Jimma University

School Of Graduate Studies

Civil Engineering Department

Investigation on the Engineering Properties of Soils in Bedelle Town

A Thesis Submitted To the School Of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Geotechnical Engineering Stream)

By

Negese Asefa Daba

December, 2016

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Advisor: Yoseph Birru (PHD)

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JIMMMA INSTITUTE OF TECHNOLOGY

POST GRAGUATE PROGRAM

This is to certify that the thesis prepared by Negese Asefa, entitled, Investigation on the engineering properties of soils in Bedelle town, and submitted in partial fulfillment of the requirements for the Degree of Master of Science (MSc.) in Geotechnical Engineering compiles with the regulation of the university and meets the accepted standards with respect to its originality and quality.

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ABSTRACT

Investigation of the ground conditions is used for the safe and economical design of the sub structure. It is also necessary to obtain sufficient information on type, characteristics and distributions of a soil and rock underlying a site for proposed structures. Therefore, in a country like Ethiopia which is under a higher rate of economic development, geotechnical investigation of engineering properties of soil is essential as it fosters availability of ready-made data for planning and design of engineering structures such as building foundations, pavements and retaining structures.

Investigating the engineering properties of typical soil in Bedele town is the objective of this research. To achieve these objective six representative disturbed and undisturbed samples at average depths of around 1.5 m and 3 m were collected and engineering properties of soil such as grain size distributions, Atterberg limits, free swell, compaction, and unconfined compression parameters have been studied.

Accordingly, Laboratory tests carried out revealed the following ranges: the natural moisture content 27-47%, specific gravity of the soils 2.45-2.75, free swell index 25-50%, liquid limits 52-74%, plastic limit 30-52% and plasticity index 12-36%. The results of grain size analysis showed that clay content ranging from 46 -80%, silt content from 19-46%, sand from 1.3 -16.7% and gravel from 0-83%. The unconfined compressive strength of the soils in the study area ranges from 225 -333kN/m^2 *and undrained shear strength; from 112.5 – 166.5 kN/m*^{2}*.*

Based on the above data, implementation of commonly used AASHTO and USCS standard soil classification techniques demonstrated that, AASHTO classification shows that soils of the study area are A-7-5 which means clay soil with poor quality as a subgrade material. USCS indicates two main types of soils, which are: CH, high plastic clay soils, and MH, high plastic silt soils.

Since pit excavation method of exploration is used, the outcomes would be applicable only for light structures which under lie their foundation up to depth of 3m.

Keywords: Investigation, Engineering properties

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SYMBOLS AND ABBREVIATIONS

AASHTO	American Association state Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CH	Inorganic clay with high plasticity
CL	Low plastic clay
ERA	Ethiopian Roads Authority
GPS	Geographical positioning system
Gs	Specific gravity
MH	Inorganic Elastic silt
MDD	Maximum dry density
PI	Plasticity index
TP	Test pit
γ_d	Dry unit weight
γ_w	Wet unit weight
UCS	Unconfined compressive strength
USCS	Unified soil classification system
UTM	Universal Transverse Mercator grid
LL	Liquid limit
PL	Plastic limit
OMC	Optimum moisture content
Su	Undrained shear strength

CHAPTER ONE

Introduction

One of the primary tasks of a geotechnical engineer is to collect, classify and investigate the engineering properties of soils. The rapid growth of cities, industry and commerce requires numerous buildings or infrastructures systems. For example, Commercial building, large public buildings, dams for electric power generation and reservoirs for water supply and irrigation, tunnels, roads and railroads, port and harbor facilities, bridges, airports and runways, mining activities, hospitals, sanitation systems, drainage systems, towers for communication systems, etc. requires stable and economic foundations. Therefore investigation the engineering property of soil is a prerequisite for the design of safe and economical civil engineering structures.

The stability of foundation of a building, a bridge, an embankment or any other structure built on soil depends on the strength and compressibility characteristics of the subsoil. The field and laboratory investigations required to obtain the essential information on the subsoil is called Soil Exploration or Soil Investigation. The success or failure of a foundation depends essentially on the reliability of the various soil parameters obtained from the field investigation and laboratory testing, and used as an input into the design of foundations. [5]

The purpose of soil investigation is to find out strength characteristics of the sub-soil over which the structure has to be built. Soil characteristics vary both with respect to depth from the ground surface and stretch in the horizontal direction. It is, therefore, the prime objective of soil exploration for a building, bridge or other civil Engineering works, to analyze the nature of soil in all respects. [11]

1.1. Statement of the Problem

All structures that are founded on earth rely on our ability to design safe and economic foundations. Structural failures do occur due to different reasons. Some failures have been catastrophic and caused severe damage to lives and properties. Failures occur because of inadequate site and soil investigations; unforeseen soil and water conditions; natural hazards; poor engineering analysis, design, construction, and quality control; post-construction activities; and usage outside the design conditions.

The work that geotechnical engineers do is often invisible once construction is completed. However, if the foundations, which are invisible, on which these structures stand, were not satisfactorily designed then these structures would not exist. A satisfactory foundation design requires the proper application of soil mechanics principles, accumulated experience and good judgment. The stability and life of any structure, e.g., buildings, roads, airports, dams, natural slopes, power plants, etc., depend on the stability, strength and deformation of soils. If the soil fails, structures founded on or within it will fail or be impaired regardless of how well the structures are designed. [2]

A detailed and comprehensive geotechnical investigation is an essential requirement for the Design and construction of civil engineering projects. The proper design of civil engineering structures like foundation of buildings, retaining walls, high ways, etc. requires adequate knowledge of sub surface conditions at the sites of the proposed structures. Many damages to Buildings, roads and other structures founded on soils are mainly due to the lack of proper investigation of substructure condition. [1].

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 [8]

Soil investigation program is necessary to provide information for design and construction and environmental assessment. The purposes of soil investigation are: to evaluate the general suitability of the site for the proposed project, to enable an adequate and economical design to be made and to disclose and make provisions for difficulties that may arise during construction due to ground and other local conditions [7]

Insufficient geotechnical investigations, faulty interpretation of results, or failure to

Portray results in a clearly understandable manner may contribute to inappropriate designs; delays in construction schedules, costly construction modifications, and use of Substandard borrow material, environmental damage to the site, post construction remedial work, and even failure of a structure and subsequent litigation. Therefore, to obtained 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. [8]

Therefore, in a country like Ethiopia which is under a higher rate of economic development, geotechnical investigation of engineering properties of soil is essential as it fosters availability of ready-made data for planning and design of engineering structures such as building foundations, pavements and retaining structures.

Bedelle (also called Buno Bedelle) is a capital town of special Woreda administrative category in south-western Ethiopia. Located in Illubabor zone of Oromia Region, this town has a longitude and latitude of $8^{0}27^{'}$N $36^{0}21^{'}$E and an elevation between 1820–2,162 meters above sea level. The town has one governmental university (Mettu university Bedelle campus), technical college, commercial buildings and private colleges. Bedelle is also the headquarters for the Bedelle Brewery, in the town, some buildings are constructed and others are under construction without adequate and detailed geotechnical investigation. Therefore, this research is intended to carry out index properties, mechanical properties and unconfined compressive strength characteristics of typical Bedelle soils so as to capture the attention of decision makers in the relevance of such knowledge as well as avail seed data for any further future development undertakings.

1.2. Objectives of the Study

1.2.1. General Objectives

The general objective of the research is Investigation on the engineering properties of soils in Bedelle town.

1.2.2 Specific Objective

- To investigate common index properties of typical soils in the town and determine range of values.
- To classify soil of Bedelle Town according to commonly used engineering soil classification techniques
- To determine the unconfined compressive strength of representative soils in the town.
- Comparison of the current with previous research.

1.4. Significance of the study

As no systematic soil investigation has been carried out in Bedelle town prior to this study, reports of the current work will be a useful initial reference for all intended future buildings and infrastructure developments as well serves as essential input for similar research undertakings.

1.5. Scope of the Study

The study is limited to investigating the index properties, Free-swell, Specific gravity standard compaction, and unconfined compressive shear strength test of soil. Due to the budget constraint, 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.

1.6. Organization of the thesis

This thesis is organized in to five Chapters. In the first Chapter Introduction, statement of the problem, objectives of the research, Limitation of the study, significance and scope of the thesis are presented. The second Chapter deals with literature review. The third Chapter deals with methods and materials. Types of laboratory tests conducted, their results and soil classification are presented in the fourth Chapter. Recommendation and conclusion are given in Chapter five.

Finally, grain size distribution curves, specific gravity, index property test results, and unconfined compression test results are given in the relevant Appendices.

CHAPTER TWO

Literature Review

2.1. General

A bulk soil, as it exists in nature, is more or less randomly assembled of soil particles, water and air. The properties of soils are complex and variable. Every civil engineering work involves the determination of soil type and its associated engineering application; certain properties are more significant than others. The common problems faced by civil engineers are related to bearing capacity and compressibility of soil and seepage through the soil. The possible solution to these Problems is arrived at based on the study of the physical and index properties of the soil [1]

In nature, Soils occur in a large variety. However, soils exhibiting similar behavior can be grouped together to form a particular group. Engineers are continually searching for simplified tests that will increase their knowledge of soils beyond that which can be gained from visual examination without having to resort to the expense, detail, and precision required with engineering properties tests. These simplified tests provide indirect information about the engineering properties of soils and are, therefore, called index tests [1]

The varieties of soil materials encountered in engineering problems is almost limitless ranging from hard, dense, large pieces of rock through to gravel, sand, silt, and clay to organic deposit of soft compressible organic peat. At any given site, a number of different soil types can be present, and the composition may vary over intervals of a little as a few inches [9]

Soils are usually cohesion less, cohesive or organic (Rufaizal, 2013). Cohesion less soils have particles that do not tend to stick together. Mostly it is composed of sand, maybe some silt. As a result, these soils tend to shift or change in consistency under different environmental conditions. Rain and wind conditions cause water and air materials to move in and out of soils. Cohesive soils on the other hand are characterized by very small particle sizes, such as clay or silt, where surface chemical effects predominate. They are both "sticky" and "plastic". Their shear strength equals about half its unconfined compressive strength. Therefore, cohesive soil is a better foundation than that of non-cohesive. Organic soils are usually found in low-lying areas where the water table is near or above the ground surface. This type of soil is typically spongy, crumbly, and compressible. They are undesirable for supporting structures (Das, 2007).

Soil index properties are used extensively by engineers to discriminate between the different kinds of soil within a broad category, e.g. clay will exhibit a wide range of engineering properties depending upon its composition. Classification tests to determine index properties will provide the engineer with valuable information when the results are compared against empirical data relative to the index properties determined [13]

Basic soil properties and parameters can be subdivided into physical, index, and engineering categories. Physical soil properties include particle size and distribution, specific gravity, and water content. Index parameters of cohesive soils include liquid limit, plastic limit, shrinkage limit, and activity. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties [25]

2.2. Soil Formation

Soils are formed by the process of weathering of the parent rock. The weathering of the Rocks might be by physical disintegration, and/or chemical decomposition. The Properties of the soil materials depend upon the properties of the rocks from which they are derived. [8]

Chemical weathering is much more important than physical weathering in soil formation. Soils at a particular site can be residual (that is weathered in place) or transported (moved by water, wind, glacier, etc.) and the geologic history of a particular deposit significantly affects its engineering behavior [7]

Natural soils generally are mixtures of several different particle sizes and may even contain organic matter. Some soils such as peat may be almost entirely organic.

Furthermore because soils are a particulate material they have voids and the voids are usually filled with water and air [7]

2.3. Soil Structure

Soil structure is defined as the geometric arrangement of soil particles with respect to one another. Among the majority factors that affect the structure of the soil are the shape, size, and mineralogical composition of soil particles, and the nature and composition of soil water. The structure of soils that is formed by natural deposition can be altered by external forces. [10]

2.3.1 Structures in Cohesion less Soil

The structures generally encountered in cohesion less soils can be divided into two major categories: single grained and honeycombed. In single-grained structures soil particles are in stable positions, with each particle in contact with the surrounding ones. The shape and size distribution of the soil particles and their relative positions influence the denseness of packing; thus, a wide range of void ratios is possible.

In honeycombed structure relatively fine sand and silt form small arches with chains of particles. Soils that exhibit a honeycombed structure have large void ratios, and they can carry an ordinary static load. However, under a heavy load or when subjected to shock loading, the structure breaks down, which results in a large amount of settlement. [10]

2.3.2 Single grained structure

Single grained structure is characteristics of coarse grained soils, with a particle greater than 0.02 mm. Gravitational force pre dominate the surface force and hence grain to grain contact results. The deposition may occur in a loose state with large voids or in a dense state with less of voids [7].

2.3.3 Honey-comp structure

This structure can occur only in fine-grained soils especially in silt and rock flour. Due to the relatively smaller size of grains, besides gravitational forces, inter-particle surface force also play an important role in the process of settling down. Miniature arches are formed which bridge over relatively large void spaces. This results in the formation of a honey comp structure each cell of a honey comp being made up of numerous individual soil grains. The structure has a large void space and may carry high loads without a significant volume change. The structure can be broken down by external disturbances [7].

2.3.4 Flocculent structure

This structure is characteristics of fine grained soils such as clays. Inter particle forces play a predominant role in the deposition. Mutual repulsion of the particles may be eliminated by means of an appropriate chemical; this will result in grains coming closer together to form ‘a floc’. The formation of floc is flocculation. [7]

2.4. Soil mineralogical composition

Soil minerals are inorganic particles which are derived from weathered parent material and decayed plants and animals. Gravels are pieces of rocks with occasional particles of quartz, feldspar and other minerals. Sand particles are made of mostly quartz and feldspar. Silts are the microscopic soil fractions that consist of very fine quartz grains and some flake-shaped particles that are fragments of micaceous minerals. Clays are mostly flake-shaped microscopic and submicroscopic particles of mica and other minerals. Clays are defined as those particles “which develop plasticity when mixed with a limited amount of water” (Grim, 1953). Clay minerals are almost always the result of chemical weathering of rock particles and are hydrates of aluminum, iron or magnesium silicate combined to create sheet-like structures. These sheets are built from two basic units, the tetrahedral unit of silica and the octahedral unit of the hydroxide of aluminum, iron or magnesium. [10]

Minerals are crystalline materials and make up the solid constituent of a soil. The mineral particles of fine-grained soils are platy. Minerals are classified according to chemical composition and structure. Most minerals of interest to geotechnical engineering are composed of oxygen and silicon, two of the most abundant elements on earth. Silicates are a group of minerals with a structural unit called the silica tetrahedron. A central silica cation (positively charged ions) is surrounded by four oxygen anion (negatively charged ions) one at each corner of the tetrahedron (Fig. 2.1a). The charge on a single tetrahedron is -4 and to achieve a neutral charge, cations must be added or single tetrahedrons must be linked to each other sharing oxygen ions. Silicate minerals are formed by addition of cations and interaction of tetrahedrons. Silica tetrahedrons combine to form sheets, called silica sheets, which are thin layers of silica tetrahedrons in which three oxygen ions are shared between adjacent tetrahedrons (Fig. 2.1 b). Silicate sheets may contain other structural units such as alumina sheets. Alumina sheets are formed by combination of alumina minerals, which consists of aluminum ion surrounded by six oxygen hydroxyl atoms in an octahedron [13].

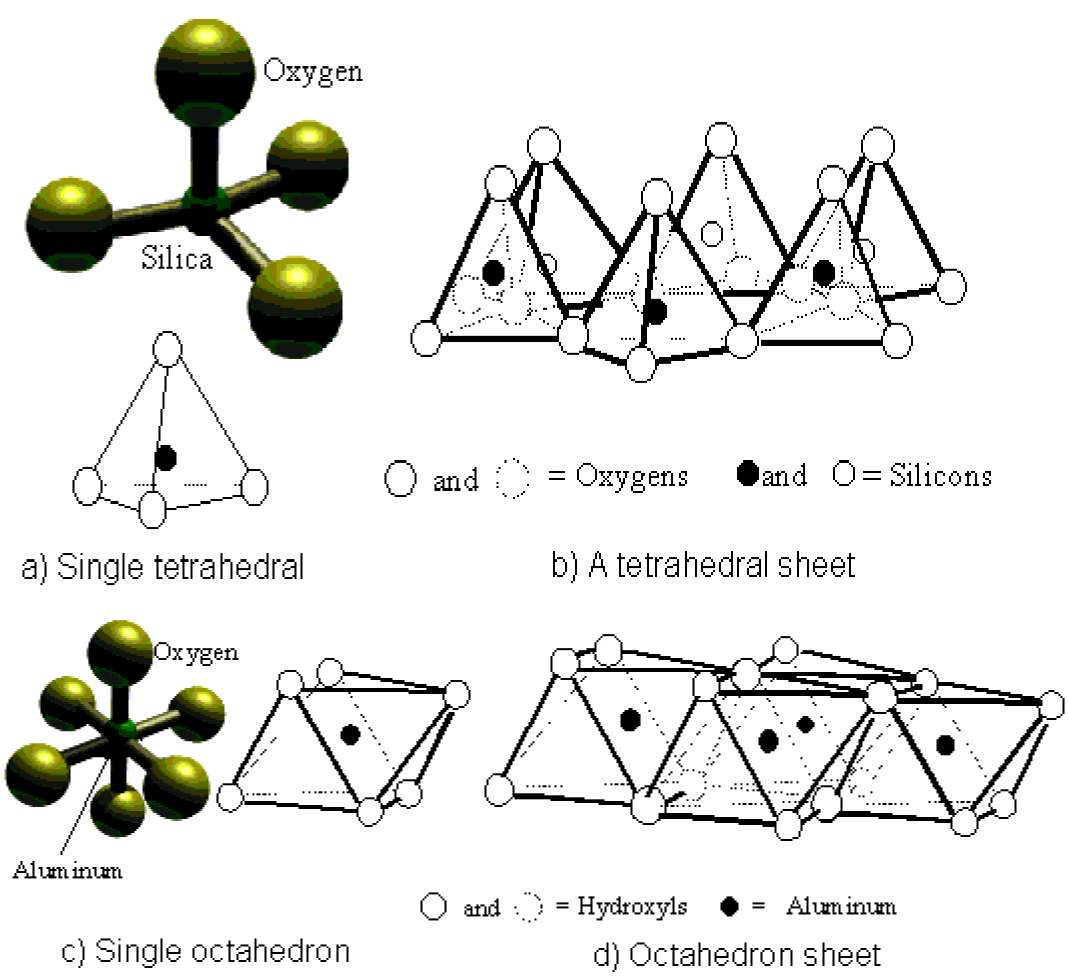

Figure 2.1: a) Silica tetrahedron b) Silica sheets c) Aluminum Octahedron d) Alumina sheet [2]

The main groups of crystalline materials that make up clays are the minerals: Kaolinite, illite, and montmorillonite.

2.4.1 Kaolinite

Kaolinite has a structure that consists of one silica sheet and one alumina sheet bonded together into a layer about 0.72nm thick and stacked repeatedly. The layers are held together by hydrogen bonds.

2.4.2 Illite

Illite consists of repeated layers of one alumina sheet sandwiched by two silicate sheets. The layers, each of thickness 0.96nm, are held together by potassium ions. Illite swells less than montmorillonite. However, swelling is more than in kaolinite.

2.4.3 Montmorillonite

Montmorillonite has a structure similar to illite, but the layers are held together by weak van der Waals forces and exchangeable ions. Water can easily enter the bond and separate the layers in montmorillonite, causing swelling. Montmorillonite is often called swelling or expansive clay.

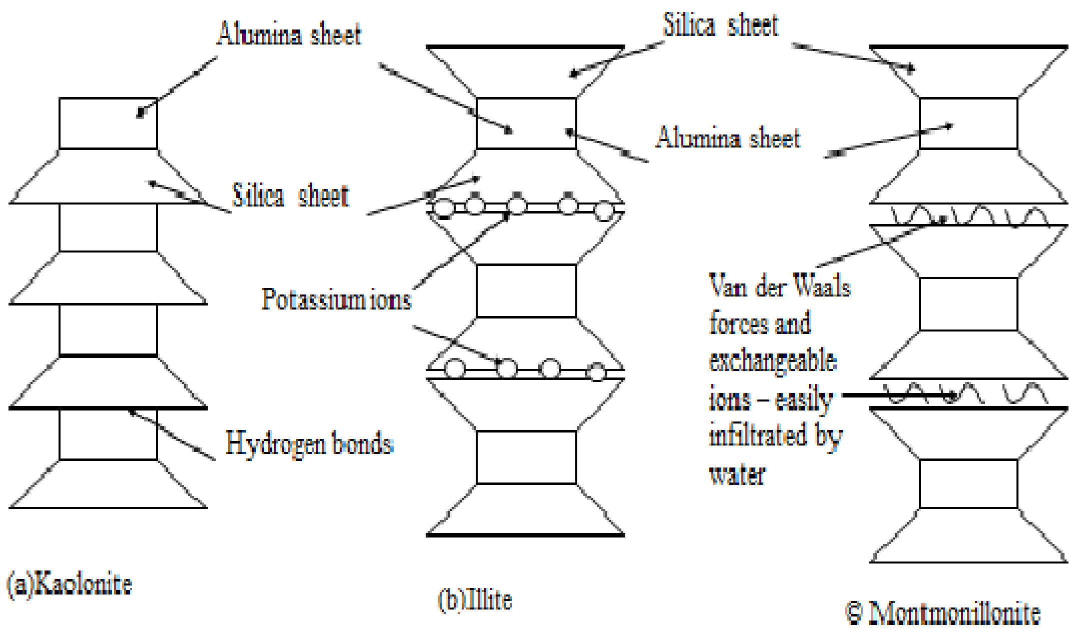

Figure 2.2 Structure of kaolinite, illite and montmorillonite **[2]**

2.5. Types of Soils

According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay. Grains having diameters in the range of 4.75 to 75 mm are called gravel. If the grains are visible to the naked eye, but less than about 4.75mm in size the soil is described as sand. The lower limit of visibility of grains for the naked eye is about 0.075mm. Soil grains ranging from 0.075 to 0.002mm are termed as silt and those that are finer than 0.002mm as clay. This classification is purely based on size which does not indicate the properties of fine grained materials [6].

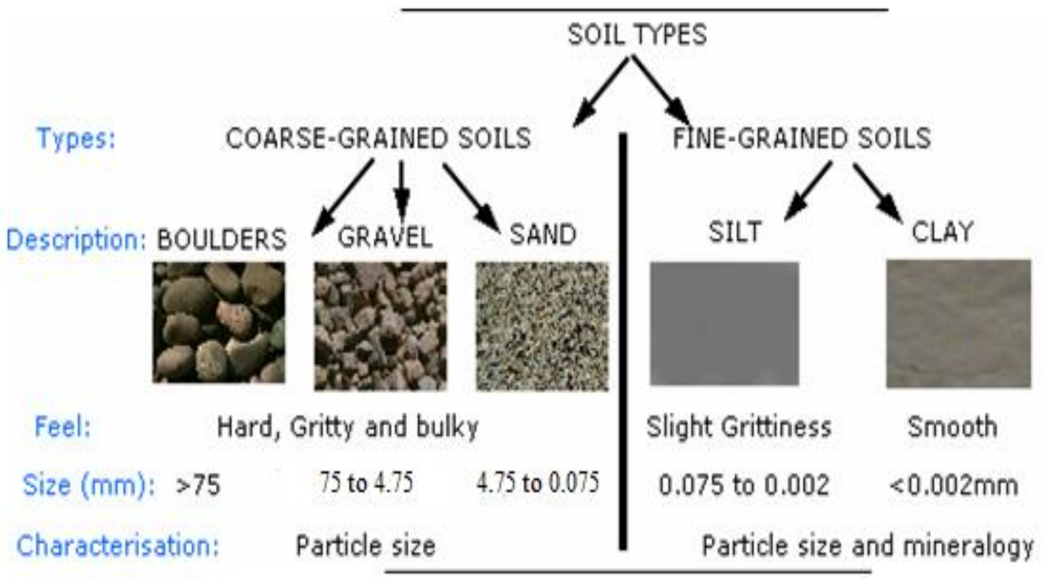

Figure 2.3 soil types according to grain size. [2]

On the basis of origin of their constituents, soils can be divided into two large groups these are Residual soils, and Transported soils.

Residual soils are those that remain at the place of their formation as a result of chemical weathering of parent rocks and may be found on level rock surfaces where the action of elements has produced a soil with little tendency to move. Residual soils can also occur whenever the rate of breakup of the rock exceeds the rate of removal. The depth of residual soils depends primarily on climatic conditions and the time of exposure. In some areas, this depth might be considerable. In temperate zones residual soils are commonly stiff and stable. Residual soils include topsoil and laterites. Laterites are formed by chemical weathering under warm, humid tropical conditions when the rain water leaches out the soluble rock material leaving behind the insoluble hydroxide of iron and aluminum, giving them their characteristic red-brown color. An important characteristic of residual soil is that the sizes of grains are indefinite. For example, when a residual sample is sieved, the amount passing any given sieve size depends greatly on the time and energy expended in shaking, because of the partially disintegrated condition.

Transported soils are soils that are found at locations far removed from their place of formation. The transporting agents of such soils are glaciers, wind and water. These soils include gravels, sands, silts and clays. As a stream or river loses its velocity it tends to some of the particles that it is carrying, dropping the larger, heavier particles first. Hence, on higher reaches of a river gravel and sand are found whilst on the lower parts silts and clays predominate. Common descriptive terms such as gravels, sands, silts, and clays are used to identify specific textures in soils. One can refer to these soil textures as soil types; that is, Sands and gravels are grouped together as coarse-grained soils. Clays and silts are fine-grained soils. To characterize fine-grained soils, one needs further information on the types of minerals present and their contents. The response of fine-grained soils to loads, known as the mechanical behavior, depends on the type of predominant minerals present.

Many of these transported soils are loose and soft to a depth of several hundred feet. Therefore, difficulties with foundations and other types of construction are generally associated with transported soils (V.N.S Murthy).

Transported soils may be classified into several groups, depending on their mode of Transportation and deposition as: [2]

- Alluvial soils - transported by running water and deposited along streams
- Aeolian soils - transported and deposited by wind
- Lacustrine soils - formed by deposition in quiet lakes
- Colluvial soils - deposited by movement of soil by gravity, such as during landslides
- Marine soils - formed by deposition in the seas
- Glacial soils - deposited as a result of glacial activities

2.6. Comparison of Coarse and Fine-Grained Soils for Engineering Use

Coarse-grained soils have good load bearing capacities and good drainage qualities, and their strength and volume change characteristics are not significantly affected by change in moisture conditions. They are practically incompressible when dense, but significant volume change can occur when they are loose.

Fine-grained soils have poor load bearing capacities compared with coarse-grained soils. Fine grained soils are practically impermeable, and change strength and volume with variations in moisture conditions. The engineering properties of coarse-grained soils are controlled mainly by the grain size of the particles and their structural arrangement. The engineering properties of fine-grained soils are controlled by mineralogical factors rather than grain size. Thin layers of fine-grained soils, even within thick deposits of coarse-grained soils, have been responsible for many geotechnical failures and therefore we need to pay special attention to fine-grained soils. [2]

CHAPTER THREE

Methods and Materials

3.1. Description of the study area

Bedele town Located in Buno Bedele zone of Oromia Region at a distance of 492km from capital city Addis Ababa and 145 km from Jimma town in south west of Ethiopia.

This town has a longitude and latitude of $8^{0}27^{'}$N $36^{0}21^{'}$E and an elevation between 1820–2,162 meters above sea level.

The town was founded in 1910 and got municipal status in1940.Bedele is one of the reform towns in the region and has a city administration, municipality and kebeles. The town was founded as a capital of Buno Bedele zone on June, 2016.

Coffee is an important cash crop of this zone. The town has one governmental university (Mettu university Bedelle campus), technical college, commercial buildings and private colleges. Bedelle is also the headquarters for the Bedele Brewery, Founded in 1993, producing about 75 million bottles of beer each year for domestic and export customers. [6]

Figure 3.1 Location of the research area on the map of Ethiopia [6]

3.2. Climate

3.2.1 Rain fall

Records of National Metrological Agency observatory substation show that the mean annual rain fall of 6 years (2010-2015) is 1870.5mm. As it can be observed from Figure 3.1, major rainfall seasons are May, June, July, August and September [6].

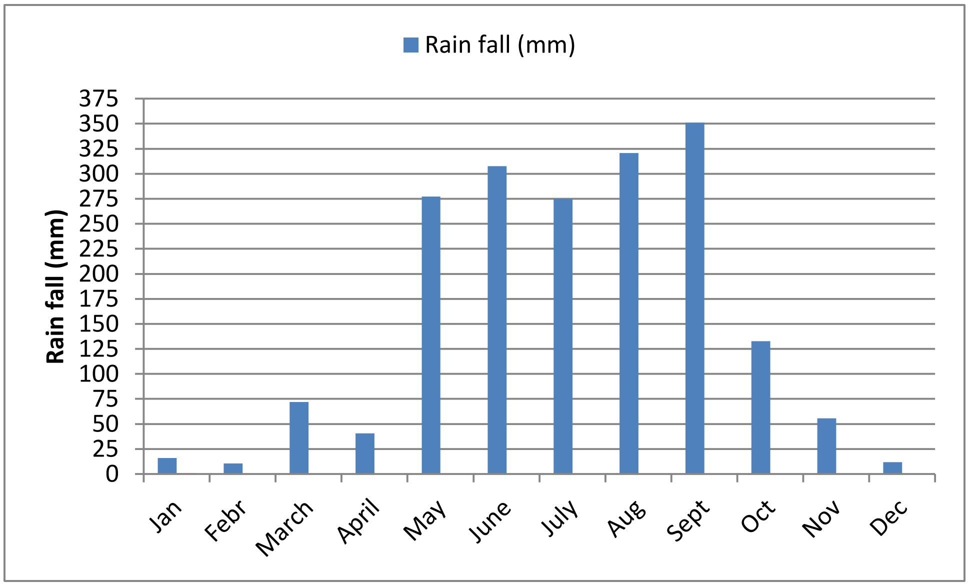

Fig 3.2 Mean monthly rainfall distribution of Bedelle town (2010-2015) [Source Ethiopian Metrological Agency, Jimma District]

3.2.2. Temperature

In a mountainous tropical country like Ethiopia altitude is by far the most important

Factor in controlling climate. It affects distribution of both temperature and rainfall.

