5m										
Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth) from table 1(Cm)	K(cor. fac.Gs) from tabel-2	D (mm)	Ctep from tabel-3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percentage of finer %	%Adjusted Finer
1	21	40	9.7	0.013	0.0405	0.2	0.99541	33.2	66.10	45.43
2	21	39	9.9	0.013	0.0289	0.2	0.99541	32.2	64.10	44.07
5	21	38	10.1	0.013	0.0185	0.2	0.99541	31.2	62.11	42.70
15	21	37	10.2	0.013	0.0107	0.2	0.99541	30.2	60.12	41.33
30	21	36	10.4	0.013	0.0077	0.2	0.99541	29.2	58.13	39.96
60	22	35	10.6	0.013	0.0055	0.4	0.99541	28.4	56.54	38.87
120	22	34	10.7	0.013	0.0039	0.4	0.99541	27.4	54.55	37.50
240	22	34	10.7	0.013	0.0027	0.4	0.99541	27.4	54.55	37.50
480	22	34	10.7	0.013	0.0019	0.4	0.99541	27.4	54.55	37.50
1440	22	33	10.9	0.013	0.0011	0.4	0.99541	26.4	52.56	36.13

Wet sieve test result for TP-3@3m				
Sieve Size (opening)	Mass retained in g	Percentage retained	Cumulative percentage retained	Percentage finer particle
9.5	0	0	0	100
4.75	0.45	0.09	0.09	99.91
2	2.9	0.58	0.67	99.33
0.85	9.1	1.82	2.49	97.51
0.425	17.4	3.48	5.97	94.03
0.3	23.9	4.78	10.75	89.25
0.15	28.9	5.78	16.53	83.47

Hydrometer test result for TP-3@3m										
Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth)(Cm)	K(cor.fac. Gs) from tabel-2	D (mm)	C_{tep} from tabel -3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percentage of finer %	% Adjusted Finer
1	21	39	9.9	0.013	0.041	0.2	0.9932	32.2	63.96	48.08
2	21	38	10.1	0.013	0.029	0.2	0.9932	31.2	61.98	46.59
5	21	37	10.2	0.013	0.018	0.2	0.9932	30.2	59.99	45.09
15	21	36	10.4	0.013	0.011	0.2	0.9932	29.2	58.00	43.60
30	21	35	10.6	0.013	0.007	0.2	0.9932	28.2	56.02	42.11
60	22	34	10.7	0.013	0.005	0.4	0.9932	27.4	54.43	40.91
120	22	33	10.9	0.013	0.004	0.4	0.9932	26.4	52.44	39.42
240	22	33	10.9	0.013	0.003	0.4	0.9932	26.4	52.44	39.42
480	22	32	11.1	0.013	0.002	0.4	0.9932	25.4	50.45	37.93
1440	22	32	11.1	0.013	0.001	0.4	0.9932	25.4	50.45	37.93

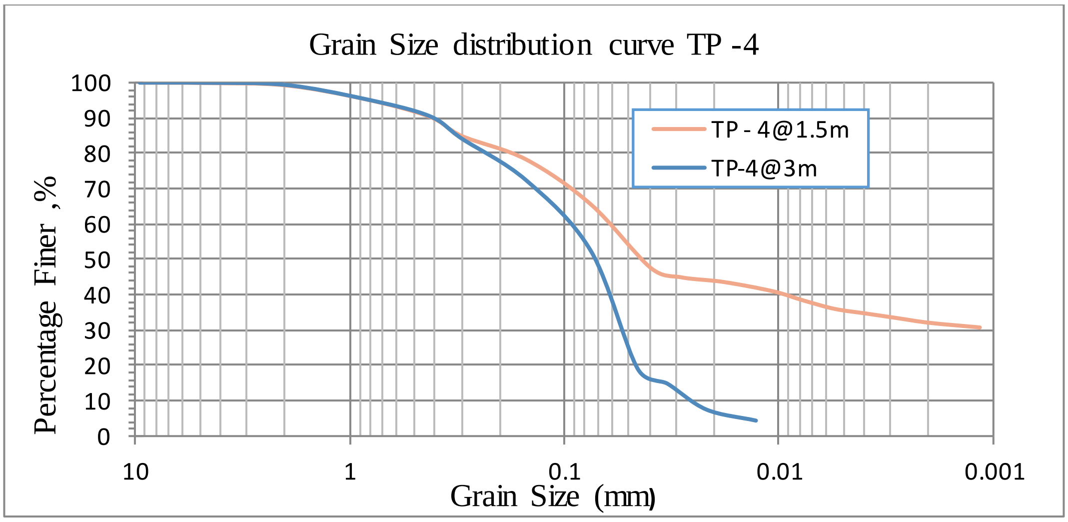


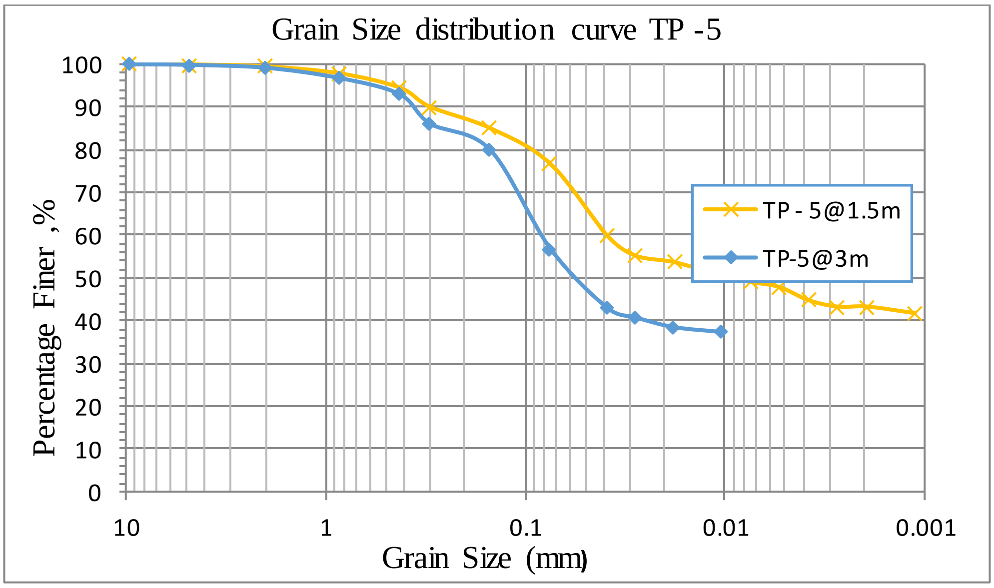
Wet sieve test result for TP-4@1.5m				
Sieve Size (opening)	Mass retained in g	Percentage retained	Cumulative percentage retained	Percentage finer particle
9.5	0	0	0	100
4.75	0.6	0.12	0.12	99.88
2	3.2	0.64	0.76	99.24
0.85	19.5	3.9	4.66	95.34
0.425	24.8	4.96	9.62	90.38
0.3	27.4	5.48	15.1	84.9
0.15	33.4	6.68	21.78	78.22

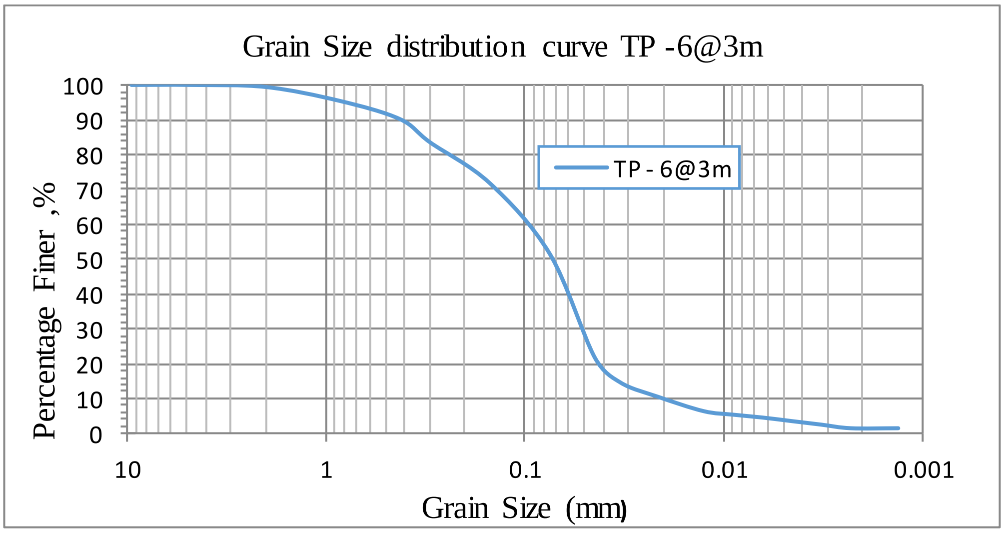
Hydrometer test result for TP-4@1.5m										
Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth) from table 1(Cm)	K(cor. fac.Gs) from tabel-2	D (mm)	C_{tep} from tabel -3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percentage of finer %	% Adjusted Finer
1	21	43	9.2	0.013	0.0394	0.2	1.002	36.2	72.56	47.54
2	21	41	9.6	0.013	0.0285	0.2	1.002	34.2	68.55	44.92
5	21	40	9.7	0.013	0.0181	0.2	1.002	33.2	66.55	43.60
15	21	38	10.1	0.013	0.0107	0.2	1.002	31.2	62.54	40.98
30	21	36	10.4	0.013	0.0077	0.2	1.002	29.2	58.53	38.35
60	22	34	10.7	0.013	0.0055	0.4	1.002	27.4	54.92	35.99
120	22	33	10.9	0.013	0.0039	0.4	1.002	26.4	52.92	34.67
240	22	32	11.1	0.013	0.0028	0.4	1.002	25.4	50.91	33.36
480	22	31	11.2	0.013	0.0020	0.4	1.002	24.4	48.91	32.05
1440	22	30	11.4	0.013	0.0012	0.4	1.002	23.4	46.90	30.73

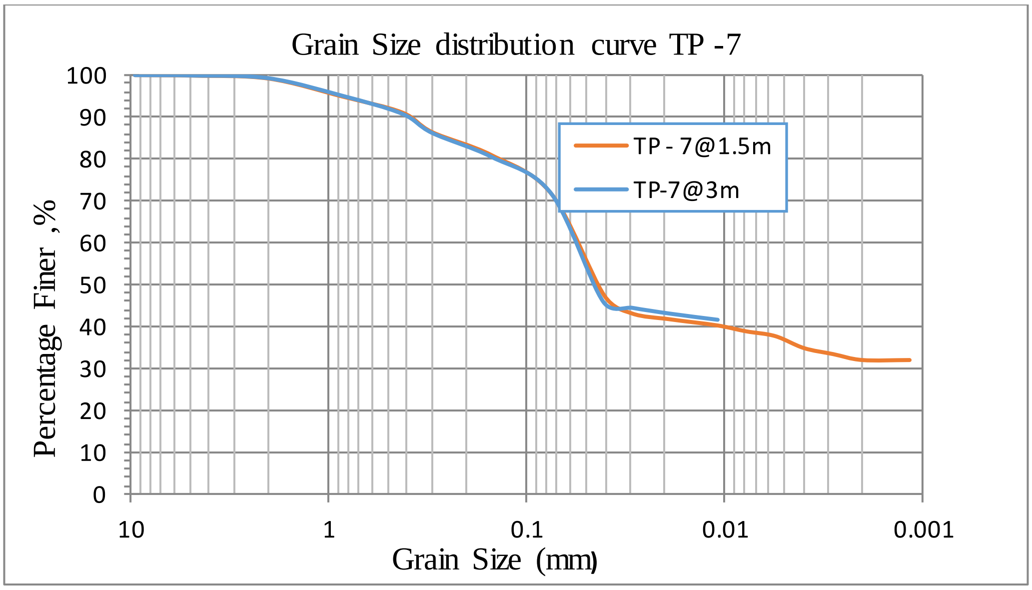
Wet sieve test result for TP-4@3m				
Sieve Size (opening)	Mass retained in g	Percentage retained	Cumulative percentage retained	Percentage finer particle
9.5	0	0	0	100
4.75	0.2	0.04	0.04	99.96
2	2.9	0.58	0.62	99.38
0.85	20	4	4.62	95.38
0.425	24.1	4.82	9.44	90.56
0.3	32	6.4	15.84	84.16
0.15	59.2	11.84	27.68	72.32

