ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

INVESTIGATION INTO SOME OF THE ENGINEERING PROPERTIES OF SOILS IN DEMBECHA TOWN, ETHIOPIA

BY

TENAW WORKIE

" A thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering "

ADVISOR:

Prof.Dr-Ing. ALEMAYEHU TEFERRA

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Approved by Board of Examiners

Prof.Dr-Ing. Alemayehu Teferra	___________	___________
(Advisor)	Signature	Date
Dr-Ing. Asrat Worku	___________	___________
(External Examiner)	Signature	Date
Dr-Ing. Henok Fikre	___________	___________
(Internal Examiner)	Signature	Date
	___________	___________
(Chair man)	Signature	Date

Dedicated to my parents,

Workie Teruneh and Berhan Alem

For their endless love, support and encouragement and whose good examples have taught me to work hard for the things that I aspire to achieve !

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SYMBOLS AND ABBREVIATIONS

AASHTO - American Association of Highway and Transportation Officials

ASTM - American Society for Testing and Materials

av- Coefficient of compressibility

BS - British standard

Cc- Compression index

Cs- Recompression index

Cv- Coefficient of consolidation

e - Void ratio

GPS- Global Positioning System

IS -Indian Standard

k - Coefficient of permeability

LI - Liquidity Index

LL - Liquid limit

MH – Inorganic Elastic silt

mv - Coefficient of volume compressibility

NCL - Normal consolidation line

O.C.R - Over Consolidation Ratio

Pc - Pre-consolidation pressure

PI - Plasticity index

PL - Plastic limit

R - Red

SL - Shrinkage Limit

TP – Test pit

qu- Unconfined compressive strength

UC - Unconfined compression

URL - Unloading reloading line

USCS - Unified Soil Classification System

USDA- United States Department of Agriculture

VCL - Virgin Consolidation Line

Y - Yellow

ω - Water content

γw - Unit weight of water

µm - Micro- meter

nm - Nano-meter

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ABSTRACT

It is vital to carry out geotechnical investigation of soils before the design of any civil engineering works as soil is the ultimate foundation material. In addition, the recent growth which is associated with urbanization in Dembecha Township calls for appropriate geotechnical investigation of soils of the area.

This work focuses mainly on the investigation into some of the engineering or geotechnical properties and prepare soil map of the study areas in Dembecha town. The area under study encompasses places of infrastructures and future expansion as per the information from the mayor's office.

Representative disturbed and undisturbed soil samples were collected from ten open test pits and were investigated for their geotechnical properties with a view to classifying for their suitability, applications or otherwise for infrastructural development.

The study area is mainly covered by two types of soils. The first groups of soils are red soils which are classified as inorganic clay and silts according to Unified Soil Classification System. These soils have a specific gravity ranging from 2.80 to 2.84, liquid limit of 61% - 80%, plasticity index of 28-41%, percent dispersion of 0% - 3.34%, clay fraction of 71.52% - 79.83%, compression index of 0.176, recompression index of 0.015, pre consolidation pressure of 200 kPa, coefficient of permeability ranging from $0.168*10^{-9}$ to $1.375*10^{-9}$ cm/sec and free swell values of 30% - 50%.

The second groups of soils are brown soils which are all classified as inorganic clay except one test pit which is classified as inorganic silt according to Unified Soil Classification System.These soils have a specific gravity ranging from 2.73 to 2.85, liquid limit of 59% - 89%, plasticity index of 26% -59%, percent dispersion of 8.32% - 78.40%, clay fraction of 45.15% - 65.69%, compression index of 0.191-0.197, recompression index of 0.026- 0.059, pre consolidation pressure ranging from 100 to150 kPa, coefficient of permeability ranging from $0.083*10^{-9}$ to $1.237*10^{-9}$ cm/sec and free swell values of 40% - 93%.

1. INTRODUCTION

1.1 General

Obviously, soil is the ultimate foundation material and considering the massive construction of civil structures in urban areas, it is really important to investigate and characterize the sub soil condition. Lack of sophisticated laboratory facilities and non-availability of the proper geotechnical information of the subsoil makes foundation and engineering works expensive, difficult and sometimes hazardous.

Dembecha is a town in northwestern Ethiopia 350 km north of Addis Ababa located in the western Gojjam Zone of the Amhara Region. Even though, there has been no investigation practice regarding construction of foundation for structures, the recent growth which is associated with urbanization in Dembecha Town calls for appropriate geotechnical investigation of soils of the area. The master plan of the town includes roads, residential areas, government offices, commercial areas, institutions, and known recreational areas which need extensive constructions and are governed by detailed investigation of soils.

This research will address the best guidelines for civil engineers who are being responsible for designing stable, safe, and economical foundation.

The objective of this research is to investigate some of the engineering properties of soils in the area with greater emphasis of expansive soils.

1.2 Objectives of the Study

The objectives of this thesis work are the following:

- ✓ To determine the index properties of soils in Dembecha town
- ✓ To determine the shear strength characteristics of soils in the town
- ✓ To determine the compressibility characterstics of soils in the town
- ✓ To investigate the permeability characteristicsof soils in the town
- ✓ To prepare a preliminary or tentative soil map of the town

1.3 Methodology

Soil properties were determined by field examination and laboratory testing. Established standard procedures were followed. During the survey, representative pits were dug and examined to identify and classify the soils and to delineate them on the soil maps. Samples were taken from some typical profiles and tested in the laboratory to determine grain-size distribution, plasticity, shear strength parameters and compressibility characteristics.

The following methods were followed to achieve the objectives of the research:

- Literature regarding engineering properties were thoroughly reviewed and studied.
- Reconnaissance survey was carried out by walking over the city in order to select location of pits.
- In the field, GPS readings were taken to locate the coordinates of the sampling area. Visual classification and test pit loggings were done.
- Disturbed and undisturbed soil samples were gathered from representative areas by appropriate sampling techniques.
- The samples were transported by vehicle from the study area to Addis Ababa University laboratory.
- Laboratory tests; specific gravity, particle size distribution,dispersivity characteristics, Atterberg limits , free swell ,unconfined compression strength test and consolidation were conducted.
- Data analysis of the test result was done, based on which Conclusions and recommendations made.

1.4 Scope of the Study

Nineteen soil samples from ten pits were collected. Although the scope of this study is limited to investigating the index properties and consolidation characteristics of soils of the town and the depth of investigation in this research is limited to a maximum depth of three meters. The coefficient of permeability of the soil in the research area is calculated from consolidation test results obeying Terzagh's one dimensional consolidation theory.

1.5 Research limitations

Because soil plays a key role in the stability of foundations, the literature survey has shed a light on the description and distinguishing definitions of soils and rocks, mentioning general soil types, categorizing soils based on available and most accepted classification standards. The research work done pays a close attention to the engineering properties of soils without the study of mineralogical composition of soils in the study area. This has a limitation regarding the assessments of expansive soils which is directly linked to mineralogy.

Since the characteristics of soils vary from one location to another, each section of investigation site has its own unique soil characteristics. As a result, the experimental work fairly represents the similarity and variation in soil properties between locations within the study area. Worse still, geo-statistical methods to model soil spatial and temporal variation are data intensive requiring a large number of point observations beyond economic context of the budget. Furthermore, common sampling problems (inappropriate sample type and insufficient samples) and measurement errors due to insufficient control of collection systems, testing procedures and analysis might affect the end results.

1.6 Structure of the Thesis

This thesis work is organized in six chapters:

Chapter one is the introductory part of the thesis which gives the background, objective of the thesis, the methodology employed to accomplish the research, the scope of the research, and the expected limitations of the thesis.

Chapter two provides an overview of literature about origin and formation of soils, soil description and classification, clay and clay mineralogy from the perspective of geotechnical engineering.

Chapter three deals the description of the study area and in-situ identification

Chapter four presents laboratory test results.

Chapter five discusses the test results from which conclusions and recommendations are generated.

Chapter six presents soil map of the study area.

Chapter seven enumerates the conclusions and recommendations drawn from the research.

Finally, all laboratory tests results, detail calculations of the consolidation test results, meteorological data and soil profiles for each test pits are included in the appendix.

2. LITERATURE REVIEW

2.1 Origin and formation of Soils

Naturally occurring deposits of the earth's crust are classified by engineers in to "soil" and "rock" with an arbitrary division based on strength, related physical properties and use. Soil, in an engineering sense, is the relatively loose mass of mineral and organic materials and sediments found above the bed rock, which can be relatively easily broken down in to its constituent mineral or organic particles. The strength for a deposit to be qualified as 'soil' is arbitrarily taken by some engineers to be such that the deposit is loose enough to be excavated without blasting and to be penetrated in borings by ordinary soil sampling equipment. Rock is considered to be a natural aggregate of mineral grains bonded together and possessing rigid internal bonds whose strength is of the same order as that of mineral grains proper. Rock is generally meant to refer to 'bed rock' or to large and hard fragments of bed rock or any of the solid rocks that make up the earth crust [1].

Soil is a particulate material (a soil mass is an accumulation of individual particles) formed by the process of ‘Weathering’ of rocks, that is, disintegration and decomposition of rocks and minerals at or near the earth’s surface through the actions of natural or mechanical and chemical agents into smaller and smaller grains [2].

The factors of weathering may be atmospheric, such as changes in temperature and pressure; erosion and transportation by wind, water and glaciers; chemical action such as crystal growth, oxidation, hydration, carbonation and leaching by water, especially rainwater, with time [3].

Based on origin soil deposits can be divided in to two groups, transported and residual soils depending on the method of deposition. "Transported soils" are the soils which have been moved from their original place of formation by agents to the other places of deposition. "Residual soils" are soils formed directly from the physical and chemical weathering of the parent material, normally rock of some sort [4]. These soils are very much different and are not as common as transported soils in their characteristics and engineering behaviour and retain many of the elements that comprise the parent rock [5].

They often exhibit a property known as “structure” ; that is the particles are packed together or even bonded together in a way that forms a soil “ skeleton” having characteristics quite different from those of a simple collection of individual particles [4].

Beyond the initial physical and chemical weathering of the parent rock and subsequent transport and redeposition,sedimentary soils undergo a various additional processesas can be seen in the Figure2.1.The factors involved in the formation of sedimentary soils are more complex than those involved in forming residual soils [4].

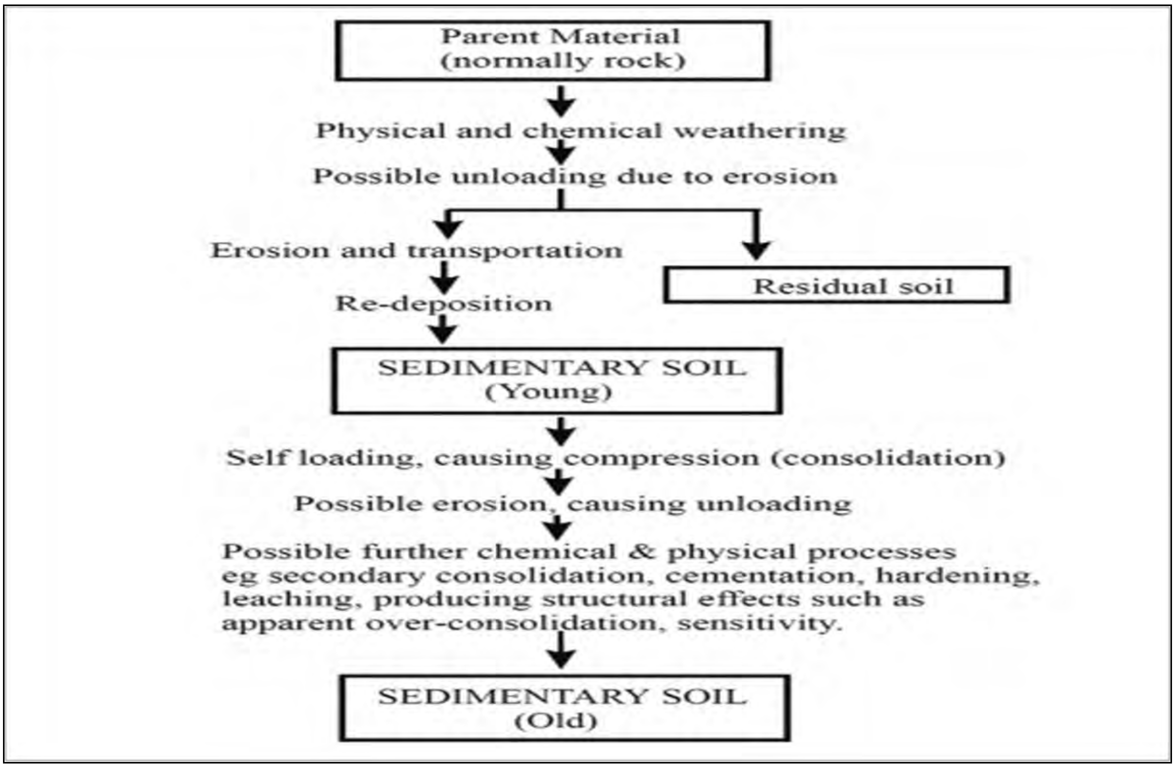


Figure 2.1: Soil formation factors influencing soil behavior [4]

The study of the engineering behaviour of the different types of soils is extremely important to civil engineers, because every engineering structure such as a building, a road, a bridge, a monument, etc. will have to be rested and founded on the ground i.e. on some kind of soil deposit. The sub-structure or the foundation portion of every such engineering structure will have to be taken below the ground and rested on the foundation soil, in such a manner that the structure does not get settled or tilted, or damaged due to some kind of failure of the foundation soil. The strength of the soil to withstand loads, under different site conditions, therefore, becomes an important factor, for using soils as building material for construction of earth dams and dykes, etc. andin designing safe foundation for the structure.

Hence, the science which deals with the study of the engineering properties and behaviour of the soils is known as the "Soil Engineering" or the "Soil Mechanics" or the "Geotechnical Engineering"[5].