Generally, regions between 1500 - 2300 meters a.m.s.l. (categorized as 'woina dega' or sub-tropical climate) have temperatures that range between 15 - 20^{o}C, areas between 500 – 1500 meters a.m.s.l. (i.e. 'kola' or tropical climate) have 20 -30^{o}C and areas below 500 Meters a.m.s.l. (i.e. 'bereha' or desert climate) have a temperature of 30^{o}C and above [8]

The town of Bedele, with an altitude ranging from 2012–2,162 meters a.m.s.l., has a mean minimum, mean maximum and mean average monthly temperatures of 12.83, 25.94 and 19.73°C respectively. The highest temperatures are during months of January,February, March, April, and May whereas July, August and September have low temperature. From Fig 3.4 the Mean monthly average temperature ranges from 17.57°c to 21.88°c. This shows there is less temperature variation throughout the year.

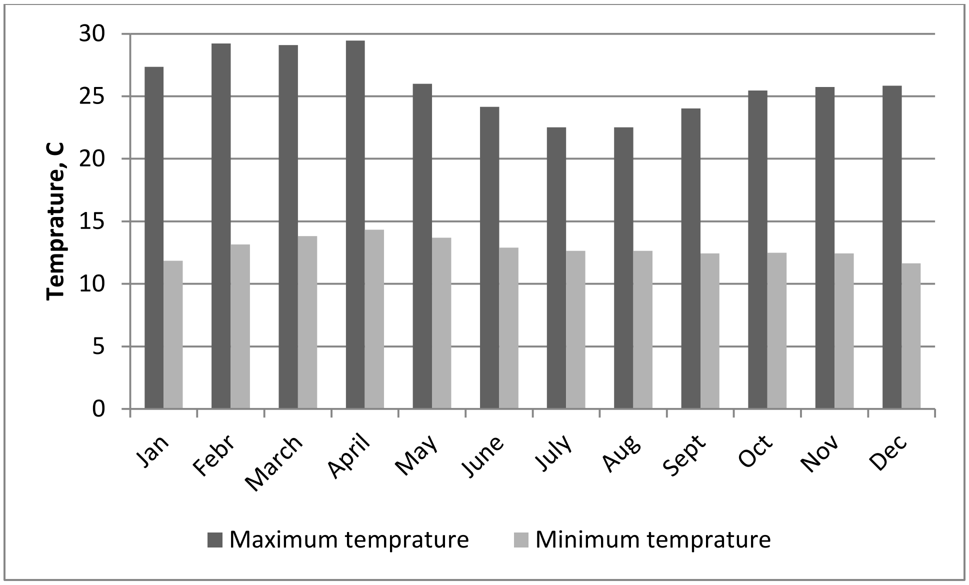

Figure 3.3 Mean maximum and minimum temperature distribution of Bedelle town (2010-2015) [Source Ethiopian Metrological Agency, Jimma District]

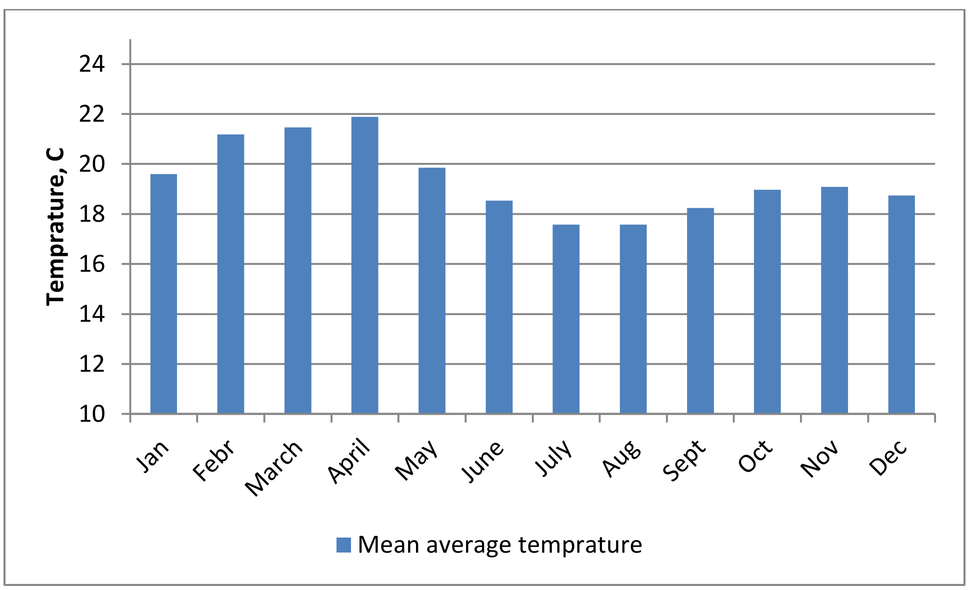

Figure 3.4 Mean monthly average temperature distribution of Bedelle town (2010-2015) [Source Ethiopian Metrological Agency, Jimma District]

3.3. Sampling and Data collection

To meet these research objectives, literature reviews of many investigators are done. Necessary information about the geology, climatic condition and topography of the site are collected and analyzed. Sampling areas were selected from different parts of the town and six pits were excavated to a maximum depth of three meters (3m). From the excavated pits both disturbed and undisturbed samples were collected for laboratory testing. In the field GPS readings was taken to locate the coordinates of sampling area.

Before selecting sampling areas, visual site investigation and information from Bedelle town municipality were collected to consider the different soil types and to take sample evenly in the whole town. Accordingly, six representative sampling areas were selected from different locations of the town (see figure 3.5) below. Pits were excavated to the maximum depth of three meters, but in some areas boulders were encountered making the digging difficult. To conduct the different laboratory tests, about 30kg of disturbed soil sample was collected in bulk randomly from each site and at each depth. After the undisturbed samples are extracted both ends of steel tube will be sealed with wax (melted candle) and tighten by polyethylene bags. After careful sampling, both the disturbed and undisturbed samples transported to the Geotechnical laboratory.

Undisturbed samples are used for one undrained shear strength, natural moisture content and unit weight tests. Disturbed samples are used to conduct index property tests such as specific gravity, Atterberg limit, grain size analysis, compaction and free swell. ASTM procedures are followed for all tests. During pits excavation, the coordinates of sampling location were taken using hand held GPS and presented in the Table 3.1

Table 3.1 coordinates of sampling areas

sample description	Location	GPS Reading (UTM)		
		Easting	Northing	Elevation (m)
TP-1	manucipality	208832	935523	2006
TP-2	Dashen bank	208652	935701	2010
TP-3	Dabo ber	208253	936088	2009
TP-4	Gore ber	208400	935660	2007
TP-5	Hospital	207252	935116	1984
TP-6	university	201942	931057	1884

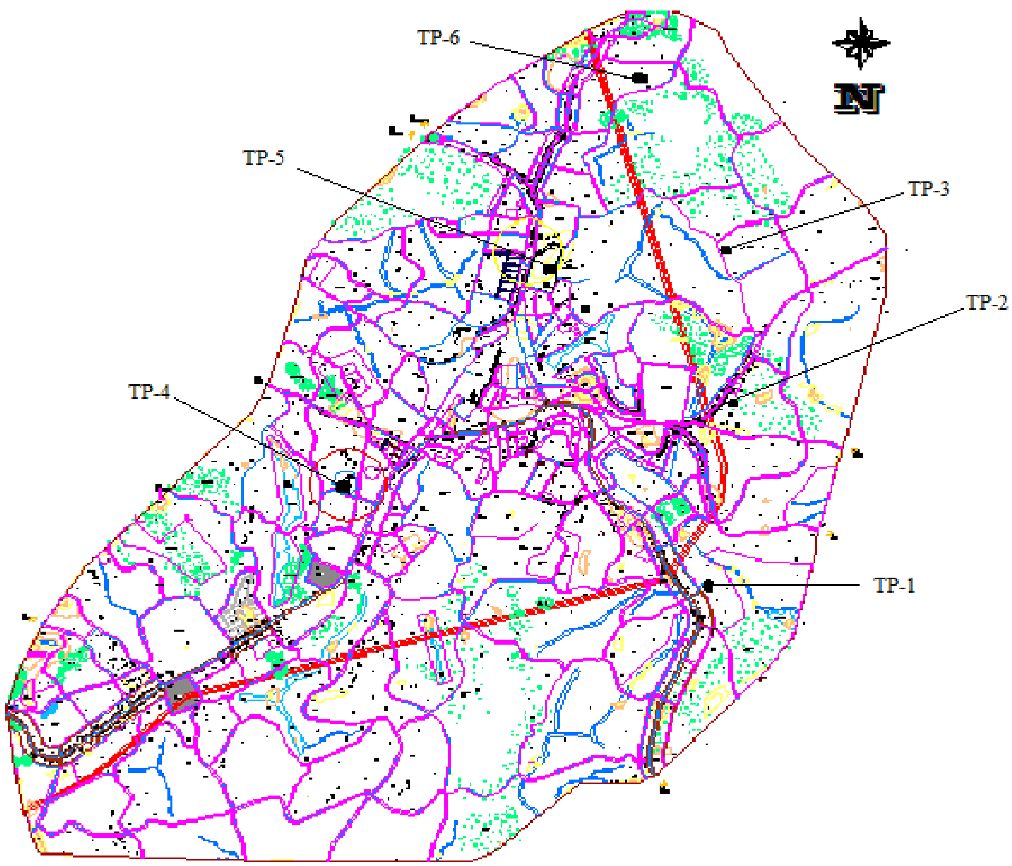

Fig. 3.5 Location of sampling areas shown on structural map of Bedelle town

Figure 3.6 Typical Profile of sample area around Bedelle municipality

3.4. Laboratory Test

3.4.1. General.

Basic soil properties and parameters can be subdivided into physical, in-situ, index, and engineering categories. Physical soil properties include particle size and distribution, specific gravity; in-situ properties include bulk density and water content. Index parameters of cohesive soils include liquid limit, plastic limit, shrinkage limit, and activity. Such parameters are useful to classify cohesive soils and provide correlations with engineering soil properties [1]

3.4.2. In-situ Density and Moisture Content Tests

The water or moisture content of a soil material is defined as the ratio between the mass of water in the sample and the mass of solid material. It is expressed as 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. In fine grained soils, the consistency of a given soil type depends on its water content. The water content of a soil along with its liquid and plastic limits is used to express its relative consistency termed as liquidity index.

Natural water content used to express the consistency of clay soil in its natural state. 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. The physical properties of clays greatly differ at different water contents. A soil which is very soft at a higher percentage of water content becomes very hard with a decrease in water content. However, it has been found that at the same water content, two samples of clay of different origins may possess different consistency. Clay may be relatively soft while the other may be hard. Further, a decrease in water content may have little effect on one sample of clay but may transform the other sample from almost a liquid to a very firm condition. Water content alone, therefore, is not an adequate index of consistency for engineering and many other purposes.

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

3.4.3. Index properties

3.4.3.1 General

Basically, soil is more complex material. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solid, liquid and gases. In many instances the solid particles vary in size from big boulders to colloidal size. Furthermore, the relative quantities of solid, liquid and gases in a given soil are found to change due to physical causes such as loading, seasonal variation and change of temperature. The physical properties of soils, which serve mainly for identification and classification, are commonly known as index properties. [9]

Soil is a heterogeneous material. The properties and characteristics of soils vary from point to point. The tests required for determination of engineering properties are generally elaborate and time consuming. Sometimes the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests. This is possible if index properties are determined. The

various properties of soils, which could be considered as index properties are: Grain size analysis, Atterberg limits and Specific gravity. [9]
The ASTM testing procedure is used in the laboratory. Most of the literature for tropical soils is carried out using this method.

3.4.3.2 Grain Size Analysis

Soils are products of mechanical and chemical weathering and are found in a wide range of particle sizes and shapes. Simple sieve analysis can be used to differentiate the different size particles of coarse-grained soils. In the sieve analysis square holes between the wires of the sieve mesh provide a limiting size of particles retained on a particular sieve. However it has to be noted that not all soil particles are spherical, cubical or of any regular shape. The sieve analysis does not provide any information on the shape of the soil grains regarding whether they are angular or rounded. Generally the behavior of cohesion less soil does not depend pre dominantly on the shape of the soil grains. Most cohesion less soils consists of roughly equal-dimensional block particles and sieve analysis provides useful information for engineering purposes.
Statistical relationships have been established between grain size and significant soil properties. The suitability criteria for road airfield and embankment construction have been based on grain size distribution. The prediction of permeability can be done using grain size analysis. The proper gradation of filter material is established from particle size distribution. Grain size analysis is usually used in engineering soil classifications.

There are two methods commonly used for the determination of grain size distribution of soil, namely sieve analysis and hydrometer analysis. Sieve analysis is used for the determination of grain size distribution of coarse grained soil (gravel and sand), while hydrometer is used for the determination of grain size of fine grained soils (clay and silt) or soils passing through sieve No 200. For grain size analysis wet sieve method is used after air drying the sample.

3.4.3.3. Specific gravity

In general, the term specific gravity is defined as the ratio of the mass of a given volume of a material to the mass of an equal volume of water. In effect, it tells us how much the material is heavier than (or lighter) than water. The particular specific gravity of a soil actually denotes the specific gravity of the solid matter of the soil and refers, therefore, to the ratio of the mass of solid matter of a given soil sample to the mass of an equal volume (i.e. equal to the volume of the solid matter) of water. Alternatively, specific gravity of soil may be defined as the ratio of the unit mass of solids (mass of solids divided by volume of solids) in the soil to the unit mass of water. [12]

The specific gravity of the minerals affects the specific gravity of soils derived from them. Most of the values fall within a range of 2.6 to 2.9. The specific gravity of solids of light-colored sand, which is mostly made of quartz, may be estimated to be about 2.65; for clayey and silty soils, it may vary from 2.6 to 2.9 (Principles of Geotechnical Engineering 5th edition by Braja M.Das).

3.4.3.4 Atterberg Limits

Atterberg limits or consistency limits are water contents at which the soil changes from one state to the other. Soil consistency is a term used to describe the degree of firmness of soil and is expressed by such terms as soft, firm or hard. It usually applies to fine grained soils whose condition is affected by changes in moisture content. Consistency limits are very important index properties of fine grained soils. As the consistency of soil changes, its engineering properties also change. Such soil properties as shearing strength and bearing capacity vary significantly with consistency. The Swedish scientist, Atterberg, established the four states of soil consistency (fig 2.4) which are called the liquid, the plastic, the semi-solid, and the solid states. He also proposed a series of tests for determining the boundaries known as Atterberg limits between the physical states of soil. Each boundary or limits is defined by the water content that produces a specified consistency. [10]

The physical and mechanical behavior of fine-grained soils is linked to four distinct states: – solid, semisolid, plastic, and liquid – in order of increasing water content.

Liquid Limit (LL)

The liquid limit of a soil is the water content at the boundary between the liquid and plastic states. The water content at this boundary is arbitrarily defined as the water content at which, two halves of a soil pat placed in a brass cup, cut with standard groove, and dropped from a height of 1cm will undergo a groove closure of about 1.3 cm when the cup is dropped 25 times at the rate of 2 drops per sec. .

Plastic Limit (PL)

The plastic limit of a soil is the water content at the boundary between the plastic and semisolid state. The water content at this boundary is arbitrarily defined as the water content at which soil begins to crumble when rolled into threads of specified size (3.2mm).

Shrinkage Limit (SL)

The term shrinkage limit, expressed as water content in percent, is typically assumed to represent the amount of water required to fill the voids of a given cohesive soil at its minimum void ratio obtained by drying (usually oven). Thus, the concept shrinkage limit can be used to evaluate the shrinkage potential or possibility of development, or both, of cracks in earthworks involving cohesive soils. Data obtained from this test method may be used to compute the volumetric shrinkage and linear shrinkage.

The objective of the Atterberg limits test is to obtain basic index information about plasticity of the soil. It is the primary form of classification for cohesive soils. Fine-grained soils are tested to determine the liquid, plastic and shrinkage limits, which are moisture contents that define boundaries between material consistency states. These standardized tests produce comparable numbers used for soil identification, classification and correlations to other properties. [9]

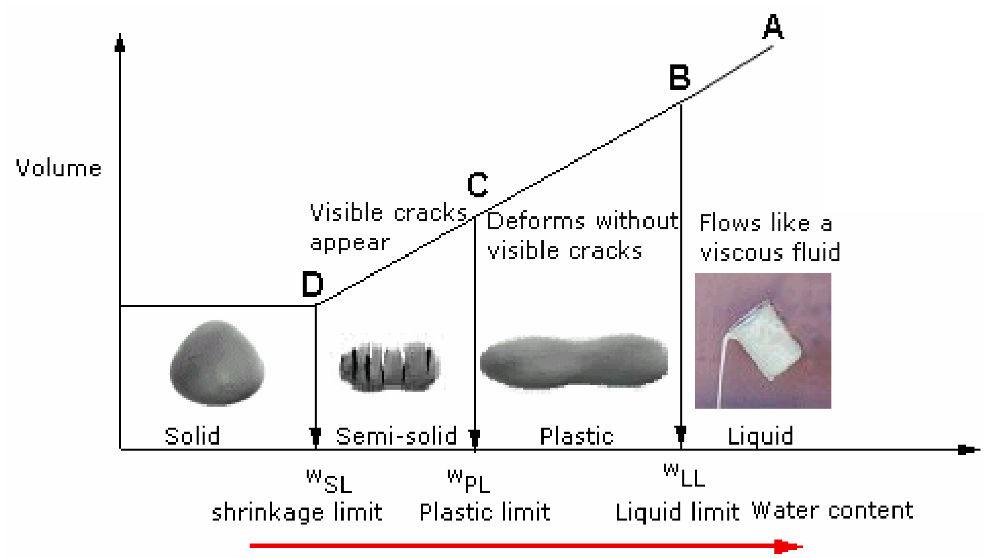

Figure 3.7 Change in soil states as a function of soil volume and water content. [2]

3.4.4. Free swell

The amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several physico-chemical aspects of the soil. Among clay minerals Montmorillonite influences the magnitude of swelling as compared to Illites and kaolinites. The free swell test is the simplest test which gives a fair approximation of the degree of expansiveness of the soil sample. The test is performed by slowly pouring 10cm3 of dry soil which has passed the No. 40 (0.425mm) sieve in to 100 cm3 graduated cylinder filled with tap water. After 24 hours, final volume of the suspension is read. Hence, free swell is defined as:

$$\text{Free swell} = \frac{\text{Final volume of soil} - \text{Initial volume of soil} * 100}{\text{Initial volume of soil}} \ldots\ldots\ldots\ldots.\ldots\ldots.3.1$$

3.4.5. Standard compaction test

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. During compaction air is expelled from the void spaces. Thus compaction results in an increase in the density of the soil. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the “maximum” density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density. Results are used to determine appropriate methods of field compaction and to provide a standard by which to judge the acceptability of field compaction. [8]

Soil placed as engineering fill (embankments, foundation pads, road bases) must be compacted to the selected density and water content to ensure the desired performance and engineering properties such as shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed in the field, and for controlling construction to assure that the target values are achieved. [1]

The optimum water content is the water content that results in the greatest density for a specified compactive effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density. [8]

Two types of compaction tests routinely performed are: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. In the Standard Proctor Test, the soil is compacted by a 24.4N hammer falling a distance of 0.305meters into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer. 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 molds used for testing. The smaller type is 0.102meters in diameter and has a volume of about 944 cm^3, and the larger type is 0.152meters in diameter and has a volume of about 2123 cm^3. If the larger mold is used each soil layer must receive 56 blows instead of 25. [8]

Generally course grained soils can be compacted to a higher dry density than fine gained soils for the some compaction effort. When some fines are added to the course 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. High plasticity clays attain much less dry density than low plasticity clays for the some completive effort. [8]

3.5. Shear strength of soils

3.5.1. General

One of the most important and basic engineering properties of soil is its shear strength or ability to resist sliding along internal surfaces within a mass. The stability of a cut, the slope of an earth dam, the foundations of structures, the natural slopes of hillsides and other structures built on soil depend upon the shearing resistance offered by the soil along the probable surfaces of slippage. There is hardly a problem in the field of engineering which does not involve the shear properties of the soil in some manner or the other. The safety of any geotechnical structure is dependent on the strength of the soil. If the soil fails, a structure founded on it can collapse, endangering lives and causing economic damage. Shear strength of a soil is the internal frictional resistance of a soil to shearing forces. Shear strength of a soil is the property that enables a soil to remain in equilibrium when its surface is not level. Shear strength is required to make estimates of the load-bearing capacity of soils and the stability of geotechnical structures, and in analyzing the stress–strain characteristics of soils (Dr. K.R. Arora).

3.5.2. Unconfined Compression Test (UCS)

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. In this study the UCS tests were carried out on four representative undisturbed samples obtained by tube sampling based on the classification, from the field.

For soils, the undrained shear strength (su) is necessary for the determination of the bearing capacity of foundations, dams, etc. The undrained shear strength (su) of clays is commonly determined from an unconfined compression test. The undrained shear strength (su) of a cohesive soil is equal to one-half the unconfined compressive strength (qu) when the soil is under the ϕ = 0 condition (ϕ = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents undrained conditions, when the undrained shear strength is basically equal to the cohesion (c). This is expressed as:

S= C= qu/2……………………………………………………………….……..…..3.2

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

The shear strength is defined as half the compressive strength. Where the equation is given as follows:

$$q_u = \frac{P}{A} \qquad \ldots\ldots 3.3$$

q_u = unconfined compressive strength (kPa)

P = Compressive force (KN)

A = cross sectional area (m^2)

Since soils tend to deform much more than concrete, the area of the specimen changes through the test to maintain constant volume. Thus, the average cross sectional area at a particular deformation during the test is calculated using the following equation 3.3:

$$A=\frac{Ao}{1-\Sigma} \quad \text{......} 3.4$$

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

Ao= original cross sectional area (m^2)

ε = axial strain (mm/mm), ε = ΔL/ Lo

3.6. Classification of the soils

3.6.1. General

Soil classification system is the arrangements of soils into different groups such that, the soils in particular group have similar behavior. Since there are a wide variety of soils covering the earth, it is desirable to classify the soils into broad groups of similar behavior. It is more convenient to study the behavior of groups than that of individual soils. The main purpose of soil classification is to make possible estimation of soil properties by association with soils of the same class whose properties are known and to provide the Engineer with accurate method of soils description. A classification system thus provides a common language between engineers dealing with soils. A soil is classified according to index properties, such as particle size and plasticity characteristics. Grouping of soils on the basis of certain definite principles would also help the engineer to rate the performance of a given soil either as a sub-base material for roads and airfield pavements, foundations of structures, etc. Many systems are in use that is based on grain size distribution and Atterberg limits of soil. The systems that are quite popular amongst engineers are the AASHTO Soil Classification System and the Unified Soil Classification System (USCS). [10] These methods are among the widely used classification systems in our country

Average grain size classification according to ASTM, 1998

Gravel 76.2 mm – 4.75 mm

Sand 4.75 mm – 0.075 mm

Coarse sand	4.75 mm – 2 mm
Medium sand	2 mm - 0.425 mm
Fine sand	0.425 mm – 0.075 mm
Silt size	0.074 mm to 0.005 mm
Clay size	< 0.005 mm
Colloids	< 0.001 mm

Average grain size classification according to USCS (Budhu, 2000)

Gravel	75 mm - 4.75 mm
Sand	4.75 mm - 0.075 mm
Silt	0.075 mm - 0.002 mm
Clay	< 0.002 mm

Average grain size classification according to AASTHO (Teferra, 1999)

Gravel	>2 mm
Sand	2 mm - 0.05 mm
Silt	0.05 mm - 0.002 mm
Clay	< 0.002 mm

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

This system was originally developed by professor A.Casagrande (1948) for use in airfield construction during World War II. It was modified in 1952 by professor casagrande, the U.S bureau of reclamation and the U.S. army corps of engineers to make the system also applicable to dams, foundations and other constructions. The bases for the USCS is that coarse grained soils can be classified according to their grain size distribution, whereas the engineering behavior of fine grained soil is primarily related to their plasticity. Only sieve and Atterberg limits are necessary to completely classify a soil in this system. [7]

Coarse grained soils are those having 50% or more materials retained on sieve No 200.Fine grained soils are those having more than 50% passing through sieve No 200. USCS uses symbols for the particle size groups. These symbols and their representations are: G-gravel, S-sand, M-silt and C-clay. These are combined with other symbols expressing gradation characteristics. ‘’W’’ for well graded and ‘’P ‘’for poorly graded and plasticity characteristics ‘’H’’ for high plastic and ‘’L’’ for low plastic and symbol ‘’O’’ indicating the presence of organic material. [7]

3.6.3. Plasticity Chart

The information provided in the plasticity chart is of great value and is the basis for the classification of fine-grained soils in the Unified Soil Classification System. Plasticity index, numerical difference between liquid limit and plastic limit, represents the range in water content through which a soil is in plastic state. A high numerical value of plasticity index is an indication of the presence of high percentage of clay in the soil sample. This implies that the plasticity values increase with the responding increase in clay content. The important feature of this chart is the empirical A-line that is given by the equation $PI = 0.73(LL - 20)$. An A-line separates the inorganic clays from the inorganic silts. Inorganic clay values lie above the A-line, and values for inorganic silts lie below the A-line. Organic silts plot in the same region below the A-line and with LL ranging from 30 to 50 as the inorganic silts of medium compressibility. Organic clays plot in the same region as inorganic silts of high compressibility but below the A-line and LL greater than 50. A line called the U-line lies above the A-line. The U-line is approximately the upper limit of the relationship of the plasticity index to the liquid limit for any currently known soil. The equation for the U-line can be given as $PI = 0.91(LL - 8)$ (Das, B.M., 1997).

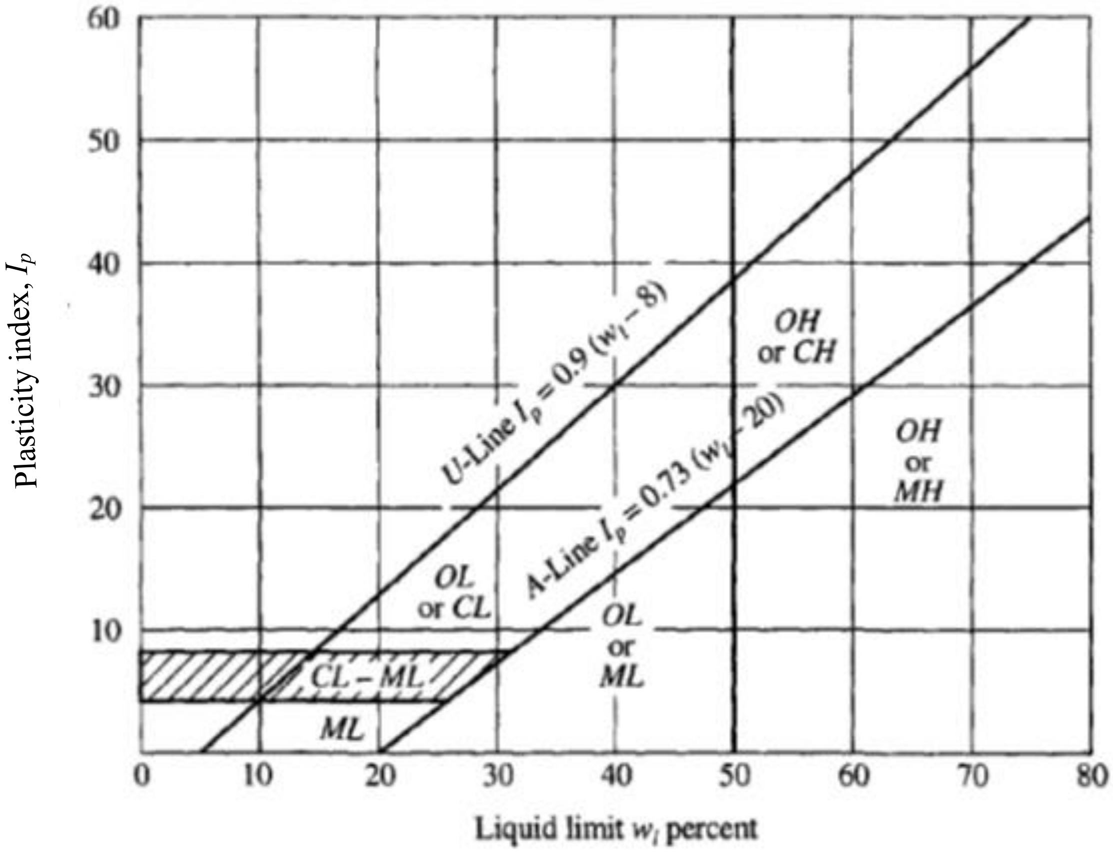

Figure 3.8 General plasticity charts for classification of fine-grained soils

3.6.4. Classification of soils using AASHTO classification system

American Association of State Highway and Transportation Official (AASHTO) classification system is useful for classifying soils for highways. The particle size analysis and the plasticity characteristics are required to classify a soil. The classification system is a complete system which classifies both coarse-grained and fine-grained soils. In this system the soils are divided into 7 types, designated as A-1 to A-7with 12 subgroups in all. The soils A-1 and A-7 are further subdivided into two categories, and the soil A-2, into four categories. To classify a soil, its particle size analysis is done, and plasticity index and liquid limit are determined. The soil with the lowest number, A-1, is the most suitable as a highway material or subgrade. [10]

3.7. Data processing and analysis

The quantitative data (material) that was gained from data collection is analyzed by experimental analysis method. In addition, the data processing starts by reading the previous findings. Then the disturbed and undisturbed samples were collected from the boreholes and laboratory tests were carried out, finally the observed results were recorded. Once I had all the necessary data, then the data was analyzed by using Excel. For laboratory works or testing samples, AASHTO and ERA and ASTM manual were used. Depending on some conditions, other references manuals and websites have been used.