Hydrometer test result for TP-4@3m										
Elapsed time (min)	Temperature	Actual hyd. Reading	L(effective depth) from table 1(Cm)	K(cor. fac.Gs) from tabel-2	D (mm)	C_{tep} from tabel -3	a (cor.f. unit weight of solid)	Corrected hyd. Reading (Rc)	percentage of finer %	% Adjusted Finer
1	21	25	12.2	0.013	0.045	0.2	0.9976	18.2	36.31	19.00
2	21	21	12.9	0.013	0.033	0.2	0.9976	14.2	28.33	14.83
5	21	14	14	0.013	0.022	0.2	0.9976	7.2	14.37	7.52
15	21	11	14.5	0.013	0.013	0.2	0.9976	4.2	8.38	4.38
30	21	10	14.7	0.013	0.009	0.2	0.9976	3.2	6.39	3.34
60	22	9	14.8	0.013	0.006	0.4	0.9976	2.4	4.79	2.51
120	22	8	15	0.013	0.005	0.4	0.9976	1.4	2.79	1.46
240	22	8	15	0.013	0.003	0.4	0.9976	1.4	2.79	1.46
480	22	7	15.2	0.013	0.002	0.4	0.9976	0.4	0.80	0.42
1440	22	7	15.2	0.013	0.001	0.4	0.9976	0.4	0.80	0.42

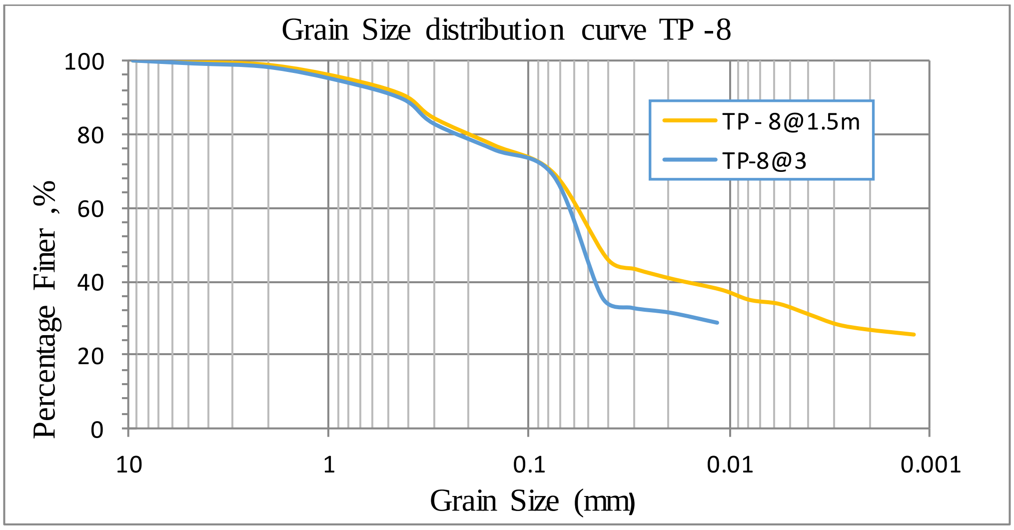

Grain Size distribution curve TP -4
Percentage Finer ,%
Grain Size (mm)
TP - 4@1.5m
TP-4@3m
100
90
80
70
60
50
40
30
20
10
0
10
1
0.1
0.01
0.001


Grain Size distribution curve TP -5
Percentage Finer ,%
Grain Size (mm)
TP - 5@1.5m
TP-5@3m
100
90
80
70
60
50
40
30
20
10
0
10
1
0.1
0.01
0.001

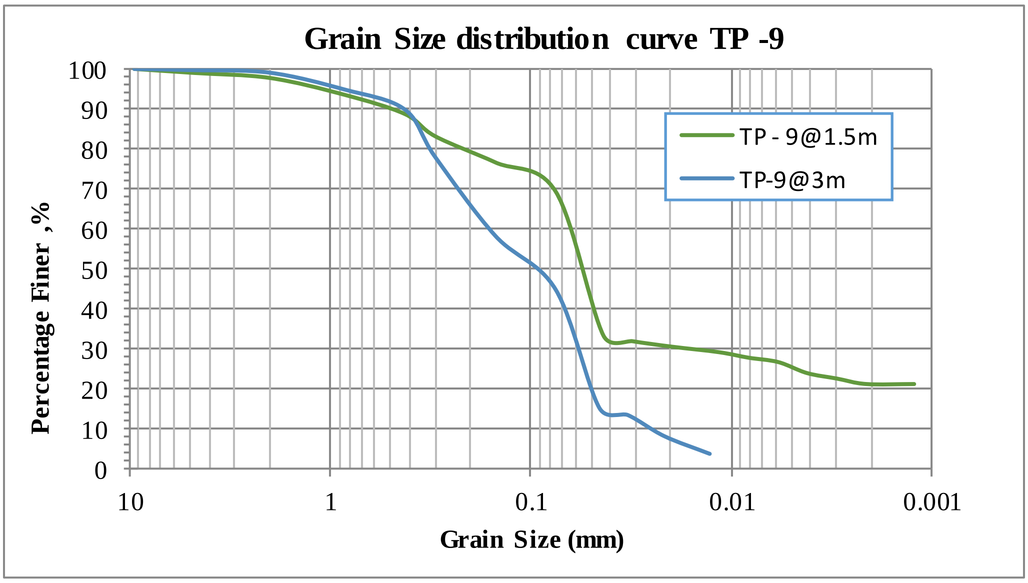

Grain Size distribution curve TP -6@3m
Percentage Finer ,%
Grain Size (mm)
TP - 6@3m
100
90
80
70
60
50
40
30
20
10
0
10
1
0.1
0.01
0.001



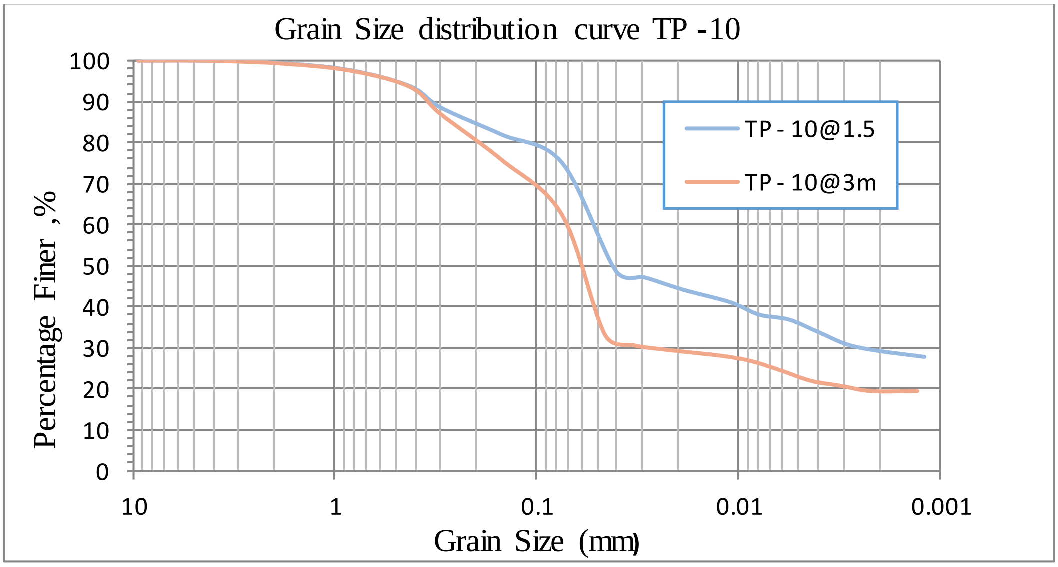
Grain Size distribution curve TP -7
Percentage Finer ,%
100
90
80
70
60
50
40
30
20
10
0
10
1
0.1
0.01
0.001
Grain Size (mm)
TP - 7@1.5m
TP-7@3m



Grain Size distribution curve TP -8
Percentage Finer ,%
100
80
60
40
20
0
10
1
0.1
0.01
0.001
Grain Size (mm)
TP - 8@1.5m
TP-8@3



Grain Size distribution curve TP -9
Percentage Finer ,%
100
90
80
70
60
50
40
30
20
10
0
10
1
0.1
0.01
0.001
Grain Size (mm)
TP - 9@1.5m
TP-9@3m


Grain Size distribution curve TP -10
100
90
80
70
60
50
40
30
20
10
0
Percentage Finer ,%
10
1
0.1
0.01
0.001
Grain Size (mm)
TP - 10@1.5
TP - 10@3m

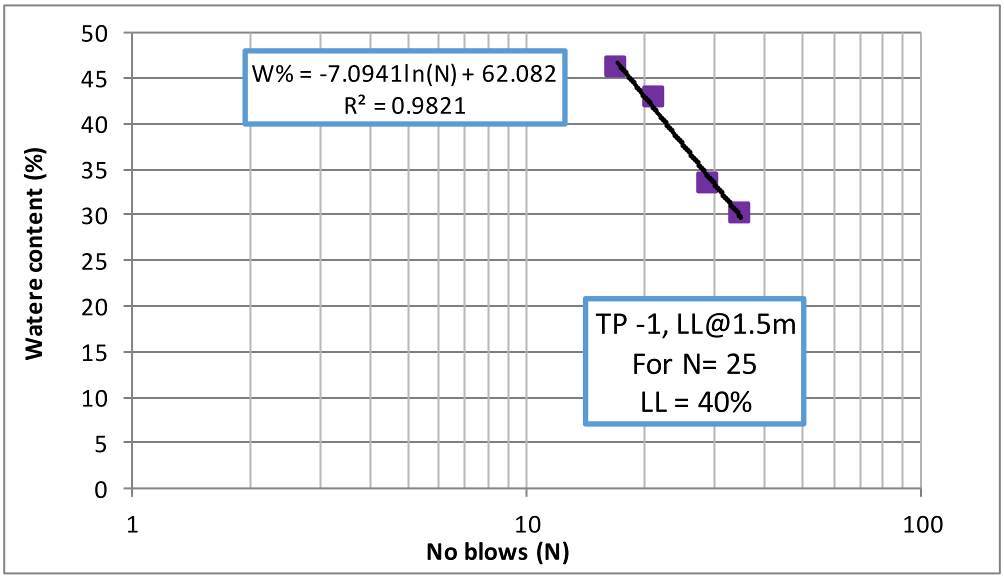
Appendix D

The detailed test results for Atterberg Limit

#For test Pit-1 at 1.5m

Table: Liquid limit and Plastic limit test results

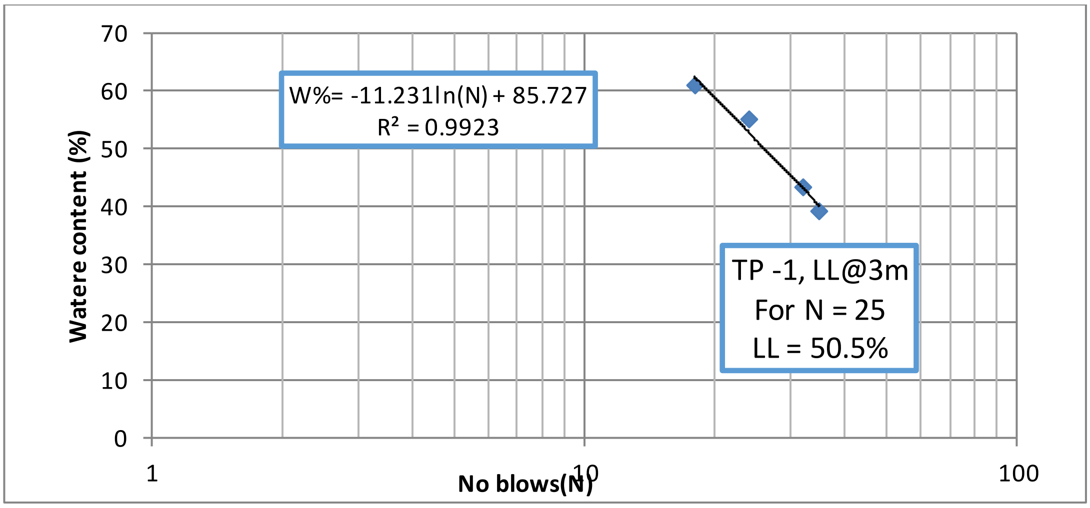
	Liquid Limit				Plastic Limit	
Sample No	1	2	3	4	1	2
Can code	A1	A2	A3	A4	B_1	B_2
Mc	17	18	17	12	18	18
Mcws	43	50	48	50	20.7	20.9
Mcds	37	42	38.7	38	20	20.15
Mds	20	24	21.7	26	2	2.15
Mw	6	8	9.3	12	0.7	0.75
W%	30.08	33.33	42.85	46.15	35	34.88
No blows	35	29	21	17	Ave = 35	