Geotechnical Engineering can also be defined as a speciality of Civil Engineering which deals with the properties,behaviour and use of earth materials (soil and rock) in engineering works. The successful practice of geotechnical engineering requires integration of knowledge from several fields, such as geology, material science and testing, mechanics and hydraulics.Soil and rock are naturally occurring, highly complex materials with variable ingredients and variable properties. Theoretical predictions of their behaviour have to be based on a number of simplifying and idealised assumptions. A lot of experience, imagination and judgment is, therefore, needed in the practice of geotechnical engineering[5]. Arguably, geotechnical engineers, possibly more than most other associated professionals, must keep up with current research [7].

2.2 Soil description and classification

It is essential that a standard language should exist for the description of soils. A comprehensive description should include the characteristics of both the soil material and the in-situ soil mass. Material characteristics can be determined from disturbed samples of the soil, i.e. samples having the same particle size distribution as the in-situsoil but in which thein-situ structure has not been preserved.The principal material characteristics are particle size distribution (or grading) and plasticity, from which thesoil name can be deduced. Particle size distribution and plasticity properties can be determined either by standard laboratory tests or by simple visual and manual procedures.Secondary material characteristics are the colour of the soil and the shape, texture and composition of the particles. Mass characteristics should ideally be determined in the field but in many cases they can be detected in undisturbed samples, i.e.samples in which the in-situ soil structure has been essentially preserved. A description of mass characteristics should include an assessment of in-situ compactive state (coarse soils) or stiffness (fine soils) and details of any bedding, discontinuities and weathering.

Soil description includes details of both material and mass characteristics, and therefore itis unlikely that any two soils will have identical descriptions. In soil classification, on the other hand, a soil is allocated to one of a limited number of groups on the basis of material characteristics only.Engineers can also draw on past experience of the behaviour of soils of similar classification [8].

The basic soil types are boulders, cobbles, gravel, sand, silt and clay, defined in terms of the particle size; added to these are organic clay, silt or sand, and peat.[8,BS]

Grains having diameters in the range of 4.75 to 76.2 mm are called gravel. If the grains are visible to the naked eye, but are less than about 4.75mm in size the soil is described as sand (both sand and gravel are coarse grained soils). The lower limit of visibility of grains for the naked eyes is about 0.075mm. Soil grains ranging from 0.075 to 0.002 mm are termed as silt and those that are finer than 0.002 mm as clay (silt and clay are fine grained soils) [9].

The coarseness of soils is determined from knowing the distribution of particle sizes, which is the primary means of classifying coarse-grained soils. To characterize fine-grained soils, we need further information on the types of minerals present and their contents [9].

2.2.1 Soil structure

The 'structure' of a soil may be defined as the manner of arrangement and state of aggregation of soil grains.In a broader sense, consideration of mineralogical composition, electrical properties, orientation and shape of soil grains, nature and properties of soil water and the interaction of soil water and soil grains, also may be included in the study of soil structure, which is typical for transported or sediments soils. Structural composition of sedimented soils influences, many of their important engineering properties such as permeability, compressibility and shear strength. Hence, a study of the structure of soils is important. The following types of structure are commonly studied (Figure 2.2):

(a) Single-grained structure

(b) Honey-comb structure

(c) Flocculent or Dispersed structure

Single-grained structure is characteristic of coarse grained soils, with a particle size greater than 0.02mm. Gravitational forces predominate the surface forces 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.

Honey-comb 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 forces 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-comb structure, each cell of a honey-comb 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.

Flocculent or Dispersed structure is characteristic 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'.

Very fine particles or particles of colloidal size (< 0.001 mm) may be in a flocculated or dispersed state. When inter-particle repulsive forces are brought back into play either by remoulding or by the transportation process, a more parallel arrangement or reorientation of the particles occurs. This means more face-to-face contacts occur for the flaky particles when these are in a dispersed state. The soils in dispersed structure generally have a low shear strength, high compressibility, and low permeability. In practice, mixed structures occur, especially in typical marine soils [2].

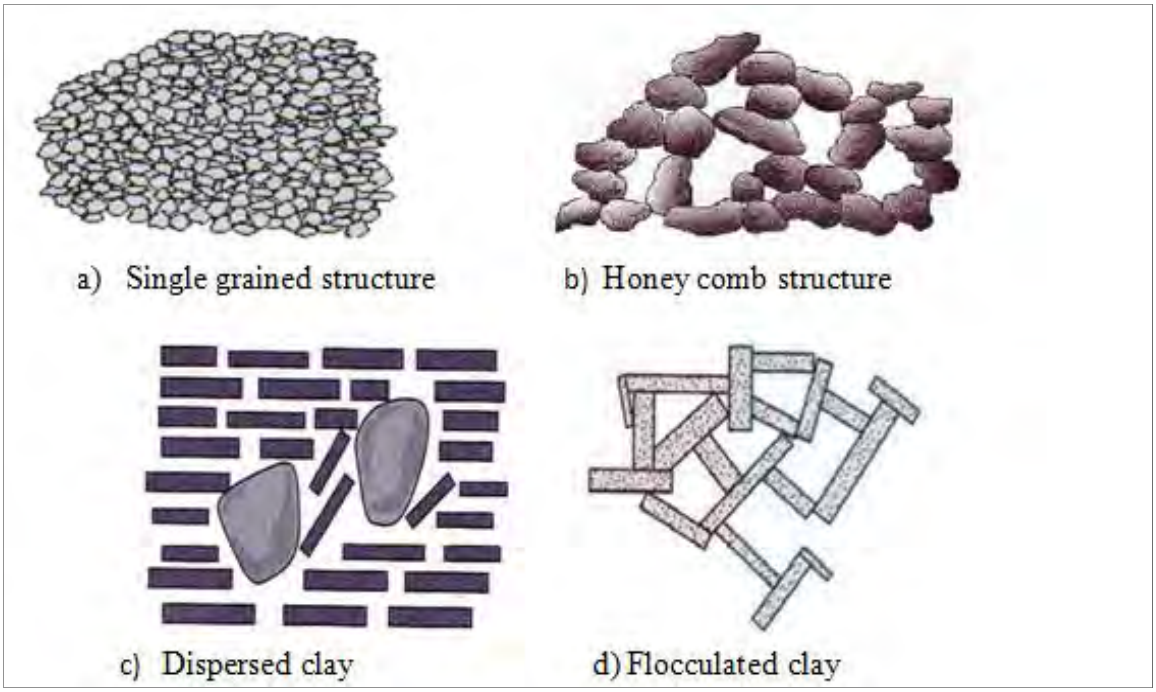


Figure 2.2: Structure of soils [2]

2.2.2 Texture

The term **'Texture'**refers to the appearance of the surface of a material, such as a fabric. It is used in a similar sense with regard to soils. Texture of a soil is reflected largely by the particle size, shape, and gradation [2].

2.3 Clay and clay mineralogy

The term 'clay' refers to a naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when dried. Although clay usually contains phyllosilicates, it may contain other materials that impart plasticity and harden when dried. Associated phases in clay may include materials that do not impart plasticity and organic matter. Plasticity is the property of moistened material deforming under the application of pressure, with the deformed shape being retained when the deforming pressure is removed [10, 11].

Clay can also be defined as very fine-grained soil of colloid size (influence of the surface charges is predominant than the influence of the force of gravity), consisting of hydrated silicate of aluminum. It is a plastic cohesive soil which shrinks on drying, expands on wetting, and when compressed gives up water [12].

Clay minerals are clay materials that are essentially composed of extremely small crystalline particles of one or more members of a small group of minerals. These minerals are phyllosilicates or layer silicates,essentially hydrous aluminum silicates, with magnesium or iron replacing wholly or in part for the aluminum, in some minerals, and in some of them alkali or alkaline earth are also present as essential constituents. Some clay materials are composed of a single clay mineral but in many there is a mixture of minerals. In addition to the clay minerals, some clays contain varying amounts of non-clay minerals such as calcite, feldspar, pyrite and quartz. Also, many types of clay contain organic material and water-soluble salts.Some clay materials may contain a clay material which is non-crystalline (e.g. allophane). However, clay materials are composed wholly or predominantly of crystalline components and are therefore the components which largely determine the property of clay [10].

The clay minerals are a group of complex alumino-silicates, i.e., oxides of aluminum and silicon with smaller amounts of metal ions substituted within the crystal. The atomic structures of clay minerals are built up of two basic units (which are held together by ionic bonds);

a) Silica tetrahedral units, and

b) Aluminum (or magnesium) octahedral unit (Figure. 2.3) [13].

There arevalency imbalances in both units, resulting in net negative charges. The basic units, therefore, do not exist in isolation but combine to form sheet structures.The tetrahedral units combine by the sharing of oxygen ions to form a silica sheet. The octahedral units combine through shared hydroxyl ions to form a gibbsite sheet [8].

From an engineering point of view, three clay minerals of interest are kaolinite, montmorillonite and illite [13].

2.3.1 Kaolinite

Kaolinite is one of the most common clay minerals in sedimentary and residual soils. A unit sheet of kaolinite, which is approximately 0.7 nm (nm = 10^{-9}m) thick, is composed of one aluminum octahedral layer and one silicon tetrahedral layer (for this reason kaolinite is also called a 1:1 clay mineral), joined together by shared oxygens. A typical particle of kaolinite consists of a stack of sheets forming a stiff hexagonal plate with flat-faced edges. It is about 100 nmin thickness with a breadth/thickness of about 5 to 10, and a specific surface of 5 to 15 m^2/g [14].

Kaolinite consists of a structure based on a single sheet of silica combined with a single sheet of gibbsite. There is very limited isomorphous substitution. The combined silica–gibbsite sheets are held together relatively strongly by hydrogen bonding. A kaolinite particle may consist of over 100 stacks [8].

Since hydrogen bonds are comparatively strong, the kaolinite crystals consist of many sheet stackings that are difficult to dislodge. The mineral is therefore,stable,and water can not enter between the sheets to expand the unitcells [14].

Kaolinites are found in soils that have undergone considerable weathering in warm, moist climates. They have low liquid limit and a low activity. Another member of the Kaolinite group appearing in some tropical soils is called halloysite, in which water molecules separate the layers. The halloysites are distinguished by one additional water molecule to the basic kaolinite [14].

Hydrated halloysite ($4H_2O$) can be dehydrated irreversibly to metahalloysite ($2H_2O$) starting at 60^o to 75°C [15].

In contrast to most other clays, which are flaky, halloysite particles are tubular or rod like [14].

2.3.2 Illite

Illite is the most common clay mineral in stiff clays and shales as well as in postglacial marine and lacustrine soft clay and silt deposits [14].

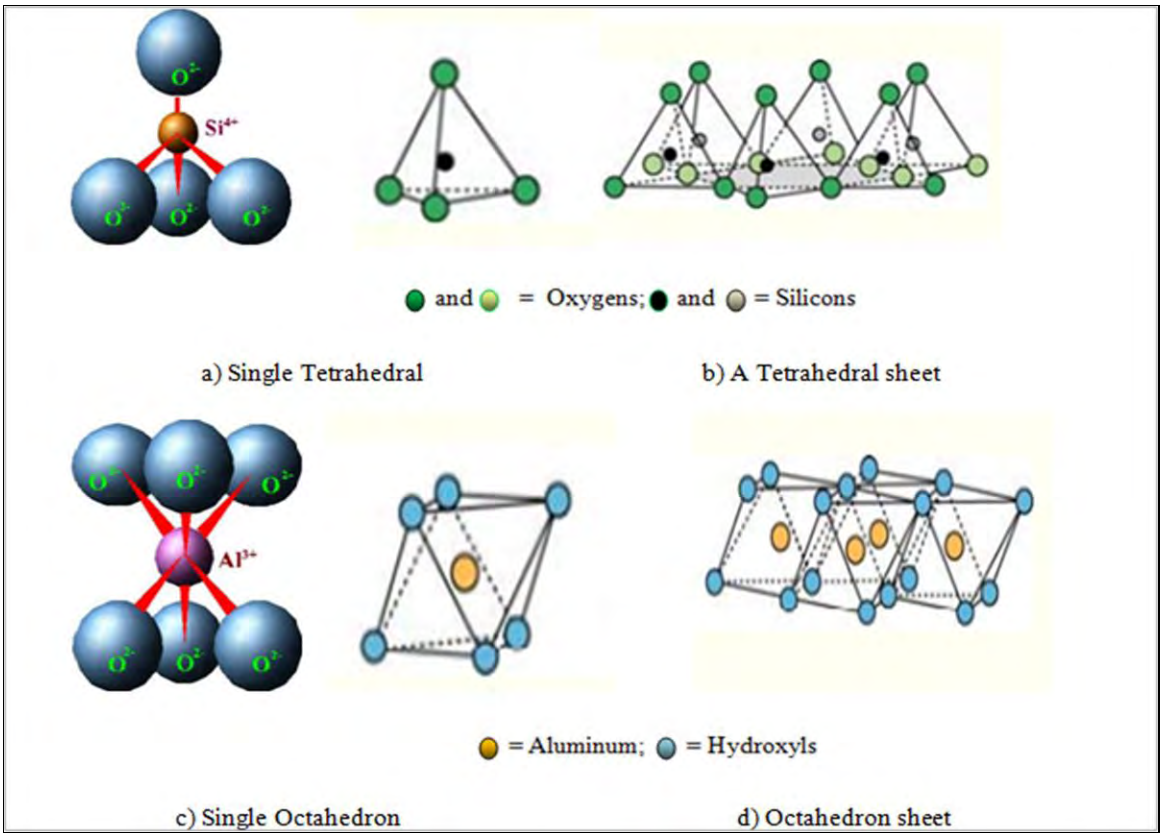
Illite consists of repeated layers of one alumina sheet sandwiched by two silicate sheets(a 2:1 clay mineral). The layers, each of thickness 0.96 nm, are held together by potassium ions [3].

This potassium bond of illite clay mineral is weaker than the hydrogen bond of kaolinite clay mineral, but is stronger than the water bond of the montomorillonite clay mineral. Due to this, illite crystal has a greater tendency to split into platelets (structural units) than that in kaolinite. However, illite structure does not swell, because the movement of water between the sheets like that of montomorillonite is not there.

Illite clay particles may be 50 Å to 500 Å thick and 1000 Å to 5000 Å in lateral dimensions, making them smaller than the kaolinite crystals [5].