3.8. Ethical Considerations

The data collected from either primary or secondary sources is confidential and used only for research purpose. The data have been collected based on the willingness of the organizations to give information.

3.9. Data Quality Assurances

This research study Data was collected very imperatively to get appropriate results and this helps all Laboratory test and field work manual has been prepared in order to avoid fallacy determination and conclusion.

The training was given for data collectors to handle the data carefully. The reliability and accuracy of data was checked. Laboratory instruments are calibrated; at least two experiments were done for one test parameters in order to avoid error of data and results.

CHAPTER FOUR

Laboratory test results and Discussions

4.1. In-situ Density and Moisture Content Tests

The in-situ bulk density test was carried out at field and used to determine bulk Densities for all samples. From the test results, it is observed that the bulk density Varies from 1.3 to 1.49 gm/cc and moisture content varies from 26 to 47%.

The in-place density is used to determine density of compacted soils used in the construction of structural fills, highway embankments, or earth dams.

Table 4.1 In-situ density and moisture content test result of different pit.

sample description	depth	bulk density ,g/cc	moisture content,%
TP-1	1.5	1.31	42
	3	1.34	47
TP-2	1.5	…	27
TP-3	1.5	1.32	42
	3	1.30	41
TP-4	1.5	1.34	36
	3	1.31	43
TP-5	1.5	1.46	26
	3	1.45	28
TP-6	1.5	1.32	37
	3	1.30	43

4.2. Specific gravity

The specific gravity of most soils under investigation lies within a narrow range of 2.45- 2.75. But organic soil or soil containing porous particles such as diatomaceous earth show low specific gravity values such as 2.3 or less. On the other hand soils containing heavy substances such as iron may have values above 3. So, from the specific gravity value of Table 4.2, below, the soils can be categorized as inorganic soils since their Gs values are greater than 2.45.

The specific gravity of the minerals affects the specific gravity of soils derived from them. The specific gravity of most rock and soil forming minerals varies from 2.50

(some Feldspars) and 2.65 (Quartz) to 3.5 (Augite or Olivine). Gypsum has a smaller value of 2.3 and salt (NaCl) has 2.1 [1].

Table 4.2 Specific Gravity of the Soil of the Study Area

S. No	Sample description	depth	specific gravity
1	TP-1	1.5	2.71
		3	2.75
2	TP-2	1.5	2.62
3	TP-3	1.5	2.48
		3	2.45
4	TP-4	1.5	2.58
		3	2.59
5	TP-5	1.5	2.51
		3	2.47
6	TP-6	1.5	2.5
		3	2.66

4.3. Grain size Analysis

The gradation of soils in the study area varies considerably (as shown in Table 4.3 and Figure 4.1). From the grain size analysis results clay content ranging from 52-80%, silt faction 19-46 % and sand fraction 1.3-16.7% and gravel fraction 0-83% the detail test results are presented in Appendix A.2.

Table 4.3 Grain size distribution of soils of the study area

S.No	Location	Test pit	depth, m	percentage amount of particle size			
				Gravel	sand	silt,%	clay,%
1	manucipality	TP-1	1.5	0.0	2.3	23.1	74.6
			3	0.0	2.6	25.4	72.0
2	Dashen bank	TP-2	1	82.6	16.7	…..	….
3	Dabo Ber	TP-3	1.5	0.6	1.3	18.6	80.1
			3	0.0	2.6	25.4	72.0
4	Gore Ber	TP-4	1.5	0.4	1.7	25.9	72.0
			3	0.3	1.5	27.0	71.2
5	Hospital	TP-5	1.5	0.9	2.0	46.0	52.0
			3	0.0	5.1	42.5	52.4
6	University	TP-6	1.5	0.0	14.5	39.2	46.3
			3	0.3	11.4	40.7	47.7

From Table 4.3 and Figure 4.1, the results of grain size analysis show that more than 90% of the total samples pass through sieve size of 75µm. This indicates that almost all samples are fine-grained soil except Samples around Dashen bank (Tp-2). From hydrometer analysis more than 30% of the soils sizes are less than 5µm (clay content as per ASTM boundaries criteria). This gives a hint that the properties of these soils are highly affected by the presence of the clay content.

Effect of sample location, is another important element observed from test results. Soils formed at the same profile and locations show similar characteristics due to their mode of weathering, deposition and soil forming factors to which they are exposed. From the test results one can see that the soil has distinct characteristics where sampled at different locations. , i.e., the more distant apart the sampling location, the different is the characteristics.

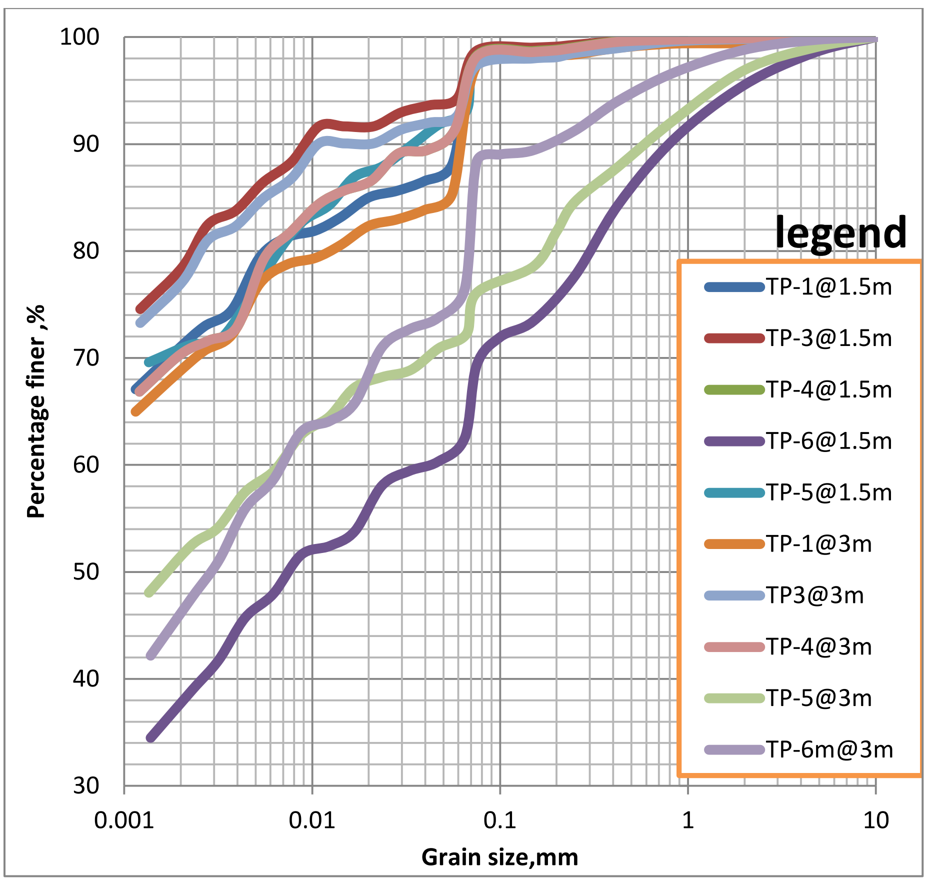

Figure 4.1 Grain size distribution curves of samples from test pits

4.4. Test Result of Atterberg Limits

From the consistency limit test results, the Atterberg Limits for all test pits of soils is conducted. And the liquid limit ranges from 52–74%, plastic limit ranges from 30–52 % and plastic index from 12 to 36%. The summary of the test result is shown in Table 4.4.

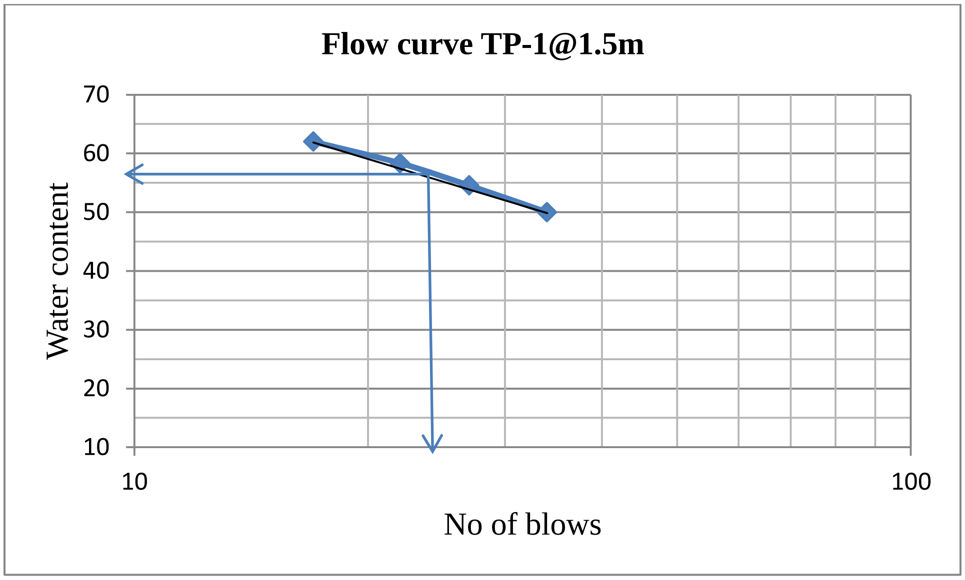

Figure 4.2 Typical Liquid limit determination

Table 4.4 Summary of Atterberg Limit Results of study area

Serial. No	Location	Test pit	depth, m	LL, (%)	PL,%	PI (%)
1	municipality	TP-1	1.5	54	38	16
			3	52	35	17
3	Dabo Ber	TP-3	1.5	58	44	14
			3	56	30	26
4	Gore Ber	TP-4	1.5	62	50	12
			3	60	31	29
5	Hospital	TP-5	1.5	60	44	16
			3	68	32	36
6	University	TP-6	1.5	74	52	22
			3	69	50	19

4.5. Test Result of Compaction

From the test results the maximum dry density (MDD) of Bedelle town ranges from1.08 to 1.44 g/cm^3 and the optimum moisture content ranges 29.43 to 37.46 percent. The summary of the test result is shown in Table 4.5.

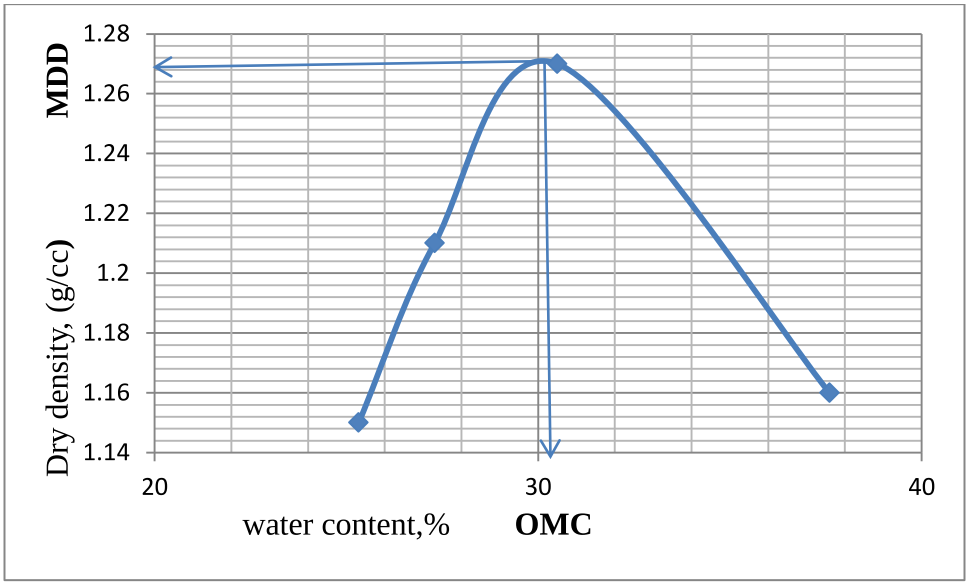

Figure 4.3 Typical standard compaction graph of test pit 1at 1.5m

Table 4.5 Summary of Optimum moisture content and the maximum dry density

Serial No	Designation	Depth, m	OMC, (%)	MDD(g/cm^3)
1	TP-1-1	1.5	30.4	1.27
2	TP-1-2	3	34.9	1.33
3	TP-2-1	1.5	30.4	1.45
4	TP-3-1	1.5	37.4	1.31
5	TP-3-2	3	29.4	1.32
6	TP-4-1	1.5	34.6	1.33
7	TP-4-2	3	30.5	1.37
8	TP-5-1	1.5	31.4	1.35
9	TP-5-2	3	26.1	1.35
10	TP-6-1	1.5	36.3	1.08
11	TP-6-2	3	31.7	1.31

4. 6. Free swell test result and Discussion.

Free swell test results for air dried sample are summarized in Table 4.6. From the test result one can see that the free swell of the soil under investigation ranges from 25% to 50%. Those soils having a free swell less than 50% are considered as low in degree of expansion. Hence all soil samples under investigation are non-expansive soils.

Table 4.6 Free swell test result of study area

serial No	Designation	Depth (m)	Free swell (%)	water used
1	Tp-1-1	1.5	40	Tap water
2	Tp-1-2	3	35	"
3	Tp-2-1	1.5	30	"
4	Tp-3-1	1.5	30	"
5	TP-3-2	3	28	"
6	TP-4-1	1.5	25	"
7	TP-4-2	3	25	"
8	TP-5-1	1.5	30	"
9	TP-5-2	3	26	"
10	TP-6-1	1.5	50	"
11	TP-6-2	3	45	"

4.7. Unconfined Compression Test (UCS) test result

The unconfined compressive strength of the soils in the study area ranges from 225 – 333 kN/m^2 and undrained shear strength ranges from 112.5 – 161.5 kN/m^2. This shows that consistency of the soil is very stiff. This high value of UCS can be mainly due to natural cementation of the sample. The summery is provided as below in table 4.7 and figure 4.4.

In this study the UCS tests were carried out on six representative undisturbed samples obtained sampling based on the classification, from unified soil classification.

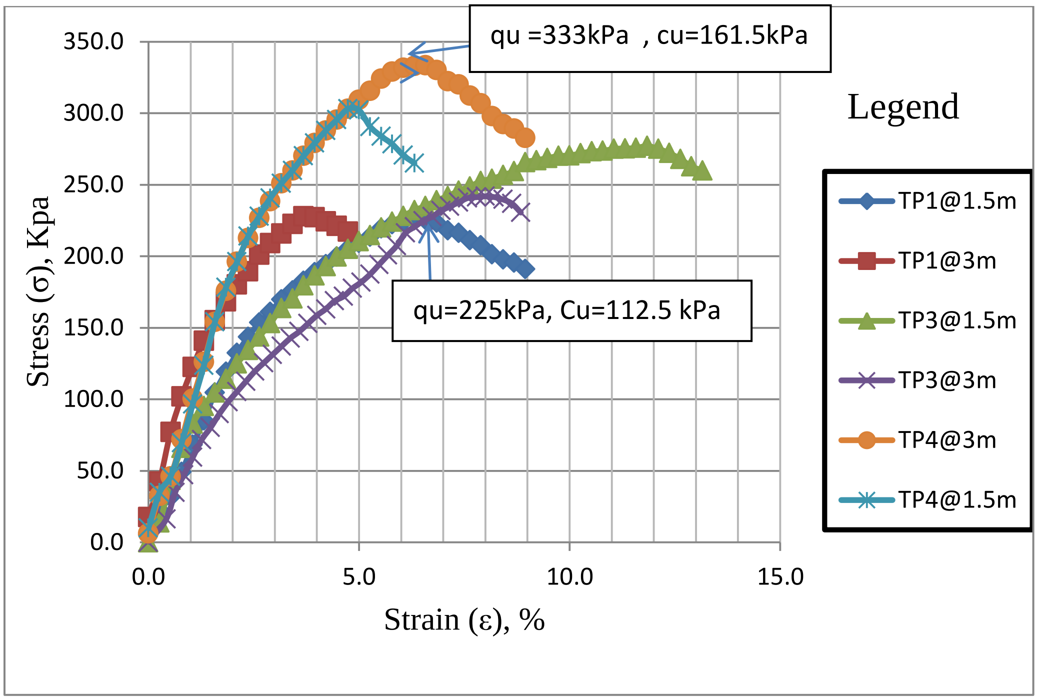

Figure 4.4 stress-strain curves for determining qu for TP 1, 3 and, 4 at depth of 1.5 and 3m

Table 4.7 Summery of UCS test results

Test pit No.	qu(kPa)	Su(kPa)	NMC (%)
TP1@1.5m	225	112.5	42
TP1@3m	227	113.5	47
TP3@1.5m	277	138.5	42
TP3@3m	241	120.5	41
TP4@1.5m	302	151	36
TP4@3m	333	161.5	43

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

According to USCS, soils of Bedelle town are classified as highly plastic silt (MH), and highly plastic clay (CH).

Table 4.8 USCS classification for soils of the study area

S.No	Location	Test pit	depth, m	percentage amount of particle size				LL, (%)	PL,%	PI(%)	USCS
				Gravel	sand	silt,%	clay,%				
1	manucipality	TP-1	1.5	0.0	2.3	23.1	74.6	54	38	16	MH
			3	0.0	2.6	25.4	72.0	52	35	17	MH
2	Dashen bank	TP-2	1	82.6	16.7	…..	….	…..	…	…	GW
3	Dabo Ber	TP-3	1.5	0.6	1.3	18.6	80.1	58	44	14	MH
			3	0.0	2.6	25.4	72.0	56	30	26	CH
4	Gore Ber	TP-4	1.5	0.4	1.7	25.9	72.0	62	50	12	MH
			3	0.3	1.5	27.0	71.2	60	31	29	MH
5	Hospital	TP-5	1.5	0.9	2.0	46.0	52.0	60	44	16	MH
			3	0.0	5.1	42.5	52.4	68	32	36	CH
6	University	TP-6	1.5	0.0	14.5	39.2	46.3	74	52	22	MH
			3	0.3	11.4	40.7	47.7	69	50	19	MH

From grain size distribution curves, Figure 4.1, one can observe that for all samples more than 50% of the soils passes sieve No. 200(0.075 mm) so that generally they can be classified as fine-grained soils. From plasticity chart using calculated value of LL and PI the soils are further classified. As we can see from Figure 4.7, using the plasticity chart of USCS, the soils lay in CH zone which is inorganic clays of high plasticity. And some soils lay below A-line, which are in MH region which is inorganic high plastic silts.

According to unified soil classification system as shown in table 4.8 above, the dark red soils of the study area fall under CH region, which shows that the soils are inorganic clays of high plasticity and the red soils fall under MH region, which are inorganic silts of high plasticity. According to grain size analysis result, red colored soils have high clay fraction thus it is better to classify the soil as red clay rather than silt.

For TP-2 percentage passing sieve number 200 is less than 50% therefore it is classified by unified soil classification as course-grained soil. Calculating coefficient of uniformity, Cu and coefficient of curvature Cc on the grain size graph

Cu= $\frac{D60}{D10}$ and Cc=$\frac{(D30)2}{D60*D10}$

Cu= $\frac{18}{0.8}$ =22 and Cc=$\frac{(6)2}{18*0.8}$ =2.5, therefore, Cu $\geq$4 and, 1$\leq$ Cc$\leq$3

The soil is classified as GW (well graded gravel) for details refer the graph at Appendix A .2

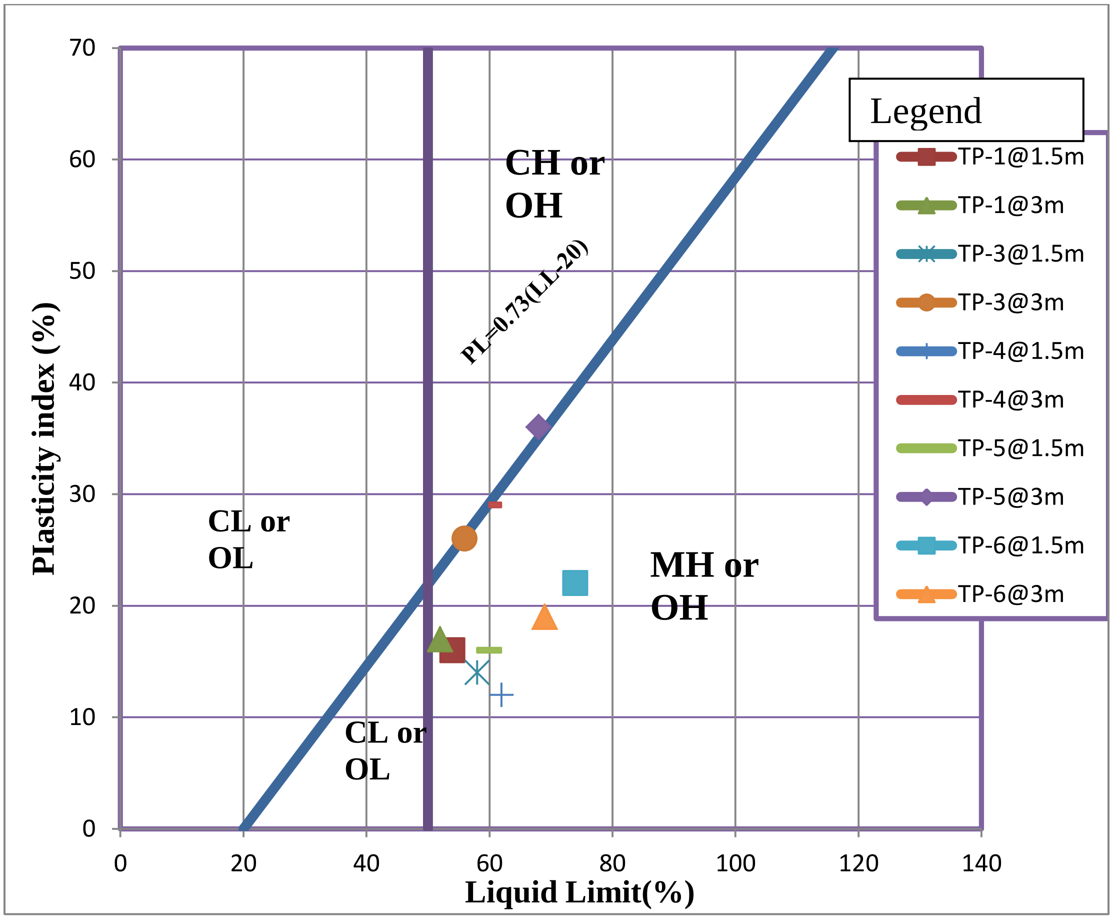

Figure 4.5 Plasticity charts of soils of the study area

4.9. Classification of soils using AASHTO classification system

From the Table 4.9, applying AASHTO classification system, the soils are classified under A-7-5 which is clay soils. These types of soils are not favorable for the construction of sub-grade of roads. From the Plasticity chart of AASHTO classification, Figure 4.6, most of the soils lay within the region of A-7-5 and two results lay in the region between A-7-5 and A-7-6 but the balance is more towards A-7-5 and therefore the classification is considered as A-7-5. Both the soil groups which are classified as A-7-5 and A-7-6 are clayey soils. But for TP-2 it is classified as granular materials (35% or less passing No.200)

Table 4.9 AASHTO classification for soils of the study area

Serial. No	Location	Test pit	Depth,m	LL, (%)	PL,%	PI (%)	AASHTO classification
1	municipality	TP-1	1.5	54	38	16	A-7-5
			3	52	35	17	A-7-5
2	Dashen bank	TP-2	1	…..	…	…	A-3
3	Dabo Ber	TP-3	1.5	58	44	14	A-7-5
			3	56	30	26	A-7-5
4	Gore Ber	TP-4	1.5	62	50	12	A-7-5
			3	60	31	29	A-7-5
5	Hospital	TP-5	1.5	60	44	16	A-7-5
			3	68	32	36	A-7-5
6	University	TP-6	1.5	74	52	22	A-7-5
			3	69	50	19	A-7-5

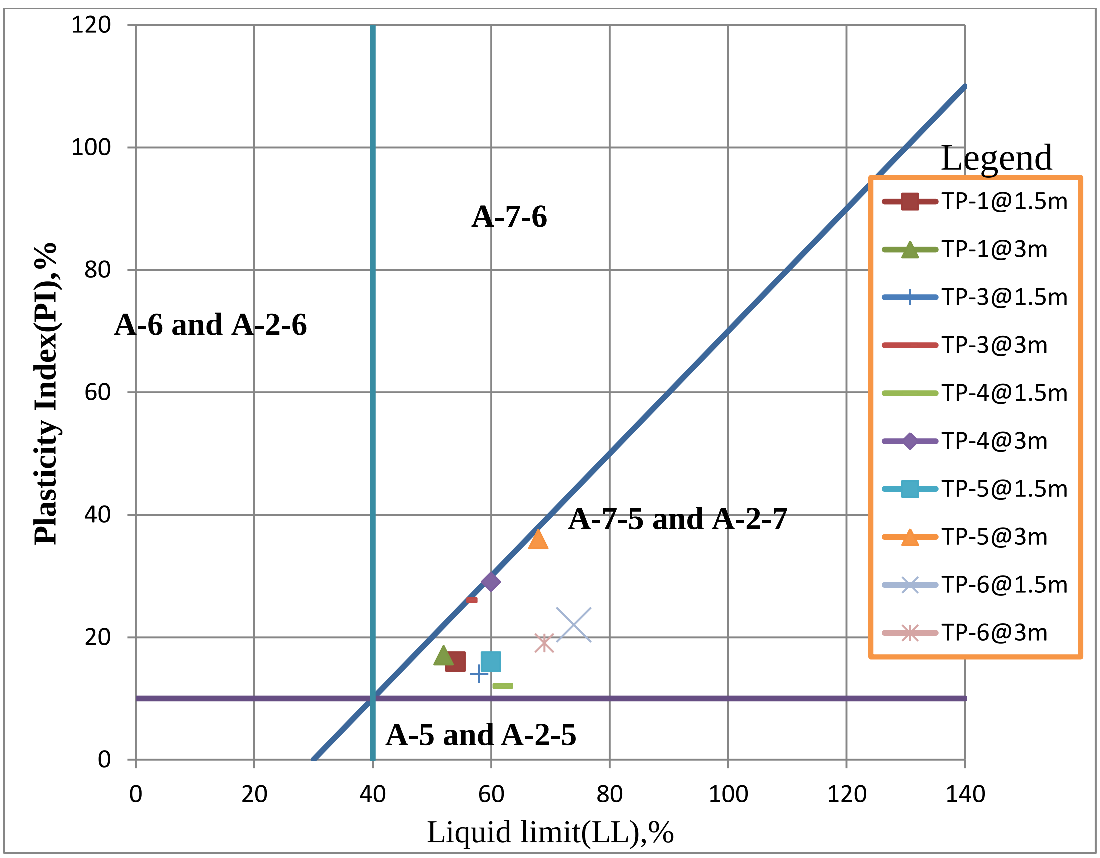

Figure 4.6 plasticity chart used for classifying soils according to AASHTO classification system

4.10. Comparison of test results with previously done researches

The laboratory test results of this investigation can be compared with the other research data as shown in the Table 4.10.

The Specific Gravity lies in the range between 2.45 to 2.75, Clay Content lies in the range 46-80 %, Plasticity Index ranges between 12-36% and a previous study carried out in other towns

Table 4.10 Comparison of current study with pervious research findings

	previous Research(Abagena,2003)	previous Research(Haile mariam,1992)	Current Research
soil type	Red clay	Red clay	Red clay
location	Bahir Dar	Addis Ababa	Bedelle
Clay content %	74- 82	48-73	43-80.
Liquid Limit,%	61-68	54-81	52-74
Plasticity Index,%	24-31	21-30	30-52
Free swell, %		10-40	25-50
specific gravity	2.75-2.83	2.61-2.79	2.45-2.75
Classification, USCS	MH,CH	CH	MH,CH
USCS, (qu) KN/m^2	148-220	49-250	225-333

As shown in the table above the soils of Bedelle town when compared with the previously tested soils of, Addis Ababa and Bahir Dar show considerable similarities with Clay content, and classification. More similarity is observed with respect to the index tests and physical properties. Moreover, the test result shows that the value of plasticity is high as these soils due to the mode of formation, i.e., they are formed at warm temperate climatic conditions. Generally, the soil of Bedelle could be classified as red clay soil with almost close characteristics with Addis Ababa and Bahir Dar soils.

The high value of UCS can be mainly due to natural cementation of the undisturbed sample.

CHAPTER FIVE

Conclusions and Recommendation

5.1. Conclusion

Grain size analysis tests revealed that, starting from few centimeters below the ground level to the depth of investigation which is three meters, the soil in Bedelle town is mostly clay, and silty clay soil in which the percentage of clay ranges from 46-80 %, silt from 19-46 %, sand from 1.3-16.7 % and gravel 0-83 %.

From consistency limit test results the LL of the soil ranges from 52-74 % PL rages from 30-52% and PI from 12-36%.