#For test Pit-1 at 3m

Table: Liquid limit and Plastic limit test results

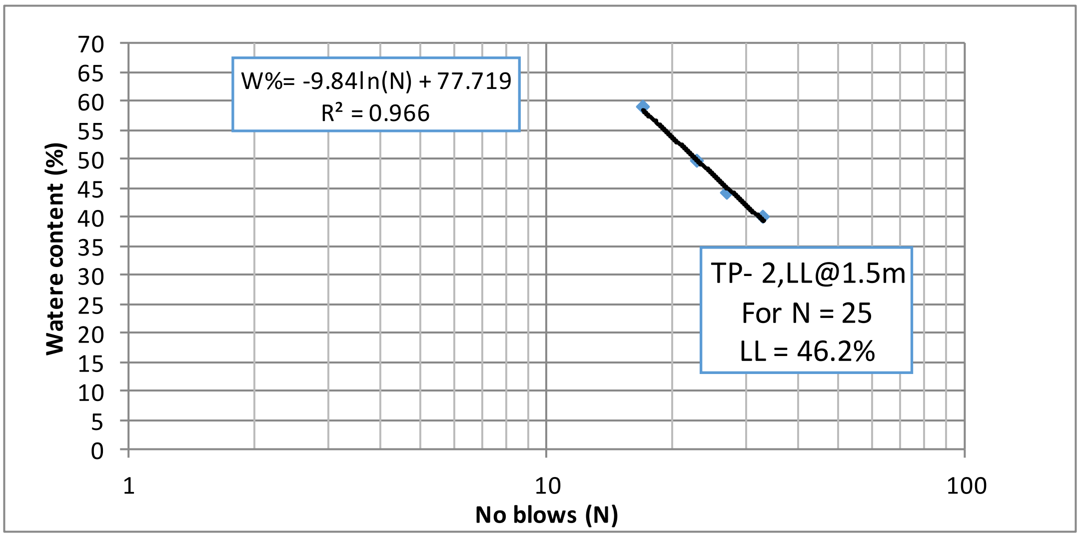
	Liquid Limit				Plastic Limit	
Sample No	1	2	3	4	1	2
Can code	A1	A2	A3	A4	B1	B2
Mc	17	17	12	12	17	12
Mcws	48	49	42	42	20	14
Mcds	41	40	32	31	19.4	13.6
Mds	24	23	20	19	2.4	1.6
Mw	7	9	10	11	0.6	0.4
W%	39.17	43.1	55	61.1	25	25
No blows	35	32	24	18	Ave = 25	



#For test Pit-2 at 1.5m

Table: Liquid limit and Plastic limit test results

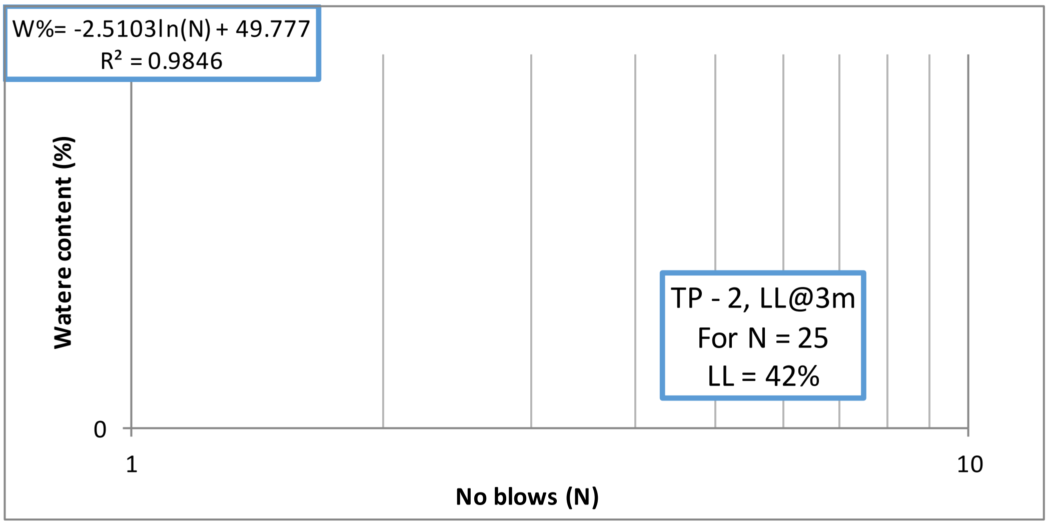
	Liquid Limit				Plastic Limit	
Sample No	1	2	3	4	1	2
Can code	A1	A2	A3	A4	d1	D2
Mc	18	17	17	18.5	18	18
Mcws	46	45.4	48.4	44.7	32	33
Mcds	38	36.7	38	31	29	29.5
Mds	20	19.7	21	16.5	11	11.5
Mw	8	8.7	10.4	10.7	3	3.5
W%	40	44.16	49.52	58.78	27.27	30.43
No blows	33	27	23	17	Ave = 30	



#For test Pit-2 at 2.8m

Table: Liquid limit and Plastic limit test results

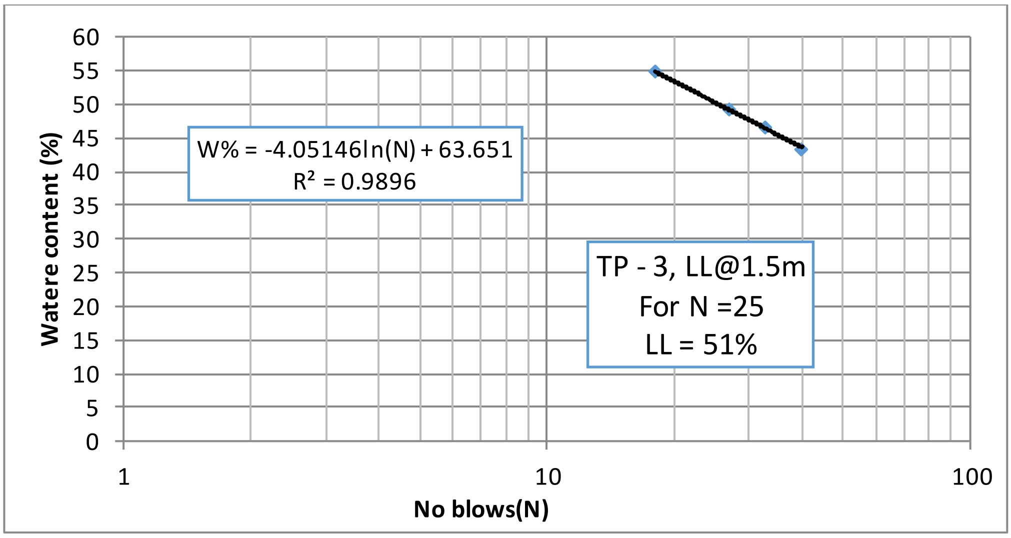
	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	H1	H2	H3	H4	h1	h2	h3
Mc	18	18	14	18	18	18	18
Mcws	40	39	37	50	20.7	20.5	21.4
Mcds	34.4	33	30	40	20.2	20	20.7
Mds	16.4	15	16	22	2.2	2	2.7
Mw	5.6	6	7	10	0.5	0.5	0.7
W%	34.15	40	43.75	45.45	22.72	25	25.9
No blows	38	28	20	16	Ave = 24.9		



#For Test Pit-3 at 1.5m

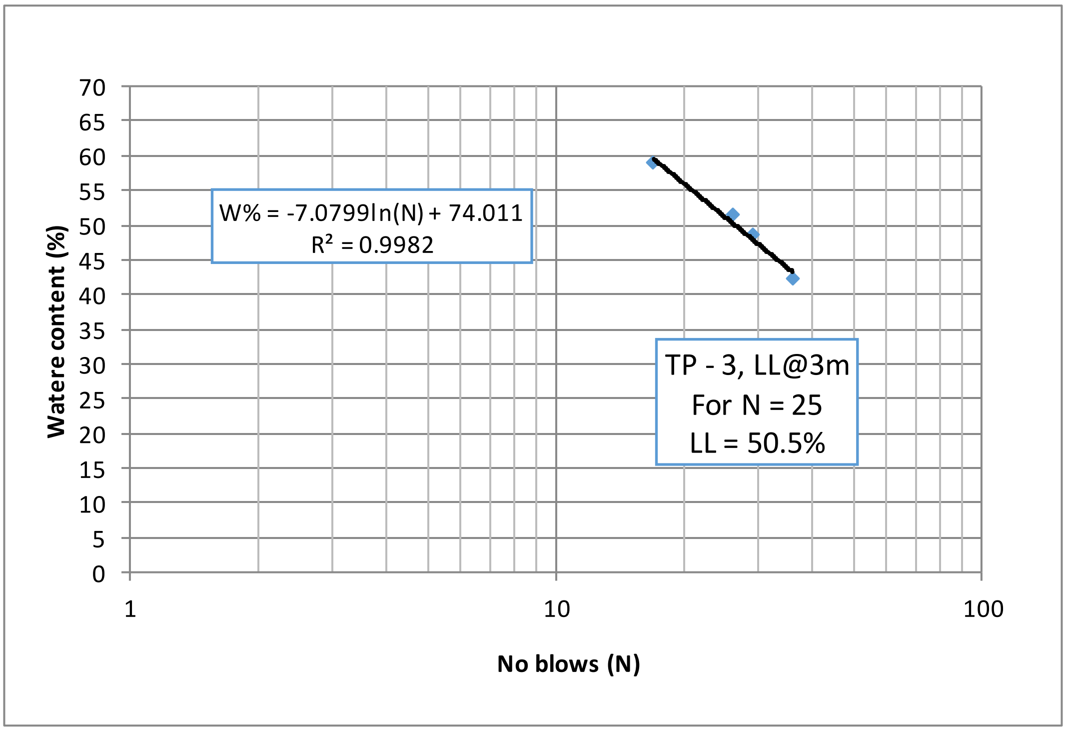
Table: Liquid limit and Plastic limit test results

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	G1	G2	G3	G4	g_1	g_2	g_3
weight of can (g)	18.2	18.2	18.4	11	18	13	12
weight of can+ moist soil (g)	42	42.1	42.7	38.4	22	25	19
weight of can+ dry soil (g)	34.8	34.5	34.7	28.7	21	22	17.5
wegit of dry soil (g)	16.6	16.3	16.3	17.7	3	9	5.5
weight of soil (g)	7.2	7.6	8	9.7	1	3	1.5
water content (%)	43.37	46.6	49.08	54.80	33.3	33.9	27.3
No blows (N)	40	33	27	18	Ave = 31.47		



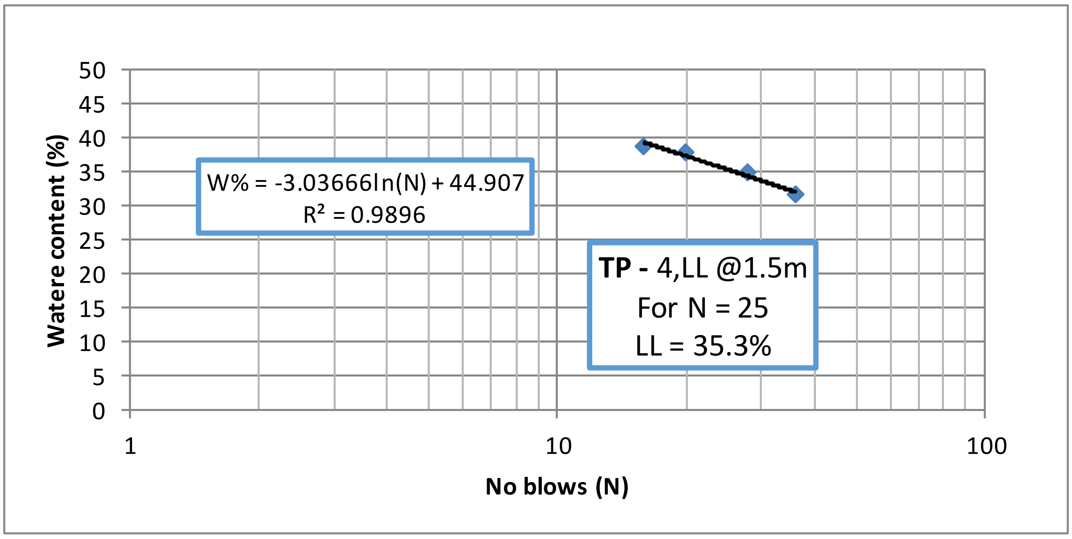
#For Test Pit-3 at 3m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	Ma1	Ma2	Ma3	Ma4	m_1	m_2	m_3
weight of can (g)	12	12.9	17	18	18	12	12
weight of can+ moist soil (g)	39	39	42	45	40	35	39
weight of can+ dry soil (g)	31	30.5	33	35	35	30	33
weight of dry soil (g)	19	17.5	16.5	17	18	17	21
weight of water (g)	8	8.5	9	10	5	5	6
water content (%)	42.1	48.6	51.5	58.8	34	31.8	33.5
No blows	36	29	26	17	Ave = 33		