2.3.3 Montmorillonite

Montmorillonite presents a more complicated structure, the single layer (of thickness of 0.96 nm) being composed of an octahedral sheet between two tetrahedral sheets (i.e. it is a 2:1 clay mineral). The bonding between the silica sheets is represented by Vander Waals' forces, so it is a weak bond. In addition, there is anegative charge deficiency in the octahedral sheet, due to isomorphous substitution of Al^{3+} with Mg^{2+}, so that exchangeable ions (sodium or calcium) lie between the layers, or are attached at the edges of the crystal. Molecular water may also occur betweenlayers. As a consequence, the crystals can be rather small (the thickness can be of the order of 1 nm) and clay soils containing montmorillonite are susceptible to swelling, with important engineering implications [16]. Montmorillonite is often called a swelling or expansive clay mineral [3,17].



a) Silica tetrahedron b) Silica sheets c) Aluminum Octahedron d) Alumina sheet

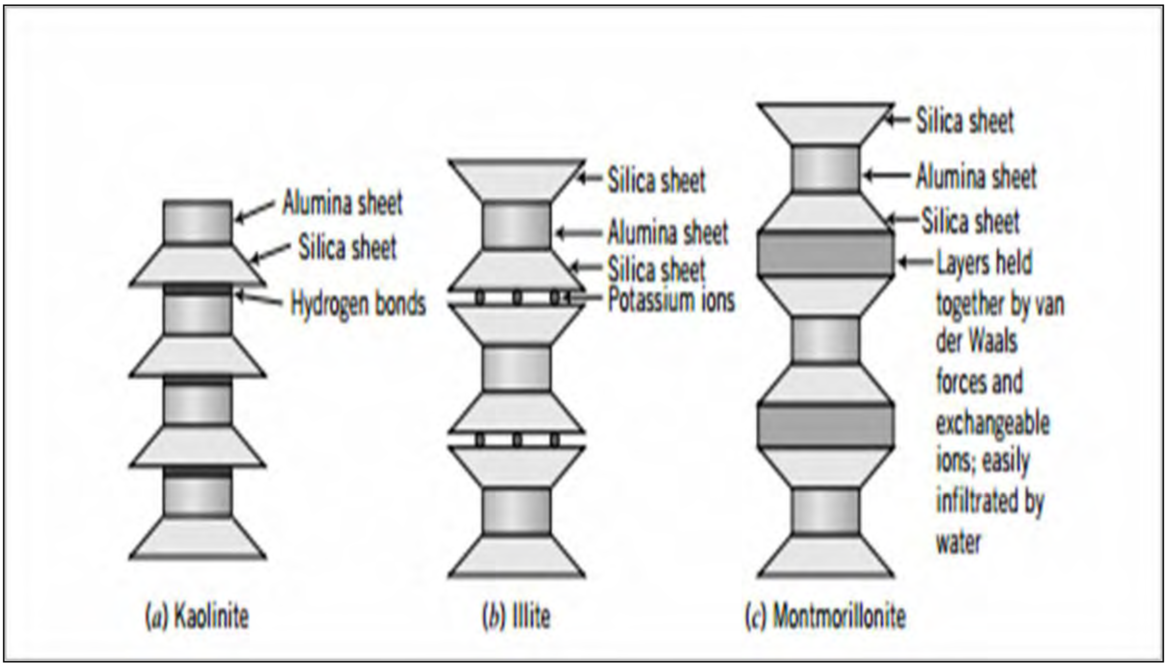


Figure 2.3: Structure of kaolinite, illite and montmorillonite

3. DESCRIPTION OF THE STUDY AREA AND IN-SITU IDENTIFICATION

3.1 Location

Dembecha was mentioned as one of the places which the Emperor Johannes passed through between 8th May and 18 th July 1683 on his journey from Yebaba to Gondar,is a town in northwestern Ethiopia 350 km north of Addis Ababa (Figure 3.1), located in the western Gojjam Zone of the Amhara Region. This town has a latitude and longitude of 10°33′N 37°29′E with an elevation of 2117 meters above sea level. It is one of the three towns (Addis Alem, Dembecha and Yechereka) in Dembecha woreda.

Dembecha has a total area of about 1140 Hectares, which has been subdivided into 3 urban Kebeles (least administrative structure) administrations.

Dembecha borders on Bure in the west, Jabi Tehnan in the northwest, Dega Damot in the north, and the Eastern Gojjam Zone in the east and south.

Rivers in this woreda include the Temchia, over which the Italian Count Salimbeni built the first bridge in Gojjam for NegusTekle Haymanot in 1884-1885. Near the town of Dembecha are hot springs and other landmarks including venerable monasteries which are both well known and popular throughout Gojjam.

There are four main seasons in the zone, namely bega (dry) from March to May, kremt (rains) from June to August (main rainy season), tibi from September to November, and meher from December to February (harvest season).

The master plan of the town includes roads, residential areas,government offices, commercial areas, institution, and known recreational areas which need extensive constructions and are governed by detailed investigation of soils.

To come up with investigation of the engineering properties of soils and have map of the study area which require extensive construction, a total of ten test pits dug by daily laborers with global coordinates (Table 3.1) were used to recover disturbed and un- disturbed samples for index, shear strength, swelling and compressibility characteristics tests.

After analysis and interpretation of the test results obeying the most accepted standards, the selected test pits are located in the map of the town in order for civil engineers use it as a guideline and future research studies be initiated.

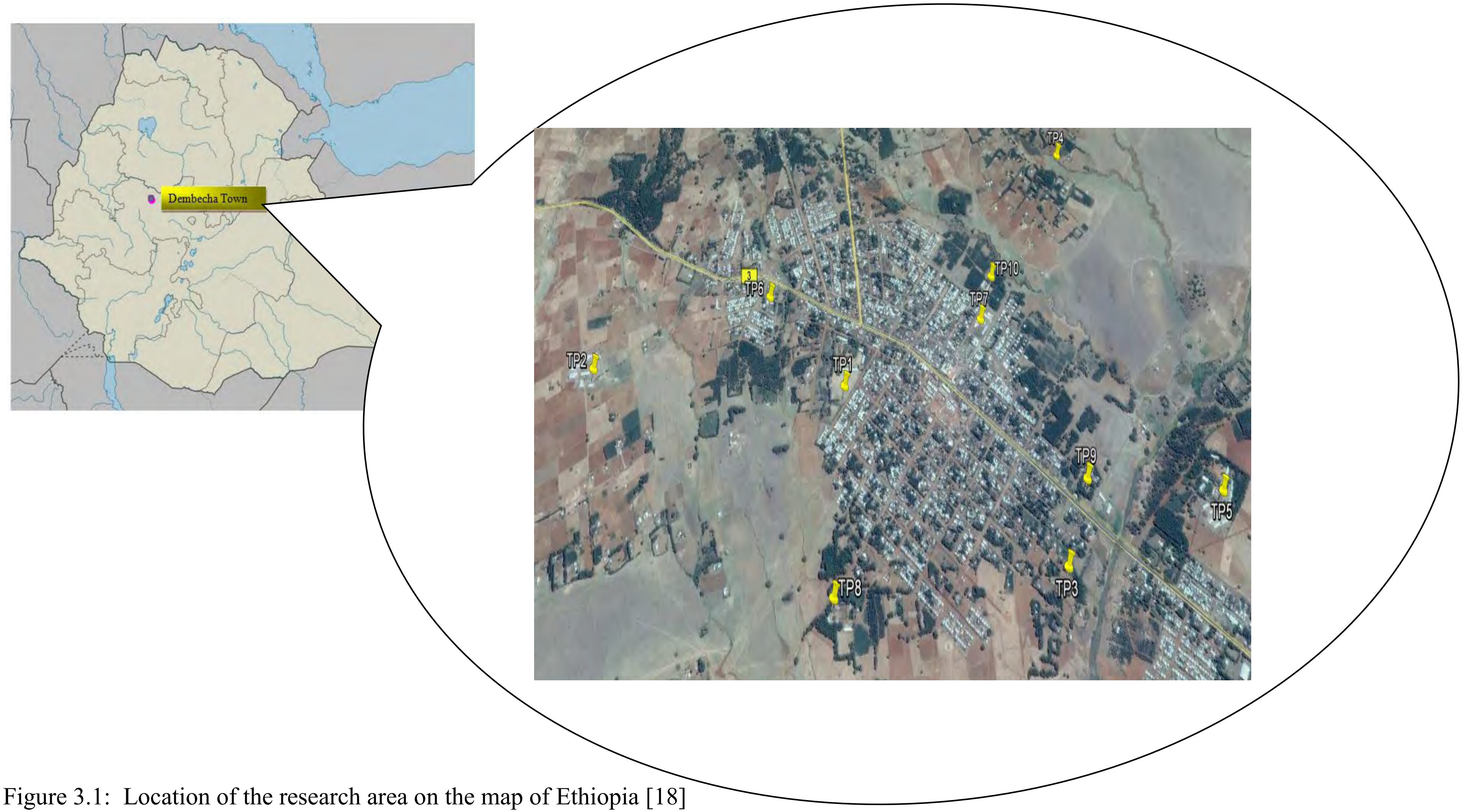


Figure 3.1: Location of the research area on the map of Ethiopia [18]

Table 3.1 Global coordinates of test pits location

Test Pit No	Easting	Northing	Elevation
TP-1	37^{0}29.160’	10^{0}33.870’	2102m
TP-2	37^{0}28.529’	10^{0}33.900’	2117m
TP-3	37^{0}29.676’	10^{0}33.574’	2076m
TP-4	37^{0}29.076’	10^{0}34.440’	2154m
TP-5	37^{0}30.048’	10^{0}33.691’	2083m
TP-6	37^{0}28.947’	10^{0}34.052’	2112m
TP-7	37^{0}29.505’	10^{0}34.019’	2086m
TP-8	37^{0}29.167’	10^{0}33.520’	2104m
TP-9	37^{0}29.740’	10^{0}33.717’	2078m
TP-10	37^{0}29.539’	10^{0}34.117’	2091m

3.2 Topography and drainage conditions

The elevation of the study area varies from 2076 meters above sea level in “Wetebet Sefer“ near river “Gudla” to 2154 meters above sea level in “Saint Michael church “.

The stretches of the town are not having even slope in that there are depressed and scattered areas. And there is a serious erosion problem on the boundary of the town.

The only perennial river in the vicinity of Dembecha is "Gudla" into which all the streams in the town join.

3.3 Climatic Characteristics

3.3.1 Rainfall

Based on 24 years of Ethiopian meteorological data i.e from 1990 to 2014 for Dembecha station, the average annual rainfall is 1210.4 mm with a maximum of 1639.60 mm in 1997 and a minimum of 30.9 mm in 2007 [19], which complies with 2013 ERA Site Investigation design manual [39].

It is shown in Figure 3.2 that more than 74% of the rainfall occurs in months of June, July, August and September and clearly observed that these months are known for receiving adequate rain fall data of the year.

3.3.2 Temperature

In a mountainous tropical country like Ethiopia, altitude is by far the most important factor 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°C, areas between 500 – 1500 meters a.m.s.l. (i.e. 'kola' or tropical climate) have 20 -30°C and areas below 500 meters a.m.s.l. (i.e. 'bereha' or desert climate) have a temperature of 30°C and above [20].

The town of Dembecha, with an altitude of 2117 meters above sea level, has a mean minimum, mean maximum and mean average monthly temperature of 8.4, 29 and 18.7^{0}C respectively. The maximum annual temperatures occur in March whereas minimum annual temperature occurs in Julyand the mean monthly average temperature ranges from 17°c to 20.7°c as can be seen in Fig 3.3. This shows the temperature variation is almost the same throughout the year since the deviation between values is negligible.

Both rain fall and temperature data are presented in Appendix A.

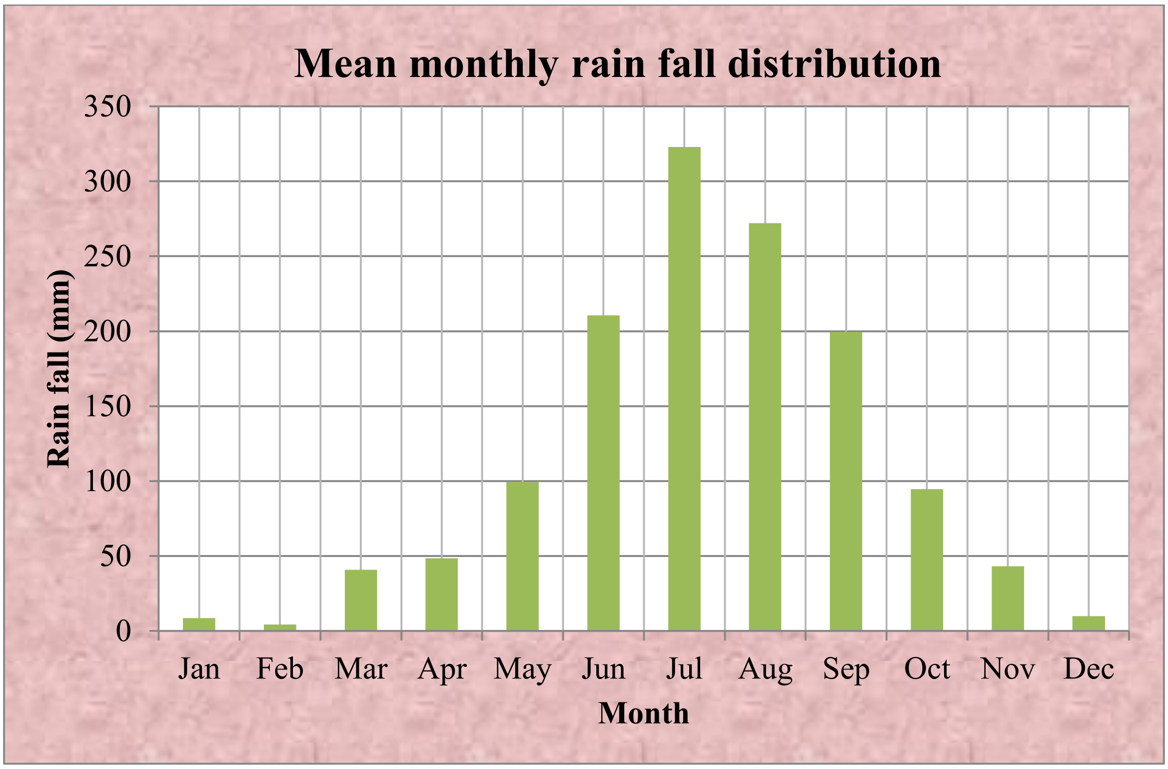


Figure 3.2: Mean monthly rainfall distribution of Dembecha [19]