Soils of the study area are classified according to AASHTO and USCS. AASHTO classification shows that soils of the study area are A-7-5 which means clay soil with poor quality as a subgrade material. USCS indicates two main types of soils, which are: CH, high plastic clay soils, MH, high plastic silt soils.

Within the depth of exploration, the specific gravity of the town ranges from 2.45 to 2.75. From compaction test results the maximum dry density (MDD) of Bedelle ranges from 1.01 to 1.44 g/cm^3 and the optimum moisture content ranges 29 to 47 percent.

All the samples have free swell value of less than 50%. This shows the soil in the study area is non-expansive with free swell value ranging from 25-50%.

The unconfined compression strength (UCS) of bedelle soil shows a high strength values. The value of UCS ranges from 225 -333kN/m^2 and undrained shear strength ranges from 112.5 – 161.5 kN/m^2. This high value of UCS can be mainly due to natural cementation of the sample.

5.2. Recommendation

1. In this research samples of soil were collected only from six test pits, by increasing the number of sampling area and depth of investigation need to be carried out to prepare a reliable geotechnical soil map of Bedelle town in future. Under such conditions advanced geo-statistical techniques could also be used in developing more scientific map.

2. Some of the basic engineering properties of the soil in this study are obtained from laboratory tests; but to obtain more reliable information it is recommended that detailed in situ investigation has to be carried out to avoid sample disturbance effect.

3. As some part of Bedelle town is covered with rocks it is recommended to study on Geological formation of the rocks.

4. Since pit excavation method of exploration is used, the outcomes would be applicable only for light structures which under lie their foundation up to depth of 3 m.

5. In this research I use convectional laboratory techniques. Since our country Ethiopia is located in tropical region Tropical laboratory techniques shall also be done.

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Appendix

(Laboratory tests result and Analysis)

Appendix A. 1 Atterberg Limits Determination
Liquid Limit and Plastic Limit Test

Test Date 13/03/2016

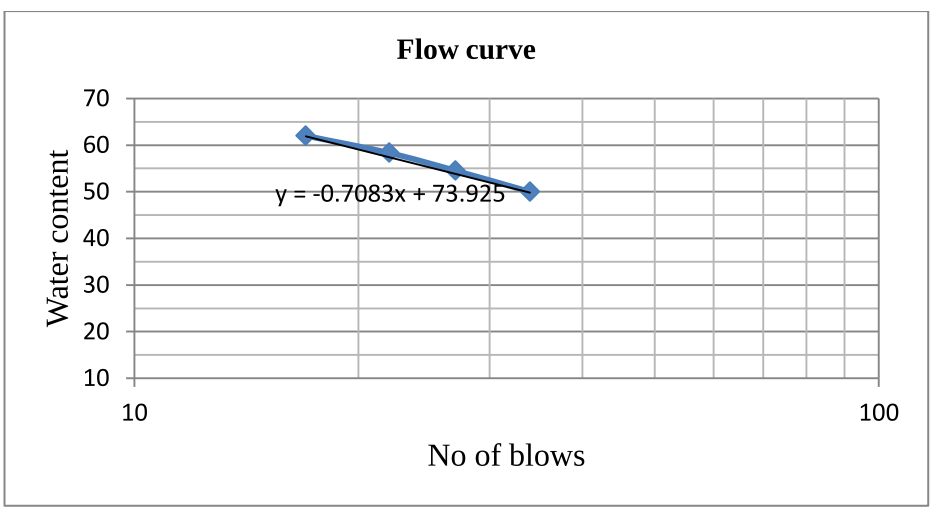
Sample No TP-1-1 @ 1.5 m depth

Sample type: Disturbed

Project : Thesis research.

	liquid limit				plastic limit		
Trial No	1	2	3	4	1	2	3
container No	m11	m12	m13	m14	m21	m22	m23
Mass of container	18	18	17	18.4	19	18	18
Mass of container +wet soil ,g	36	35	36	34	30	32	29
mass of container +Dry soil ,g	30	29	29	28	27	28	26
mass of water ,g	6	6	7	6	3	4	3
mass of dry soil ,g	12	11	12	9.6	8	10	8
water content,%	50	54.5	58.3	62.5	37.5	40	37.5
No of blows	34	27	22	17	……..	……..	……..

LL=56 PL= 38.33



Test Date 13/03/2016

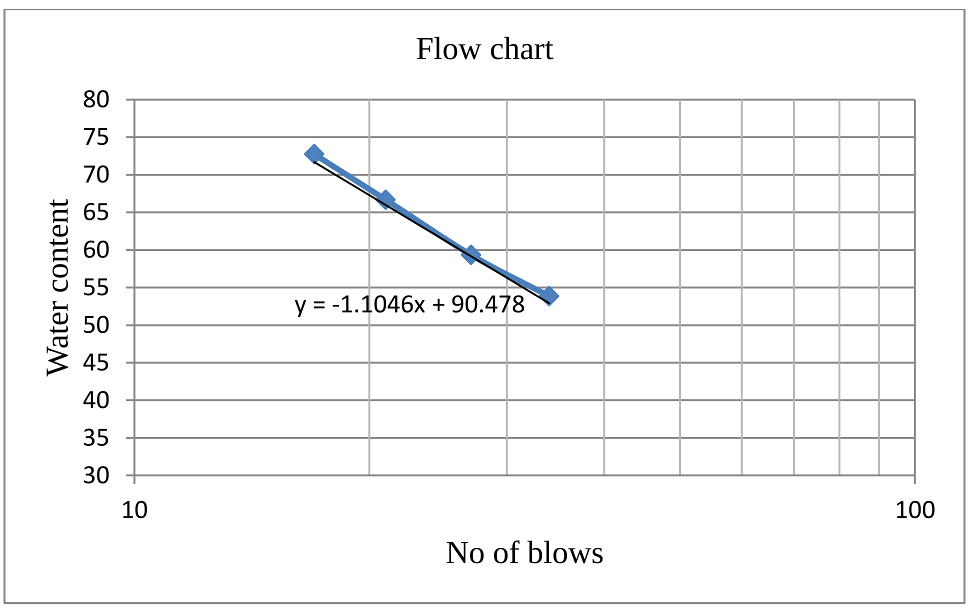
Sample No TP-1-1 @ 3 m depth

Sample type: Disturbed

Project: Thesis research.

	liquid limit				plastic limit		
Trial No	1	2	3	4	1	2	3
container No	M21	M22	M23	M24	P21	P22	P23
Mass of container ,g	18	17	18	19	19	17	18
Mass of container +wet soil ,g	38	36	38	38	30	37	29
mass of container +Dry soil ,g	31	29	30	30	27	31	26
mass of water ,g	7	7	8	8	3	6	3
mass of dry soil ,g	13	12	12	11	8	14	8
water content,%	53.8	58.3	66.6	72.7	37.5	42.8	37.5
No of blows	34	27	22	17	……..	……..	……..

LL=61% PL=39.28%



Test Date 13/03/2016

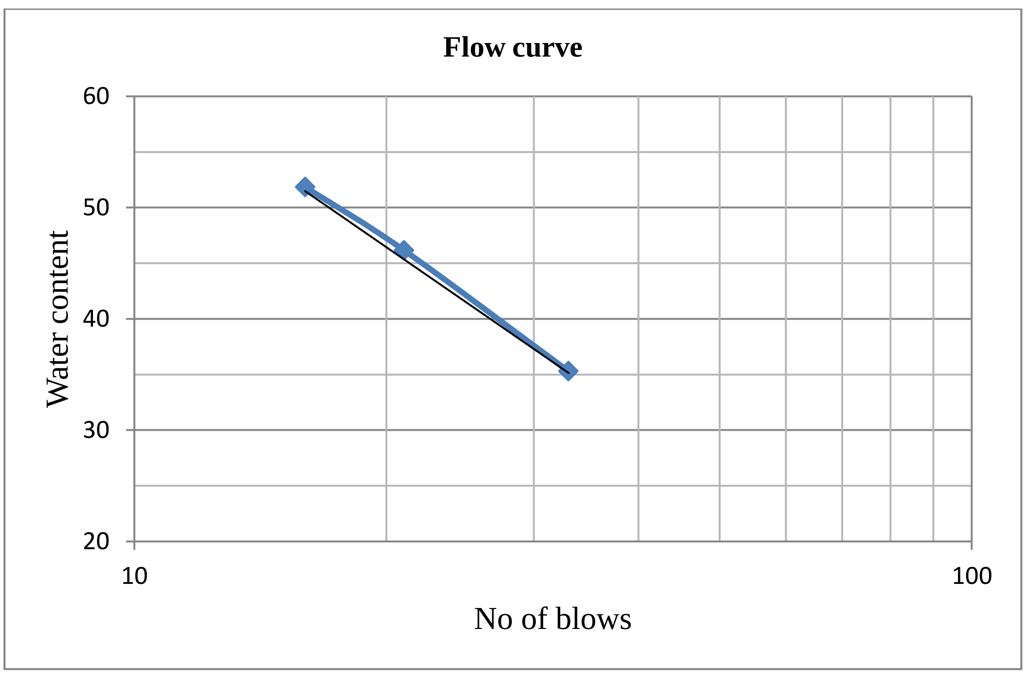
Sample No TP-2-1 @ 1.5 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit			plastic limit		
Trial No	1	2	3	1	2	3
container No	D11	D12	D13	P11	P12	P13
Mass of container ,g	19	17	17.5	17	17	19
Mass of container +wet soil ,g	42	36	38	27	28	28
mass of container +Dry soil ,g	36	30	31	24	25	26
mass of water ,g	6	6	7	3	4	5
mass of dry soil ,g	17	13	13.5	7	8	7
water content,%	35.2	46.1	51.8	36.2	37.3	36.1
No of blows	33	21	16	……..	……..	……..

LL=42 PL=36.3



Test Date 13/03/2016

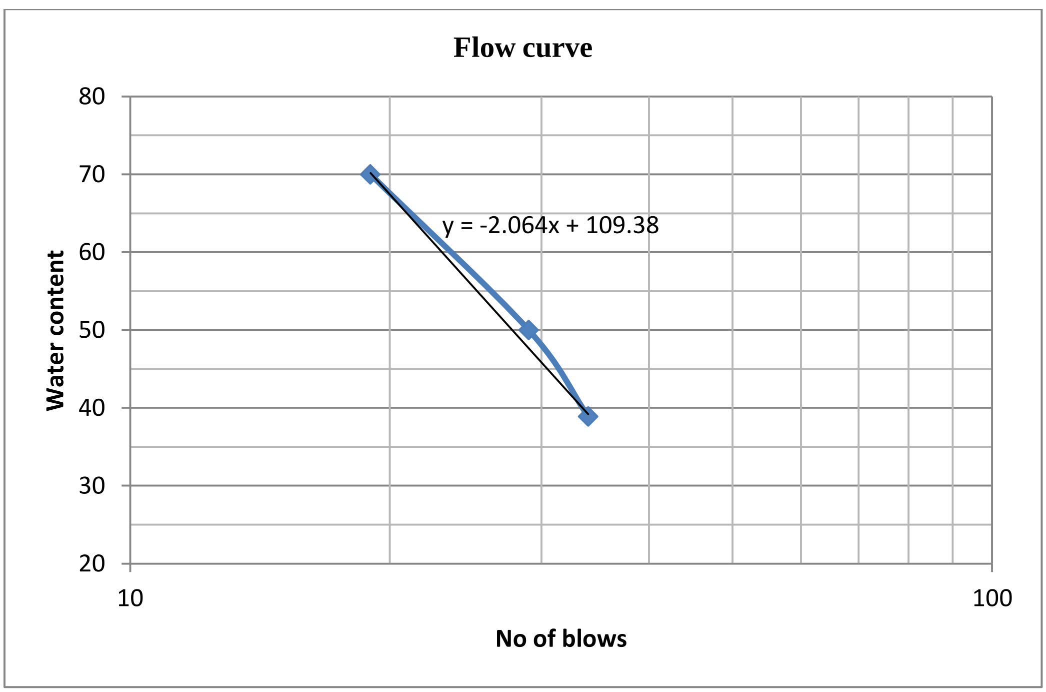
Sample No TP-3-1 @ 1.5 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit			plastic limit	
Trial No	1	2	3	1	2
container No	D11	D12	D13	P11	P12
Mass of container ,g	16	15	18	17	17
Mass of container +wet soil ,g	41	39	35	30	30
mass of container +Dry soil ,g	34	31	28	26	26
mass of water ,g	7	8	7	4	4
mass of dry soil ,g	18	16	10	9	9
water content,%	38.8	50	70	44.4	44.4
No of blows	34	29	19	……..	……..

LL = 58 PL=44.4



Test Date 5/04/2016

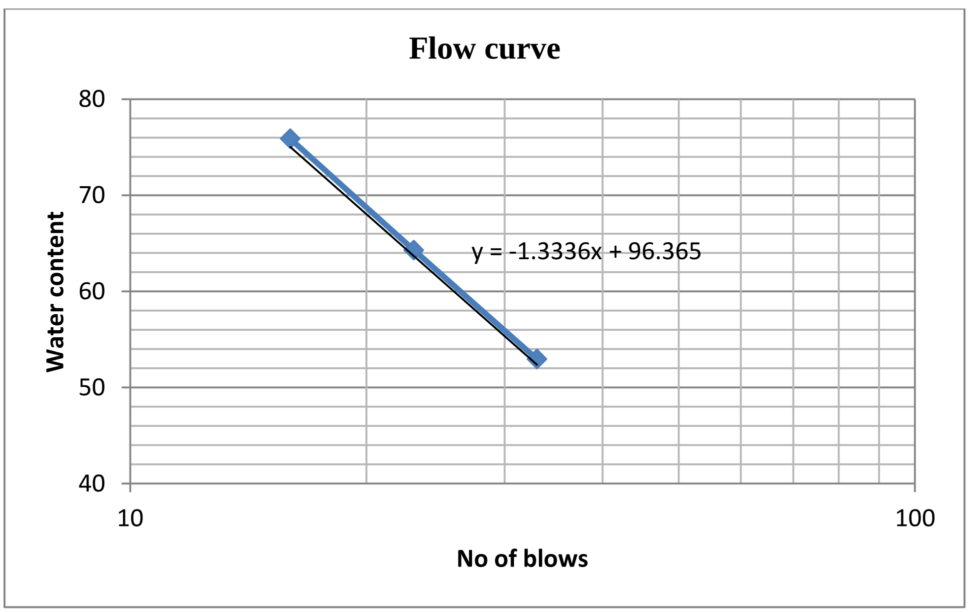
Sample No TP-3-2 @ 3 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit			plastic limit		
Trial No	1	2	3	1	2	3
container No	D21	D22	D33	P21	P22	P23
Mass of container ,g	19	17	17.5	17	17	19
Mass of container +wet soil ,g	45	40	43	27	37	33
mass of container +Dry soil ,g	36	31	32	24	31	29
mass of water ,g	9	9	11	3	6	4
mass of dry soil ,g	17	14	14.5	7	14	10
water content,%	52.9	64.2	75.8	42.8	42.9	40
No of blows	33	21	16	……..	……..	……..

LL=63% PL=41.9%



Test Date 13/03/2016

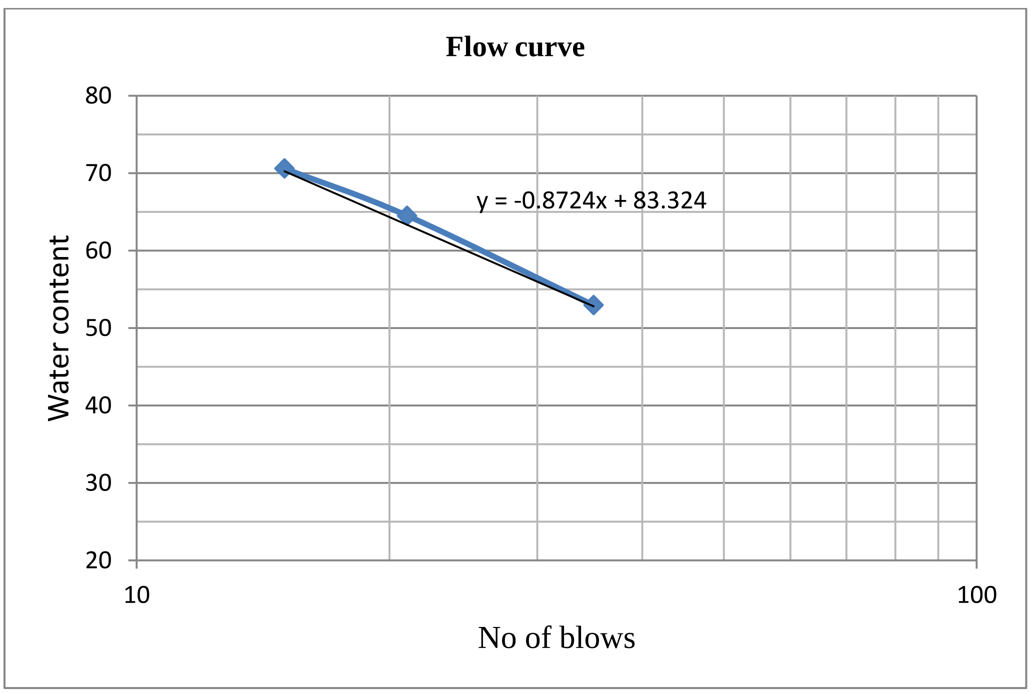
Sample No TP-4-1 @ 1.5 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit			plastic limit	
Trial No	1	2	3	1	2
container No	G11	G12	G13	GP1	GP2
Mass of container ,g	18	18	17	18	17
Mass of container +wet soil ,g	44	44	46	30	29
mass of container +Dry soil ,g	35	34	34	26	25
mass of water ,g	9	10	12	4	4
mass of dry soil ,g	17	16	17	8	8
water content,%	52.94	62.5	70.58	50	50
No of blows	35	21	15	……..	……..

LL=62 PL=50



Test Date 7/04/2016

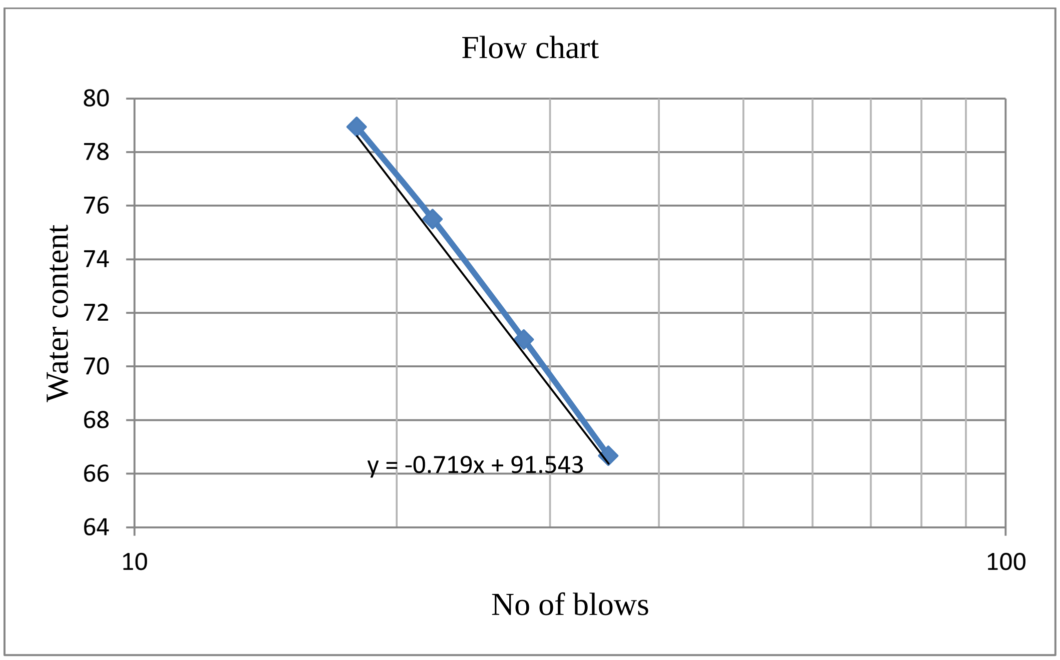
Sample No TP-4-2 @ 3 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit				plastic limit		
Trial No	1	2	3	4	1	2	3
container No	H21	H22	H23	H24	P21	P22	P23
Mass of container ,g	17	18	17	18	17	17	17
Mass of container +wet soi,g	47	52	59	52	34	29	35
mass of container +Dry soil ,g	35	38	41	37	28	25	29
mass of water ,g	12	14	18	15	6	4	6
mass of dry soil ,g	18	20	24	19	11	8	12
water content,%	66.6	70	75	78.9	52.5	50	50
No of blows	35	27	21	18	……..	……..	……..

LL=73% PL=51.51%



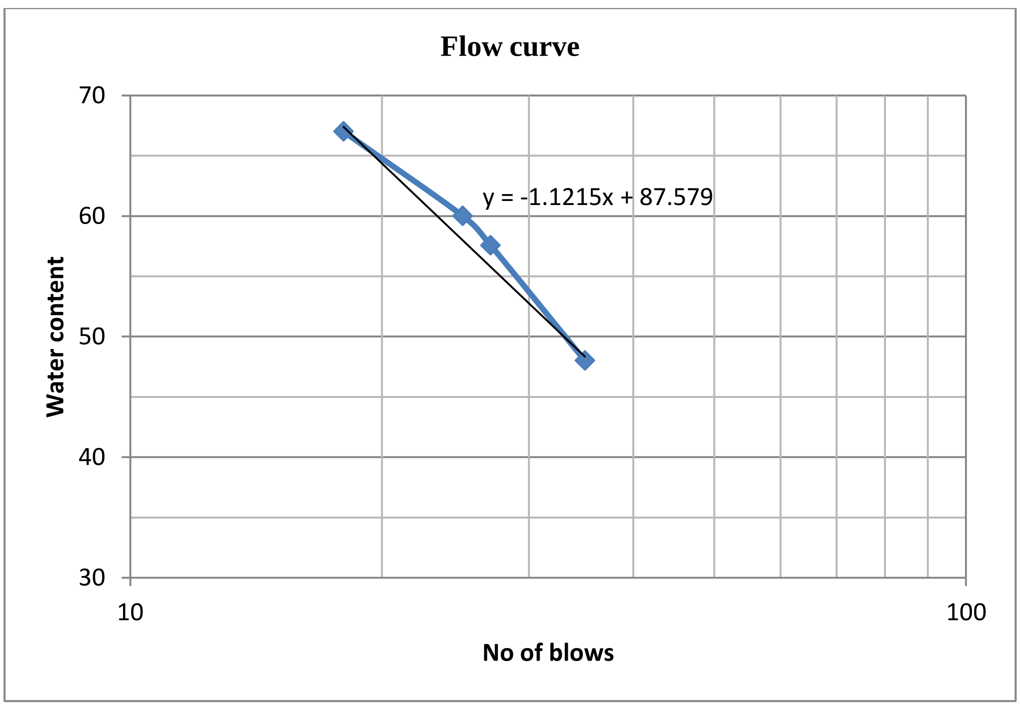
Test Date 14/03/2016

Sample No TP-5-1 @ 1.5 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit				plastic limit		
Trial No	1	2	3	4	1	2	3
container No	h11	h12	H13	H14	P11	P12	P13
Mass of container ,g	18	17	18	17	17	17	17
Mass of container +wet soil ,g	52	59	50	47	27	28	29
mass of container +Dry soil ,g	41	44	38	35	24	24	26
mass of water ,g	11	15	12	12	3	5	4
mass of dry soil ,g	23	27	20	18	7	7	9
water content,%	47.82	55.55	60	66.66	42.85	44.14	45
No of blows	35	27	25	18	……..	……..	……..
	LL=60				PL=44		



Test Date 7/04/2016

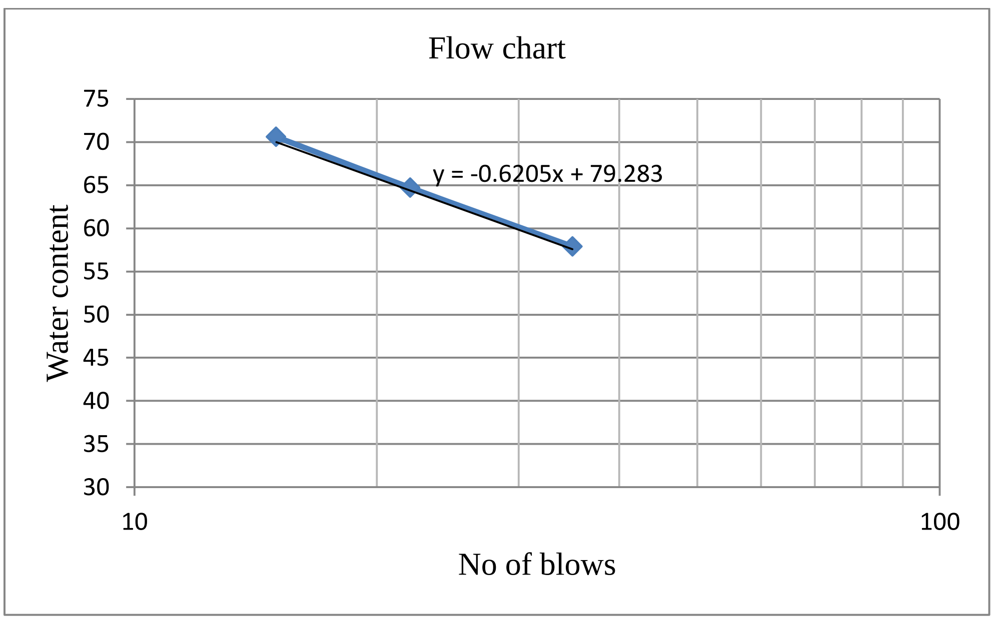
Sample No TP-5-2 @ 3 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit			plastic limit	
Trial No	1	2	3	1	2
container No	H11	H12	H13	HP1	HP2
Mass of container ,g	17	18	18	18	16
Mass of container +wet soil ,g	47	46	47	32	34
mass of container +Dry soil ,g	36	35	35	28	29
mass of water ,g	11	11	12	4	5
mass of dry soil ,g	19	17	17	10	13
water content,%	57.89	64.7	70.59	40	38.46
No of blows	35	22	15	……..	……..

LL=62% PL=39.23%



Test Date 14/03/2016

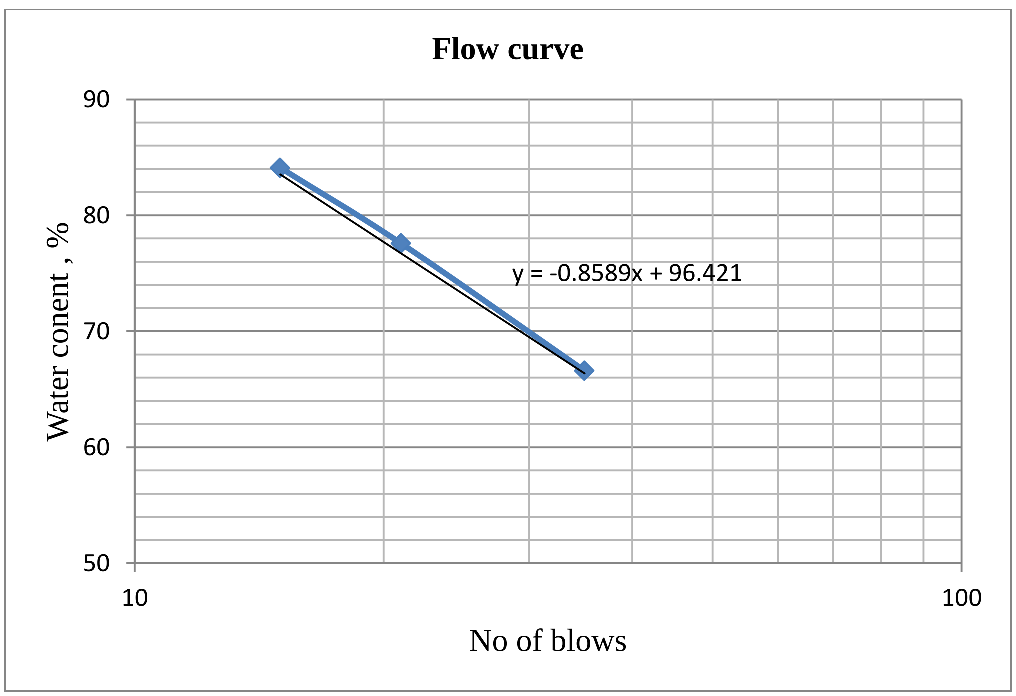
Sample No TP-6-1 @ 1.5 m depth

Sample type: Disturbed

Project: Thesis research

	liquid limit			plastic limit		
Trial No	1	2	3	1	2	3
container No	U11	U12	U13	H11	H12	H13
Mass of container ,g	17	18.4	16	18	20	17
Mass of container +wet soil ,g	32	39	42	32	23	29
mass of container +Dry soil ,g	26	30	30	27	22	25
mass of water ,g	6	9	12	5	1	4
mass of dry soil ,g	9	11.6	14	9	2	8
water content,%	66.66	77.58	85.71	52.55	50	50
No of blows	35	21	15	…	……	…

LL=74 PL=52.