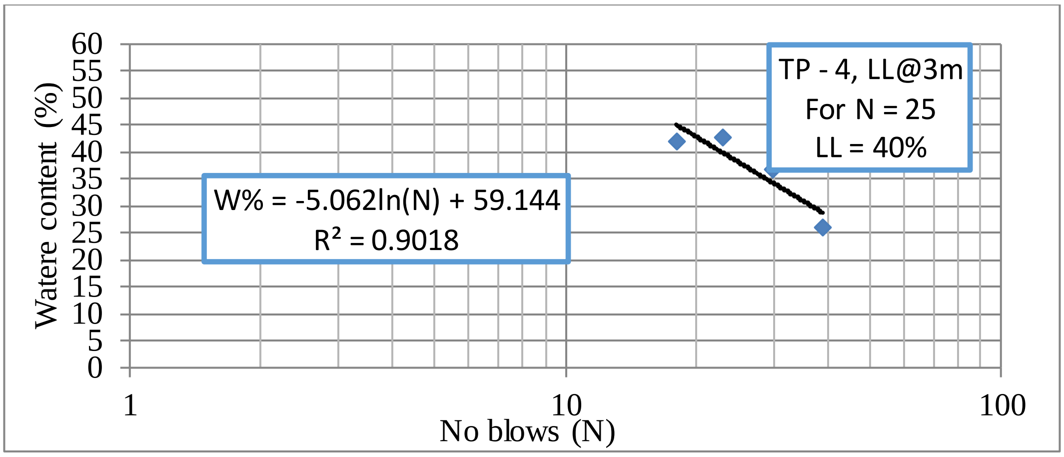
#For Test Pit-4 at 1.5m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	a1	a2	a3	a4	b1	b2	b3
weight of can (g)	17.2	17	14	17.5	17	18	17.5
weight of can+ moist soil (g)	41.4	38.1	33.5	46.9	22	22	21.2
weight of can+ dry soil (g)	35.6	32.7	28	38.7	21.2	21.1	20.4
weight of dry soil (g)	18.4	15.5	14.5	21.2	4.15	3.1	2.9
weight of water (g)	5.8	6	7	8.2	0.85	0.9	0.8
water content (%)	31.5	34.8	37.9	38.7	20.5	29	27.6
No blows (N)	36	28	20	16	Ave = 26.0		



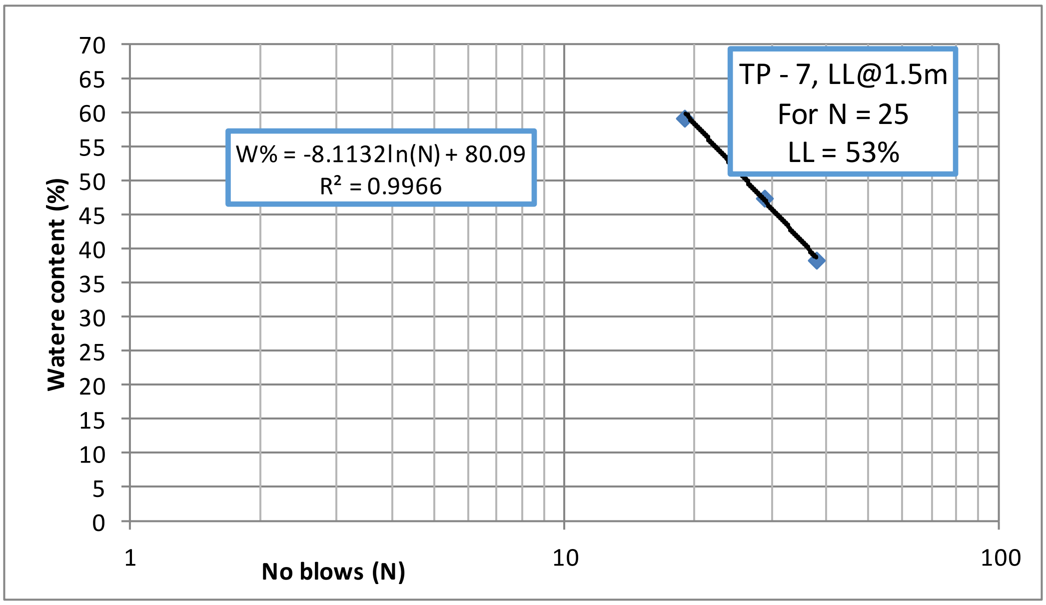
#For Test Pit-4 at 3m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	F1	F2	F3	F4	f_1	f_2	f_3
weight of can (g)	18	18	18	18	17	18	17.5
weight of can+ moist soil (g)	47	44	43	45	23.3	19	21.7
weight of can+ dry soil (g)	41	37	35.5	37	22.4	18	20.6
weight of dry soil (g)	23	19	17.5	19	4.4	6.1	3.1
weight of water (g)	6	7	7.5	8	0.9	1	1.1
water content (%)	26.1	36.8	42.8	42.1	20.4	16.4	35.5
No blows (N)	39	30	23	18	Ave = 26		



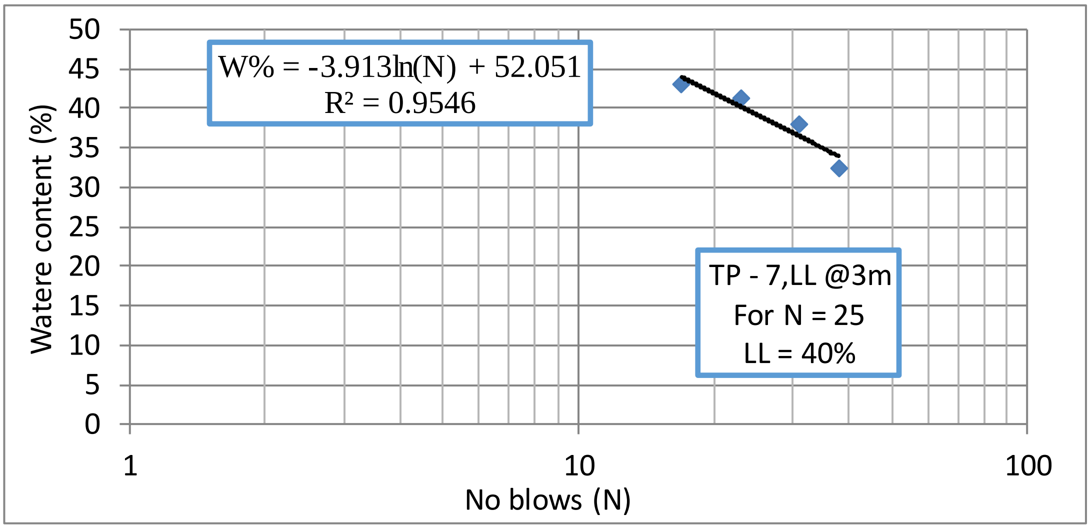
#For Test Pit-7 at 1.5m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	ME1	ME2	ME3	ME4	e_1	e_2	e_3
Weight of can (g)	12	14	17	17	15	11.6	11.3
Weight of can+wet soil (g)	40.3	39	42	42.5	19.2	16.7	17.1
Weight of can+ dry soil(g)	32.5	32	33.5	33	18	15.5	15.6
Weight of dry soil (g)	20.5	17	16.5	16	1.2	1.2	1.5
Weight of water (g)	7.8	8	8.5	9.45	0.9	1.8	0.9
Water content (%)	38.1	47.1	51.5	59.1	37	31	34
No blows	38	29	26	19	Ave = 34.45		



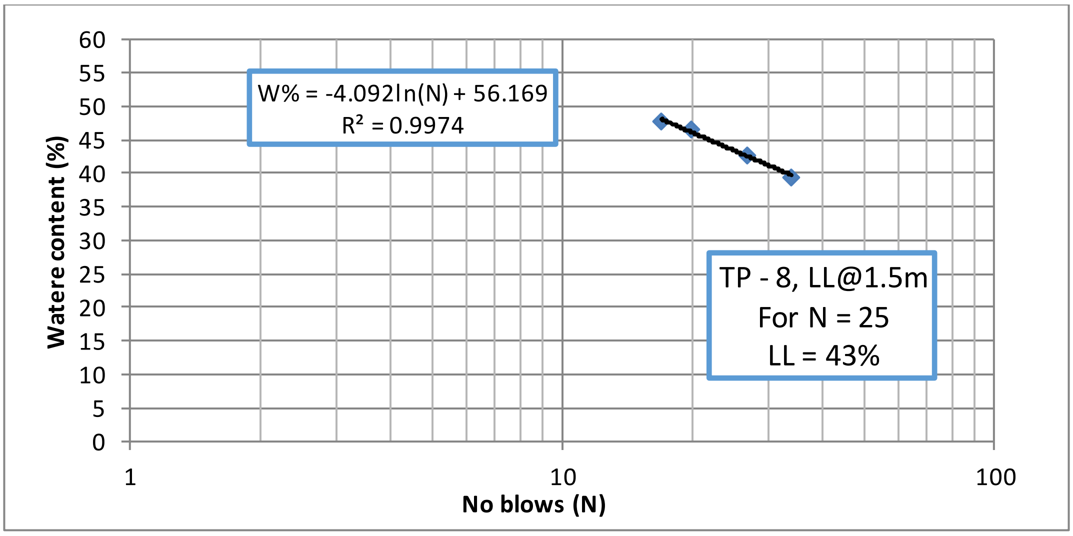
#For Test Pit-7 at 3m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	H1	H2	H3	H4	h_1	h_2	h_3
weight of can (g)	17.2	17.2	13.5	17.5	18	16	18
weight of can+moist soil (g)	36.8	36.5	39.9	39.3	22	19.8	21.5
weight of can+ dry soil (g)	31.7	31	33.5	32	21	19	21
weight of dry soil (g)	15.7	14.5	15.5	17	3	3	3
weight of water (g)	5.1	5.5	6.4	7.3	1	0.75	0.55
water content (%)	32.5	37.9	41.3	42.9	30	25	28
No blows (N)	38	31	23	17	Ave = 25.6		



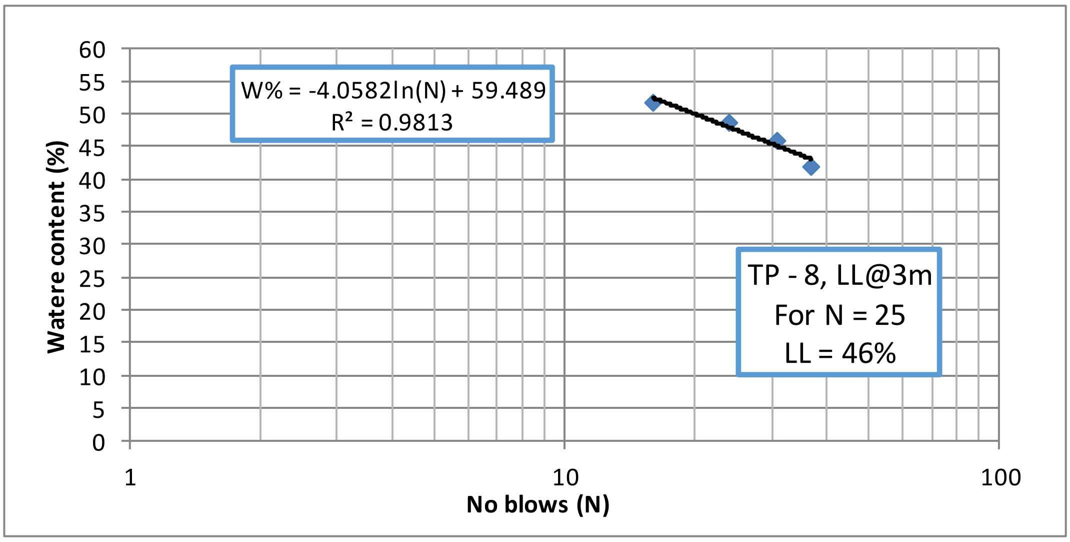
#For Test Pit-8 at 1.5m

	Liquid Limit				Plastic Limit	
Sample No	1	2	3	4	1	2
Can code	D1	D2	D3	D4	d_1	d_2
weight of can (g)	17.5	17	17	17.5	18	17
weight of can+ moist soil (g)	45.4	45.4	49	43.9	21.4	21
weight of can+ dry soil (g)	37.5	36.9	38.8	35.7	20.5	20
weight of dry soil (g)	20	20	22	17.2	2.5	3
weight of water (g)	7.9	8.5	10.2	11	0.9	1
Water content (%)	39.5	42.7	46.6	47.7	36	33.3
No blows (N)	34	27	20	17	Ave = 30.9	