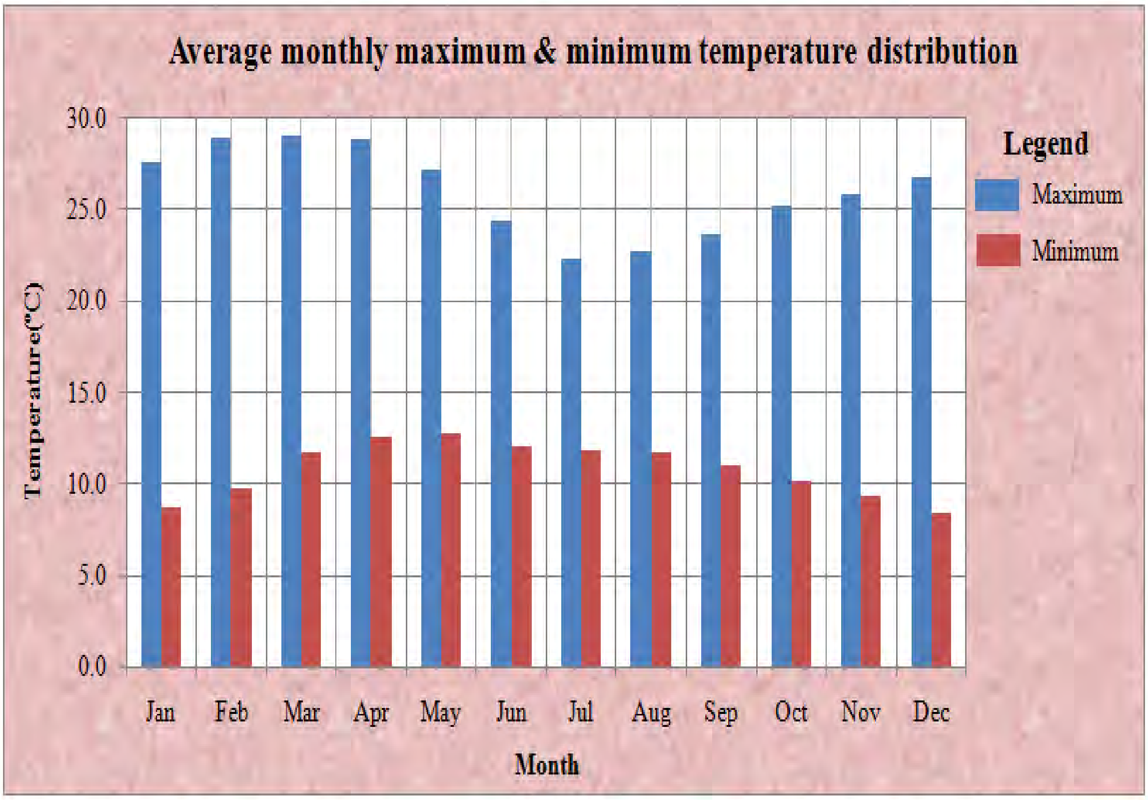


Figure 3.3:Average monthly maximum and minimum temperature distribution in Dembecha(1990-2014) [19]

3.4 In-situ Identification of Soil in the Study Area

3.4.1 General

Soil is classified for engineering purposes in accordance with the Unified Soil Classification System (USCS). Soils sharing a common classification possess similar engineering properties, including strength, permeability, and compressibility, so the USCS is useful for specifying soil types to achieve a desired performance. When quantified data regarding *LL*, *PI*, and gradation are available, the soil can be classified using ASTM D2487. However, it is prudent when recovering soil specimens from a test boring to classify the soil in the field as it is logged, then visual- manual classification in accordance with ASTM D2488 is very important [21].

Basically, coarse-grained and fine-grained soils are distinguished based on whether the individual soil grains can be seen with naked eye or not. Thus, grain-size itself may be adequate to distinguish between gravel and sand : but silt and clay cannot be distinguished by this technique [22].

Classification of fine-grained inorganic soils is mostly based on the estimate of the plasticity of the soil. Since liquid and plastic limit testing cannot be easily performed in the field, estimation of soil plasticity is based on several diagnostic tests: Dry Strength, Dilatency, Toughness, Hand Wash, Mud Crack [21].

Moisture and soil colours are also distinguishing factors to properly investigate the in-situ soil property.

Colour of soil is one of the most obvious of its features. Soil colour may vary widely, ranging from white through red to black; it mainly depends upon the mineral matter, quantity and nature of organic matter and the amount of colouring oxides of iron and manganese, besides the degree of oxidation [2].

3.4.2 Soil Color designation using Munsell chart

Soil colors are most conveniently measured by comparison with a color chart. The seven charts in the soil collection display 199 different standard color chips systematically arranged according to Munsell notations, on cards carried in a loose leaf notebook. The arrangement is by the three simple variables that combined to describe all colors (i.e. Hue, Value and Chroma).

The Hue notation indicates the color's relation to Red, Yellow, Green Blue and Purple; the Value notation indicates its lightness; and the Chroma notation indicates its strength (or departure from a neutral of the same lightness). The Munsell notation is especially useful for international correlation, since no translation of color names are needed [23].

Hence, before going to directly select and start retrieving samples, reconnaissance of the area was made with representative bodies from the mayor office to really gather information regarding the study area.

Consequently, ten representative test pits were selected from different locations, including future expansion areas and infrastructures and excavated to a maximum depth of three meters except TP-3 which was difficult as a result of existence of boulders and sound materials beyond 1.80m deep excavation. Then test pit logs were properly presented along with colour of soils using Munsell chart which is shown in Table 3.2 and Appendix B.

Table 3.2. Insitu soil colours using Munsell Chart

Test Pit Number	Depth (m)	Hue	When Dry			When Wet		
			Value	Chroma	Color	Value	Chroma	Color
TP-1	1.5	10R	4	4	Weak Red Soil	3	4	Dusky Red Soil
	3.0	10R	3	4	Dusky Red Soil	3	3	Dusky Red Soil
TP-2	1.5	2.5YR	4	4	Reddish Brown Soil	3	6	Dark Red Soil
	3.0	2.5YR	3	4	Dark Reddish Brown Soil	3	6	Dark Red Soil
TP-3	1.8	7.5YR	4	6	Strong Brown Soil	3	4	Dark Brown Soil
TP-4	1.5	5YR	3	3	Dark Reddish Brown Soil	3	2	Dark Reddish Brown Soil
	3.0	10YR	5	2	Greyish Brown Soil	4	3	Dark Brown Soil
TP-5	1.5	2.5YR	3	6	Dark Red Soil	3	4	Dark Reddish Brown Soil
	3.0	10R	3	4	Dusky Red Soil	3	3	Dusky Red Soil
TP-6	1.5	10YR	5	1	Grey Soil	4	1	Dark Grey Soil
	3.0	10YR	6	2	Light Brownish Grey Soil	5	2	Greyish Brown Soil
TP-7	1.5	5YR	5	6	Yellowish Red Soil	4	6	Yellowish Red Soil
	3.0	10YR	5	6	Yellowish Brown Soil	4	4	Dark Yellowish Brown Soil
TP-8	1.5	10R	3	4	Dusky Red Soil	3	3	Dusky Red Soil
	3.0	2.5YR	4	4	Reddish Brown Soil	3	4	Dark Reddish Brown Soil
TP-9	1.5	5Y	5	2	Olive Grey Soil	5	2	Olive Grey Soil
	3.0	5Y	7	4	Pale Yellow Soil	6	4	Pale Olive Soil
TP-10	1.5	10YR	5	1	Grey Soil	4	1	Dark Grey Soil
	3.0	10YR	4	3	Dark Brown Soil	3	3	Dark Brown Soil

4. LABORATORY TEST RESULTS

4.1 General

In geotechnical engineering, more than in any other field of civil engineering, success depends on practical experience. The design of ordinary soil-supporting or soil-supported structures is necessarily based on simple empirical rules, but these rules can be used safely only by the engineer who has a background experience. Large projects involving unusual features may call for extensive application of scientific methods to design, but the program for the required investigations cannot be laid out wisely, nor can the results be interpreted intelligently, unless the engineer in charge of design possesses a large amount of experience [14].

Proper laboratory testing of soils to determine their physical properties is an integral part in the design and construction of structural foundations, the placement and improvement of soil properties, and the specification and quality control of soil compaction works [24].

One of the foremost aims in attempts to reduce the hazards in dealing with soils has been to find simple methods for discriminating among the different kinds of soil in a given category. The properties on which the distinctions are based are known as index properties, and the tests required to determine the index properties are classification tests.The index properties of soils investigated in this study include natural moisture content,particle size distribution , Atterberg limits, specific gravity and free swell [14].

4.2 Index properties

4.2.1 Natural moisture content

Soil samples were collected from selected test pits and put inside poly ethylene bags to prevent natural moisture content loss. In the standard method ASTM D2216, the water content is determined by measuring the mass of the moist specimen, oven drying the specimen to constant mass in a 110 +/- 5˚C oven, generally overnight, allowing the specimen to cool in a moisture - limited environment (such as desiccators) or in covered tares, then measuring the mass of the cooled, oven - dry specimen [25].

The results are presented in Table 4.1 and for detail observations see appendix C.

Table 4.1. Natural moisture content test results

Test pit No.	Depth of sample (m)	Natural moisture content (%)
TP-1	1.5	31.40
	3.0	34.71
TP-2	1.5	34.51
	3.0	37.85
TP-3	1.8	25.00
TP-4	1.5	29.72
	3.0	37.70
TP-5	1.5	33.61
	3.0	37.21
TP-6	1.5	43.81
	3.0	45.52
TP-7	1.5	36.51
	3.0	48.00
TP-8	1.5	31.21
	3.0	32.51
TP-9	1.5	34.21
	3.0	33.33
TP-10	1.5	32.82
	3.0	31.51

4.2.2 Particle size distribution

A sieve analysis is performed by washing the soil on the No. 200 sieve in order to remove all the fines (i.e., silt and clay size particles) [26].

The specimen fraction that is finer than the 75 µm (No. 200) sieve is analyzed using sedimentation method [25].The combined test results are presented in Table 4.2 and the particle size distribution curves are shown in Fig 4.1and Fig 4.2 and detail calculations are presented in appendix D.

Table 4.2. Particle size analysis test result

Sr.No	Test pit Naming	Test pit designation	Depth of sample (m)	Percent amount of particle size					
				Gravel	Sand	Silt	Clay	PP_{40}	PP_{200}
1	Junior secondary school	TP-1	1.5	0.00	0.43	23.82	75.72	99.81	99.57
			3.0	0.00	0.71	19.46	79.83	99.59	99.29
2	Technical & Vocational school	TP-2	1.5	0.02	2.99	25.47	71.52	97.44	96.99
			3.0	0.00	0.54	27.07	72.39	99.68	99.46
3	Wetebet	TP-3	1.8	5.52	7.90	41.42	45.16	87.96	86.58
4	Saint Michael Church	TP-4	1.5	7.66	10.48	36.71	45.15	83.01	81.86
			3.0	0.38	5.24	34.36	60.02	95.54	94.38
5	Preparatory school	TP-5	1.5	0.00	0.25	26.19	73.56	99.89	99.75
			3.0	0.00	1.11	22.22	76.66	99.36	98.89
6	Health center	TP-6	1.5	0.00	4.20	37.45	58.35	97.11	95.80
			3.0	0.14	14.90	29.68	55.27	88.49	84.96
7	Mayor office	TP-7	1.5	0.09	2.19	34.05	63.66	98.79	97.72
			3.0	0.01	1.56	34.77	63.66	99.50	98.43
8	Addisamba elementary school	TP-8	1.5	0.00	0.29	23.27	76.44	99.85	99.71
			3.0	0.07	0.66	24.36	74.91	99.47	99.27
9	Health center office	TP-9	1.5	0.03	9.06	38.64	52.27	92.95	90.91
			3.0	0.03	2.25	35.35	62.36	98.39	97.72
10	Sisomesk elementary school	TP-10	1.5	0.03	3.20	34.36	62.41	98.15	96.77
			3.0	0.07	3.56	30.67	65.69	99.01	96.37

Where : PP_{40} = percent passing through No. 40 sieve

PP_{200} = percent passing through No. 200 sieve

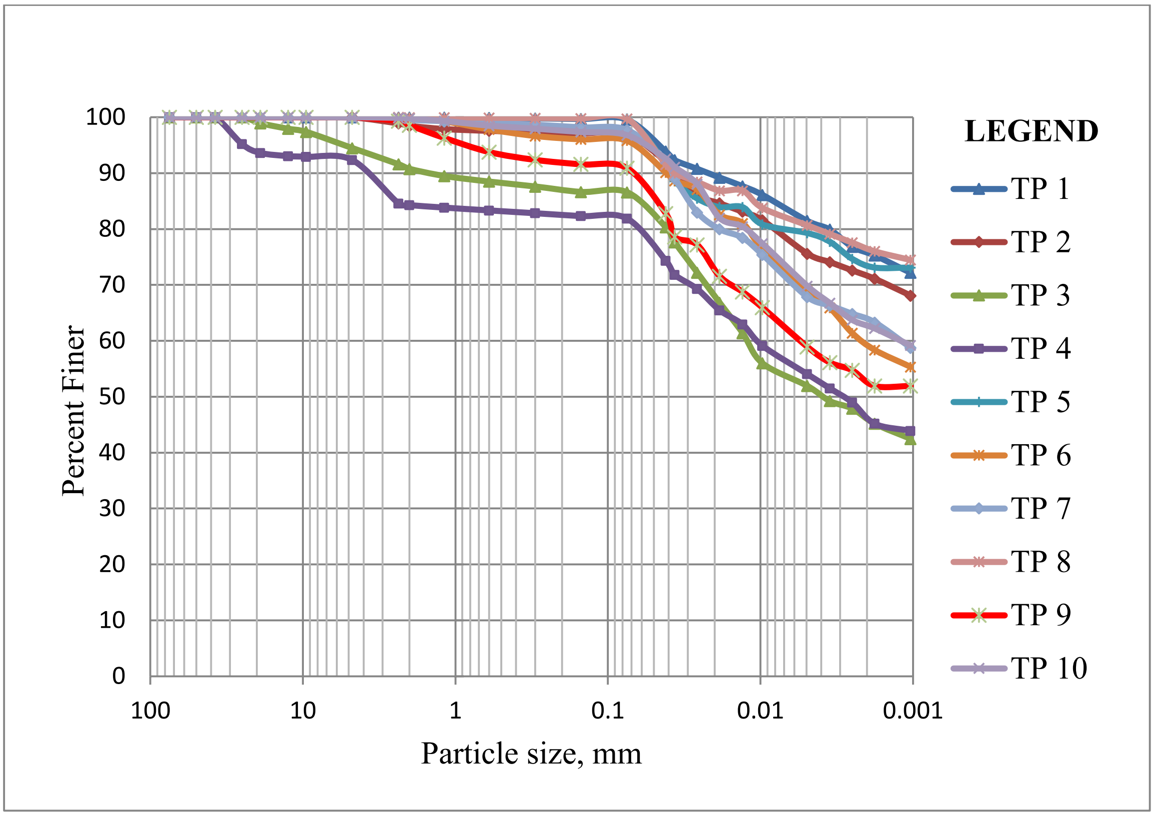


Figure 4.1: Particle size distribution curves at a depth of 1.5 m and 1.8 m (at TP 3)