Test Date 14/03/2016

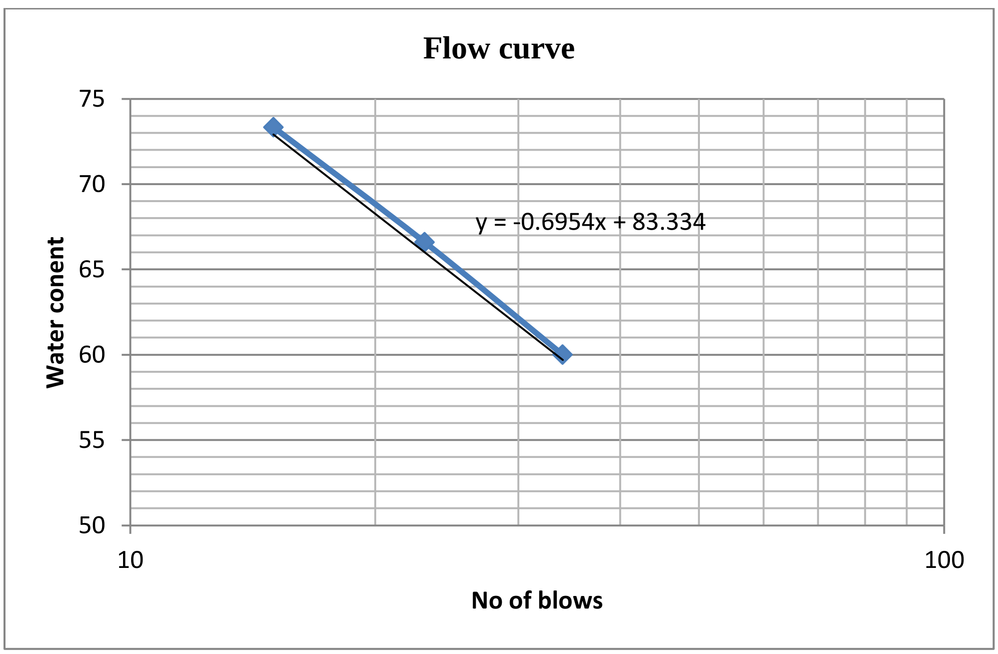
Sample No TP-6-2 @ 3 m depth.

Sample type: Disturbed

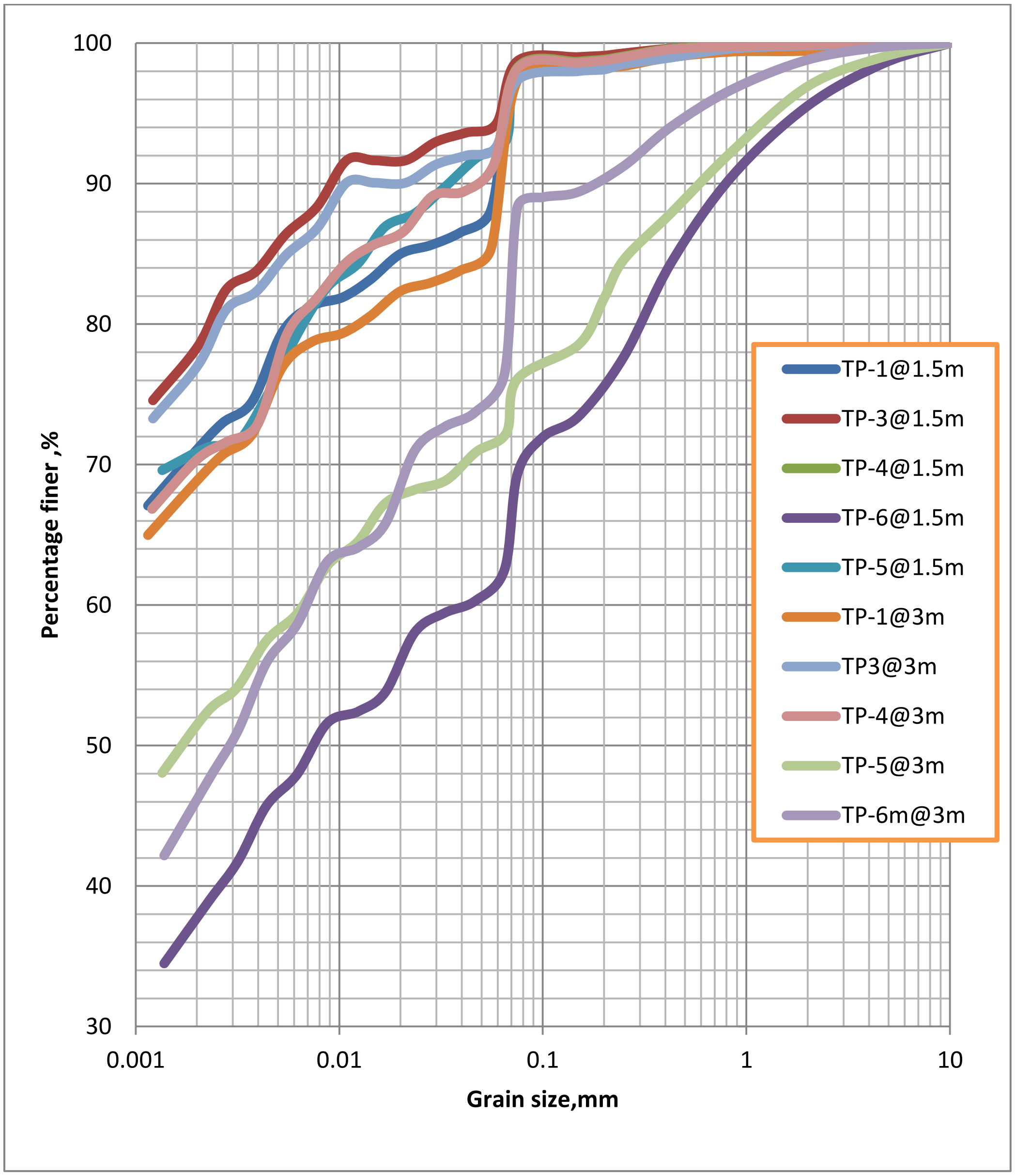
Project: Thesis research

	liquid limit			plastic limit		
Trial No	1	2	3	1	2	3
container No	U21	U22	U33	H21	H22	H33
Mass of container ,g	18	19	17	18	19	18
Mass of container +wet soil ,g	42	39	43	36	42	38
mass of container +Dry soil ,g	33	31	32	30	34	31
mass of water ,g	9	8	11	6	8	7
mass of dry soil ,g	15	12	15	12	15	13
water content,%	60	66.67	73.3	50	53.3	53.8
No of blows	35	23	15	……..	……..	……..

LL=66% PL=52.



Appendix A.2 Particle Size Distribution Curves:



Sieve Analysis

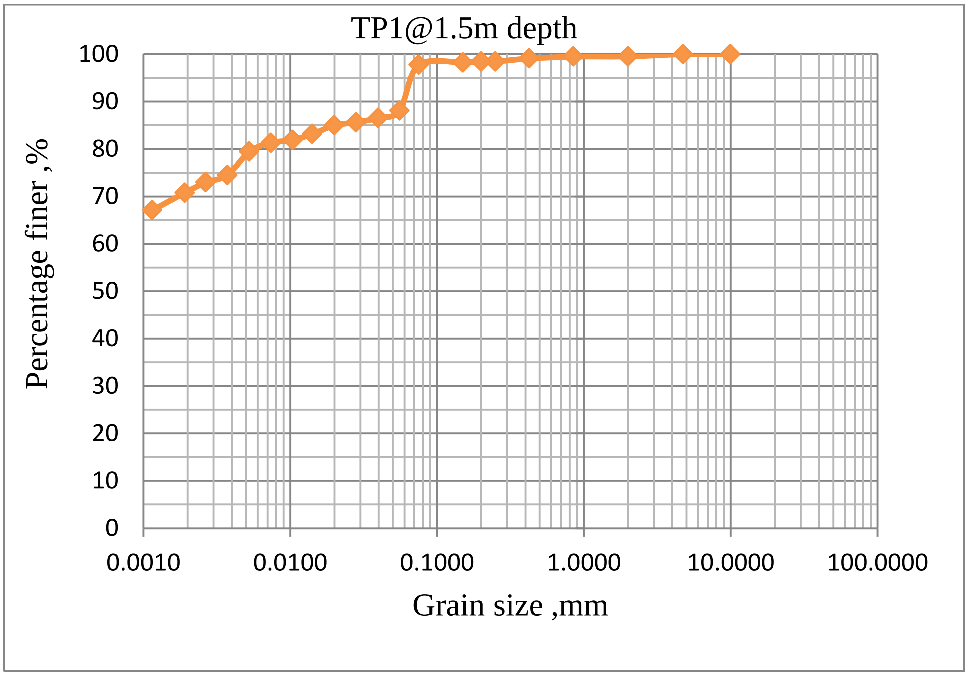
Sample No Tp1@1.5m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0	0	0	100
10	2	9.2	0.46	0.46	99.54
20	0.85	1	0.05	0.51	99.49
40	0.425	8	0.4	0.91	99.09
60	0.25	12.6	0.63	1.54	98.46
80	0.2	0.6	0.03	1.57	98.43
100	0.15	3.4	0.17	1.74	98.26
200	0.075	10.6	0.53	2.27	97.73
	pan	1950.6	97.53	99.8	…………
	Total weight	1996			

Hydrometer analysis

Elapsed Time (min)	Actual Hydrometer Reading	Compos ite Correcti	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient , k	Grain Size (mm)	Perc.Fi ner(%)	Perc. Finer Combin	Test Temp eratur
0.5	1.0320	-0.004	1.0285	7.84	0.014044	0.0556	90.14	87.91	16
1	1.0315	-0.004	1.0280	7.97	0.014044	0.0396	88.56	86.37	16
2	1.0312	-0.004	1.0277	8.05	0.014044	0.0282	87.61	85.45	16
4	1.0310	-0.004	1.0275	8.10	0.014044	0.0200	86.98	84.83	16
8	1.0302	-0.003	1.0269	8.31	0.013880	0.0141	85.08	82.98	17
15	1.0298	-0.003	1.0265	8.42	0.013880	0.0104	83.81	81.74	17
30	1.0296	-0.003	1.0263	8.47	0.013880	0.0074	83.18	81.13	17
60	1.0290	-0.003	1.0257	8.63	0.013880	0.0053	81.28	79.28	17
120	1.0270	-0.003	1.0241	9.16	0.013528	0.0037	76.22	74.34	19
240	1.0265	-0.003	1.0236	9.29	0.013528	0.0027	74.64	72.80	19
480	1.0260	-0.0031	1.0229	9.42	0.013704	0.0019	72.43	70.64	18
1440	1.0252	-0.004	1.0217	9.63	0.014044	0.0011	68.63	66.94	16



Sieve Analysis

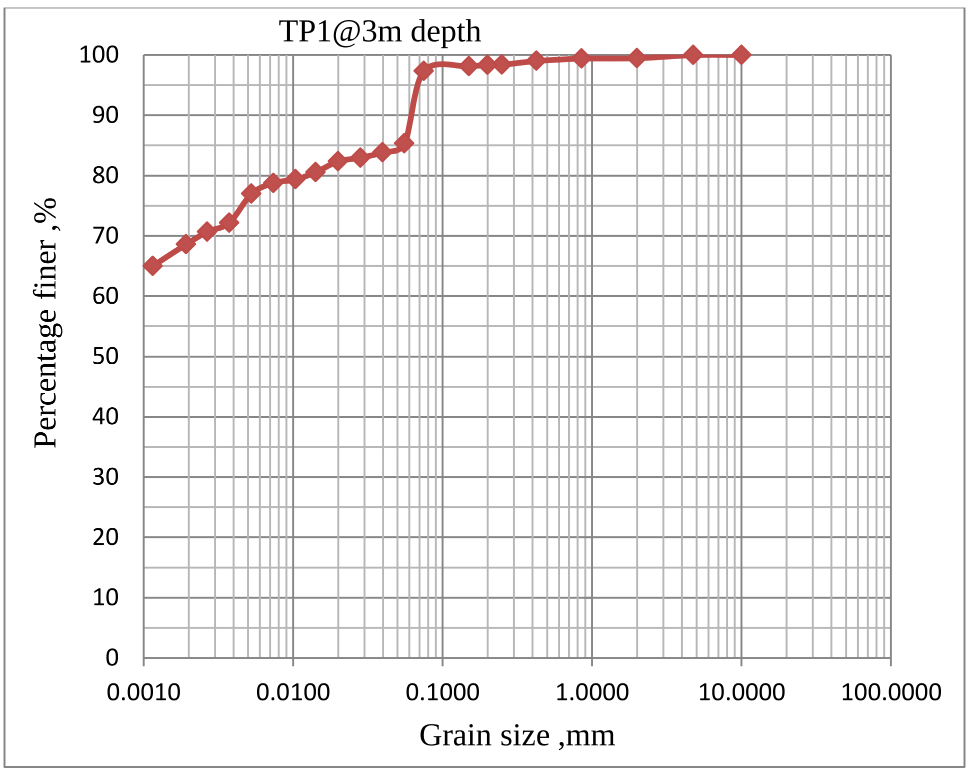
Sample No Tp1@3m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0.5	0.025	0.025	99.9
10	2	10.3	0.515	0.54	99.4
20	0.85	1.3	0.065	0.60	99.3
40	0.425	8	0.4	1.005	98.9
60	0.25	12.4	0.62	1.6	98.3
80	0.2	1.2	0.06	1.6	98.3
100	0.15	4.2	0.21	1.8	98.1
200	0.075	15.4	0.77	2.6	97.3
	pan	1905.6	95.28	97.9	…………
	Total weight	1958.9			

Hydrometer analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0320	-0.0035	1.0285	7.84	0.014044	0.0556	89.57	85.34	16
1	1.0325	-0.0035	1.0290	7.70	0.014044	0.0390	91.14	86.84	16
2	1.0322	-0.0035	1.0287	7.78	0.014044	0.0277	90.20	85.94	16
4	1.0310	-0.0035	1.0275	8.10	0.014044	0.0200	86.43	82.35	16
8	1.0302	-0.0033	1.0269	8.31	0.013880	0.0141	84.54	80.55	17
15	1.0298	-0.0033	1.0265	8.42	0.013880	0.0104	83.29	79.35	17
30	1.0296	-0.0033	1.0263	8.47	0.013880	0.0074	82.66	78.76	17
60	1.0290	-0.0033	1.0257	8.63	0.013880	0.0053	80.77	76.96	17
120	1.0270	-0.0029	1.0241	9.16	0.013528	0.0037	75.74	72.17	19
240	1.0255	-0.0029	1.0226	9.55	0.013528	0.0027	71.03	67.68	19
480	1.0250	-0.0031	1.0219	9.69	0.013704	0.0019	68.83	65.58	18
1440	1.0242	-0.0035	1.0207	9.90	0.014044	0.0012	65.06	61.99	16

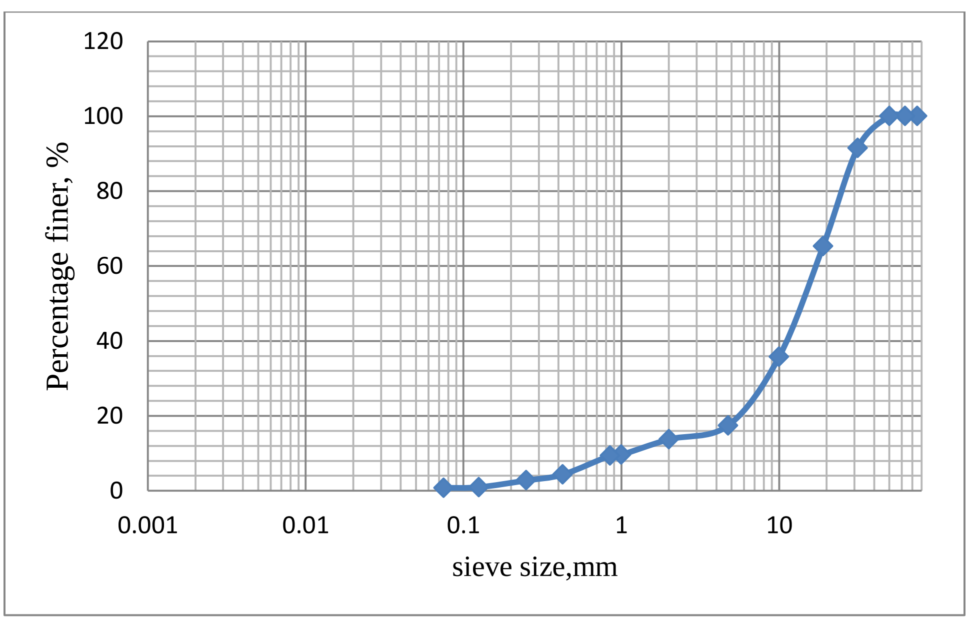


Sieve Analysis

Sample No Tp2@1.5m depth

Project- thesis research

Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
75	0	0	0	100
63	0	0	0	100
50	0	0	0	100
31.5	485.1	8.46	8.46	91.51
19	1505.3	26.27	34.73	65.26
10	1690.2	29.49	64.23	35.77
4.75	1050.1	18.32	82.56	17.44
2	212.5	3.71	86.26	13.73
1	235.4	4.11	90.37	9.62
0.85	12.7	0.22	90.59	9.40
0.425	290.2	5.06	95.66	4.33
0.25	90.1	1.57	97.23	2.76
0.125	103.2	1.8	99.03	0.96
0.075	10.6	0.18	99.22	0.77
pan	42.2	0.7	99.95	………..
Total weight	5727.6			



Sieve Analysis

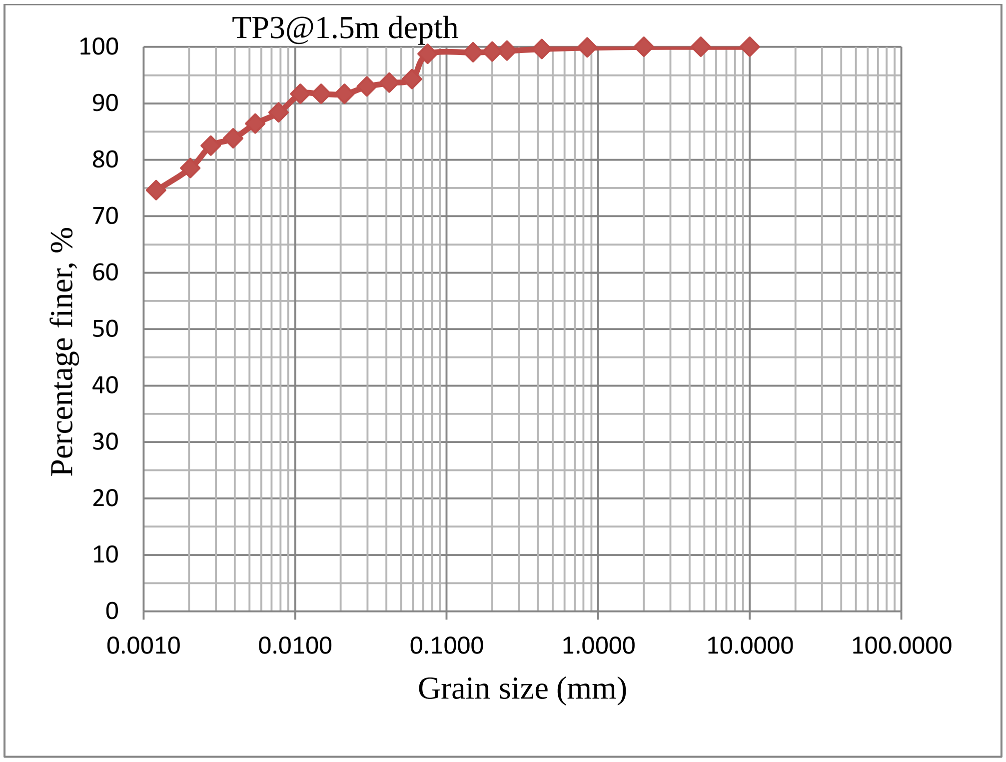
Sample No Tp3@1.5m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0	0	0	100
10	2	0.3	0.015	0.015	99.98
20	0.85	2.6	0.13	0.145	99.85
40	0.425	4.7	0.235	0.38	99.62
60	0.25	6.7	0.335	0.71	99.28
80	0.2	3.4	0.17	0.88	99.11
100	0.15	1.9	0.095	0.98	99.02
200	0.075	5.9	0.295	1.27	98.72
	pan	1960.5	98.025	99.3	…………
	Total weight	1986			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Fine r(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0320	-0.0033	1.0287	7.84	0.014956	0.0592	96.99	92.65	17
1	1.0318	-0.0033	1.0285	7.89	0.014956	0.0420	96.31	92.00	17
2	1.0316	-0.0033	1.0283	7.94	0.014956	0.0298	95.63	91.35	17
4	1.0312	-0.0033	1.0279	8.05	0.014956	0.0212	94.28	90.06	17
8	1.0310	-0.0031	1.0279	8.10	0.01477	0.0149	94.28	90.06	18
15	1.0310	-0.0031	1.0279	8.10	0.01477	0.0109	94.28	90.06	18
30	1.0300	-0.0031	1.0269	8.36	0.01477	0.0078	90.90	86.84	18
60	1.0290	-0.0027	1.0263	8.63	0.01441	0.0055	88.88	84.90	20
120	1.0282	-0.0027	1.0255	8.84	0.01441	0.0039	86.17	82.32	20
240	1.0278	-0.0027	1.0251	8.95	0.01441	0.0028	84.82	81.02	20
480	1.0270	-0.0031	1.0239	9.16	0.01477	0.0020	80.77	77.15	18
1440	1.0262	-0.0035	1.0227	9.37	0.01507	0.0012	76.71	73.28	16



Sieve Analysis

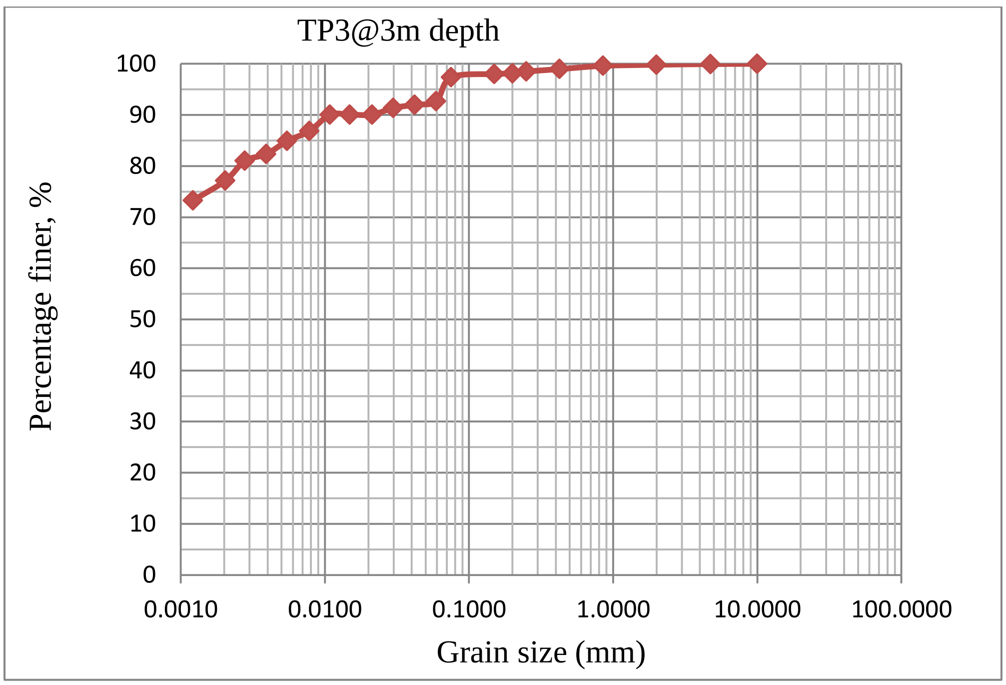
Sample No Tp3@3m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0.9	0.045	0.045	99.95
10	2	2.6	0.13	0.175	99.82
20	0.85	4.3	0.215	0.39	99.61
40	0.425	12.8	0.64	1.03	98.97
60	0.25	9.4	0.47	1.5	98.5
80	0.2	7.5	0.375	1.875	98.12
100	0.15	2.3	0.115	1.99	98.01
200	0.075	12.9	0.64	2.635	97.36
	pan	1910.5	95.52	98.16	…………
	Total weight	1963.2			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0325	-0.0033	1.0292	7.70	0.014956	0.0587	97.86	95.93	17
1	1.0318	-0.0033	1.0285	7.89	0.014956	0.0420	95.51	93.63	17
2	1.0316	-0.0033	1.0283	7.94	0.014956	0.0298	94.84	92.97	17
4	1.0312	-0.0033	1.0279	8.05	0.014956	0.0212	93.50	91.66	17
8	1.0310	-0.0031	1.0279	8.10	0.01477	0.0149	93.50	91.66	18
15	1.0310	-0.0031	1.0279	8.10	0.01477	0.0109	93.50	91.66	18
30	1.0300	-0.0031	1.0269	8.36	0.01477	0.0078	90.15	88.37	18
60	1.0290	-0.0027	1.0263	8.63	0.01441	0.0055	88.14	86.40	20
120	1.0282	-0.0027	1.0255	8.84	0.01441	0.0039	85.46	83.77	20
240	1.0278	-0.0027	1.0251	8.95	0.01441	0.0028	84.12	82.46	20
480	1.0270	-0.0031	1.0239	9.16	0.01477	0.0020	80.10	78.52	18
1440	1.0261	-0.0035	1.0226	9.40	0.01507	0.0012	75.74	74.24	16



Sieve Analysis

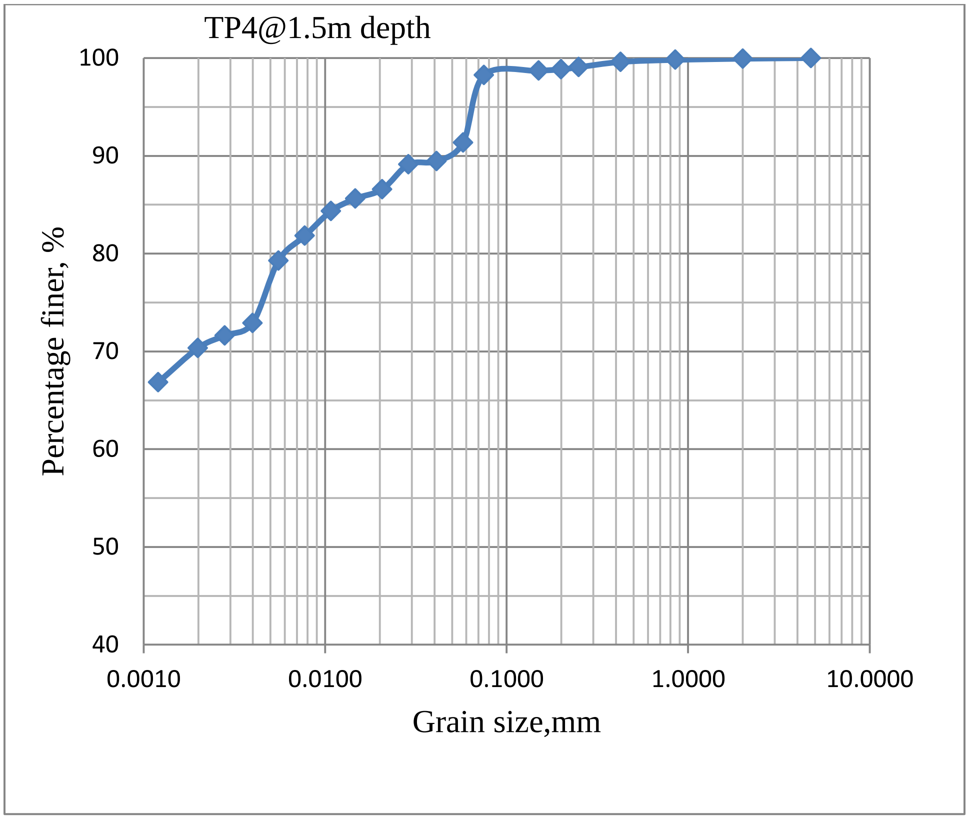
Sample No Tp4@1.5m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0	0	0	100
10	2	1.3	0.065	0.065	99.935
20	0.85	2.4	0.12	0.185	99.815
40	0.425	4.2	0.21	0.395	99.605
60	0.25	10.7	0.535	0.93	99.07
80	0.2	4.6	0.23	1.16	98.84
100	0.15	2.9	0.145	1.305	98.695
200	0.075	8.7	0.435	1.74	98.26
	pan	1954.2	97.71	99.45	…………
	Total weight	1989			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0322	-0.0035	1.0287	7.78	0.01458	0.0575	93.50	91.36	16
1	1.0316	-0.0035	1.0281	7.94	0.01458	0.0411	91.55	89.45	16
2	1.0313	-0.0033	1.0280	8.02	0.01440	0.0288	91.22	89.13	17
4	1.0305	-0.0033	1.0272	8.23	0.01440	0.0207	88.61	86.58	17
8	1.0302	-0.0033	1.0269	8.31	0.01440	0.0147	87.64	85.63	17
15	1.0298	-0.0033	1.0265	8.42	0.01440	0.0108	86.33	84.36	17
30	1.0290	-0.0033	1.0257	8.63	0.01440	0.0077	83.73	81.81	17
60	1.0282	-0.0033	1.0249	8.84	0.01440	0.0055	81.12	79.26	17
120	1.0260	-0.0031	1.0229	9.42	0.01420	0.0040	74.61	72.90	18
240	1.0254	-0.0029	1.0225	9.58	0.01404	0.0028	73.30	71.62	19
480	1.0250	-0.0029	1.0221	9.69	0.01404	0.0020	72.00	70.35	19
1440	1.0245	-0.0035	1.0210	9.82	0.01458	0.0012	68.42	66.85	16