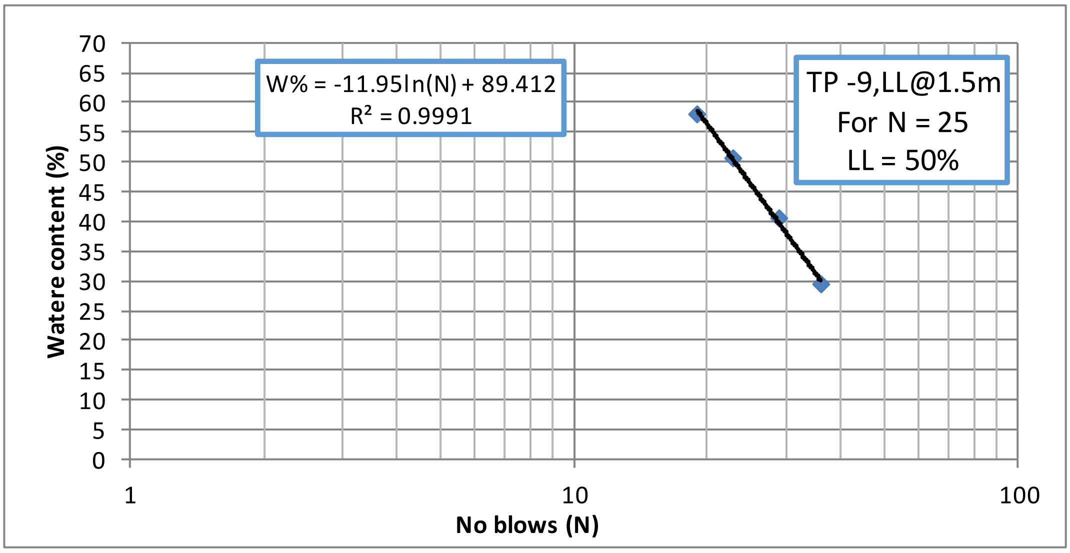
#For Test Pit-8 at 3m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	M1	M2	M3	M4	m_{21}	m_{22}	m_{23}
weight of can (g)	12.5	12.7	18	12	18	18.2	18.1
weight of can+moist soil (g)	37.2	36.5	40	32	21	20.9	21.8
weight of can+ dry soil (g)	29.9	29	32.8	25	20.4	20.2	21
weight of dry soil (g)	17.4	16.3	14.8	13.5	2.4	2	2.9
weight of water (g)	7.3	7.5	7.2	7	0.6	0.7	0.8
water content (%)	41.9	46.0	48.6	51.8	25	35	27.6
No blows (N)	37	31	24	16	Ave = 30.2		



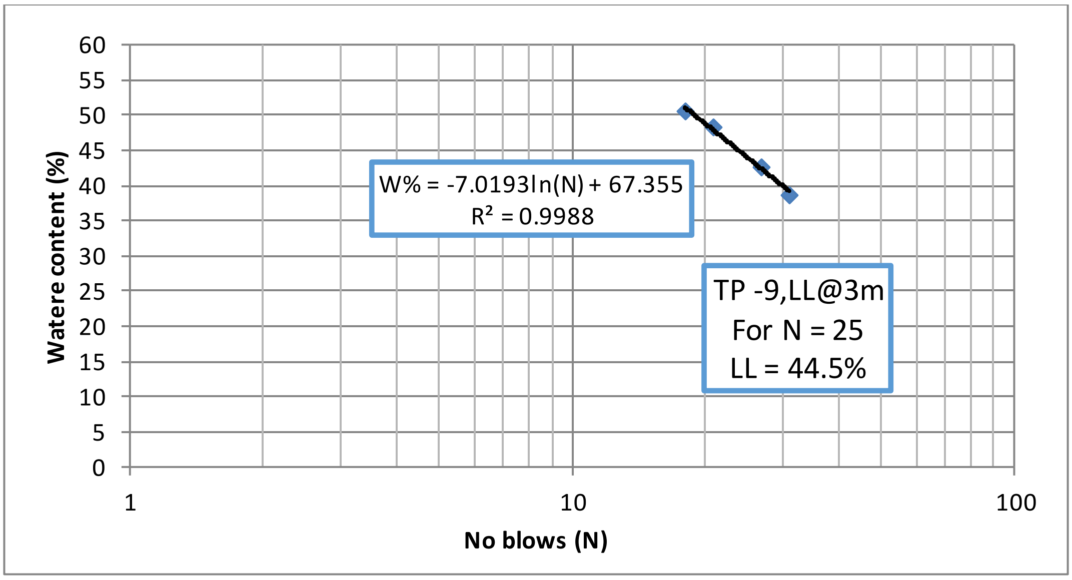
#For Test Pit-9 at 1.5m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	U1	U2	U3	U4	u1	u2	u3
weight of can (g)	18	17.2	18.2	17.7	17.5	17.5	18
weight of can+moist soil (g)	40	38.4	39	38.7	21.9	23	21
weight of can+ dry soil (g)	35	32.3	32	31	20.9	21.7	20.3
weight of dry soil (g)	17	15.1	13.8	13.3	3.4	4.2	2.3
weight of water (g)	5	6.1	7	7.7	1	1.3	0.7
water content (%)	29.4	40.4	50.7	57.9	29.4	31	30.4
No blows (N)	37	31	24	16	Ave = 34.3		



#For Test Pit-9 at 3m

	Liquid Limit				Plastic Limit		
Sample No	1	2	3	4	1	2	3
Can code	U21	U22	U23	U24	u21	u22	u3
weight of can (g)	17.5	17	17	17.5	17	12	12
weight of can+moist soil (g)	50.1	49	42.2	41.6	21	16	15
weight of can+ dry soil (g)	41	39.4	34	33.5	20.1	15.1	14.3
weight of dry soil (g)	23.5	22.5	17	16	3.1	3.1	2.3
weight of water (g)	8.1	8.6	9.1	9.6	0.9	0.9	0.7
water content (%)	38.7	42.7	48.2	50.6	29	29	30.4
No blows (N)	31	27	21	18	Ave = 30.5		


60
55
50
45
40
35
30
25
20
15
10
5
0
Watere content (%)
W% = -7.0193ln(N) + 67.355
R² = 0.9988
TP -9,LL@3m
For N = 25
LL = 44.5%
1
10
100
No blows (N)

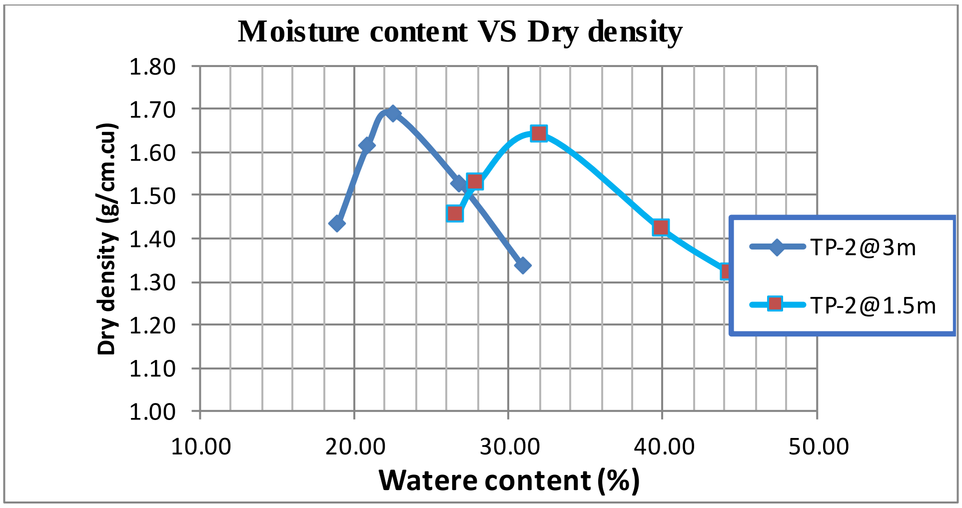
Appendix E

Compaction test results

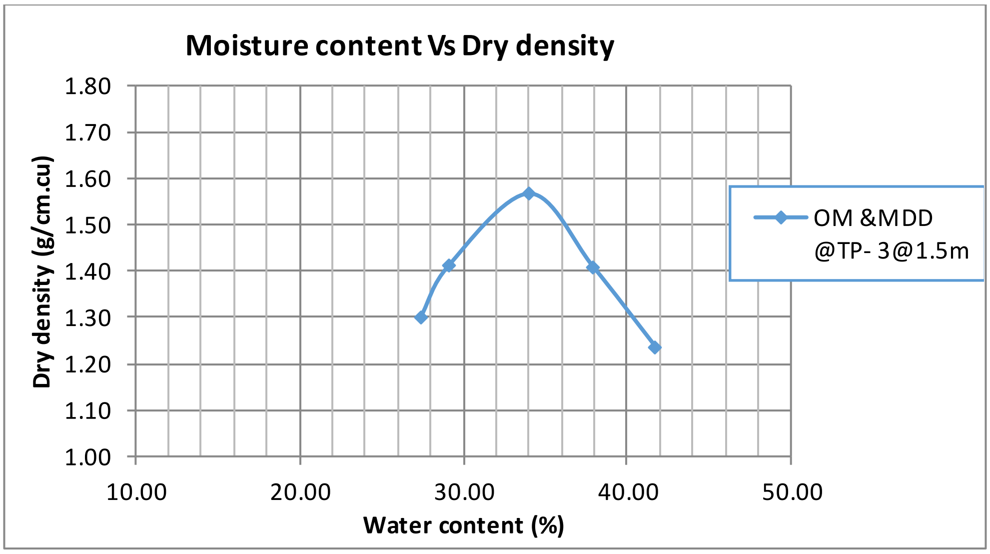
The detailed compaction test results

Modified method (ASTM D-1557) **TP-2@1.5m** Class - A No. of blows = 25 / No. of layers = 5 Weight of hammer, kg = 4.5 / Volume of mold, cm3 = 944					
Number of trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3444	3554	3752	3583	3505
Volume of mold	944	944	944	944	944
Weight of soil	1737	1847	2045	1876	1798
Bulk density	1.84	1.96	2.17	1.99	1.90
Weight of can	18	18	18.2	16.5	17
Weight of can+ soil	75	82	80	84	82
Weight of can+ dry soil	63	68	65	65.8	62
Weight of soil	45	50	46.8	45.5	45
Weight of water	12	14	15	18.2	20
Water content (%)	26.67	28.00	32.05	40.00	44.44
Dry density	1.45	1.53	1.64	1.42	1.32

Modified method (ASTM D-1557) TP-2@3m Class - A No. of blows = 25 / No. of layers = 5 Weight of hammer, kg = 4.5 / Volume of mold, cm3 = 944					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold +soil	3317	3553	3661	3536	3358
Volume of mold	944	944	944	944	944
Weight of soil	1610	1846	1954	1829	1651
Bulk density	1.71	1.96	2.07	1.94	1.75
Weight of can	16.9	17.5	17.2	17.2	17
Weight of can+ soil	92.7	92.3	98	96.8	94.7
Weight of can+ dry soil	80	78.3	81.6	78	74
Weight of soil	67	67	73	70	67
Weight of water	12.7	14	16.4	18.8	20.7
Water content (%)	18.96	20.90	22.47	26.86	30.90
Dry density	1.43	1.62	1.69	1.53	1.34



Modified method (ASTM D-1557) **TP-3@1.5m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of Trial	G1	G2	G3	G4	G5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold +soil	3270	3429	3690	3542	3361
Volume of mold	944	944	944	944	944
Weight of soil	1563	1722	1983	1835	1654
Bulk density	1.66	1.82	2.10	1.94	1.75
Weight of can	18	18	11.2	18	12
Weight of can+ soil	38	47.7	36.4	58	52.4
Weight of can+ dry soil	33.7	41	30	47	40.5
Weight of soil	15.7	23	18.8	29	28.5
Weight of water	4.3	6.7	6.4	11	11.9
Water content (%)	27.39	29.13	34.04	37.93	41.75
Dry density	1.30	1.41	1.57	1.41	1.24



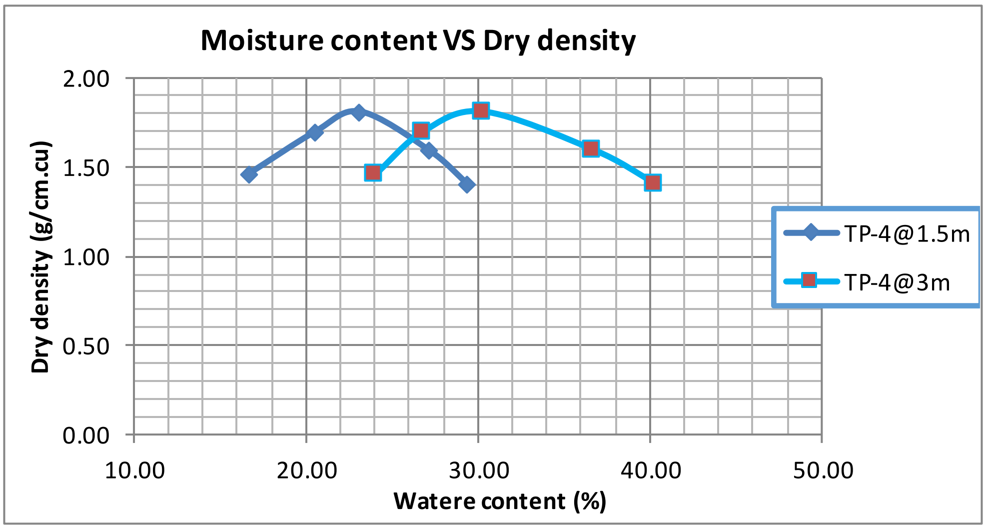
Modified method (ASTM D-1557) **TP-4@1.5m**
Class - A
No. of blows = 25 | Weight of hammer, kg = 4.5
No. of layers = 5 | Volume of mold, cm3 = 944

Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3318	3639	3814	3624	3428
Volume of mold	944	944	944	944	944
Weight of soil	1611	1932	2107	1917	1721
Bulk density	1.71	2.05	2.23	2.03	1.82
Weight of can	17.5	16.9	17.9	16.9	17
Weight of can+ soil	45	58	61.5	65	65.6
Weight of can+ dry soil	40	50	52.7	53.6	53
Weight of soil	30	39	38	42	42.9
Weight of water	5	8	8.8	11.4	12.6
Water content (%)	16.67	20.51	23.16	27.14	29.37
Dry density	1.46	1.70	1.81	1.60	1.41