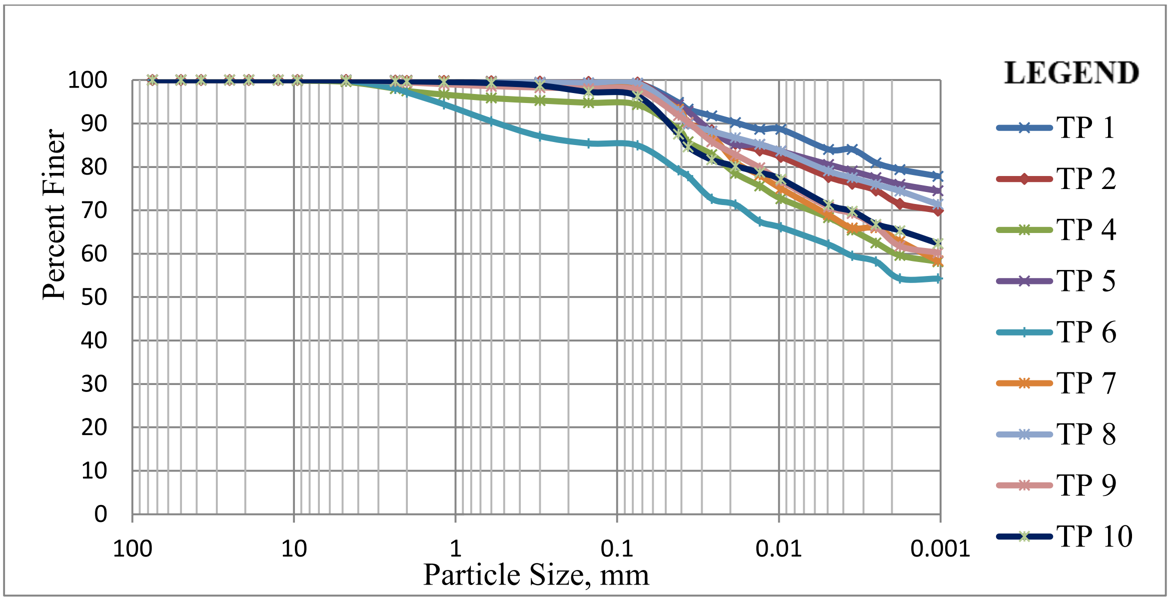


Figure 4.2: Particle size distribution curves at a depth of 3.0 m

4.2.3 Dispersibility

Dispersive soils are characterized by an unstable structure.They easily flocculate in water, and have very high erodibility [27]. Using dispersive clay soils in hydraulic structures, embankment dams, or other structures such as roadway embankments can cause serious engineering problems if these soils are not identified and used appropriately. This problem is common worldwide, and structural failures attributed to dispersive soils have occurred in many countries [28].

Erosion occurs when shearing stress induced by fluid flow on a surface is large enough to cause particle removal from the surface. The resistance to erosion is offered by the submerged weight of the sediment, i.e. gravity forces for non-cohesive soils. But in cohesive soil, the structure of the soil and the interaction between pore and eroding fluids at the surface is the phenomenon involved in soil erosion. The amount and type of clay, PH, organic matter, temperature, water content, thixotropy and type and concentration of ions in the pore and eroding fluids are the factors that affect the critical shear stress required to initiate erosion [29].

Dispersive clays are highly erosive because they contain a higher percentage of dissolved sodium cations in their pore water than do ordinary clays [30].

Visual classification, Atterberg's limits and particle size analysis do not provide sufficient basis to differentiate between dispersive clays and ordinary erosion resistant clays [29].

Dispersive clay identified by ASTM tests such as: Pinhole test, Crumb test,double hydrometer test and chemical test. The researcher conducted dispersivity test in accordance with ASTM D 4221 using Double Hydrometer method.

The particle size distribution is first determined using the standard hydrometer test in which the soil specimen is dispersed in distilled water with strong mechanical agitation and a chemical dispersant. A parallel hydrometer test is then made on a duplicate soil specimen, but without mechanical agitation and without a chemical dispersant. Percent dispersion is the ratio of percent passing 5-μm free from dispersion agent and stirrer to percent passing 5-μm by usual hydrometer and multiplying the result by 100.

$$D = \frac{\%\ \text{Passing } 5\mu\text{m (with out dispersant agent)}}{\%\ \text{Passing } 5\ \mu\text{m (with standard)}} * 100 \qquad (4.1)$$

Some of the guide lines describing the dispersive properties of soils are given in Table 4.3

Table 4.3.Dispersive properties of soils as per different authors

Authors	Percent dispersion (%)	Dispersion property
ASTM Standard D4221-99 [27]	Near 100	Completely dispersive
	Near 0	Soil no dispersive
Sherard JL, Dunnigan L.P., and Decker R.S, (1977) [31]	< 35	No dispersivity problem
	35 - 50	Probable dispersivity
	> 50	Problem of dispersivity
Knodel PC (1991) [22]	< 30	No dispersive
	30 - 50	Intermediate
	> 50	Dispersive

Table 4.4. Dispersion characteristics of soils in the study area

Sr. No	Test pit designation	Depth of determination	Dispersion Property Percent Dispersion and Comments **ASTM D4221-99** [27]	**Decker et Dunnigan** [31]	**Knodel** [22]
1	TP-1	1.5 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
		3.0 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
2	TP-2	1.5 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
		3.0 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
3	TP-3	1.8 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
4	TP-4	1.5 m	19.70 (not dispersive)	19.70 (not dispersive)	19.70 (not dispersive)
		3.0 m	78.24 (Completely dispersive)	78.24 (Problem of dispersivity)	78.24 (Dispersive)
5	TP-5	1.5 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
		3.0 m	3.34 (not dispersive)	3.34 (not dispersive)	3.34 (not dispersive)
6	TP-6	1.5 m	30.12 (not dispersive)	30.12 (not dispersive)	30.12 (Intermediate)
		3.0 m	12.97 (not dispersive)	12.97 (not dispersive)	12.97 (not dispersive)
7	TP-7	1.5 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
		3.0 m	11.92 (not dispersive)	11.92 (not dispersive)	11.92 (not dispersive)
8	TP-8	1.5 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
		3.0 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
9	TP-9	1.5 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
		3.0 m	0 (not dispersive)	0 (not dispersive)	0 (not dispersive)
10	TP-10	1.5 m	14 (not dispersive)	14 (not dispersive)	14 (not dispersive)
		3.0 m	8.32 (not dispersive)	8.32 (not dispersive)	8.32 (not dispersive)

The above results show that there is intermediate dispersibility in test pit 6 at a depth of 1.50m and critical dispersibility problem in test pit 4 at 3.0m depth.

Detailed presentation of the soils' dispersivity and curves are shown in appendix E.

4.2.4 Atterberg limits

'Consistency' is that property of a material which is manifested by its resistance to flow. In this sense, consistency of a soil refers to the resistance offered against forces that tend to deform or rupture the soil aggregate. In other words, it represents the relative ease with which the soil may be deformed. Consistency may also be looked upon as the degree of firmness of a soil and is often directly related to strength. This is applicable specifically to clay soils and is generally related to the water content [2].

Atterberg formally distinguished the stages of consistency–liquid, plastic, semi-solid, and solid. The water contents at which the soil passes from one of these states to the next have been arbitrarily designated as 'consistency limits'–Liquid limit, Plastic limit and Shrinkage limit, in that order. These are called 'Atterberg limits' in honour of the originator of the concept [2]. By far the most important of these are the plastic limit and the liquid limit [4].

The upper and lower limits of the range of water content over which the soil exhibits plastic behavior are defined as the **liquid limit** (LL) and the plastic limit (PL), respectively. Above the **liquid limit**, the soil flows like a liquid (slurry); below the plastic limit, the soil is brittle and crumbly. The water content range itself is defined as the plasticity index (PI).

The transition between the semi- solid and solid states occurs at the **shrinkage limit** (SL), defined as the water content at which the volume of the soil reaches its lowest value as it dries out.

The natural water content (ω) of a soil relative to the liquid and plastic limits can be represented by means of the liquidity index (LI), which is given by:

$$\mathrm{LI} = \frac{(\omega - \mathrm{PL})}{\mathrm{PI}} \tag{4.2}$$

Atterberg limits were carried out in accordance with ASTM D 4318 and the results are presented in Table 4.5. And detailed calculations are presented in appendix F.

Furthermore, Atterberg limits and grain size distribution results may be combined to gather information about the nature of soils. One parameter of interest is the Activity, A of Clay, which is defined as:

$$A = \frac{PI}{\text{clay fraction}} \tag{4.3}$$

Where clay fraction is the percentage of soils smaller than 0.002mm. Activity indicates the relationship between mineral composition, specific surface, percentage of clay fraction and the plasticity index of soils [15].

Table 4.5. Atterberg Limit test results

Sr.No.	Test pit designation	Depth of sample (m)	Liquid limit, %	Plastic limit, %	Plasticity index,%	Activity (A)
1	TP-1	1.5	61	32	29	0.38
		3.0	70	32	38	0.48
2	TP-2	1.5	73	36	37	0.52
		3.0	80	39	41	0.57
3	TP-3	1.8	59	33	26	0.58
4	TP-4	1.5	68	30	38	0.84
		3.0	89	30	59	0.98
5	TP-5	1.5	68	36	32	0.44
		3.0	62	30	32	0.42
6	TP-6	1.5	77	30	47	0.81
		3.0	85	33	52	0.94
7	TP-7	1.5	70	31	39	0.61
		3.0	68	30	38	0.60
8	TP-8	1.5	72	39	33	0.43
		3.0	65	37	28	0.37
9	TP-9	1.5	80	33	47	0.90
		3.0	68	29	39	0.63
10	TP-10	1.5	85	31	54	0.87
		3.0	82	33	49	0.75

There is a fairly close correlation between clay mineral type and activity. Kaolinite, halloysite, and allophone are of low activity; illite is of medium, or normal activity; and montmorillonite (or smectite) is of high activity [4]. If mineralogy test was carried, it would be possible to group soils accurately in the study area. The soils in the study area are in the normal and inactive ranges. And the soils based on activity are presented in Figure 4.3.

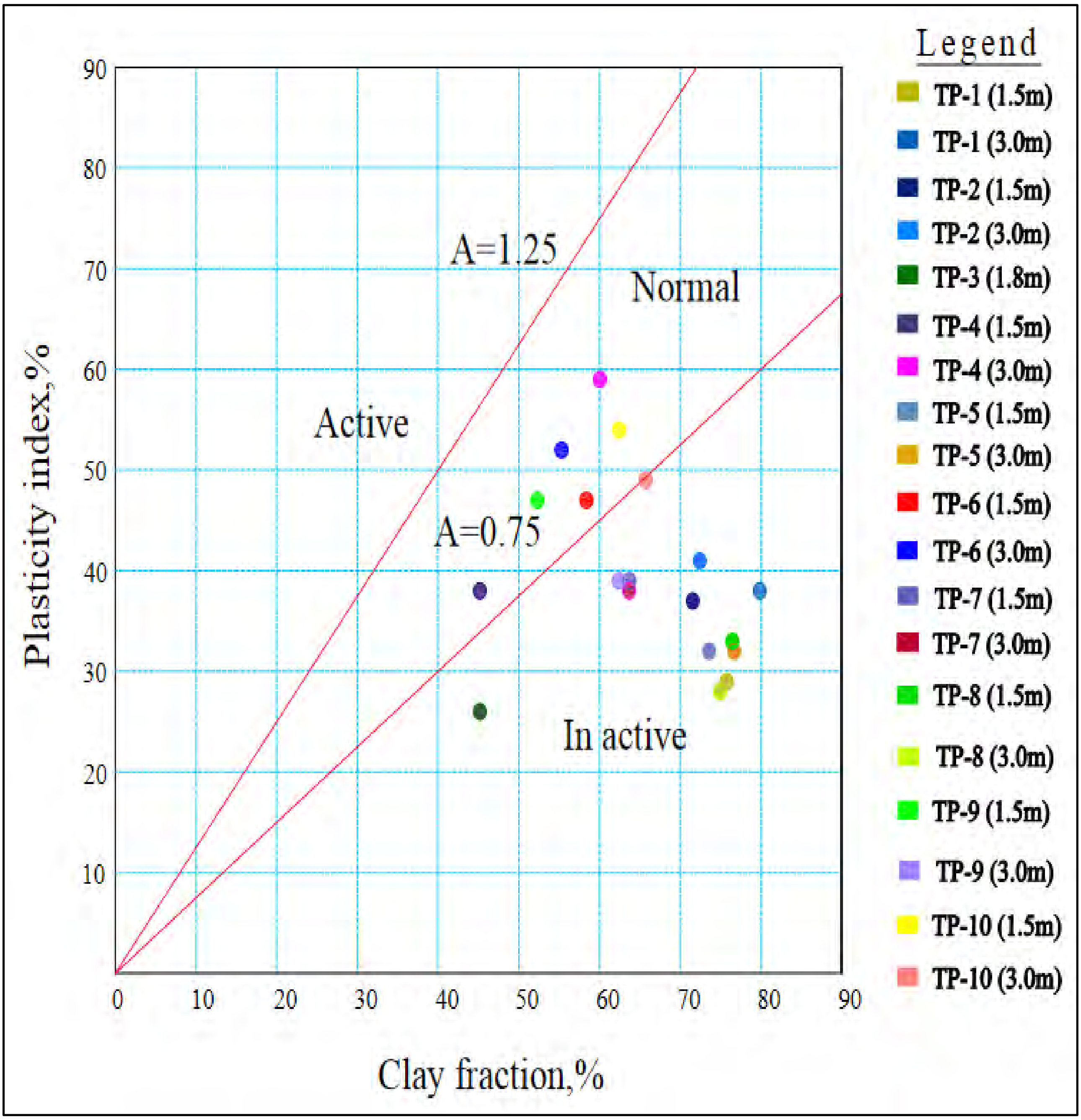


Figure 4.3: Activity chart of soils in the study area

Inactive clays are those clays that have an activity less than 0.75, normal activity clays are those clays having an activity between 0.75 and 1.25, and active clays are those clays having an activity greater than 1.25 [26].