Sieve Analysis

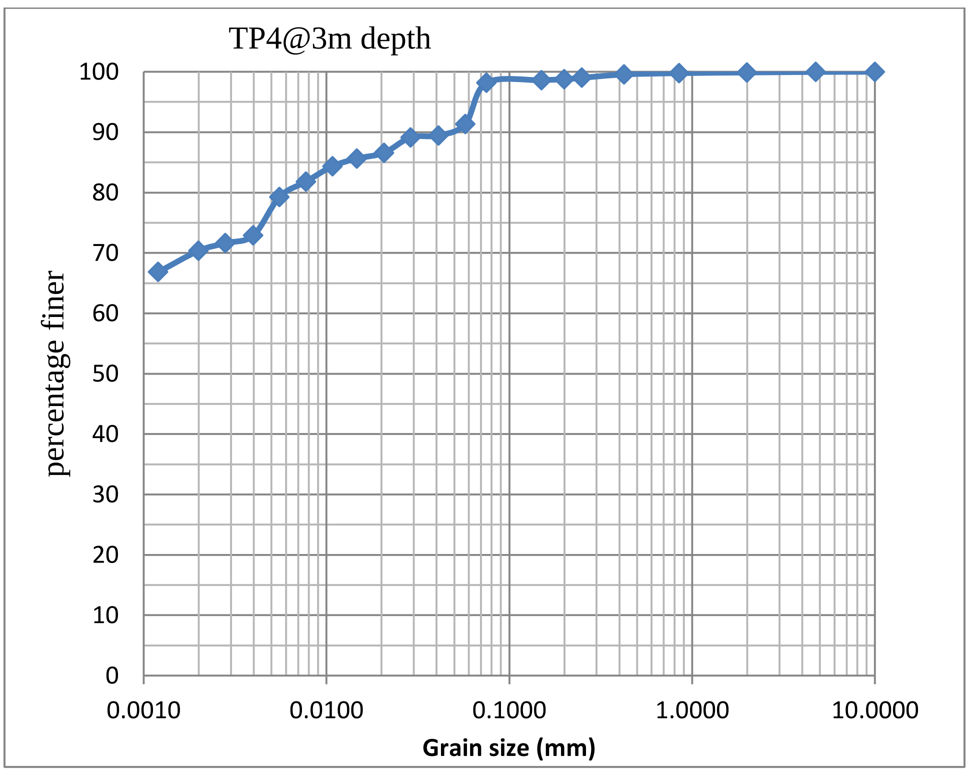
Sample No Tp4@3m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0.6	0.03	0.03	99.97
10	2	1.7	0.085	0.115	99.88
20	0.85	2.3	0.115	0.23	99.77
40	0.425	4.2	0.21	0.44	99.56
60	0.25	11.1	0.555	0.99	99.005
80	0.2	4.8	0.24	1.23	98.76
100	0.15	3.2	0.16	1.39	98.60
200	0.075	8.4	0.42	1.81	98.18
	pan	1954.2	97.71	99.52	…………
	Total weight	1990.5			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0320	-0.0035	1.0285	7.84	0.01458	0.0577	92.85	90.72	16
1	1.0315	-0.0035	1.0280	7.97	0.01458	0.0412	91.22	89.13	16
2	1.0313	-0.0033	1.0280	8.02	0.01440	0.0288	91.22	89.13	17
4	1.0305	-0.0033	1.0272	8.23	0.01440	0.0207	88.61	86.58	17
8	1.0302	-0.0033	1.0269	8.31	0.01440	0.0147	87.64	85.63	17
15	1.0298	-0.0033	1.0265	8.42	0.01440	0.0108	86.33	84.36	17
30	1.0290	-0.0033	1.0257	8.63	0.01440	0.0077	83.73	81.81	17
60	1.0282	-0.0033	1.0249	8.84	0.01440	0.0055	81.12	79.26	17
120	1.0260	-0.0031	1.0229	9.42	0.01420	0.0040	74.61	72.90	18
240	1.0252	-0.0029	1.0223	9.63	0.01404	0.0028	72.65	70.99	19
480	1.0250	-0.0029	1.0221	9.69	0.01404	0.0020	72.00	70.35	19
1440	1.0220	-0.0035	1.0185	10.48	0.01458	0.0012	60.27	58.89	16



Sieve Analysis

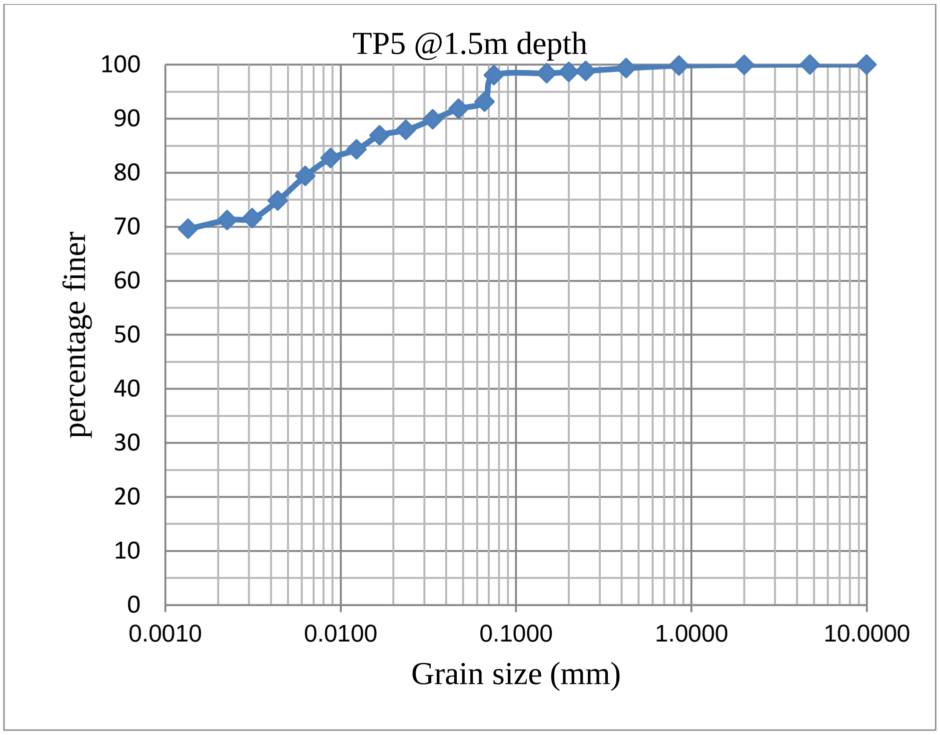
Sample No Tp5@1.5m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	0	0	0	100
10	2	1	0.05	0.05	99.95
20	0.85	2.8	0.14	0.19	99.81
40	0.425	9.5	0.475	0.67	99.33
60	0.25	10.2	0.51	1.18	98.82
80	0.2	3.9	0.195	1.37	98.63
100	0.15	4.6	0.23	1.6	98.4
200	0.075	7.5	0.375	1.97	98.025
	pan	1950.5	97.52	99.5	…………
	Total weight	1990			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0260	-0.0035	1.0225	9.42	0.01505	0.0653	75.61	68.14	16
1	1.0244	-0.0035	1.0209	9.85	0.01505	0.0472	70.24	63.30	16
2	1.0242	-0.0035	1.0207	9.90	0.01505	0.0335	69.56	62.69	16
4	1.0235	-0.0033	1.0202	10.08	0.01486	0.0236	67.88	61.18	17
8	1.0233	-0.0033	1.0200	10.14	0.01486	0.0167	67.21	60.57	17
15	1.0224	-0.0033	1.0191	10.37	0.01486	0.0124	64.19	57.84	17
30	1.0220	-0.0033	1.0187	10.48	0.01486	0.0088	62.84	56.63	17
60	1.0210	-0.0033	1.0177	10.75	0.01486	0.0063	59.48	53.60	17
120	1.0200	-0.0029	1.0171	11.01	0.01449	0.0044	57.47	51.79	19
240	1.0190	-0.0029	1.0161	11.27	0.01449	0.0031	54.10	48.76	19
480	1.0185	-0.0031	1.0154	11.41	0.01467	0.0023	51.75	46.64	18
1440	1.0174	-0.0035	1.0139	11.70	0.01505	0.0014	46.71	42.10	16



Sieve Analysis

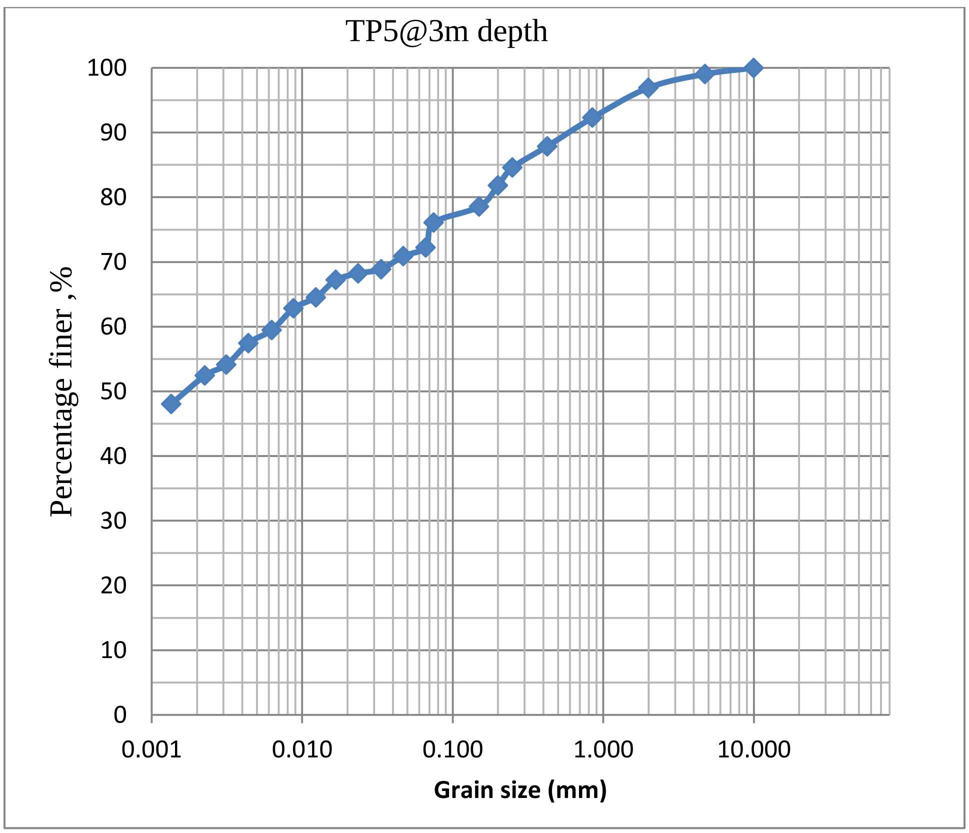
Sample No Tp5@3m depth

Project- thesis research

Sieve No	Sieve Size (opening),mm	mass retained ,g	percentage retained	cumulative percentage retained	percentage finer
	10	0	0	0	100
4	4.75	19.2	0.96	0.96	99.04
10	2	42.3	2.115	3.075	96.92
20	0.85	92.5	4.625	7.7	92.3
40	0.425	88.4	4.42	12.12	87.88
60	0.25	65.8	3.29	15.41	84.59
80	0.2	55	2.75	18.16	81.84
100	0.15	66	3.3	21.46	78.54
200	0.075	49	2.45	23.91	76.09
	pan	1802.4	90.12	114.03	…………
	Total weight	2280.6			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer	Composite Correcti	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0250	0.0035	1.0285	9.69	0.01505	0.0662	95.00	92.65	16
1	1.0246	0.0035	1.0281	9.79	0.01505	0.0471	93.67	91.35	16
2	1.0240	0.0035	1.0275	9.95	0.01505	0.0336	91.67	89.40	16
4	1.0236	0.0033	1.0269	10.06	0.01486	0.0236	89.67	87.45	17
8	1.0233	0.0033	1.0266	10.14	0.01486	0.0167	88.67	86.47	17
15	1.0225	0.0033	1.0258	10.35	0.01486	0.0123	86.00	83.87	17
30	1.0220	0.0033	1.0253	10.48	0.01486	0.0088	84.33	82.25	17
60	1.0210	0.0033	1.0243	10.75	0.01486	0.0063	81.00	79.00	17
120	1.0200	0.0029	1.0229	11.01	0.01449	0.0044	76.33	74.44	19
240	1.0190	0.0029	1.0219	11.27	0.01449	0.0031	73.00	71.19	19
480	1.0187	0.0031	1.0218	11.35	0.01467	0.0023	72.67	70.87	18
1440	1.0178	0.0035	1.0213	11.59	0.01505	0.0014	71.00	69.24	16



Sieve Analysis

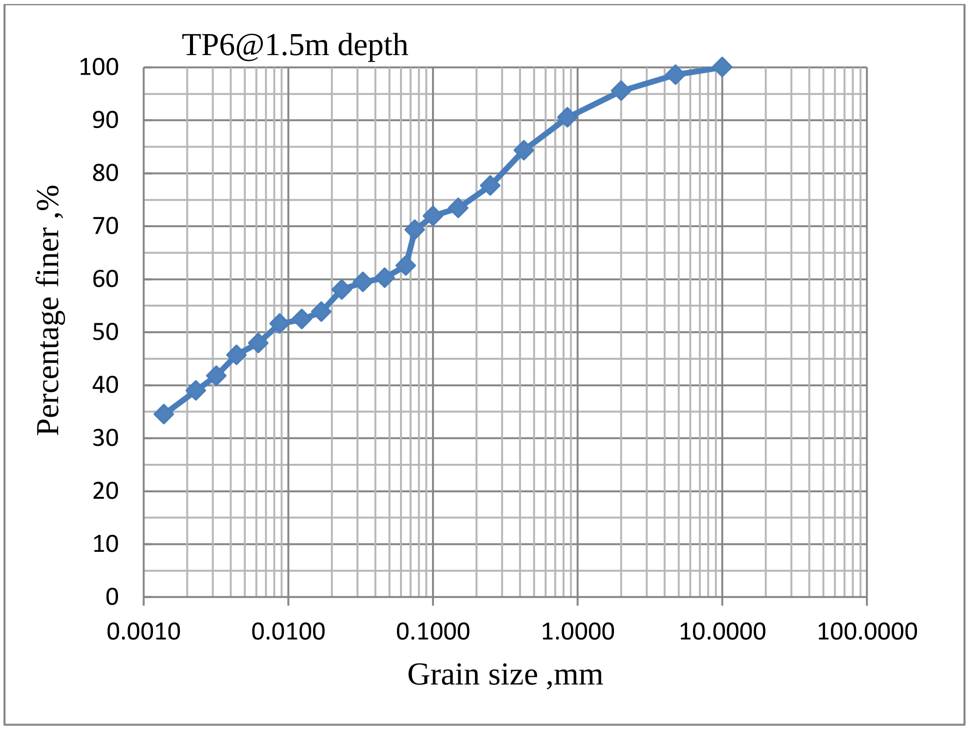
Sample No Tp6@1.5m depth

Project- thesis research

Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
10	0	0	0	100
4.75	28.4	1.42	1.42	98.58
2	60.9	3.045	4.46	95.53
0.85	100.2	5.01	9.475	90.52
0.425	124.2	6.21	15.68	84.31
0.25	132.8	6.64	22.32	77.67
0.15	84.8	4.24	26.56	73.43
0.1	29.7	1.485	28.05	71.95
0.075	52.8	2.64	30.69	69.31
pan	1682.3	84.115	114.80	………
Total weight	2296.1			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0256	-0.0033	1.0223	9.53	0.01486	0.0649	74.33	62.53	17
1	1.0248	-0.0033	1.0215	9.74	0.01486	0.0464	71.67	60.28	17
2	1.0245	-0.0033	1.0212	9.82	0.01486	0.0329	70.67	59.44	17
4	1.0240	-0.0033	1.0207	9.95	0.01486	0.0234	69.00	58.04	17
8	1.0225	-0.0033	1.0192	10.35	0.01486	0.0169	64.00	53.83	17
15	1.0220	-0.0033	1.0187	10.48	0.01486	0.0124	62.33	52.43	17
30	1.0215	-0.0031	1.0184	10.61	0.01467	0.0087	61.33	51.59	18
60	1.0200	-0.0029	1.0171	11.01	0.01449	0.0062	57.00	47.95	19
120	1.0190	-0.0027	1.0163	11.27	0.01431	0.0044	54.33	45.70	20
240	1.0178	-0.0029	1.0149	11.59	0.01449	0.0032	49.67	41.78	19
480	1.0170	-0.0031	1.0139	11.80	0.01467	0.0023	46.33	38.97	18
1440	1.0158	-0.0035	1.0123	12.12	0.01505	0.0014	41.00	34.49	16



Sieve Analysis

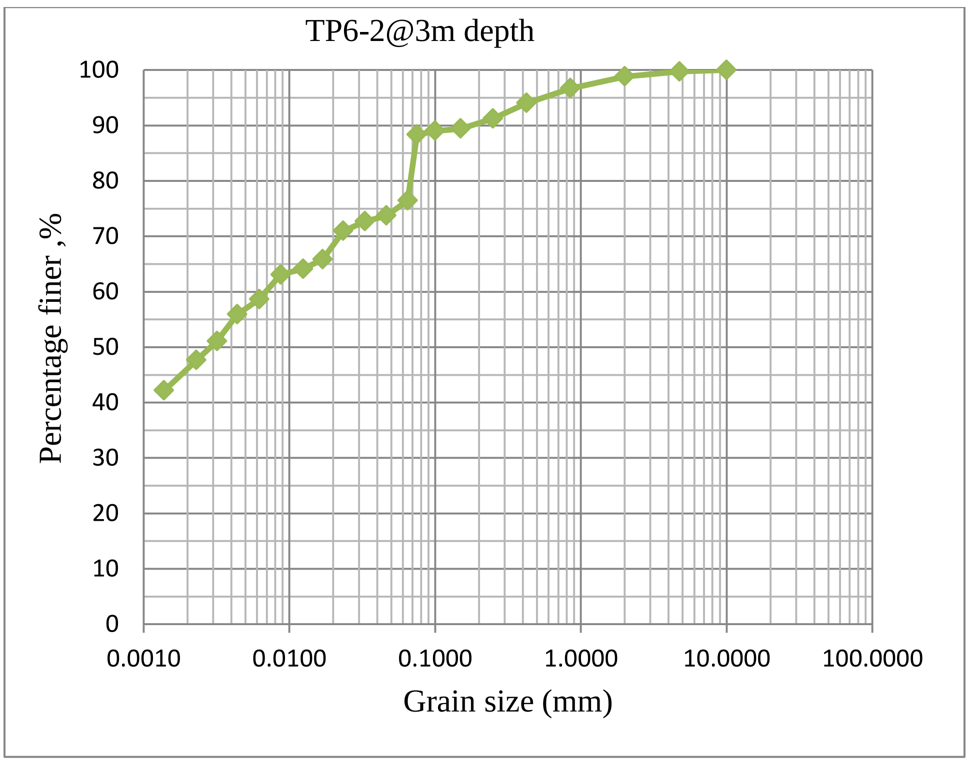
Sample No Tp6@3m depth

Project- thesis research

Sieve Size (opening),mm	mass retained, g	percentage retained	cumulative percentage retained	percentage finer
10	0	0	0	100
4.75	5.2	0.26	0.26	99.74
2	18.4	0.92	1.18	98.82
0.85	42.3	2.115	3.29	96.70
0.425	53.4	2.67	5.96	94.03
0.25	55.6	2.78	8.74	91.255
0.15	36.7	1.835	10.58	89.42
0.1	7.8	0.39	10.97	89.03
0.075	14.3	0.715	11.68	88.31
pan	1746.2	87.31	98.99	………
Total weight	1979.9			

Hydrometer Analysis

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient, k	Grain Size (mm)	Perc.Finer(%)	Perc. Finer Combine	Test Temperature,
0.5	1.0266	-0.0033	1.0233	9.26	0.01486	0.0640	79.89	69.75	17
1	1.0258	-0.0033	1.0225	9.48	0.01486	0.0457	77.14	67.35	17
2	1.0255	-0.0033	1.0222	9.55	0.01486	0.0325	76.11	66.46	17
4	1.0250	-0.0033	1.0217	9.69	0.01486	0.0231	74.40	64.96	17
8	1.0235	-0.0033	1.0202	10.08	0.01486	0.0167	69.26	60.47	17
15	1.0230	-0.0033	1.0197	10.22	0.01486	0.0123	67.54	58.97	17
30	1.0225	-0.0031	1.0194	10.35	0.01467	0.0086	66.51	58.07	18
60	1.0220	-0.0029	1.0191	10.48	0.01449	0.0061	65.49	57.18	19
120	1.0200	-0.0027	1.0173	11.01	0.01431	0.0043	59.31	51.79	20
240	1.0178	-0.0029	1.0149	11.59	0.01449	0.0032	51.09	44.60	19
480	1.0172	-0.0031	1.0141	11.75	0.01467	0.0023	48.34	42.21	18
1440	1.0168	-0.0035	1.0133	11.86	0.01505	0.0014	45.60	39.81	16



Appendix A.3 Standard Proctor Compaction Test

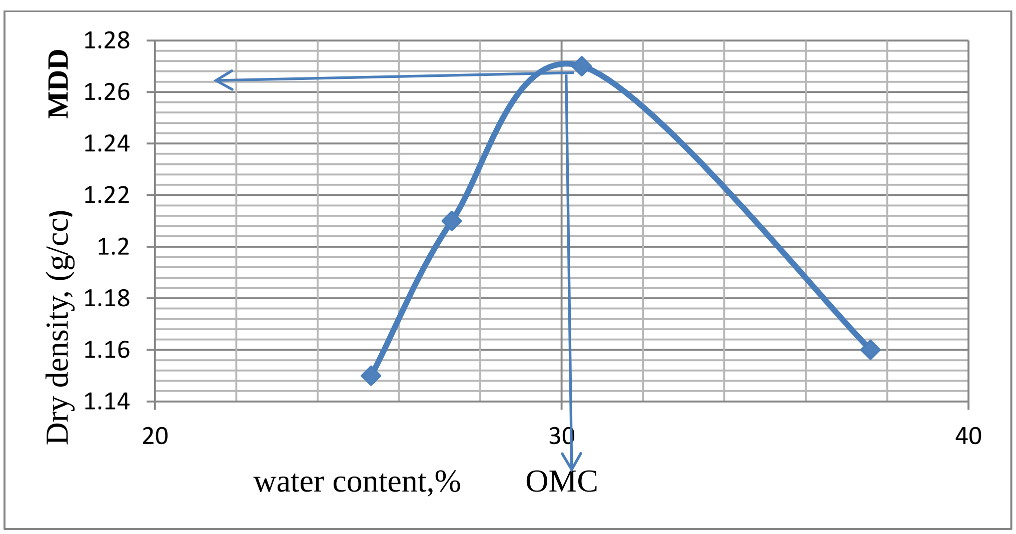
Water Content Determination (sample TP1-1@1.5m depth)

compacted soil sample no	1			2		3		4	
moisture Content can no	M11	M12	M13	M21	M22	M31	M32	M41	M42
MC = Mass of empty, clean can + lid (grams)	18	18	18	18	18	18	17	19	20
MCMS = Mass of can, lid, and moist soil (grams)	122	140	109	130	134	99	107	62	61
MCDS = Mass of can, lid, and dry soil (grams)	102	115	90	106	109	80	86	50	50
MS = Mass of soil solids (grams)	84	97	72	88	91	62	69	31	30
MW = Mass of pore water (grams)	20	25	19	24	25	19	21	12	11
w = Water content, w%	23.81	25.8	26.4	27	27.5	30.65	30.4	38.71	37
Average water content ,w%	25.32			27.37		30.54		37.69	

Density Determination:

Volume of mold = 944 cm3

Compacted Soil - Sample no.	1	2	3	4
mass of mold (grams)	3120	3123	2990	1848
Mass of compacted soil and mold (grams)	4480	4565	4560	3358
Wet mass of soil in mold (grams)	1360	1442	1570	1510
Wet density, ρ , (g/cm)	1.44	1.53	1.66	1.60
Dry density, ρd , (g/cm3)	1.15	1.2	1.274	1.162



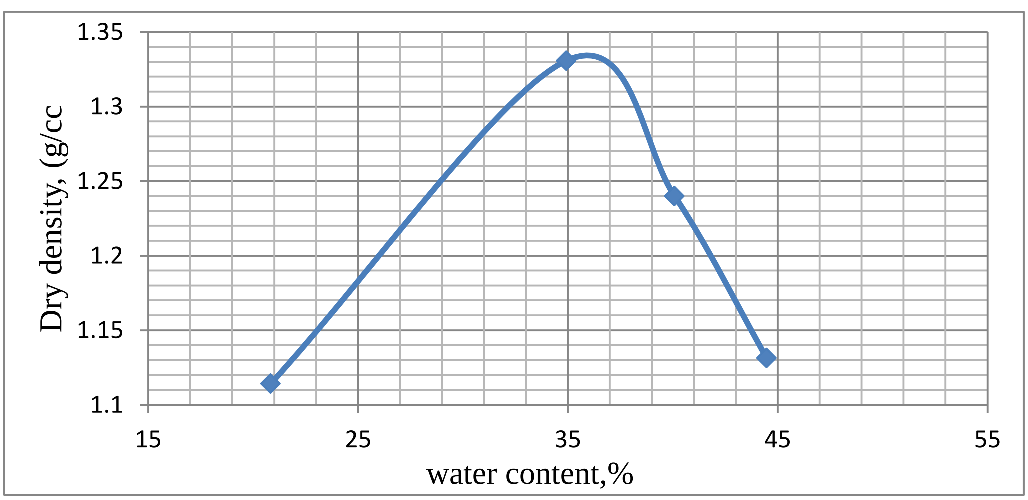
Water Content Determination TP1-2@3m depth

compacted soil sample no	1		2		3		4	
moisture Content can no	11	12	21	23	31	32	41	42
MC = Mass of empty, clean can + lid (grams)	20.5	17.5	19.2	18	18.3	18.6	18.3	18.6
MCMS = Mass of can, lid, and moist soil (grams)	70.5	65.6	56	58	76.8	64.2	68.7	81.4
MCDS = Mass of can, lid, and dry soil (grams)	62.2	57	46.2	48	60	51.2	53	62.3
MS = Mass of soil solids (grams)	41.7	39.5	27	30	41.7	32.6	34.7	43.7
MW = Mass of pore water (grams)	8.3	8.6	9.8	10	16.8	13	15.7	19.1
w = Water content, w%	19.9	21.77	36.3	34	40.3	39.9	45.2	43.7
Average water content ,w%	20.84		34.93		40.08		44.47	

Density Determination:

Volume of mold = 944 cm3

Compacted Soil - Sample no.	1	2	3	4
mass of mold (grams)	1745	1745	1745	1745
Mass of compacted soil and mold (grams)	3016	3440	3316	3288
Wet mass of soil in mold (grams)	1271	1695	1571	1543
Wet density, ρ , (g/cc)	1.35	1.79	1.66	1.63
Dry density, ρd , (g/cc)	1.11	1.33	1.18	1.13



Water Content Determination (TP2-1 @1.5m)

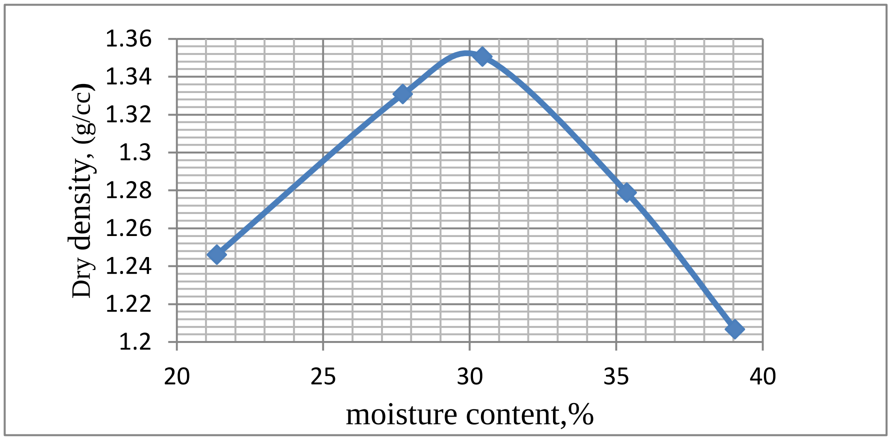
compacted soil sample no	1			2			3		
moisture Content can no	D11	D12	D13	D21	D22	D23	D31	D32	D33
MC = Mass of empty, clean can + lid (grams)	17	17	17	17	17	17	17	25	18
MCMS = Mass of can, lid, and moist soil (grams)	61	70	102	77	62	68	86	104	109
MCDS = Mass of can, lid, and dry soil (grams)	53	61	87	64	53	57	71	85	87
MS = Mass of soil solids (grams)	36	44	70	47	36	40	54	60	69
MW = Mass of pore water (grams)	8	9	15	13	9	11	15	19	22
w = Water content, w%	22.2	20.5	21.4	27.7	25	27.5	27.8	31.7	32
Average water content ,w%	21.37			26.72			30.44		

compacted soil sample no	4			5		
moisture Content can no	D41	D42	D43	D51	D52	D53
MC = Mass of empty, clean can + lid (grams)	17	18	17	17	18	18
MCMS = Mass of can, lid, and moist soil (grams)	68	96	124	112	95	89
MCDS = Mass of can, lid, and dry soil (grams)	54	76	97	86	74	68
MS = Mass of soil solids (grams)	37	58	80	69	56	50
MW = Mass of pore water (grams)	14	20	27	26	21	21
w = Water content, w%	37.8	34.5	33.8	37.7	37.5	42
Average water content ,w%	35.36			39.06		

Density Determination:

Volume of mold 944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
mass of mold (grams)	1724	1724	1724	1724	1724
Mass of compacted soil and mold (grams)	3152	3316	3387	3358	3308
Wet mass of soil in mold (grams)	1428	1592	1663	1634	1584
Wet density, ρ , (kg/m)	1.51	1.69	1.76	1.73	1.68
Dry density, ρd , (kg/m)	1.25	1.33	1.35	1.28	1.21



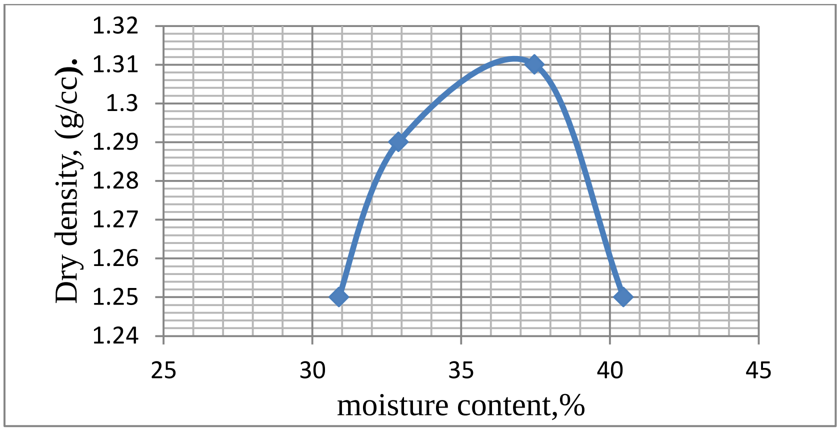
Water Content Determination:
TP3.1@1.5m depth.

compacted soil sample no	1			2			3			4		
moisture Content can no	D31	D32	D33	D41	D42	D43	D51	D52	D53	D61	D62	D63
MC = Mass of empty, clean can + lid (grams)	17	18	17	19	18	18	18	18	17	18	16	17
MCMS = Mass of can, lid, and moist soil (grams)	120	76	124	125	107	114	112	83	108	97	103	81
MCDS = Mass of can, lid, and dry soil (grams)	96	62	99	99	85	90	87	65	83	74	79	62
MS = Mass of soil solids (grams)	79	44	82	80	67	72	69	47	66	56	63	45
MW = Mass of pore water (grams)	24	14	25	26	22	24	25	18	25	23	24	19
w = Water content, w%	30.4	31.82	30	32.5	32.8	33.3	36.2	38.3	38	41.1	38	42.2
Average water content, w%	30.8			32.8			37.4			40.4		

Density Determination:

Volume of mold = 944 cm3

Compacted Soil - Sample no.	1	2	3	4
mass of mold (grams)	1724	1724	1724	1724
Mass of compacted soil and mold (grams)	3269	3340	3421	3392
Wet mass of soil in mold (grams)	1545	1616	1697	1668
Wet density, ρ , (kg/m)	1.64	1.71	1.8	1.77
Dry density, ρd , (kg/m)	1.19	1.29	1.31	1.26

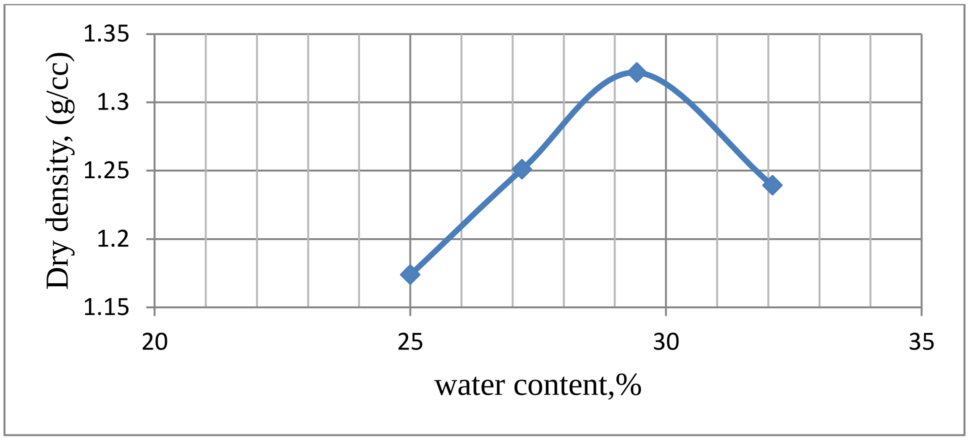


Water Content Determination:TP3-2@ 3m depth

compacted soil sample no	1		2		3		4	
moisture Content can no	D11	D12	D21	D23	D31	D32	D41	D42
MC = Mass of empty, clean can + lid (g)	18	18	18	18	18	18	18	18
MCMS = Mass of can, lid, and moist soil (g)	73	68	54	57	72	61	63	76
MCDS = Mass of can, lid, and dry soil (g)	62	58	46	49	60	51	52	62
MS = Mass of soil solids (grams)	44	40	28	31	42	33	34	44
MW = Mass of pore water (g)	11	10	8	8	12	10	11	14
w = Water content, w%	25	25	28.6	25.8	29	30	32	32
Average water content ,w%	25		27.19		29.44		32.08	

Density Determination:
Volume of mold
= 944 cm3

Compacted Soil - Sample no.	1	2	3	4
mass of mold (grams)	1745	1745	1745	1745
Mass of compacted soil and mold (grams)	3130	3211	3360	3290
Wet mass of soil in mold (grams)	1385	1466	1615	1545
Wet density, ρ , (g/cc)	1.47	1.55	1.71	1.64
Dry density, ρd , (g/cc)	1.17	1.22	1.32	1.24



Water Content Determination:TP4-1@1.5m depth

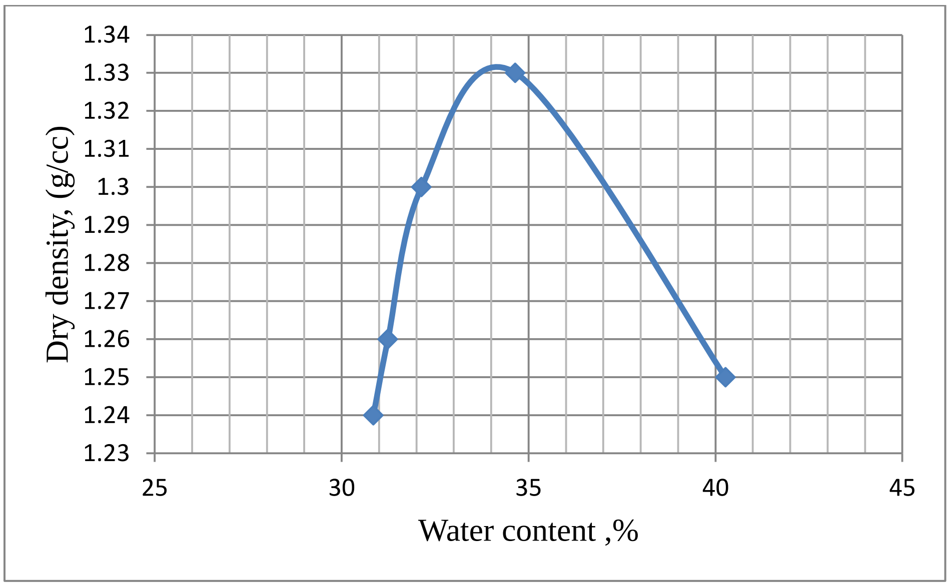
compacted soil sample no	1			2			3		
moisture Content can no	G11	G12	G13	G21	G22	G23	G31	G32	G33
MC = Mass of empty, clean can + lid (grams)	19	17	18	16	19	17	19	18	17
MCMS = Mass of can, lid, and moist soil (grams)	72	100	91	87	100	92	85	118	76
MCDS = Mass of can, lid, and dry soil (grams)	59	81	74	70	81	74	69	93	62
MS = Mass of soil solids (grams)	40	64	56	54	62	57	50	75	45
MW = Mass of pore water (grams)	13	19	17	17	19	18	16	25	14
w = Water content, w%	32.5	29.69	30.4	31.5	30.6	32	32	33.3	31
Average water content ,w%	30.85			31.23			32.15		

compacted soil sample no	4			5		
moisture Content can no	G41	G42	G43	G51	G52	G53
MC = Mass of empty, clean can + lid (grams)	17	17	25	27	27	26
MCMS = Mass of can, lid, and moist soil (grams)	95	103	102	143	142	108
MCDS = Mass of can, lid, and dry soil (grams)	75	81	82	111	107	85
MS = Mass of soil solids (grams)	58	64	57	84	80	59
MW = Mass of pore water (grams)	20	22	20	32	35	23
w = Water content, w%	34.483	34.38	35.1	38.1	43.8	39
Average water content ,w%	34.65			40.28		

Density Determination:

Volume of mold = 944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
mass of mold (grams)	1724	1724	1724	1724	1724
Mass of compacted soil and mold (grams)	3270	3334	3379	3410	3385
Wet mass of soil in mold (grams)	1532	1610	1655	1686	1661
Wet density, ρ , (kg/m)	1.62	1.71	1.75	1.79	1.76
Dry density, ρd , (kg/m)	1.24	1.30	1.33	1.33	1.25



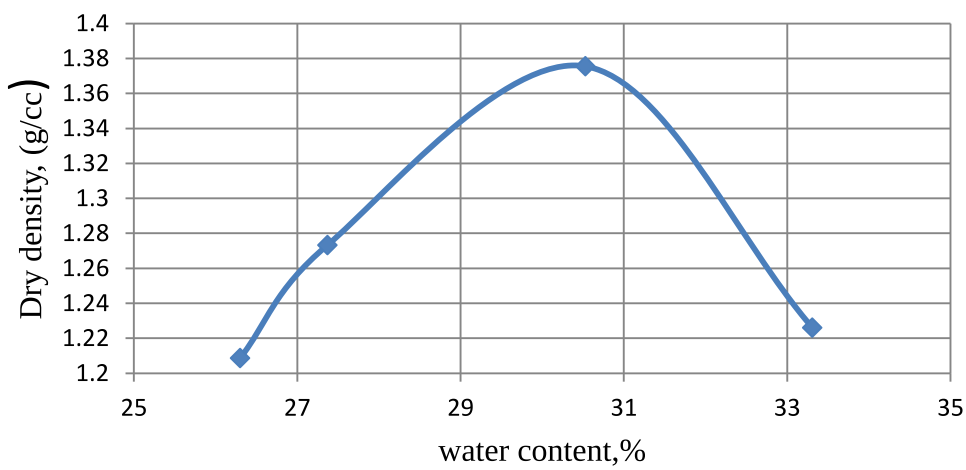
Water Content Determination:TP4-2@3m depth

compacted soil sample no	1		2		3		4	
moisture Content can no	G11	G12	G21	G23	G31	G32	G41	G42
MC = Mass of empty, clean can + lid (grams)	18	18	18	18	18	17	19	18
MCMS = Mass of can, lid, and moist soil (grams)	122	140	130	134	99	107	60	61
MCDS = Mass of can, lid, and dry soil (grams)	100	115	106	109	80	86	50	50
MS = Mass of soil solids (grams)	82	97	88	91	62	69	31	32
MW = Mass of pore water (grams)	22	25	24	25	19	21	10	11
w = Water content, w%	26.8	25.8	27.3	27.5	30.6	30.4	32.3	34.4
Average water content ,w%	26.30		27.37		30.54		33.32	

Density Determination:

Volume of mold = 944 cm3

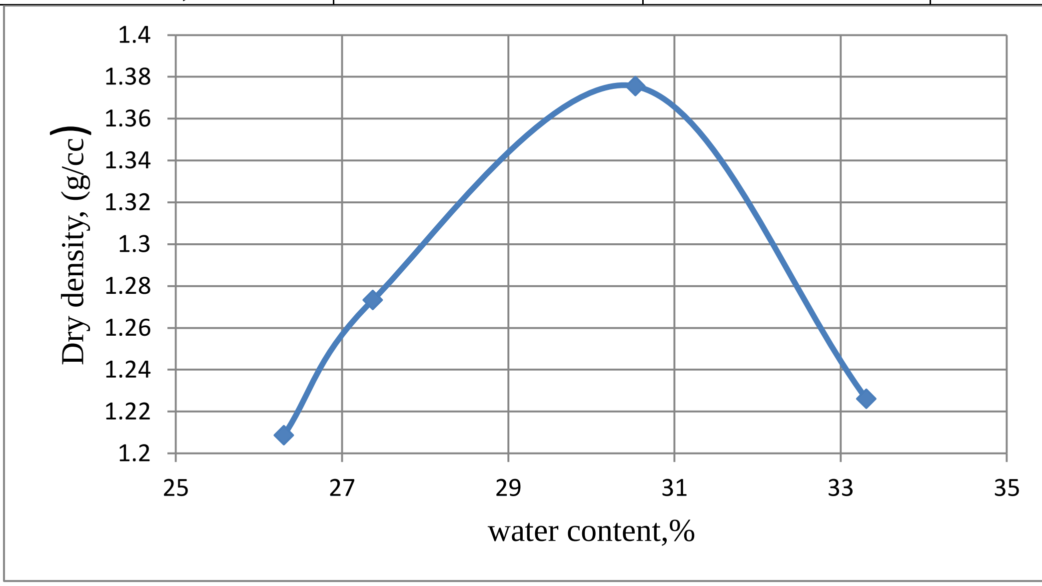
Compacted Soil - Sample no.	1	2	3	4
mass of mold (grams)	1745	1745	1745	1745
Mass of compacted soil and mold (grams)	3186	3276	3440	3288
Wet mass of soil in mold (grams)	1441	1531	1695	1543
Wet density, ρ , (g/cc)	1.53	1.62	1.8	1.63
Dry density, ρd , (g/cc)	1.21	1.27	1.38	1.23



Water Content Determination:TP5-1 @1.5m depth

compacted soil sample no	1			2			3		
moisture Content can no	H11	H12	H13	H21	H22	H23	H31	H32	H33
MC = Mass of empty, clean can + lid (grams)	18	18	18	17	18	18	18	18	18
MCMS = Mass of can, lid, and moist soil (grams)	89	90	80	66	84	100	87	103	96
MCDS = Mass of can, lid, and dry soil (grams)	74	75	68	56	70	82	72	83	79
MS = Mass of soil solids (grams)	56	57	50	39	52	64	54	65	61
MW = Mass of pore water (grams)	15	15	12	10	14	18	15	20	17
w = Water content, w%	26.8	26.3	24	25.6	26.92	28.13	27.78	30.77	27.87
Average water content ,w%	25.70			26.89			28.81		

compacted soil sample no	4			5			6		
moisture Content can no	H41	H42	H43	H51	H52	H53	H61	H62	H63
MC = Mass of empty, clean can + lid (grams)	17	17	18	18	17	17	18	18	18
MCMS = Mass of can, lid, and moist soil (grams)	119	90	69	74	85	99	109	106	68
MCDS = Mass of can, lid, and dry soil (grams)	95	72	57	59	68	78	84	83	54
MS = Mass of soil solids (grams)	78	55	39	41	51	61	66	65	36
MW = Mass of pore water (grams)	24	18	12	15	17	21	25	23	14
w = Water content, w%	30.80	32.70	30.77	36.6	33.33	34.43	37.88	35.38	38.89
Average water content, w%	31.42			34.78			37.38		

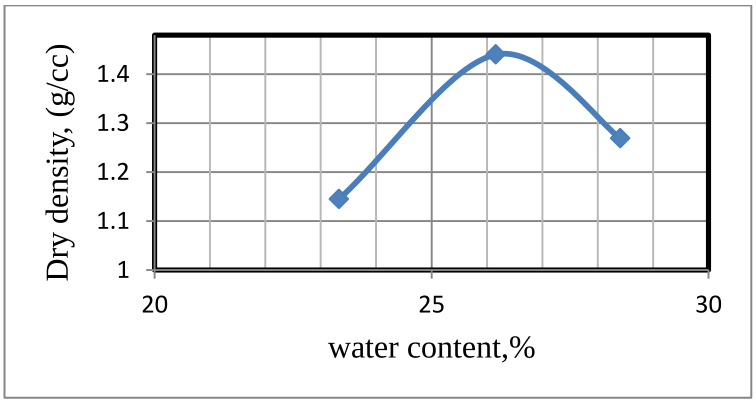


Water Content Determination:TP5-2@5.2 m depth

compacted soil sample no	1		2		3	
moisture Content can no	H11	H12	H21	H22	H31	H32
MC = Mass of empty, clean can + lid (g)	18	17	18	17	19	17
MCMS = Mass of can, lid, and moist soil (g)	61	69	95	79	64	76
MCDS = Mass of can, lid, and dry soil (g)	53	59	78	67	54	63
MS = Mass of soil solids (grams)	35	42	60	50	35	46
MW = Mass of pore water (g)	8	10	17	12	10	13
w = Water content, w%	22.9	23.8	28	24	28.6	28
Average water content ,w%	23.33		26.17		28.42	

Density Determination:
Volume of mold
= 944 cm3

Compacted Soil - Sample no.	1	2	3	4	5	6
mass of mold (grams)	1724	1724	1724	1724	1724	1724
Mass of compacted soil and mold (g)	3171	3245	3319	3401	3395	3316
Wet mass of soil in mold (grams)	1447	1521	1595	1677	1671	1592
Wet density, ρ , (kg/m)	1.53	1.61	1.69	1.78	1.77	1.69
Dry density, ρd , (kg/m)	1.22	1.27	1.31	1.35	1.31	1.23



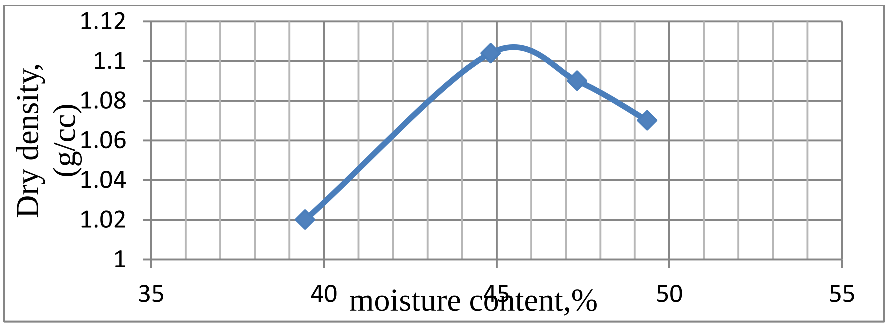
Water Content Determination:TP6-1@1.5m depth.

compacted soil sample no	1			2			3		
moisture Content can no	U11	U12	U13	U21	U22	U23	U31	U32	U33
MC = Mass of empty, clean can + lid (grams)	17	17	17	18	17	17	17	25	18
MCMS = Mass of can, lid, and moist soil (grams)	95	70	102	97	62	68	112	104	109
MCDS = Mass of can, lid, and dry soil (grams)	72	55	79	73	48	52	82	78	80
MS = Mass of soil solids (grams)	55	38	62	55	31	35	65	53	62
MW = Mass of pore water (g)	23	15	23	24	14	16	30	26	29
w = Water content, w%	42	39	37.1	44	45	46	46	49	47
Average water content ,w%	39.46			44.84			47.33		

Density Determination:

Volume of mold = 944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
mass of mold (grams)	1724	1724	1724	1724	1724
Mass of compacted soil and mold (g)	3176	3234	3237	3240	3232
Wet mass of soil in mold (grams)	1452	1510	1513	1516	1508
Wet density, ρ , (kg/m)	1.54	1.6	1.6	1.61	1.6
Dry density, ρd , (kg/m)	1.1	1.1	1.09	1.08	1.04



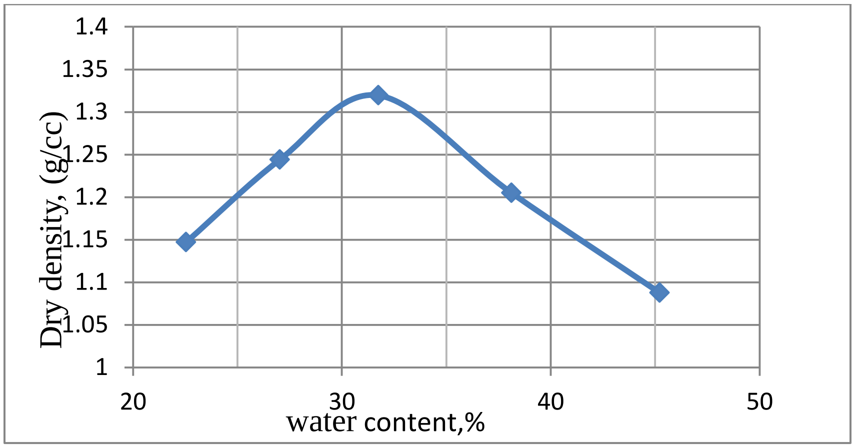
Water Content Determination:TP6-2@3m depth

compacted soil sample no	1		2		3		4		5	
moisture Content can no	11	12	21	23	31	32	41	42	51	53
MC = Mass of empty, clean can + lid (g)	44.1	42.5	45	25.2	45.6	46.2	45	34.7	45.3	27.2
MCMS = Mass of can, lid, and moist soil (g)	70	83.8	84.2	76.3	63.1	71.6	73.1	55.2	91.6	63.9
MCDS = Mass of can, lid, and dry soil (g)	65.3	76.1	75.8	65.5	58.8	65.6	65.4	49.5	77	52.6
MS = Mass of soil solids (g)	21.2	33.6	30.8	40.3	13.2	19.4	20.4	14.8	31.7	25.4
MW = Mass of pore water (g)	4.7	7.7	8.4	10.8	4.3	6	7.7	5.7	14.6	11.3
w = Water content, w%	22.2	22.9	27.3	26.8	32.6	30.9	37.7	38.5	46.1	44.5
Average water content ,w%	22.54		27.03		31.75		38.13		45.27	

Density Determination:

Volume of mold = 944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
mass of mold (grams)	3119	3119	3119	3119	3119
Mass of compacted soil and mold (g)	4446	4611	4760	4690	4645
Wet mass of soil in mold (grams)	1327	1492	1641	1571	1526
Wet density, ρ , (g/cc)	1.41	1.58	1.74	1.66	1.62
Dry density, ρd , (g/cc)	1.15	1.24	1.32	1.21	1.11


1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
Dry density, (g/cc)
20
30
40
50
water content,%

Appendix A. 4 Unconfined compression tests

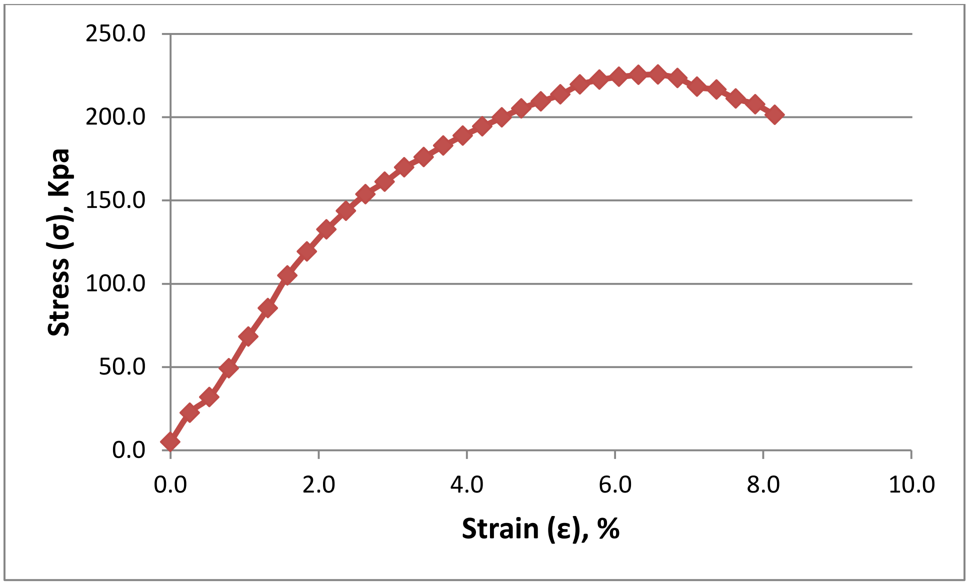
Sample number TP-1@1.5m depth

Unconfined Compression Test Data (Deformation Dial: 1 Unit = 0.01mm;

Load Dial: 1 unit = 1.42N/Div.   Strain Rate: 0.8/minute

Deformation Dial Reading	Load Dial Reading	Sample eformatio ΔL (mm)	strain (ε)	% Strain	Corrected Area, A' (mm^2)	Load (N)	Load (KN)	Stress (Kpa)
0	4	0	0.00	0.0	1134.1	5.7	0.0	5.0
20	18	0.2	0.00	0.3	1137.1	25.6	0.0	22.5
40	26	0.4	0.01	0.5	1140.1	36.2	0.0	31.8
60	40	0.6	0.01	0.8	1143.1	56.1	0.1	49.1
80	55	0.8	0.01	1.1	1146.2	78.1	0.1	68.1
100	69	1	0.01	1.3	1149.2	98.0	0.1	85.3
120	85	1.2	0.02	1.6	1152.3	120.7	0.1	104.7
140	97	1.4	0.02	1.8	1155.4	137.7	0.1	119.2
160	108	1.6	0.02	2.1	1158.5	153.4	0.2	132.4
180	118	1.8	0.02	2.4	1161.6	166.9	0.2	143.6
200	126	2	0.03	2.6	1164.8	178.9	0.2	153.6
220	133	2.2	0.03	2.9	1167.9	188.2	0.2	161.1
240	140	2.4	0.03	3.2	1171.1	198.8	0.2	169.8
260	146	2.6	0.03	3.4	1174.3	206.6	0.2	175.9
280	152	2.8	0.04	3.7	1177.5	215.1	0.2	182.7
300	157	3	0.04	3.9	1180.7	222.9	0.2	188.8
320	162	3.2	0.04	4.2	1184.0	230.0	0.2	194.3
340	167	3.4	0.04	4.5	1187.2	237.1	0.2	199.7
360	172	3.6	0.05	4.7	1190.5	244.2	0.2	205.2
380	176	3.8	0.05	5.0	1193.8	249.9	0.2	209.3
400	180	4	0.05	5.3	1197.1	255.6	0.3	213.5
420	186	4.2	0.06	5.5	1200.5	263.4	0.3	219.4
440	189	4.4	0.06	5.8	1203.8	267.7	0.3	222.4
460	191	4.6	0.06	6.1	1207.2	270.5	0.3	224.1
480	192	4.8	0.06	6.3	1210.6	272.6	0.3	225.2
500	193	5	0.07	6.6	1214.0	273.7	0.3	225.5
520	192	5.2	0.07	6.8	1217.4	271.9	0.3	223.4
540	188	5.4	0.07	7.1	1220.9	266.3	0.3	218.1
560	187	5.6	0.07	7.4	1224.3	264.8	0.3	216.3
580	183	5.8	0.08	7.6	1227.8	259.2	0.3	211.1
600	180	6	0.08	7.9	1231.3	255.6	0.3	207.6
620	175	6.2	0.08	8.2	1234.9	248.5	0.2	201.2
640	173	6.4	0.08	8.4	1238.4	245.0	0.2	197.8
660	171	6.6	0.09	8.7	1242.0	242.8	0.2	195.5
680	168	6.8	0.09	8.9	1245.6	237.9	0.2	191.0

Stress-strain curve for TP1@1.5m depth



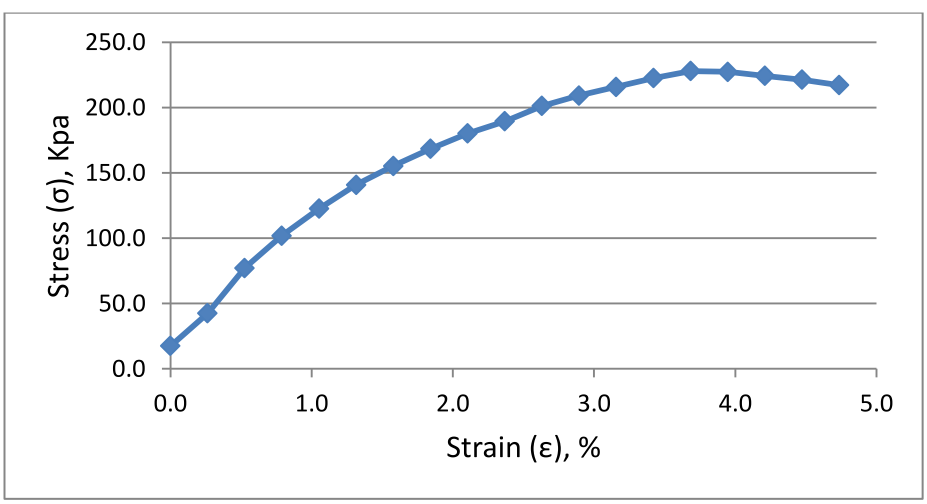
Sample number TP-1@3m depth

Unconfined Compression Test Data (Deformation Dial: 1 Unit = 0.01mm;

Load Dial: 1 unit = 1.42N/Div.   Strain Rate: 0.8/minute

Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	strain (ε)	% Strain	Corrected Area, A'(mm^2)	Load (N)	Load (KN)	Stress (Kpa)
0	14	0	0.00	0.0	1134.1	19.9	0.0	17.5
20	34	0.2	0.00	0.3	1137.1	48.3	0.0	42.5
40	62	0.4	0.01	0.5	1140.1	88.0	0.1	77.2
60	82	0.6	0.01	0.8	1143.1	116.4	0.1	101.9
80	99	0.8	0.01	1.1	1146.2	140.6	0.1	122.7
100	114	1	0.01	1.3	1149.2	161.9	0.2	140.9
120	126	1.2	0.02	1.6	1152.3	178.9	0.2	155.3
140	137	1.4	0.02	1.8	1155.4	194.5	0.2	168.4
160	147	1.6	0.02	2.1	1158.5	208.7	0.2	180.2
180	155	1.8	0.02	2.4	1161.6	220.1	0.2	189.5
200	165	2	0.03	2.6	1164.8	234.3	0.2	201.2
220	172	2.2	0.03	2.9	1167.9	244.2	0.2	209.1
240	178	2.4	0.03	3.2	1171.1	252.8	0.3	215.8
260	184	2.6	0.03	3.4	1174.3	261.3	0.3	222.5
280	189	2.8	0.04	3.7	1177.5	268.4	0.3	227.9
300	189	3	0.04	3.9	1180.7	268.4	0.3	227.3
320	187	3.2	0.04	4.2	1184.0	265.5	0.3	224.3
340	185	3.4	0.04	4.5	1187.2	262.7	0.3	221.3
360	182	3.6	0.05	4.7	1190.5	258.4	0.3	217.1