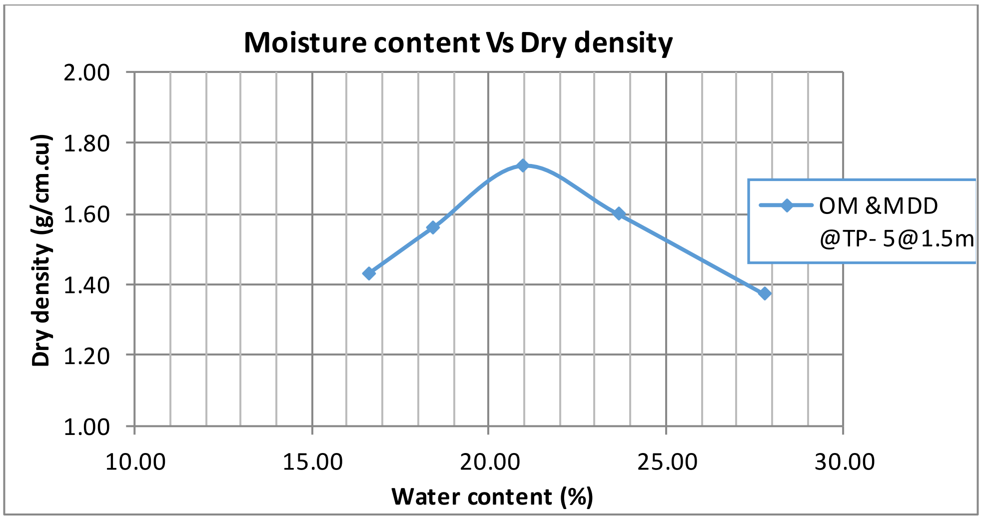
Modified method (ASTM D-1557) **TP-4@3m**
Class - A
No. of blows = 25 | Weight of hammer, kg = 4.5
No. of layers = 5 | Volume of mold, cm3 = 944

Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3435	3607	3765	3632	3559
Volume of mold	944	944	944	944	944
Weight of soil	1728	1900	2058	1925	1852
Bulk density	1.83	2.01	2.18	2.04	1.96
Weight of can	12.7	11.9	11.3	11.6	11.3
Weight of can+ soil	56.5	52.6	56	47.7	65.6

Weight of can+ dry soil	48	44	45.6	38	50
Weight of soil	35.3	32.1	34.3	26.4	38.7
Weight of water	8.5	8.6	10.4	9.7	15.6
Water content (%)	24.08	26.79	30.32	36.74	40.31
Dry density	1.48	1.59	1.67	1.49	1.40



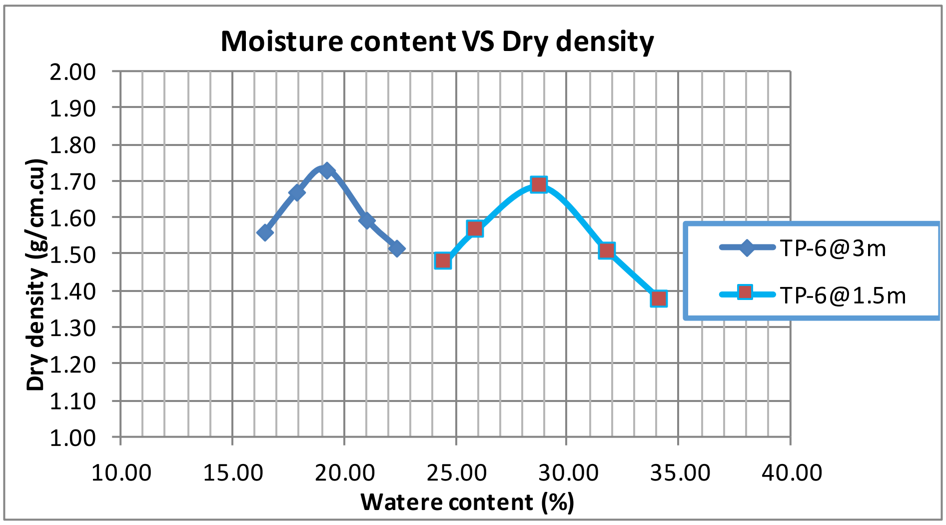
Modified method (ASTM D-1557) **TP-5@1.5m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold+soil	3285	3454	3688	3572	3362
Volume of mold	944	944	944	944	944
Weight of soil	1578	1747	1981	1865	1655
Bulk density	1.67	1.85	2.10	1.98	1.75
Weight of can	18	18	11.2	18	12
Weight of can+ soil	39.1	37.9	47.7	36.4	58
Weight of can+ dry soil	36.09	34.8	43.3	28	48
Weight of soil	18.09	16.8	21	35.5	36
Weight of water	3.01	3.1	4.4	8.4	10
Water content (%)	16.64	18.45	20.95	23.66	27.78
Dry density	1.43	1.56	1.73	1.60	1.37



Modified method (ASTM D-1557) **TP-6@1.5m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold+soil	3447	3568	3755	3579	3449
Volume of mold	944	944	944	944	944
Weight of soil	1740	1861	2048	1872	1742
Bulk density	1.84	1.97	2.17	1.98	1.85
Weight of can	18	18.5	12	17.5	17.5
Weight of can+ soil	75.3	82.1	79	84.1	81.9
Weight of can+ dry soil	64	69	64	68	65.5
Weight of soil	46	50.5	52	50.5	48
Weight of water	11.3	13.1	15	16.1	16.4
Water content (%)	24.57	25.94	28.85	31.88	34.17
Dry density	1.48	1.57	1.68	1.50	1.38

Modified method (ASTM D-1557) **TP-6@3m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3422	3568	3657	3526	3461
Volume of mold	944	944	944	944	944
Weight of soil	1715	1861	1950	1819	1754
Bulk density	1.82	1.97	2.07	1.93	1.86
Weight of can	17	18	17.5	17.5	17
Weight of can+ soil	92.7	92.3	98	96.8	94.7

Weight of can+ dry soil	82	81	85	83	80.5
Weight of soil	65	63	67.5	65.5	63.5
Weight of water (%)	10.7	11.3	13	13.8	14.2
Water content (%)	16.46	17.94	19.26	21.07	22.36
Dry density	1.56	1.67	1.73	1.59	1.52



Modified method (ASTM D-1557) **TP-7@1.5m**

Class - A

No. of blows = 25 Weight of hammer, kg = 4.5

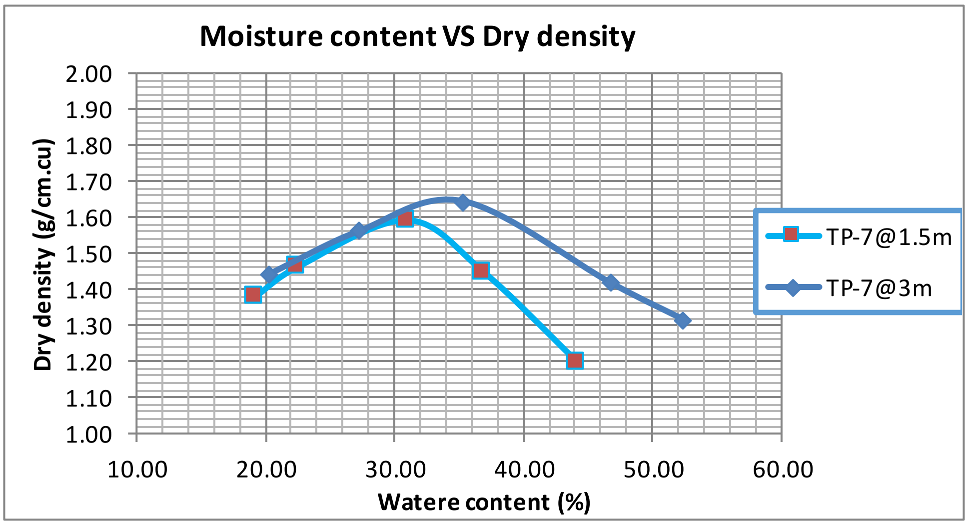
No. of layers = 5 Volume of mold, cm3 = 944

Number of trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3262	3398.7	3675	3579	3338
Volume of mold	944	944	944	944	944
Weight of soil	1555	1691.7	1968	1872	1631
Bulk density	1.65	1.79	2.08	1.98	1.73
Weight of can	18	17.5	17.5	19	18
Weight of can+ soil	99.1	95.3	94.1	98.4	97.3
Weight of can+ dry soil	86	81	76	77	73
Weight of soil	68	63.5	58.5	58	55
Weight of water	13.1	14.3	18.1	21.4	24.3
Water content (%)	19.26	22.52	30.94	36.90	44.18
Dry density (g/cm.cu)	1.38	1.46	1.59	1.45	1.20

TP-7@3m

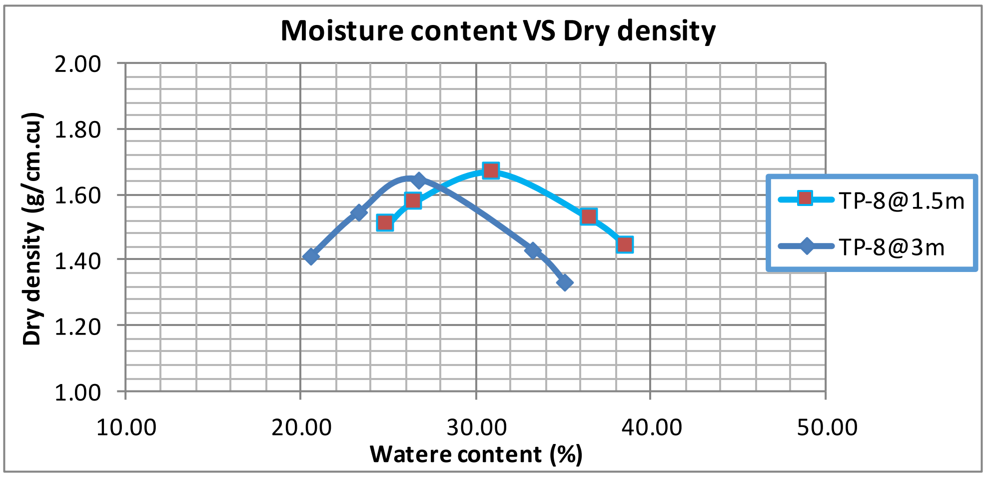
Number of trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3345.4	3585.6	3808.7	3671.6	3601
Volume of mold	944	944	944	944	944
Weight of soil	1638.4	1878.6	2101.7	1964.6	1894

Bulk density	1.74	1.99	2.23	2.08	2.01
Weight of can	17	17.5	17.5	18	18
Weight of can+ soil	100	95.8	96.7	100.2	100.3
Weight of can+ dry soil	86	79	76	74	72
Weight of soil	69	61.5	58.5	56	54
Weight of water	14	16.8	20.7	26.2	28.3
Water content (%)	20.29	27.32	35.38	46.79	52.41
Dry density (g/cm.cu)	1.44	1.56	1.64	1.42	1.32



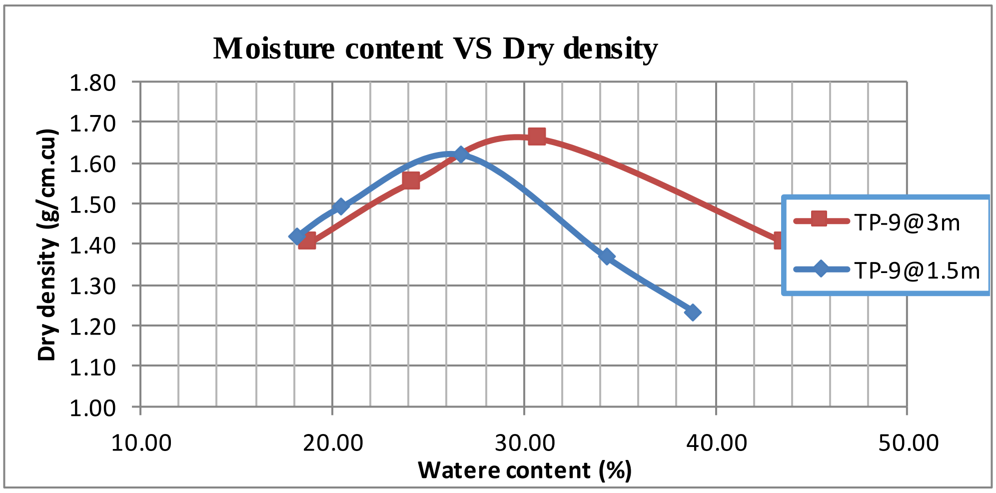
Modified method (ASTM D-1557) **TP-8@1.5m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold+soil	3486	3590	3768	3673	3596
Volume of mold	944	944	944	944	944
Weight of soil	1779	1883	2061	1966	1889
Bulk density	1.88	1.99	2.18	2.08	2.00
Weight of can	18	18	18.2	17.5	17
Weight of can+ soil	73	80	90	81	78
Weight of can+ dry soil	62	67	73	64	61
Weight of soil	44	49	54.8	46.5	44
Weight of water	11	13	17	17	17
Water content (%)	25.00	26.53	31.02	36.56	38.64
Dry density (g/cm.cu)	1.51	1.58	1.67	1.53	1.44
TP-8@3m					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707