4.2.5 Specific gravity

Specific gravity of soil solids, Gs, is the mass density of the mineral solids in soil normalized relative to the mass density of water. Alternatively, it can be viewed as the mass of a given volume of soil solids normalized relative to the mass of an equivalent volume of water [21].

The specific gravity test was conducted by using density bottle as per ASTM D854 and the results are presented in Table 4.6 and detail calculations are presented in appendix G.

Table 4.6. Specific gravity test results

Test pit No.	Depth (m)	Specific gravity
TP-1	1.5	2.80
	3.0	2.80
TP-2	1.5	2.83
	3.0	2.82
TP-3	1.8	2.78
TP-4	1.5	2.82
	3.0	2.85
TP-5	1.5	2.83
	3.0	2.84
TP-6	1.5	2.73
	3.0	2.84
TP-7	1.5	2.82
	3.0	2.84
TP-8	1.5	2.80
	3.0	2.84
TP-9	1.5	2.84
	3.0	2.85
TP-10	1.5	2.76
	3.0	2.85

The specific gravity of soils in this research ranges between 2.73 and 2.85, which is similar to the results obtained by a previous study carried out in Dangila, Merawi, and Bahir Dar [32,33,34] respectively.

4.2.6 Free swell

Generally highly plastic clays, and specially black cotton soils, have a tendency to swell in varying proportions, when submerged in water. Free swell or differential free swell is the increase in volume of a soil without any external constraint when subjected to submergence in water.

Soils with high free swell index value have a possibility to damage the structure when the ground water table reaches the influence zone.

This test is carried out by placing 10 ml volume of oven dried soil (which passes No.40) in water as usual and in Kerosene oil (a non-polar liquid) in 100 ml graduated glass cylinders for 24 hours or more. Then the difference between the final swell volume and initial volume (of Kerosene oil) divided by the initial volume (of Kerosene oil) expressed as a percentage is differential free swell [35].

The differential free swell is hence used as an indication of the degree of expansion of a soil [1].

The free swell test results carried out using air dry, oven dry and Kerosene oil are presented in Table 4.7 and 4.8 and detail calculations are presented in appendix H.

And the following are guide lines for differential free swell index [1].

Differential free swell (%)	Degree of expansiveness
< 20	Low
20-35	Moderate
35-50	High
> 50	Very high

Table 4.7. Free swell test results using usual practice (IS: 2720-11)

Sr.No.	Test pit Naming	Test pit designation	Depth of sample (m)	Free Swell ,%	
				Air dry	Oven dry
1	Junior Secondary school	TP-1	1.5	28	48
			3.0	30	43
2	Technical & Vocational school	TP-2	1.5	40	48
			3.0	38	43
3	Wetebet	TP-3	1.8	20	40
4	Saint Michael Church	TP-4	1.5	30	48
			3.0	63	75
5	Preparatory school	TP-5	1.5	20	30
			3.0	48	50
6	Health center	TP-6	1.5	50	55
			3.0	63	80
7	Mayor office	TP-7	1.5	43	63
			3.0	63	63
8	Addisamba elementary school	TP-8	1.5	25	45
			3.0	40	48
9	Health center office	TP-9	1.5	78	93
			3.0	47	58
10	Sisomesk elementary school	TP-10	1.5	65	68
			3.0	73	85

Based on the findings of this research, the free swell index values of a few soils of the study area show smaller values even less than 50% and more than half of the soils have marginal values, which are less than 100%. As per Holtz, soils having free swell value as low as 100 percent can cause considerable damage to lightly loaded structures and soils having free swell value below 50 percent seldom exhibit appreciable volume change even under very light loadings [36]. The differential free swell indices were determined and test results are presented in Table 4.8.

Table 4.8. Free swell test results using Kerosene IS: 2720-11

Test pit No.	Depth (m)	Differential free swell Index (%)	Degree of expansiveness
TP-1	1.5	18	Low
	3.0	22	Moderate
TP-2	1.5	23	Moderate
	3.0	27	Moderate
TP-3	1.8	12	Low
TP-4	1.5	23	Moderate
TP-5	1.5	10	Low
	3.0	25	Moderate
TP-8	1.5	23	Moderate
	3.0	17	Low

From values the research presented, the degree of expansiveness of soils in the study lies from low to moderate expansion.

4.3 Shear Strength Tests

4.3.1 General

Soils like any other materials fail at some point when they are subjected to increasing shear stresses. They cannot withstand a shear stress larger than their shear strength and deform extensively when the applied shear stress approaches their shear strength value. Shear strength is a very important soil property to determine the stability of foundations, retaining walls, slopes, and embankments [37].

The safety of any geotechnical structure is dependent on the shear strength of the soil. If the soil fails, a structure founded on it can collapse, endangering lives and causing economic damages. The shear strength of soils, is therefore, of paramount importance to geotechnical engineers [3].

4.3.2 Unconfined compression test

To determine shear strength parameters, there are a number of laboratory methods available. Among these, Direct shear test, Unconfined compression test, Laboratory Vane shear test and Triaxial compression tests are the most common ones.

The unconfined compression (UC) test is used widely to determine the consistency of saturated clays and other cohesive soils [3]. Unconfined compressive strength testing also provides a quick and simple means to measure the unconfined compressive strength (q_u) and undrained shear strength (Su) of normally consolidated and slightly over consolidated cylindrical specimens of cohesive soil [21].

The unconfined compression test was conducted as per ASTM D2166 and the results are presented in Figure 4.4. and 4.5.

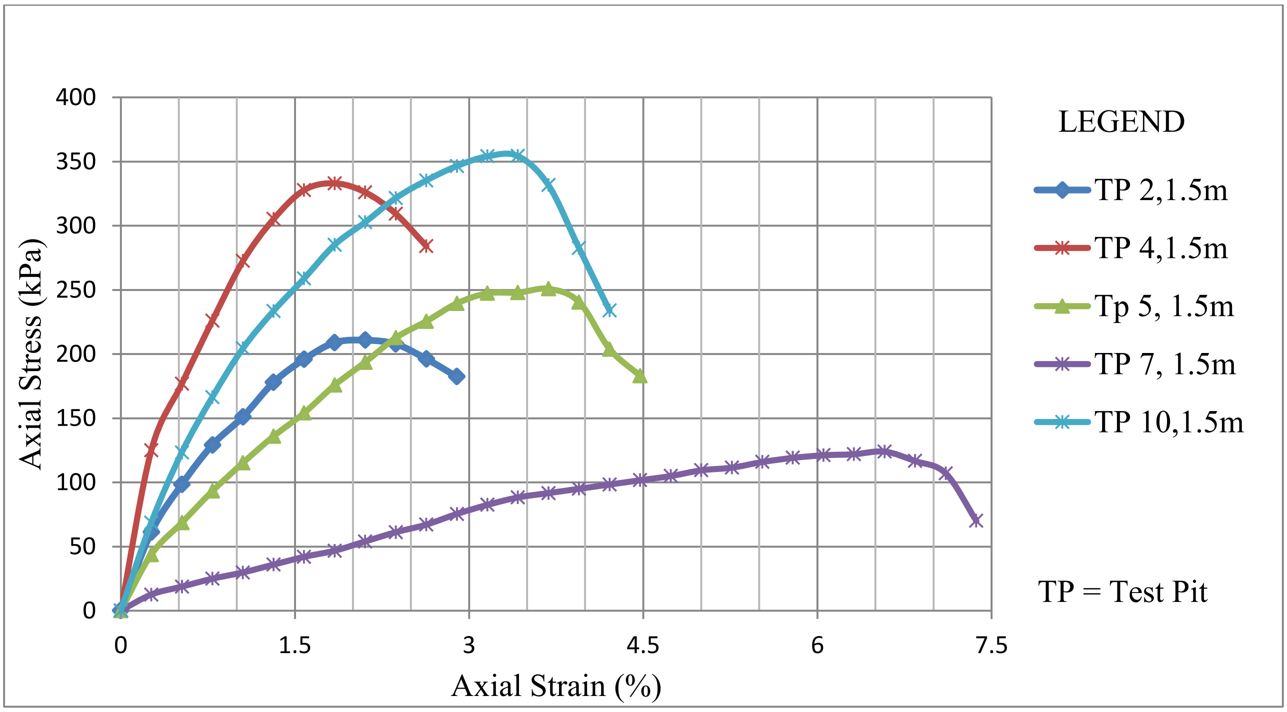


Figure 4.4: Curves for unconfined compression test results at a depth of 1.5 m

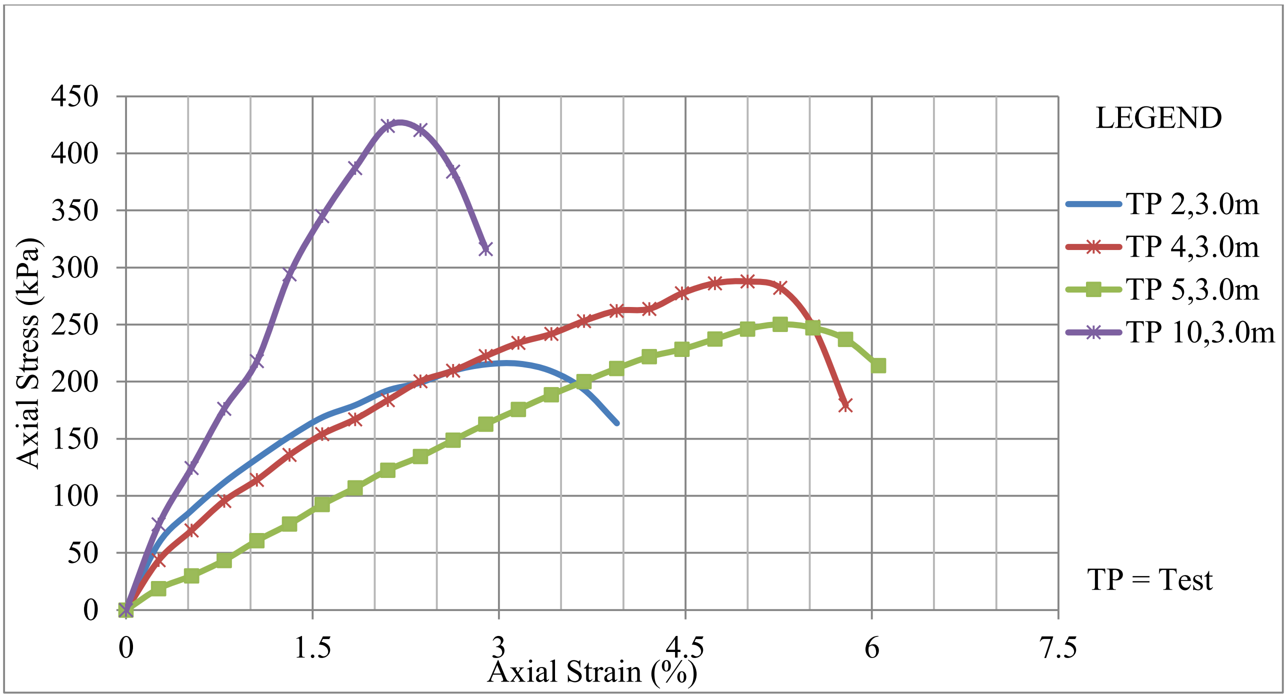


Fig 4.5: Curves for unconfined compression test results at a depth of 3.0 m

The relationship between consistency and unconfined compressive strength of clays is also presented inTable 4.9 and detail calculations of unconfined compression test is shown in appendix I.

Table 4.9. Unconfined compression test results

Test pit No	Depth (m)	q_u (kPa)	Liquidity Index (I_L)	Consistency
TP-2	1.5	210.82	-0.040	Hard
	3.0	215.83	-0.028	Hard
TP-4	1.5	333.06	0	Stiff
	3.0	287.85	0.130	Stiff
TP-5	1.5	250.84	-0.074	Hard
	3.0	250.28	0.225	Stiff
TP-7	1.5	123.99	0.141	Stiff
TP-10	1.5	354.31	0.033	Stiff
	3.0	424.10	-0.030	Hard

Consistency and Liquidity Index (LI) are related as follows [5]:

Stiff soils (LI = 0-0.25)

Medium Stiff (LI = 0.25-0.50)

Soft (LI = 0.50-0.75)

4.4 Consolidation tests

4.4.1 General

The main purpose of the consolidation test on soil samples is to obtain the necessary information about the compressibility properties of a saturated soil for use in determining the magnitude and rate of long term settlement of structures [9].

Based on previously retrieved undisturbed samples from the study area, consolidation tests were conducted in accordance with BS 1377:Part 5: 1990, ASTM D2435, and detailed calculations are presented in Appendix J.