Stress-strain curve for TP1@3m depth

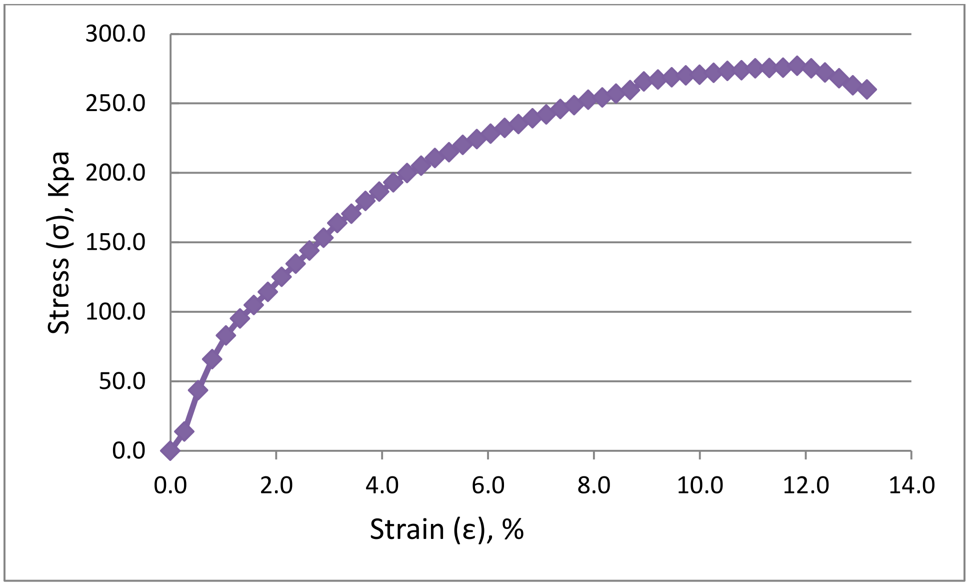


Sample number TP-3@1.5m depth

Unconfined Compression Test Data (Deformation Dial: 1 Unit = 0.01mm;

Load Dial: 1 unit = 1.42N/Div.   Strain Rate: 0.8/minute

Stress-strain curve for TP-3 @1.5m depth



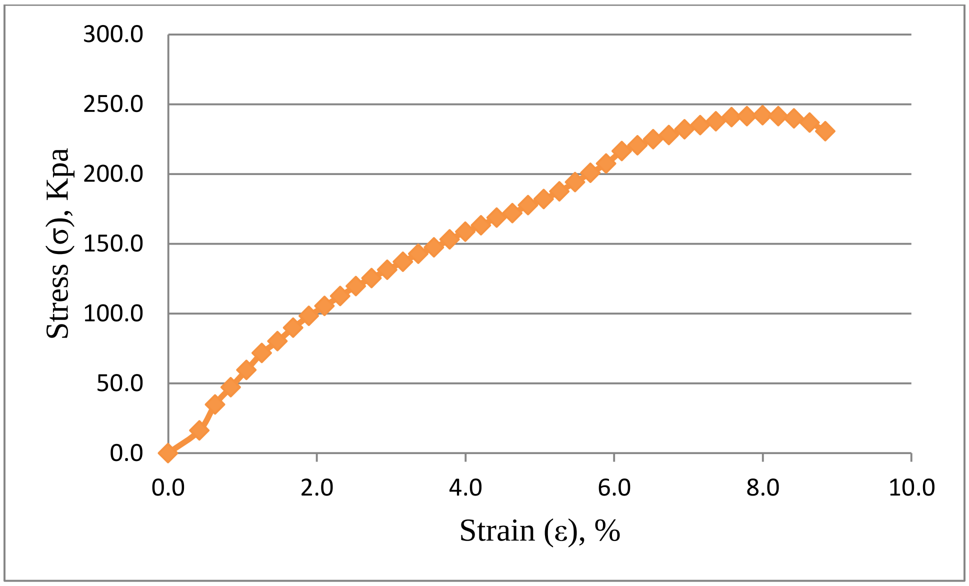
Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	strain (ε)	% Strain	Corrected Area, A'(mm^2)	Load (N)	Load (KN)	Stress (Kpa)
0	0	0	0	0.0	1134.1	0.0	0.0	0.0
20	11	0.2	0.00	0.3	1137.1	15.6	0.0	13.7
40	35	0.4	0.01	0.5	1140.1	49.7	0.0	43.6
60	53	0.6	0.01	0.8	1143.1	75.3	0.1	65.8
80	67	0.8	0.01	1.1	1146.2	95.1	0.1	83.0
100	77	1	0.01	1.3	1149.2	109.3	0.1	95.1
120	85	1.2	0.02	1.6	1152.3	120.7	0.1	104.7
140	93	1.4	0.02	1.8	1155.4	132.1	0.1	114.3
160	102	1.6	0.02	2.1	1158.5	144.8	0.1	125.0
180	110	1.8	0.02	2.4	1161.6	156.2	0.2	134.5
200	118	2	0.03	2.6	1164.8	167.6	0.2	143.9
220	126	2.2	0.03	2.9	1167.9	178.9	0.2	153.2
240	135	2.4	0.03	3.2	1171.1	191.7	0.2	163.7
260	141	2.6	0.03	3.4	1174.3	200.2	0.2	170.5
280	149	2.8	0.04	3.7	1177.5	211.6	0.2	179.7
300	155	3	0.04	3.9	1180.7	220.1	0.2	186.4
320	161	3.2	0.04	4.2	1184.0	228.6	0.2	193.1
340	167	3.4	0.04	4.5	1187.2	237.1	0.2	199.7
360	172	3.6	0.05	4.7	1190.5	244.2	0.2	205.2
380	177	3.8	0.05	5.0	1193.8	251.3	0.3	210.5
400	181	4	0.05	5.3	1197.1	257.0	0.3	214.7
420	186	4.2	0.06	5.5	1200.5	264.1	0.3	220.0
440	190	4.4	0.06	5.8	1203.8	269.8	0.3	224.1
460	194	4.6	0.06	6.1	1207.2	275.5	0.3	228.2
480	198	4.8	0.06	6.3	1210.6	281.2	0.3	232.3
500	201	5	0.07	6.6	1214.0	285.4	0.3	235.1
520	205	5.2	0.07	6.8	1217.4	291.1	0.3	239.1
540	208	5.4	0.07	7.1	1220.9	295.4	0.3	241.9
560	212	5.6	0.07	7.4	1224.3	301.0	0.3	245.9
580	215	5.8	0.08	7.6	1227.8	305.3	0.3	248.7
600	219	6	0.08	7.9	1231.3	311.0	0.3	252.6
620	221	6.2	0.08	8.2	1234.9	313.8	0.3	254.1
640	224	6.4	0.08	8.4	1238.4	318.1	0.3	256.8
660	227	6.6	0.09	8.7	1242.0	322.3	0.3	259.5
680	233	6.8	0.09	8.9	1245.6	330.9	0.3	265.6
700	235	7	0.09	9.2	1249.2	333.7	0.3	267.1
720	237	7.2	0.09	9.5	1252.8	336.5	0.3	268.6
740	239	7.4	0.10	9.7	1256.5	339.4	0.3	270.1
760	240	7.6	0.10	10.0	1260.1	340.8	0.3	270.4
780	242	7.8	0.10	10.3	1263.8	343.6	0.3	271.9
800	244	8	0.11	10.5	1267.5	346.5	0.3	273.3
820	245	8.2	0.11	10.8	1271.3	347.9	0.3	273.7
840	247	8.4	0.11	11.1	1275.0	350.7	0.4	275.1
860	248	8.6	0.11	11.3	1278.8	352.2	0.4	275.4
880	249	8.8	0.12	11.6	1282.6	353.6	0.4	275.7
900	251	9	0.12	11.8	1286.5	356.4	0.4	277.1
920	250	9.2	0.12	12.1	1290.3	355.0	0.4	275.1

Sample number TP-3@3m depth

Unconfined Compression Test Data (Deformation Dial: 1 Unit = 0.01mm;

Load Dial: 1 unit = 1.42N/Div.   Strain Rate: 0.8/minute

Stress-strain curve for TP-3 @3m depth



Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	strain (ε)	% Strain	Corrected Area, A'(mm^2)	Load (N)	Load (KN)	Stress (Kpa)
0	0	0	0.00	0.0	1134.1	0.0	0.0	0.0
40	13	0.4	0.00	0.4	1138.9	18.5	0.0	16.2
60	28	0.6	0.01	0.6	1141.3	39.8	0.0	34.8
80	38	0.8	0.01	0.8	1143.7	54.0	0.1	47.2
100	48	1	0.01	1.1	1146.2	68.2	0.1	59.5
120	58	1.2	0.01	1.3	1148.6	82.4	0.1	71.7
140	65	1.4	0.01	1.5	1151.1	92.3	0.1	80.2
160	73	1.6	0.02	1.7	1153.5	103.7	0.1	89.9
180	80	1.8	0.02	1.9	1156.0	113.6	0.1	98.3
200	86	2	0.02	2.1	1158.5	122.1	0.1	105.4
220	92	2.2	0.02	2.3	1161.0	130.6	0.1	112.5
240	98	2.4	0.03	2.5	1163.5	139.2	0.1	119.6
260	103	2.6	0.03	2.7	1166.0	146.3	0.1	125.4
280	108	2.8	0.03	2.9	1168.6	153.4	0.2	131.2
300	113	3	0.03	3.2	1171.1	160.5	0.2	137.0
320	118	3.2	0.03	3.4	1173.6	167.6	0.2	142.8
340	122	3.4	0.04	3.6	1176.2	173.2	0.2	147.3
360	127	3.6	0.04	3.8	1178.8	180.3	0.2	153.0
380	132	3.8	0.04	4.0	1181.4	187.4	0.2	158.7
400	136	4	0.04	4.2	1184.0	193.1	0.2	163.1
420	141	4.2	0.04	4.4	1186.6	200.2	0.2	168.7
440	144	4.4	0.05	4.6	1189.2	204.5	0.2	171.9
460	149	4.6	0.05	4.8	1191.8	211.6	0.2	177.5
480	153	4.8	0.05	5.1	1194.5	217.3	0.2	181.9
500	158	5	0.05	5.3	1197.1	224.4	0.2	187.4
520	164	5.2	0.05	5.5	1199.8	232.9	0.2	194.1
540	170	5.4	0.06	5.7	1202.5	241.4	0.2	200.8
560	176	5.6	0.06	5.9	1205.2	249.9	0.2	207.4
580	184	5.8	0.06	6.1	1207.9	261.3	0.3	216.3
600	188	6	0.06	6.3	1210.6	267.0	0.3	220.5
620	192	6.2	0.07	6.5	1213.3	272.6	0.3	224.7
640	195	6.4	0.07	6.7	1216.0	276.9	0.3	227.7
660	199	6.6	0.07	6.9	1218.8	282.6	0.3	231.9
680	202	6.8	0.07	7.2	1221.6	286.8	0.3	234.8
700	205	7	0.07	7.4	1224.3	291.1	0.3	237.8
720	208	7.2	0.08	7.6	1227.1	295.4	0.3	240.7
740	209	7.4	0.08	7.8	1229.9	296.8	0.3	241.3
760	210	7.6	0.08	8.0	1232.7	298.2	0.3	241.9
780	210	7.8	0.08	8.2	1235.6	298.2	0.3	241.3
800	209	8	0.08	8.4	1238.4	296.8	0.3	239.6
820	207	8.2	0.09	8.6	1241.3	293.9	0.3	236.8
840	202	8.4	0.09	8.8	1244.1	286.8	0.3	230.6

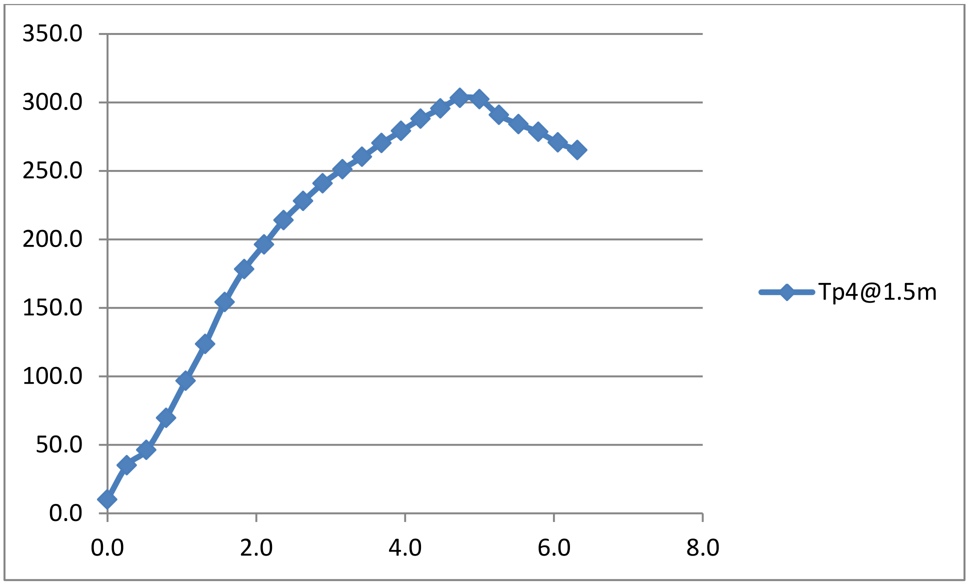
Sample number TP-4@1.5m depth

Unconfined Compression Test Data (Deformation Dial: 1 Unit = 0.01mm;

Load Dial: 1 unit = 1.42N/Div.   Strain Rate: 0.8/minute

Deformation Dial Reading	Load Dial Reading	Sample Deformation ΔL (mm)	strain (ε)	% Strain	Corrected Area, A'	Load (N)	Load (KN)	Stress (Kpa)
0	8	0	0.00	0.0	1134.1	11.4	0.0	10.0
20	28	0.2	0.00	0.3	1137.1	39.8	0.0	35.0
40	37	0.4	0.01	0.5	1140.1	52.5	0.1	46.1
60	56	0.6	0.01	0.8	1143.1	79.5	0.1	69.6
80	78	0.8	0.01	1.1	1146.2	110.8	0.1	96.6
100	100	1	0.01	1.3	1149.2	142.0	0.1	123.6
120	125	1.2	0.02	1.6	1152.3	177.5	0.2	154.0
140	145	1.4	0.02	1.8	1155.4	205.9	0.2	178.2
160	160	1.6	0.02	2.1	1158.5	227.2	0.2	196.1
180	175	1.8	0.02	2.4	1161.6	248.5	0.2	213.9
200	187	2	0.03	2.6	1164.8	265.5	0.3	228.0
220	198	2.2	0.03	2.9	1167.9	281.2	0.3	240.7
240	207	2.4	0.03	3.2	1171.1	293.9	0.3	251.0
260	215	2.6	0.03	3.4	1174.3	305.3	0.3	260.0
280	224	2.8	0.04	3.7	1177.5	318.1	0.3	270.1
300	232	3	0.04	3.9	1180.7	329.4	0.3	279.0
320	240	3.2	0.04	4.2	1184.0	340.8	0.3	287.8
340	247	3.4	0.04	4.5	1187.2	350.7	0.4	295.4
360	254	3.6	0.05	4.7	1190.5	360.7	0.4	303.0
380	254	3.8	0.05	5.0	1193.8	360.7	0.4	302.1
400	245	4	0.05	5.3	1197.1	347.9	0.3	290.6
420	240	4.2	0.06	5.5	1200.5	340.8	0.3	283.9
440	236	4.4	0.06	5.8	1203.8	335.1	0.3	278.4
460	230	4.6	0.06	6.1	1207.2	326.6	0.3	270.5
480	226	4.8	0.06	6.3	1210.6	320.9	0.3	265.1

Stress-strain curve for TP-4 @1.5m depth



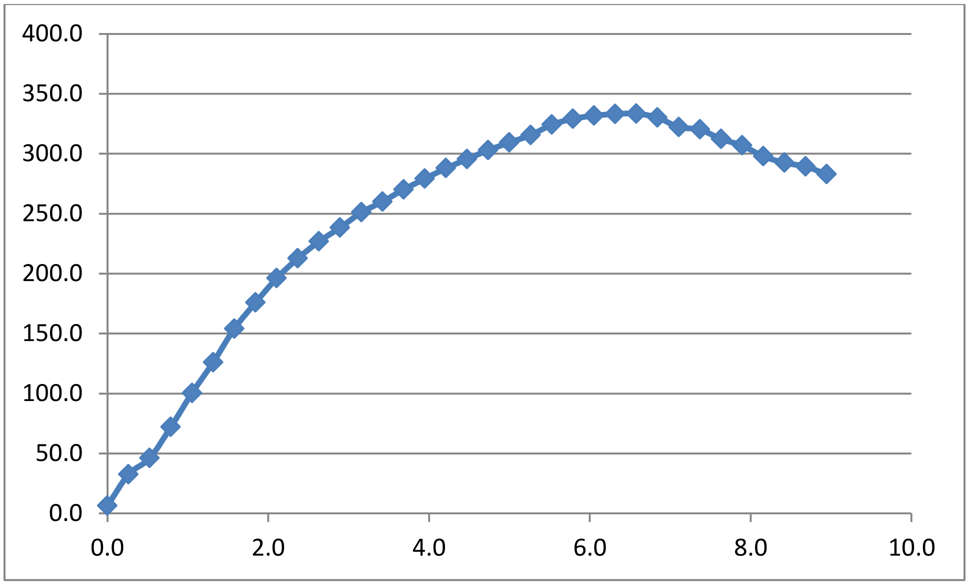
Sample number TP-4@3m depth

Unconfined Compression Test Data (Deformation Dial: 1 Unit = 0.01mm;

Load Dial: 1 unit = 1.42N/Div.   Strain Rate: 0.8/minute

Deformation Dial Reading	Load Dial Reading	Sample Deformatio ΔL (mm)	strain (ε)	% Strain	Corrected Area, A'	Load (N)	Load (KN)	Stress (Kpa)
0	5	0	0.00	0.0	1134.1	7.1	0.0	6.3
20	26	0.2	0.00	0.3	1137.1	36.9	0.0	32.5
40	37	0.4	0.01	0.5	1140.1	52.5	0.1	46.1
60	58	0.6	0.01	0.8	1143.1	82.4	0.1	72.0
80	81	0.8	0.01	1.1	1146.2	115.0	0.1	100.4
100	102	1	0.01	1.3	1149.2	144.8	0.1	126.0
120	125	1.2	0.02	1.6	1152.3	177.5	0.2	154.0
140	143	1.4	0.02	1.8	1155.4	203.1	0.2	175.7
160	160	1.6	0.02	2.1	1158.5	227.2	0.2	196.1
180	174	1.8	0.02	2.4	1161.6	247.1	0.2	212.7
200	186	2	0.03	2.6	1164.8	264.1	0.3	226.8
220	196	2.2	0.03	2.9	1167.9	278.3	0.3	238.3
240	207	2.4	0.03	3.2	1171.1	293.9	0.3	251.0
260	215	2.6	0.03	3.4	1174.3	305.3	0.3	260.0
280	224	2.8	0.04	3.7	1177.5	318.1	0.3	270.1
300	232	3	0.04	3.9	1180.7	329.4	0.3	279.0
320	240	3.2	0.04	4.2	1184.0	340.8	0.3	287.8
340	247	3.4	0.04	4.5	1187.2	350.7	0.4	295.4
360	254	3.6	0.05	4.7	1190.5	360.7	0.4	303.0
380	260	3.8	0.05	5.0	1193.8	369.2	0.4	309.3
400	266	4	0.05	5.3	1197.1	377.7	0.4	315.5
420	274	4.2	0.06	5.5	1200.5	389.1	0.4	324.1
440	279	4.4	0.06	5.8	1203.8	396.2	0.4	329.1
460	282	4.6	0.06	6.1	1207.2	400.4	0.4	331.7
480	284	4.8	0.06	6.3	1210.6	403.3	0.4	333.1
500	285	5	0.07	6.6	1214.0	404.7	0.4	333.4
520	283	5.2	0.07	6.8	1217.4	401.9	0.4	330.1
540	277	5.4	0.07	7.1	1220.9	393.3	0.4	322.2
560	276	5.6	0.07	7.4	1224.3	391.9	0.4	320.1
580	270	5.8	0.08	7.6	1227.8	383.4	0.4	312.3
600	266	6	0.08	7.9	1231.3	377.7	0.4	306.8
620	259	6.2	0.08	8.2	1234.9	367.8	0.4	297.8
640	255	6.4	0.08	8.4	1238.4	362.1	0.4	292.4
660	253	6.6	0.09	8.7	1242.0	359.3	0.4	289.3
680	248	6.8	0.09	8.9	1245.6	352.2	0.4	282.7

Stress-strain curve for TP-4 @3m depth



Appendix A. 5. Specific gravity Determination

Sample description Disturbed

Sample number TP-1@1.5m depth

Test method ASTM D854

Test date 1/06/2016

Determination No.	1	2	3
pycnometer No	M1	O1	N1
Mass of dry, clean Calibrated pycnometer, M_p	162	162	152
Mass of specimen + pycnometer, $M_{ps,}$ in g	190	207	198
Weight of dry soil , ws (gm)	28	45	46
Mass of pycnometer + soil + water, M_{psw}, in g	677	687	678
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	23	23	23
Mass of pycnometer + water at temperature T_x ,g	659	659	649
K for T_x	0.9993	0.9993	0.9993
Specific gravity	2.79	2.64	2.70
Average Specific gravity at 20^oc, G_s	2.71		

Sample description Disturbed

Sample number TP-1@3m depth

Test method ASTM D854

Test date 5/07/2016

Determination No.	1	2	3
pycnometer No	M11	O11	N11
Mass of dry, clean Calibrated pycnometer, M_p	162	162	152
Mass of specimen + pycnometer, $M_{ps,}$ in g	195	198	185
Weight of dry soil , ws (gm)	33	36	33
Mass of pycnometer + soil + water, M_{psw}, in g	680	682	670
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	20	20	20
Mass of pycnometer + water at temperature T_x,g	659	659	649
K for T_x	1.0000	1.0000	1.0000
Specific gravity	2.75	2.77	2.75
Average Specific gravity at 20^oc, G_s	2.75		

Sample description Disturbed

Sample number TP-2@1.5m depth

Test method ASTM D854

Test date 2/06/2016

Determination No.	1	2	3
pycnometer No	M3	N3	O3
Mass of dry, clean Calibrated pycnometer, M_p	162	152	162
Mass of specimen + pycnometer, $M_{ps,}$ in g	199	175	197
Weight of dry soil , ws (gm)	37	23	35
Mass of pycnometer + soil + water, M_{psw}, in g	682	663	681
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	30	30	30
Mass of pycnometer + water at temperature T_x,g	659	649	659
K for T_x	0.9993	0.9993	0.9993
Specific gravity	2.64	2.55	2.69
Average Specific gravity at 20^oc, G_s	2.62		

Sample description Disturbed

Sample number TP-4@1.5m depth

Test method ASTM D854

Test date 05/07/2016

Determination No.	1	2	3
pycnometer No	H1	L1	K1
Mass of dry, clean Calibrated pycnometer, M_p	96	99	120
Mass of specimen + pycnometer, $M_{ps,}$ in g	132	130	157
Weight of dry soil , ws (gm)	36	31	37
Mass of pycnometer + soil + water, M_{psw}, in g	364	363	389
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	30	30	30
Mass of pycnometer + water at temperature T_x,g	342	344	366
K for T_x	0.99567	0.99567	0.99567
Specific gravity	2.56	2.57	2.63
Average Specific gravity at 20^oc, G_s	2.58		

Sample description Disturbed

Sample number TP-4@3m depth

Test method ASTM D854

Test date 06/06/2016

Determination No.	1	2	3
pycnometer No	K22	L22	H22
Mass of dry, clean Calibrated pycnometer, M_p	118	94	93
Mass of specimen + pycnometer, $M_{ps,}$ in g	151	126	132
Weight of dry soil , ws (gm)	33	32	39
Mass of pycnometer + soil + water, M_{psw}, in g	386	364	366
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	30	30	30
Mass of pycnometer + water at temperature T_x,g	366	344	342
K for T_x	0.99567	0.99567	0.99567
Specific gravity	2.53	2.65	2.59
Average Specific gravity at 20^oc, G_s	2.59		

Sample description Disturbed

Sample number TP-3@1.5m depth

Test method ASTM D854

Test date 06/06/2016

Determination No.	1	2	3
pycnometer No	M6	N6	N6
Mass of dry, clean Calibrated pycnometer, M_p	162	152	162
Mass of specimen + pycnometer, $M_{ps,}$ in g	217	202	211
Weight of dry soil , ws (gm)	55	50	49
Mass of pycnometer + soil + water, M_{psw}, in g	692	679	688
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	25	16	25
Mass of pycnometer + water at temperature T_x,g	659	649	659
K for T_x	0.9988	0.9988	0.9988
Specific gravity	2.49	2.49	2.45
Average Specific gravity at 20^oc, G_s	2.48		

Sample description Disturbed

Sample number TP-3@3m depth

Test method ASTM D854

Test date 06/07/2016

Determination No.	1	2	3
pycnometer No	M63	N63	O63
Mass of dry, clean Calibrated pycnometer, M_p	162	152	162
Mass of specimen + pycnometer, $M_{ps,}$ in g	202	193	206
Weight of dry soil , ws (gm)	40	41	44
Mass of pycnometer + soil + water, M_{psw}, in g	683	673	685
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^{o}c	22	22	22
Mass of pycnometer + water at temperature T_x,g	659	649	659
K for T_x	0.9996	0.9996	0.9996
Specific gravity	2.50	2.41	2.44
Average Specific gravity at 20^{o}c, G_s	2.45		

Sample description Disturbed

Sample number TP-5@1.5m depth

Test method ASTM D854

Test date 06/06/2016

Determination No.	1	2	3
pycnometer No	N4	M4	O4
Mass of dry, clean Calibrated pycnometer, M_p	152	162	162
Mass of specimen + pycnometer, $M_{ps,}$ in g	205	208	211
Weight of dry soil , ws (gm)	53	46	49
Mass of pycnometer + soil + water, M_{psw}, in g	681	687	688
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	16	16	16
Mass of pycnometer + water at temperature T_x,g	649	659	659
K for T_x	1.0007	1.0007	1.0007
Specific gravity	2.53	2.56	2.45
Average Specific gravity at 20^oc, G_s		2.51	

Sample description Disturbed

Sample number TP-5@3m depth

Test method ASTM D854

Test date 08/07/2016

Determination No.	1	2	3
pycnometer No	N43	M43	O43
Mass of dry, clean Calibrated pycnometer, M_p	152	162	162
Mass of specimen + pycnometer, $M_{ps,}$ in g	184	201	205
Weight of dry soil , ws (gm)	32	39	43
Mass of pycnometer + soil + water, M_{psw}, in g	668	682	685
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^{o}c	30	30	30
Mass of pycnometer + water at temperature T_x,g	649	659	659
K for T_x	0.9993	0.9993	0.9993
Specific gravity	2.46	2.43	2.53
Average Specific gravity at 20^{o}c, G_s		2.47	

Sample description Disturbed

Sample number TP-6@1.5m depth

Test method ASTM D854

Test date 07/06/2016

Determination No.	1	2	3
pycnometer No	H5	K5	L5
Mass of dry, clean Calibrated pycnometer, M_p	98	122	99
Mass of specimen + pycnometer, $M_{ps,}$ in g	142	152	130
Weight of dry soil , ws (gm)	44	30	31
Mass of pycnometer + soil + water, M_{psw}, in g	368	384	362
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^oc	27	27	27
Mass of pycnometer + water at temperature T_x,g	342	366	343
K for T_x	0.998	0.998	0.998
Specific gravity	2.44	2.49	2.58
Average Specific gravity at 20^oc, G_s	2.50		

Sample description Disturbed

Sample number TP-6@3m depth

Test method ASTM D854

Test date 9/07/2016

Determination No.	1	2	3
pycnometer No	M33	O33	N33
Mass of dry, clean Calibrated pycnometer, M_p	162	162	152
Mass of specimen + pycnometer, $M_{ps,}$ in g	191	189	176
Weight of dry soil , ws (gm)	29	27	24
Mass of pycnometer + soil + water, M_{psw}, in g	677	676	664
Temperature of contents of pycnometer when M_{psw} was taken, T_x, in ^{o}c	27	27	27
Mass of pycnometer + water at temperature T_x,g	659	659	649
K for T_x	0.9983	0.9983	0.9983
Specific gravity	2.63	2.69	2.66
Average Specific gravity at 20^{o}c, G_s	2.66		

DECLARATION

I, the undersigned, declare that this thesis entitled “Investigation on the engineering properties of soils in Bedelle town,” is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of materials used for the thesis have been duly acknowledged.

Name: Negese Asefa Daba

Signature: _____________

Place Institute of Technology,

Jimma University,

Jimma, Ethiopia

December, 2016