Weight of mold + soil	3318	3507	3676	3506	3410
Volume of mold	944	944	944	944	944
Weight of soil	1611	1800	1969	1799	1703
Bulk density	1.71	1.91	2.09	1.91	1.80
Weight of can	17	17.5	17.5	17	18
Weight of can+ soil	93	92	98	97	95
Weight of can+ dry soil	80	78	81	77	75
Weight of soil	63	60	63.5	60	57
Weight of water	13	14	17	20	20
Water content (%)	20.63	23.33	26.77	33.33	35.09
Dry density	1.41	1.55	1.65	1.43	1.34



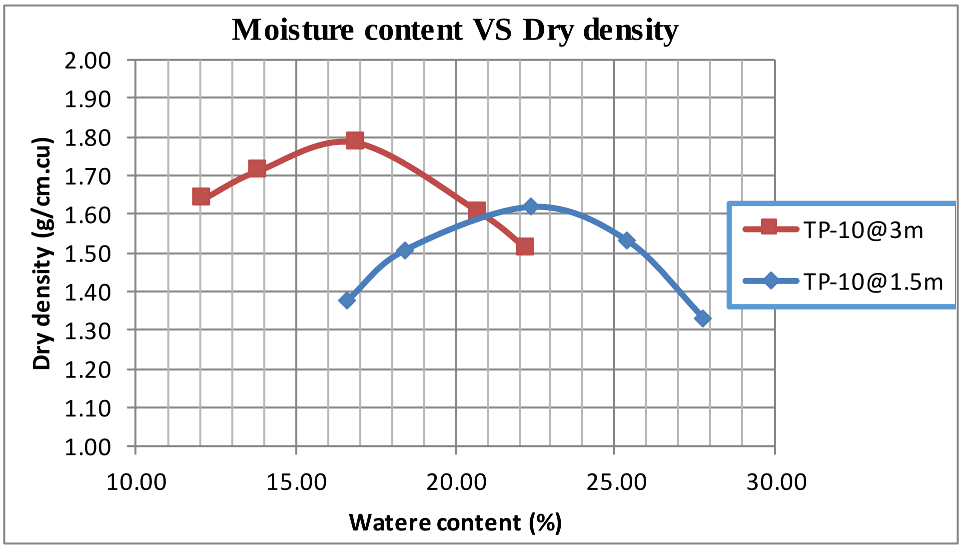
Modified method (ASTM D-1557) **TP-9@1.5m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3291	3405	3645	3441	3325
Volume of mold	944	944	944	944	944
Weight of soil	1584	1698	1938	1734	1618
Bulk density	1.68	1.80	2.05	1.84	1.71
Weight of can	18	17	17.5	17	18
Weight of can+ soil	109	108.2	107	105.7	104.5
Weight of can+ dry soil	95	92.6	88	82.7	80
Weight of soil	77	76	71	67	63
Weight of water	14	15.6	19	23	24.5
Water content (%)	18.18	20.53	26.76	34.33	38.89
Dry density	1.42	1.49	1.62	1.37	1.23

TP-9@3m					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3282	3530	3755	3610	3535
Volume of mold	944	944	944	944	944
Weight of soil	1575	1823	2048	1903	1828
Bulk density	1.67	1.93	2.17	2.02	1.94
Weight of can	17	18	17.5	18	17.8
Weight of can+ soil	100.2	95.3	94	97	98
Weight of can+ dry soil	87	80.2	76	73	72
Weight of soil	70	62.2	58.5	55	54.2
Weight of water	13.2	15.1	18	24	26
Water content (%)	18.86	24.28	30.77	43.64	47.97
Dry density	1.40	1.55	1.66	1.40	1.31



Modified method (ASTM D-1557) **TP-10@1.5m** Class - A No. of blows = 25 Weight of hammer, kg = 4.5 No. of layers = 5 Volume of mold, cm3 = 944					
Number of Trial	1	2	3	4	5
Weight of mold	1707	1707	1707	1707	1707
Weight of mold + soil	3225	3394	3578	3522	3312
Volume of mold	944	944	944	944	944
Weight of soil	1518	1687	1871	1815	1605
Bulk density	1.61	1.79	1.98	1.92	1.70
Weight of can	18	18	11.2	18	12
Weight of can+ soil	39.1	37.9	48	37	58
Weight of can+ dry soil	36.09	34.8	43.3	28	48
Weight of soil	18.09	16.8	21	35.5	36

Weight of water	3.01	3.1	4.7	9	10
Water content (%)	16.64	18.45	22.38	25.35	27.78
Dry density	1.38	1.51	1.62	1.53	1.33



Appendix-F

The results of unconfined compressive strength test

#For Test Pit - 3

Sample depth…………1.5m

Diameter of the sample =36mm

Length of sample =83mm

Ring Calibration Factor =0.007905 kN/div

Table C-1: Computation of UCS values

Axial Sample Deformation ΔL (mm)	Axial Strain (€) (L/L_o)	Strain (€%)	A_c=Corrected Area (A/1-e) (m^2)	Axial Load (kN)	Stress (P/A) (Kpa)
0.00	0.0000	0.000	0.0010	0.000	0.00
0.20	0.0024	0.242	0.0010	0.017	16.47
0.40	0.0048	0.485	0.0010	0.025	24.65
0.60	0.0073	0.727	0.0010	0.034	32.79
0.80	0.0097	0.970	0.0010	0.038	36.79
1.00	0.0121	1.212	0.0010	0.042	40.78
1.20	0.0145	1.455	0.0010	0.043	41.50
1.40	0.0170	1.697	0.0010	0.046	44.64
1.60	0.0194	1.939	0.0010	0.050	48.58
1.80	0.0218	2.182	0.0010	0.052	50.07
2.00	0.0242	2.424	0.0010	0.057	54.78
2.20	0.0267	2.667	0.0010	0.059	56.26
2.40	0.0291	2.909	0.0010	0.060	56.92
2.60	0.0315	3.152	0.0011	0.061	58.37
2.80	0.0339	3.394	0.0011	0.064	60.62
3.00	0.0364	3.636	0.0011	0.067	63.65
3.20	0.0388	3.879	0.0011	0.068	64.28
3.40	0.0412	4.121	0.0011	0.069	64.91
3.60	0.0436	4.364	0.0011	0.071	67.12
3.80	0.0461	4.606	0.0011	0.074	69.31
4.00	0.0485	4.848	0.0011	0.076	70.71
4.20	0.0509	5.091	0.0011	0.076	71.31
4.40	0.0533	5.333	0.0011	0.077	71.91

4.60	0.0558	5.576	0.0011	0.079	73.29
4.80	0.0582	5.818	0.0011	0.081	75.43
5.00	0.0606	6.061	0.0011	0.083	76.79
5.20	0.0630	6.303	0.0011	0.084	77.36
5.40	0.0655	6.545	0.0011	0.085	77.93
5.60	0.0679	6.788	0.0011	0.086	78.50
5.80	0.0703	7.030	0.0011	0.087	79.06
6.00	0.0727	7.273	0.0011	0.088	80.39
6.20	0.0752	7.515	0.0011	0.089	80.94
6.40	0.0776	7.758	0.0011	0.091	82.25
6.60	0.0800	8.000	0.0011	0.092	82.80
6.80	0.0824	8.242	0.0011	0.092	83.34
7.00	0.0848	8.485	0.0011	0.092	83.12
7.20	0.0873	8.727	0.0011	0.093	83.65
7.40	0.0897	8.970	0.0011	0.094	83.80
7.60	0.0921	9.212	0.0011	0.094	83.96
7.80	0.0945	9.455	0.0011	0.095	84.48
8.00	0.0970	9.697	0.0011	0.095	84.25
8.20	0.0994	9.939	0.0011	0.096	84.77
8.40	0.1018	10.182	0.0011	0.097	85.28
8.60	0.1042	10.424	0.0011	0.097	85.05
8.80	0.1067	10.667	0.0011	0.097	84.82
9.00	0.1091	10.909	0.0011	0.097	84.59
9.20	0.1115	11.152	0.0011	0.097	84.36

#For Test Pit - 3

Sample depth…………..3m

Diameter of the sample =36mm

Length of sample =82mm

Ring Calibration Factor =0.007905 kN/div

Table C-2: Computation of UCS values

Axial Sample Deformation ΔL (mm)	Axial Strain (€) (L/L_o)	Axial Strain (€%)	A_c=Corrected Area (A/1-e) (m^2)	Axial Load (kN)	Axial Stress (P/A) (Kpa)
0.000	0.000	0.000	0.001	0.000	0.000
0.200	0.002	0.241	0.001	0.017	16.474
0.400	0.005	0.482	0.001	0.025	24.651
0.600	0.007	0.723	0.001	0.042	40.985
0.800	0.010	0.964	0.001	0.050	49.062
1.000	0.012	1.205	0.001	0.055	53.022
1.200	0.014	1.446	0.001	0.059	56.961
1.400	0.017	1.687	0.001	0.067	64.939
1.600	0.019	1.928	0.001	0.071	68.829
1.800	0.022	2.169	0.001	0.076	72.698
2.000	0.024	2.410	0.001	0.078	74.937
2.200	0.027	2.651	0.001	0.082	78.771
2.400	0.029	2.892	0.001	0.084	80.179
2.600	0.031	3.133	0.001	0.088	83.979
2.800	0.034	3.373	0.001	0.091	86.164
3.000	0.036	3.614	0.001	0.092	87.541
3.200	0.039	3.855	0.001	0.093	88.116
3.400	0.041	4.096	0.001	0.094	88.687
3.600	0.043	4.337	0.001	0.095	89.254
3.800	0.046	4.578	0.001	0.100	93.756
4.000	0.048	4.819	0.001	0.101	94.305
4.200	0.051	5.060	0.001	0.102	94.850
4.400	0.053	5.301	0.001	0.102	95.391
4.600	0.055	5.542	0.001	0.103	95.929
4.800	0.058	5.783	0.001	0.104	96.462
5.000	0.060	6.024	0.001	0.105	96.991
5.200	0.063	6.265	0.001	0.107	98.290
5.400	0.065	6.506	0.001	0.108	99.581
5.600	0.067	6.747	0.001	0.109	100.095
5.800	0.070	6.988	0.001	0.110	100.604
6.000	0.072	7.229	0.001	0.111	101.109

6.200	0.075	7.470	0.001	0.112	101.611
6.400	0.077	7.711	0.001	0.113	102.108
6.600	0.080	7.952	0.001	0.113	102.601
6.800	0.082	8.193	0.001	0.113	102.333
7.000	0.084	8.434	0.001	0.113	102.064
7.200	0.087	8.675	0.001	0.113	101.796
7.400	0.089	8.916	0.001	0.113	101.527
7.600	0.092	9.157	0.001	0.113	101.259
7.800	0.094	9.398	0.001	0.113	100.990
8.000	0.096	9.639	0.001	0.113	100.721
8.200	0.099	9.880	0.001	0.113	100.453
8.400	0.101	10.120	0.001	0.113	100.184
8.600	0.104	10.361	0.001	0.111	97.695
8.800	0.106	10.602	0.001	0.109	95.956
9.000	0.108	10.843	0.001	0.108	94.962
9.200	0.111	11.084	0.001	0.105	91.768

#For Test Pit - 5

Sample depth…………1.5m

Diameter of the sample =36mm

Length of sample =76mm

Ring Calibration Factor =0.007905 kN/div

Table C-2: Computation of UCS values

Axial Sample Deformation ΔL (mm)	Axial Strain (€) (L/L_o)	Axial Strain (€%)	A_c=Corrected Area (A/1-e) (m^2)	Axial Load (kN)	Axial Stress (P/A) (Kpa)
0.00	0.00	0.00	0.001	0.000	0.000
0.20	0.00	0.24	0.001	0.017	16.474
0.40	0.00	0.48	0.001	0.025	24.651
0.60	0.01	0.72	0.001	0.032	31.149
0.80	0.01	0.96	0.001	0.040	39.250
1.00	0.01	1.20	0.001	0.046	44.865
1.20	0.01	1.45	0.001	0.055	52.892
1.40	0.02	1.69	0.001	0.059	56.822
1.60	0.02	1.93	0.001	0.067	64.780