4.4.2 Determination of consolidation coefficients and Related parameters

4.4.2.1 Compression and Swelling Indices

The compression index Cc is the slope of the virgin consolidation line (VCL) inthe e-log P axes, whereas the swelling index Cs is the slope of a swelling curve. Swelling index is also referred to as the recompression index Cr and the determination of the swelling index is important in the estimation of consolidation settlement of overconsolidated clays.These indices are :

$$c_c = -\frac{e_2 - e_1}{\log \frac{p_2}{p_1}} \quad (4.4)$$

$$c_s = -\frac{e_2 - e_1}{\log \frac{p_2}{p_1}} \quad (4.5)$$

where subscripts 1 and 2 denote two arbitrarily selected points on the Normal Consolidation Line (NCL) in case of compression index and two arbitrarily selected points on the Unloading Reloading Line (URL) in case of recompression [37,17].

The consolidation parameters of selected samples are presented in Table 4.10.

4.4.3 Preconsolidation Pressure

The maximum previous consolidation pressure, Pc, represents the highest vertical effective stress that the soil has ever experienced. The Casagrande method is a graphical method for determining Pc as described in ASTM D2435 [21]. The method is presented in Figure 4.6.

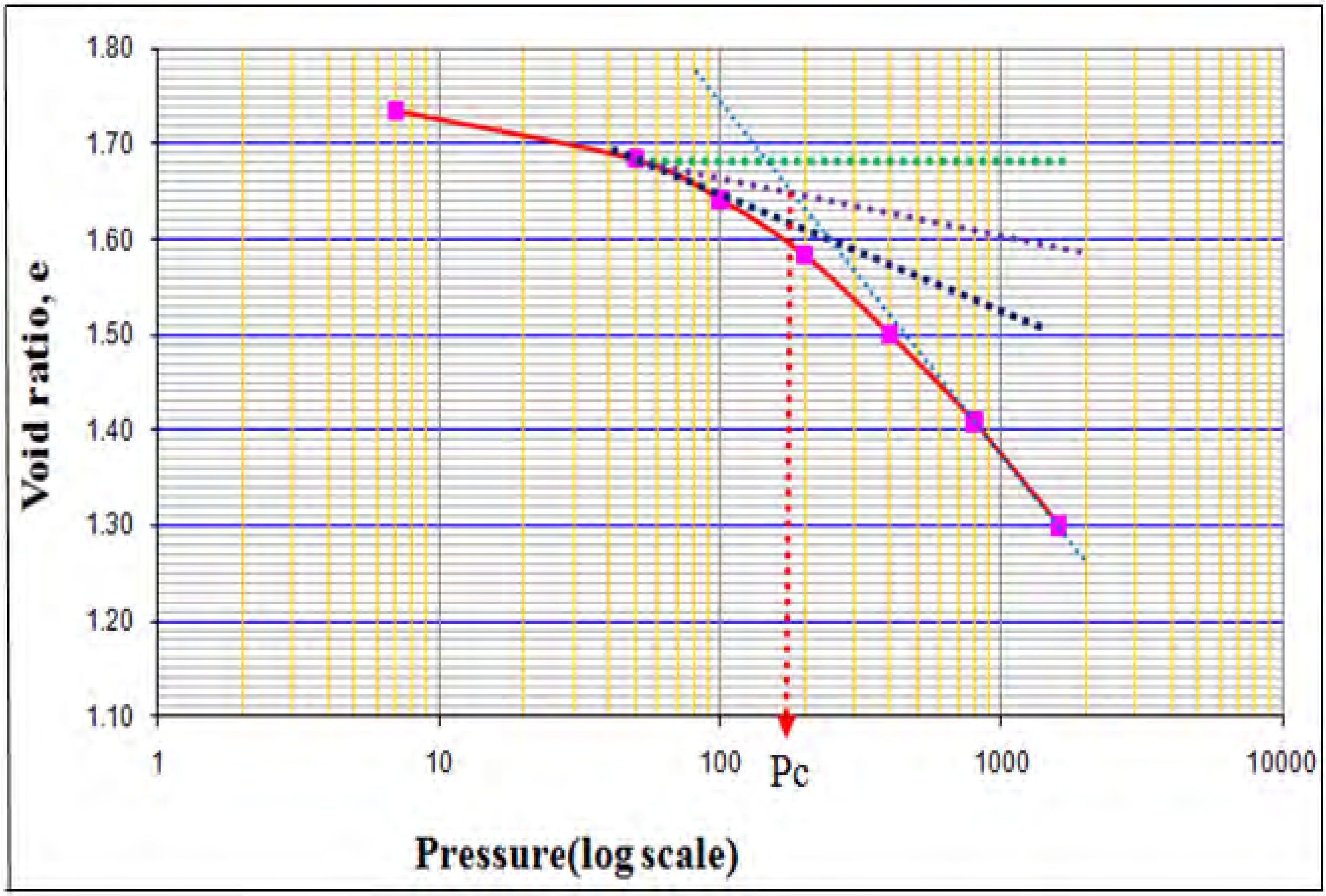


Figure 4.6: Determination of preconsolidation pressure according to Casagrande

Table 4.10. Consolidation parameters

Test pit No	Depth (m)	Cc	Cs	Pc (kN/m^2)	O.C.R
TP-2	3.0	0.176	0.015	200	3.97
TP-4	3.0	0.191	0.026	150	2.90
TP-10	3.0	0.197	0.059	100	1.82

4.4.4 Coefficient of consolidation

In order to apply consolidation theory in practice, it is necessary to determine the value of the coefficient of consolidation. The value of Cv for a particular pressure increment in the oedometer test can be determined by comparing the characteristics of the experimental and theoretical consolidation curves, the procedure being referred to as curve-fitting.

The characteristics of the curves are brought out clearly if time is plotted to a square root or a logarithmic scale. It should be noted that once the value of C_v has been determined, the coefficient of permeability can be calculated. Hence, the oedometer test is a useful method for obtaining the permeability of fine-grained soils [38]. From the perspective of its simplicity (always possible to estimate linear fit and yield result), predicting end of consolidation properly,Taylor'ssquare root of time fitting method has been used in this study [25]. A typical procedure is indicated in Figure. 4.7. The values of coefficient of consolidation for these test pits are presented in Table 4.11. and the corresponding curve of coefficient of consolidation Vspressure are shown in Figure 4.8.

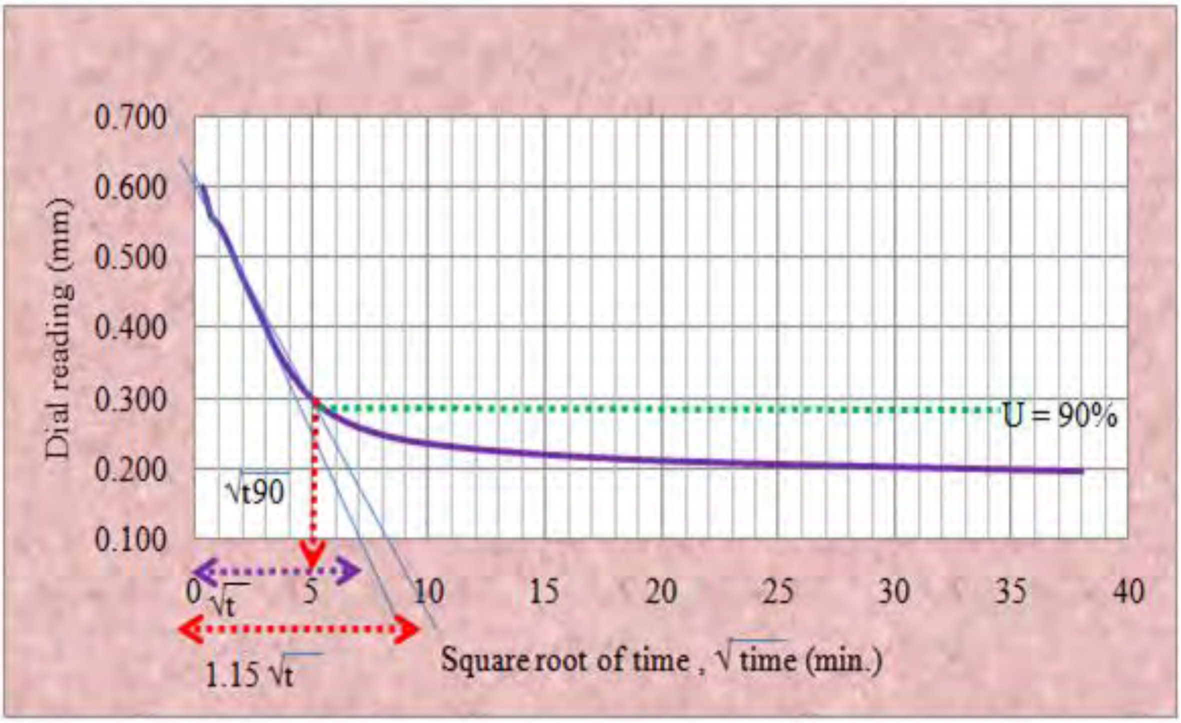


Figure 4.7: Typical curve of TP-2 (3.0 m) at loading of 1600 kPa

Table 4.11. Coefficient of consolidation results

Test pit No.	Depth (m)	Pressure P,(kN/m^2)	Coefficient of consolidation, c_v (x10^{-3}cm^2/sec)
TP-2	3.0	400	1.676
		800	1.040
		1600	0.480
TP-4	3.0	400	0.263
		800	0.249
		1600	0.228
TP-10	3.0	400	0.873
		800	0.430
		1600	0.375

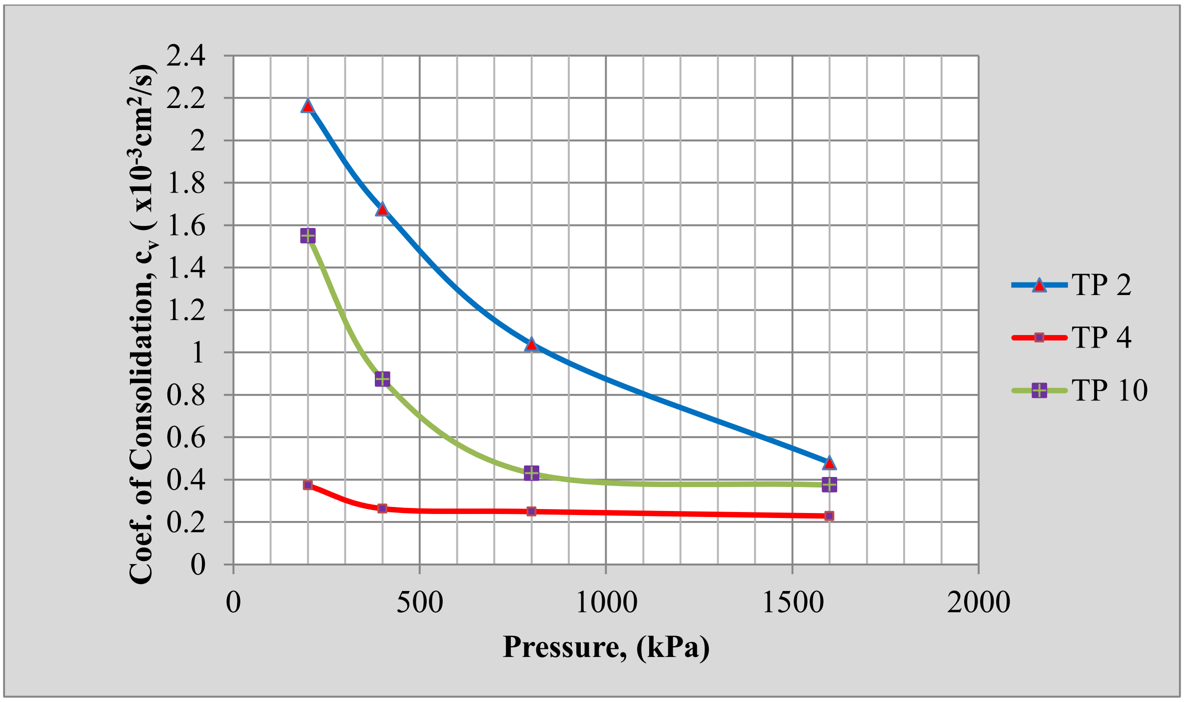


Figure 4.8: Coefficient of Consolidation versus Pressure for the loading ranges of 200kPa -1600kPa

4.4.5 Coefficient of permeability

The coefficient of permeability of fine grained soil can be indirectly determined from consolidation tests. The coefficient of permeability, k , can be calculated using the relation:

$$C_v = \frac{k\,(1+e_o)}{a_v * \gamma_w} \quad \text{or} \quad C_v = \frac{k}{m_v * \gamma_w} \qquad (4.6)$$

Where C_v= coefficient of consolidation

a_v= coefficient of compressibility

γ_w = unit weight of water

e_o= initial void ratio

m_v =coefficient of volume compressibility, which is given by: $m_v = \frac{(a_v)}{(1+e_0)}$

The parameters associated with this relation for the study area are determined. The values of k and m_V are given in Table 4.12. The values of a_v can be computed from void ratio versus pressure curve.The relationship between coefficient of permeability and pressureis shown in Fig 4.9.