1.80	0.02	2.17	0.001	0.084	80.776
2.00	0.02	2.41	0.001	0.092	88.635
2.20	0.03	2.65	0.001	0.101	96.454
2.40	0.03	2.89	0.001	0.109	104.233
2.60	0.03	3.13	0.001	0.118	111.972
2.80	0.03	3.37	0.001	0.126	119.672
3.00	0.04	3.61	0.001	0.134	127.332
3.20	0.04	3.86	0.001	0.151	142.890
3.40	0.04	4.10	0.001	0.160	150.450
3.60	0.04	4.34	0.001	0.164	154.022
3.80	0.05	4.58	0.001	0.168	157.573
4.00	0.05	4.82	0.001	0.172	161.104
4.20	0.05	5.06	0.001	0.176	164.616
4.40	0.05	5.30	0.001	0.178	165.762
4.60	0.06	5.54	0.001	0.181	167.680
4.80	0.06	5.78	0.001	0.182	168.808
5.00	0.06	6.02	0.001	0.182	168.376
5.20	0.06	6.27	0.001	0.181	167.171
5.40	0.07	6.51	0.001	0.181	165.969
5.60	0.07	6.75	0.001	0.176	161.691
5.80	0.07	6.99	0.001	0.175	159.738
6.00	0.07	7.23	0.001	0.170	154.728
6.20	0.07	7.47	0.001	0.160	145.158
6.40	0.08	7.71	0.001	0.151	137.160
6.60	0.08	7.95	0.001	0.143	129.202
6.80	0.08	8.19	0.001	0.130	117.493

#For Test Pit - 5

Sample depth…………3m

Diameter of the sample =36mm

Length of sample =76mm

Ring Calibration Factor =0.007905 kN/div

Table C-2: Computation of UCS values

Axial Sample Deformation ΔL (mm)	Strain (€) (L/L_o)	Axial Strain (€%)	A_c=Corrected Area (A/1-e) (m^2)	Axial Load (kN)	Axial Stress (P/A) (Kpa)
0.00	0.000	0.00	0.001	0.000	0.000
0.20	0.002	0.24	0.001	0.017	16.473
0.40	0.005	0.49	0.001	0.025	24.649
0.60	0.007	0.73	0.001	0.034	32.785
0.80	0.010	0.98	0.001	0.040	39.245
1.00	0.012	1.22	0.001	0.046	44.858
1.20	0.015	1.46	0.001	0.050	48.815
1.40	0.017	1.71	0.001	0.059	56.810
1.60	0.020	1.95	0.001	0.067	64.764
1.80	0.022	2.20	0.001	0.076	72.679
2.00	0.024	2.44	0.001	0.084	80.553
2.20	0.027	2.68	0.001	0.092	88.387
2.40	0.029	2.93	0.001	0.097	92.173
2.60	0.032	3.17	0.001	0.101	95.938
2.80	0.034	3.41	0.001	0.109	103.671
3.00	0.037	3.66	0.001	0.118	111.364
3.20	0.039	3.90	0.001	0.126	119.017
3.40	0.041	4.15	0.001	0.133	125.046
3.60	0.044	4.39	0.001	0.137	128.675
3.80	0.046	4.63	0.001	0.143	133.859
4.00	0.049	4.88	0.001	0.150	139.799
4.20	0.051	5.12	0.001	0.155	144.141
4.40	0.054	5.37	0.001	0.162	150.803
4.60	0.056	5.61	0.001	0.168	155.870
4.80	0.059	5.85	0.001	0.176	163.240
5.00	0.061	6.10	0.001	0.181	166.694
5.20	0.063	6.34	0.001	0.181	167.034
5.40	0.066	6.59	0.001	0.182	167.371
5.60	0.068	6.83	0.001	0.178	163.087
5.80	0.071	7.07	0.001	0.172	157.289

6.00	0.073	7.32	0.001	0.170	154.581
6.20	0.076	7.56	0.001	0.160	145.015

#For Test Pit - 7

Sample depth…………1.5m

Diameter of the sample =36mm

Length of sample =73mm

Ring Calibration Factor =0.007905 kN/div

Table C-2: Computation of UCS values

Axial Sample Deformation ΔL (mm)	Axial Strain (€) (L/L_o)	Axial Strain (€%)	A_c=Corrected Area (A/1-e) (m^2)	Axial Load (kN)	Axial Stress (P/A) (Kpa)
0.00	0.000	0.00	0.001	0.000	0.000
0.20	0.002	0.24	0.001	0.040	39.536
0.40	0.005	0.48	0.001	0.059	57.518
0.60	0.007	0.72	0.001	0.084	81.970
0.80	0.010	0.96	0.001	0.101	98.125
1.00	0.012	1.20	0.001	0.118	114.201
1.20	0.014	1.45	0.001	0.134	130.197
1.40	0.017	1.69	0.001	0.151	146.113
1.60	0.019	1.93	0.001	0.164	157.901
1.80	0.022	2.17	0.001	0.172	165.591
2.00	0.024	2.41	0.001	0.178	170.823
2.20	0.027	2.65	0.001	0.181	172.813
2.40	0.029	2.89	0.001	0.182	173.989
2.60	0.031	3.13	0.001	0.182	173.557
2.80	0.034	3.37	0.001	0.181	171.530
3.00	0.036	3.61	0.001	0.175	165.531
3.20	0.039	3.86	0.001	0.168	158.767
3.40	0.041	4.10	0.001	0.160	150.450
3.60	0.043	4.34	0.001	0.151	142.174
3.80	0.046	4.58	0.001	0.139	129.998
4.00	0.048	4.82	0.001	0.126	117.881

#For Test Pit – 7 at 3m

Diameter of the sample =36mm , Length of sample =76mm

Ring Calibration Factor =0.007905 kN/div

Table C-3: Computation of UCS values

Axial Sample Deformation ΔL (mm)	Axial Strain (€) (L/L_o)	Axial Strain (€%)	Ac=Corrected Area (A/1-e) (m^2)	Axial Load (kN)	Axial Stress (P/A) (Kpa)
0.00	0.000	0.00	0.001	0.000	0.000
0.20	0.003	0.26	0.001	0.025	24.706
0.40	0.005	0.51	0.001	0.042	41.072
0.60	0.008	0.77	0.001	0.059	57.352
0.80	0.010	1.03	0.001	0.076	73.548
1.00	0.013	1.28	0.001	0.092	89.659
1.20	0.015	1.54	0.001	0.105	101.620
1.40	0.018	1.79	0.001	0.118	113.519
1.60	0.021	2.05	0.001	0.133	127.779
1.80	0.023	2.31	0.001	0.147	141.157
2.00	0.026	2.56	0.001	0.164	156.877
2.20	0.028	2.82	0.001	0.176	168.499
2.40	0.031	3.08	0.001	0.179	170.456
2.60	0.033	3.33	0.001	0.182	173.197
2.80	0.036	3.59	0.001	0.185	175.126
3.00	0.038	3.85	0.001	0.187	177.042
3.20	0.041	4.10	0.001	0.189	178.153
3.40	0.044	4.36	0.001	0.186	175.308
3.60	0.046	4.62	0.001	0.185	173.263
3.80	0.049	4.87	0.001	0.183	171.226
4.00	0.051	5.13	0.001	0.182	169.981
4.20	0.054	5.38	0.001	0.181	167.960
4.40	0.056	5.64	0.001	0.174	161.272
4.60	0.059	5.90	0.001	0.170	156.949
4.80	0.062	6.15	0.001	0.164	151.097
5.00	0.064	6.41	0.001	0.158	145.275
5.20	0.067	6.67	0.001	0.147	134.859
5.40	0.069	6.92	0.001	0.134	122.961

Appendix-G

The results of one-dimensional consolidation test

#For Test Pit – 3@3m

Type of specimen	undisturbed
Specimen Diameter(D),cm	5.00
Specimen Thickness(Ho),cm	2.00
Area(A),cm2	19.63
Volume(V),cm3	39.25
Mass of Ring,gm	101.87
Mass of Ring +Specimen,gm	139.00
mass of dry	53.3
dry density (dd)	1.36
Mass of specimen,gm	141.16
Void ratio (e)	1.12
Hight of solid (Hs)	10.059
Specific Gravity(Gs)	2.7
Initial moisture (wo),%	22.50

Pressure (KPa)	Do	Deformation dial reading at 50% consolidation	Deformation Dial reading Representing 100% Primary Consolidation	Time for 50% consolidation	Thickness of specimen at 50% consolidation	Half-thickness of specimen at 50% consolidation	Initial deformation reading	Change in Thickness of Specimen, ΔH	Change in Void Ratio [$\Delta e=\Delta H/H_s$]	Void Ratio [$e=e_0-\Delta e$]	Coefficient of consolidation Cv (m2/year)	Compression index (CC)	Swelling index (CS)	Coefficient of compressibility (av) 10-4 (m2/kN)	Coefficient of permeability (av) 10-4 (cm2/sec)
50	0.120	0.146	0.171	3.33	19.854	9.9	0.02	0.151	0.015	0.659	*0.0583*			2.03	2.97537
100	0.325	0.391	0.456	0.8	19.609	9.8	0.02	0.436	0.043	0.631	*0.2367*			2.78	8.59113
200	0.986	1.093	1.2	0.5	18.907	9.5	0.02	1.18	0.116	0.558	*0.3521*			3.67	11.6256
400	1.580	1.828	2.076	0.2	18.172	9.1	0.02	2.056	0.203	0.471	*0.8132*			3.15	10.1281
800	3.430	3.590	3.75	0.5	16.410	8.2	0.02	3.73	0.367	0.307	*0.2652*			2.84	9.18719
1600	3.778	4.339	4.9	0.143	15.661	7.8	0.02	4.88	0.481	0.193	*0.8447*	0.404		1.85	6.00985
800	4.901	4.897	4.8925	11.5	15.103	7.6	0.02	4.8725	0.480	0.194	*0.0098*			3.71	12.0012
400	4.864	4.848	4.831	26.5	15.153	7.6	0.02	4.811	0.474	0.200	*0.0043*			7.38	23.6995
200	4.812	4.795	4.777	56.25	15.206	7.6	0.02	4.757	0.469	0.205	*0.0020*			14.78	46.867
100	4.785	4.757	4.728	4	15.244	7.6	0.02	4.708	0.464	0.210	*0.0286*			30.03	92.7685
50	4.715	4.700	4.7	120	15.300	7.7	0.02	4.68	0.461	0.213	*0.0010*		0.0179	63.02	92.2167

#For Test Pit – 5@3m

Sample parameters	**Before test**	**After test**
Height (H) cm	2	1.7
Diameter (D) cm	5	5
Area (A) m^2	19.625	19.625
Volume (V) cm^3	39.25	33.3625
Mass (M) g	58.2	53
Moisture content w%	25.28301887	25.28301887
Specific gravity(Gs)	2.66	2.66
Wet density ρo(g/cm^3)	1.482802548	1.990258524
Dry density ρdo (g/cm^3)	1.183562275	1.588609966
Volume of solid (g/cm^3)	19.92481203	19.92481203
Height of solid (cm)	1.015277046	1.015277046
Void ratio (e)	1.247452506	0.674419811
Degree of saturation (S) (%)	53.30864276	100

Pressure (KPa)	Do	Deformation dial reading at 50% consolidation	Deformation Dial reading Representing 100% Primary Consolidation	Time for 50% consolidation	Thickness of specimen at 50% consolidation	Half-thickness of specimen at 50% consolidation	Initial deformation reading	Change in Thickness of Specimen, ΔH	Change in Void Ratio [$\Delta e=\Delta H/H_s$]	Void Ratio [$e=e_0-\Delta e$]	Coefficient of consolidation Cv (10-4cm2/sec)	Compression index (CC)	Swelling index (CS)	Coefficient of compressibility (av) 10-4 (m2/kN)	Coefficient of premeability (K) 10-6 (cm2/sec)
50	0.120	0.146	0.171	3.33	19.854	9.9	0.02	0.151	0.015	0.659	*9.7*			2.98	17.42485
100	0.325	0.391	0.456	6	19.609	9.8	0.02	0.436	0.043	0.631	*5.3*			4.30	13.85381
200	0.986	1.093	1.2	9	18.907	9.5	0.02	1.18	0.116	0.558	*3.3*			5.81	12.166
400	1.580	1.828	2.076	10	18.172	9.1	0.02	2.056	0.203	0.471	*2.7*			5.06	9.328578
800	3.430	3.590	3.75	12	16.410	8.2	0.02	3.73	0.367	0.307	*1.8*			4.59	6.476348
1600	3.778	4.339	4.9	14	15.661	7.8	0.02	4.88	0.481	0.193	*1.4*	0.40		3.00	3.621447
800	4.901	4.897	4.8925	11.5	15.103	7.6	0.02	4.8725	0.480	0.194	*1.6*			6.00	8.182848
400	4.864	4.848	4.831	16.5	15.153	7.6	0.02	4.811	0.474	0.200	*1.1*			11.85	11.27883
200	4.812	4.795	4.777	28.5	15.206	7.6	0.02	4.757	0.469	0.205	*0.7*			23.43	12.94621
100	4.785	4.757	4.728	34	15.244	7.6	0.02	4.708	0.464	0.210	*0.6*			46.38	21.50176
50	4.715	4.700	4.7	120	15.300	7.7	0.02	4.68	0.461	0.213	*0.2*		0.02	92.22	12.17406