Table 4.12. Coefficient of volume compressibility and coefficient of permeability values

Test pit No.	Depth,m	Pressure P, (kN/m^2)	Coefficient of consolidation, c_v ($x10^{-3}cm^2/sec$)	Coefficient of volume compressibility,m_v ($x10^{-4}m^2/kN$)	Coefficient of permeability,k ($x10^{-9}cm/sec$)
TP-2 (Technic)	3.0	400	1.676	0.821	1.375
		800	1.040	0.575	0.598
		1600	0.480	0.349	0.168
TP-4 (Saint Michael)	3.0	400	0.263	1.186	0.312
		800	0.249	0.767	0.191
		1600	0.228	0.364	0.083
TP-10 (Sisomesk)	3.0	400	0.873	1.418	1.237
		800	0.430	0.804	0.346
		1600	0.375	0.358	0.134

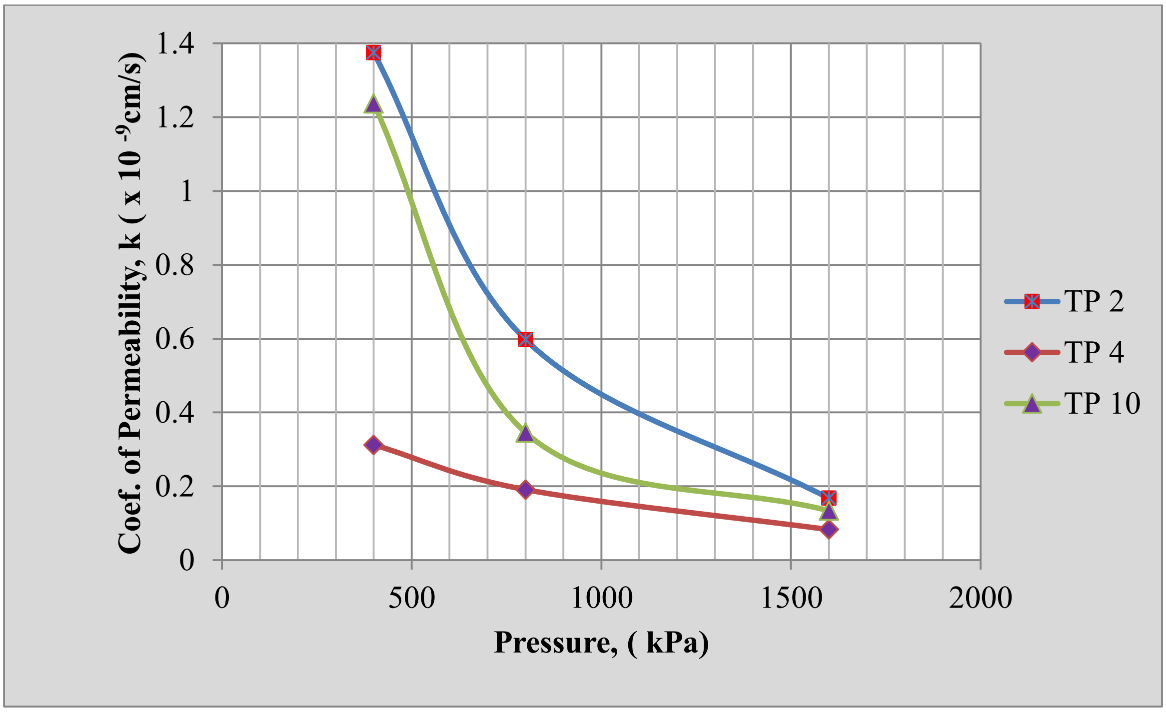


Figure 4.9: Coefficient of permeability versus Pressure

4.4.6 Swelling Pressure test

Whenthe most expansive clay mineral montimorillonite,is exposed to moisture, water is absorbed between inter layering lattice structures and exert an upward pressure.This upward pressure, known as swelling pressure, causes most ofthe damages associated with expansive soils. Hence at least an equal amount of pressure has to be placed in order to prevent damages associated with expansive soils. Such a pressure can be determined by making use of oedometer apparatus. For the study area, a maximum swelling pressure (P_s) of 125 kPa has been found and the result is shown in Figure 4.10.

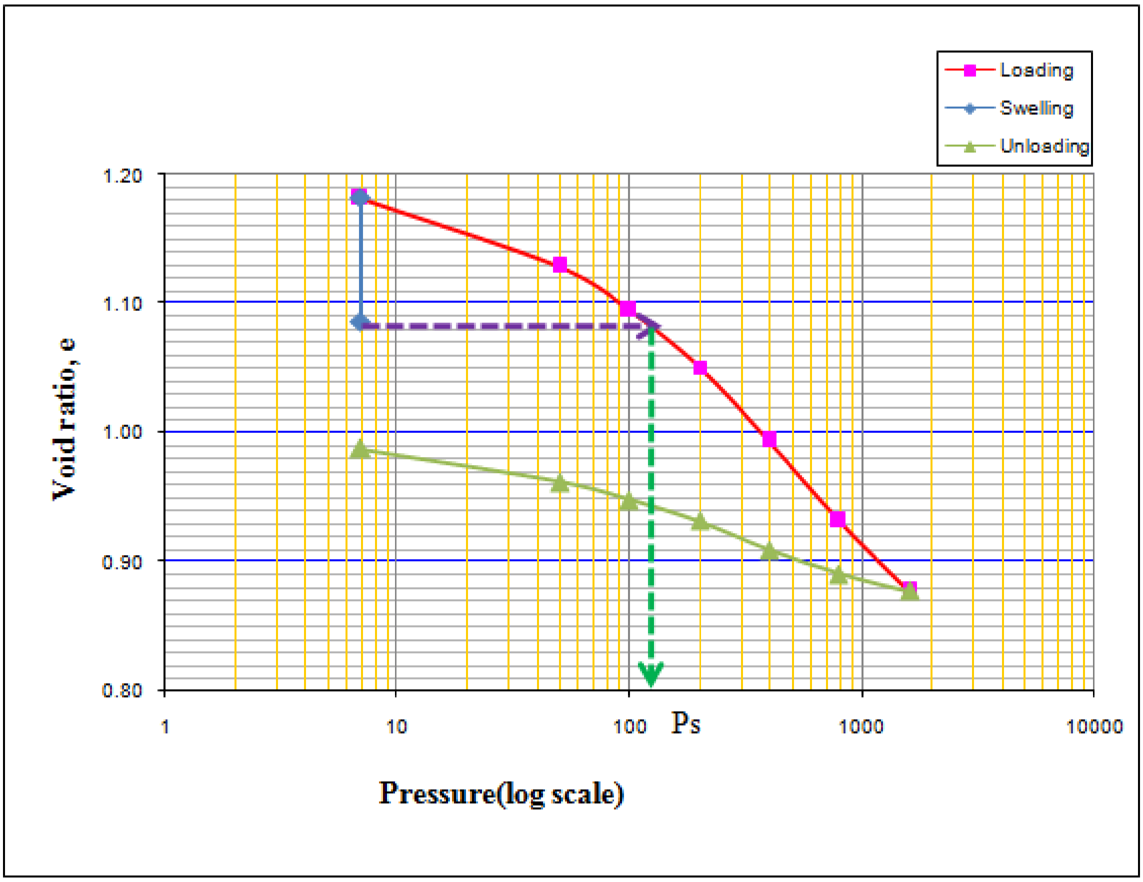


Figure 4.10: Plot of void ratio versus log-pressure for sample in Sisomesk (TP-10, 3.0 m)

5. DISCUSSION OF THE TEST RESULTS

5.1 Index properties

As per the grain size analysis, the soils found in the study area are fine-grained soils at all depths except the existence of boulders beyond 1.80 m in TP-3, in which sample was not retrieved.

The proportions of soil particles in red soils contain clay fractions of 71.52% - 79.83 %, silt fraction of 19% - 27.07 %, sand fraction of 0.25% - 1.11% and a gravel fraction of 0% - 0.07%.

Brown soils contain clay fractions of 45.15% - 65.69%, silt fraction of 29% - 41.42%, sand fraction of 1% - 14.9 % and a gravel fraction of 0% - 7.66%.

The red soils in the study area have liquid limit ranging from 61% - 80%, plastic limit ranging from 30% - 39%, and plastic index ranging from 28% - 41%. While the brown soils have liquid limit ranging from 59% - 89%, plastic limit ranging from 29% - 33%, and plastic index from 26% - 59%.

Fine grained soils are classified based on USCS as shown in Figure 5.1, along with the classification symbols in table 5.1.

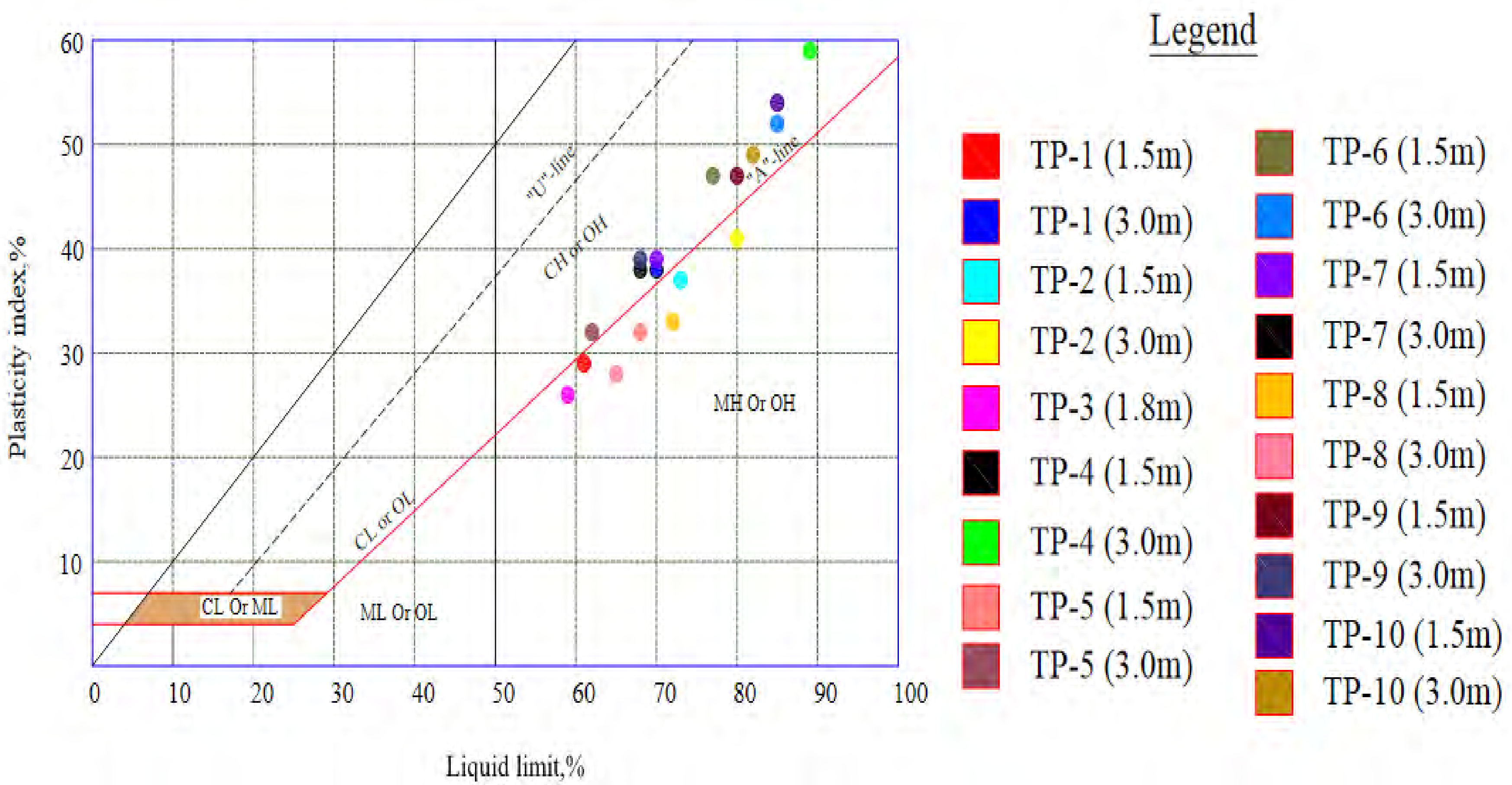


Figure 5.1: Soils of the study area on the Plasticity chart according to USCS

Table 5.1. USCS of soils in Dembecha town

Sr. No .	Test pit designation	Depth of sample	Percent amount of particle size				LL, %	PL, %	PI, %	USCS
			Gravel	Sand	Silt	Clay				
1	TP-1	1.5 m	0.00	0.43	23.82	75.72	61	32	29	CH-MH
		3.0 m	0.00	0.71	19.46	79.83	70	32	38	CH
2	TP-2	1.5 m	0.02	2.99	25.47	71.52	73	36	37	MH
		3.0 m	0.00	0.54	27.07	72.39	80	39	41	MH
3	TP-3	1.8 m	5.52	7.90	41.42	45.16	59	33	26	MH
4	TP-4	1.5 m	7.66	10.48	36.71	45.15	68	30	38	CH
		3.0 m	0.38	5.24	34.36	60.02	89	30	59	CH
5	TP-5	1.5 m	0.00	0.25	26.19	73.56	68	36	32	MH
		3.0 m	0.00	1.11	22.22	76.66	62	30	32	CH
6	TP-6	1.5 m	0.00	4.20	37.45	58.35	77	30	47	CH
		3.0 m	0.14	14.90	29.68	55.27	85	33	52	CH
7	TP-7	1.5 m	0.09	2.19	34.05	63.66	70	31	39	CH
		3.0 m	0.01	1.56	34.77	63.66	68	30	38	CH
8	TP-8	1.5 m	0.00	0.29	23.27	76.44	72	39	33	MH
		3.0 m	0.07	0.66	24.36	74.91	65	37	28	MH
9	TP-9	1.5 m	0.03	9.06	38.64	52.27	80	33	47	CH
		3.0 m	0.03	2.25	35.35	62.36	68	29	39	CH
10	TP-10	1.5 m	0.03	3.20	34.36	62.41	85	31	54	CH
		3.0 m	0.07	3.56	30.67	65.69	82	33	49	CH

As per USCS, C= Inorganic clay , M= Inorganic silt,L= Low plasticity (LL<50%) and H= High plasticity (LL>50%).

In Table 5.1, red soils found during investigation are classified as high plasticity inorganic silts (MH), high plasticity inorganicclays (CH), and their combination (CH – MH) where as brown soils are classified as high plasticity inorganic silts (MH) and high plasticity inorganic clays (CH)and scattered in the plasticity chart as shown in Figure 5.1. Except colour difference these soils share similar properties.

Most soils in the study area plot above A line on the plasticity chart and the rest few soils fall below A line. But since A line is not developed for soils in our country, it should be used in great caution for classification and consider practical recommendation by Wesley [4]. To consider this, based on Textural Soil Classification those soils named as MH are all clays.

AASHTO classification of the study area is shown in Figure 5.2. along with soil group and sub grade rating in Table 5.2

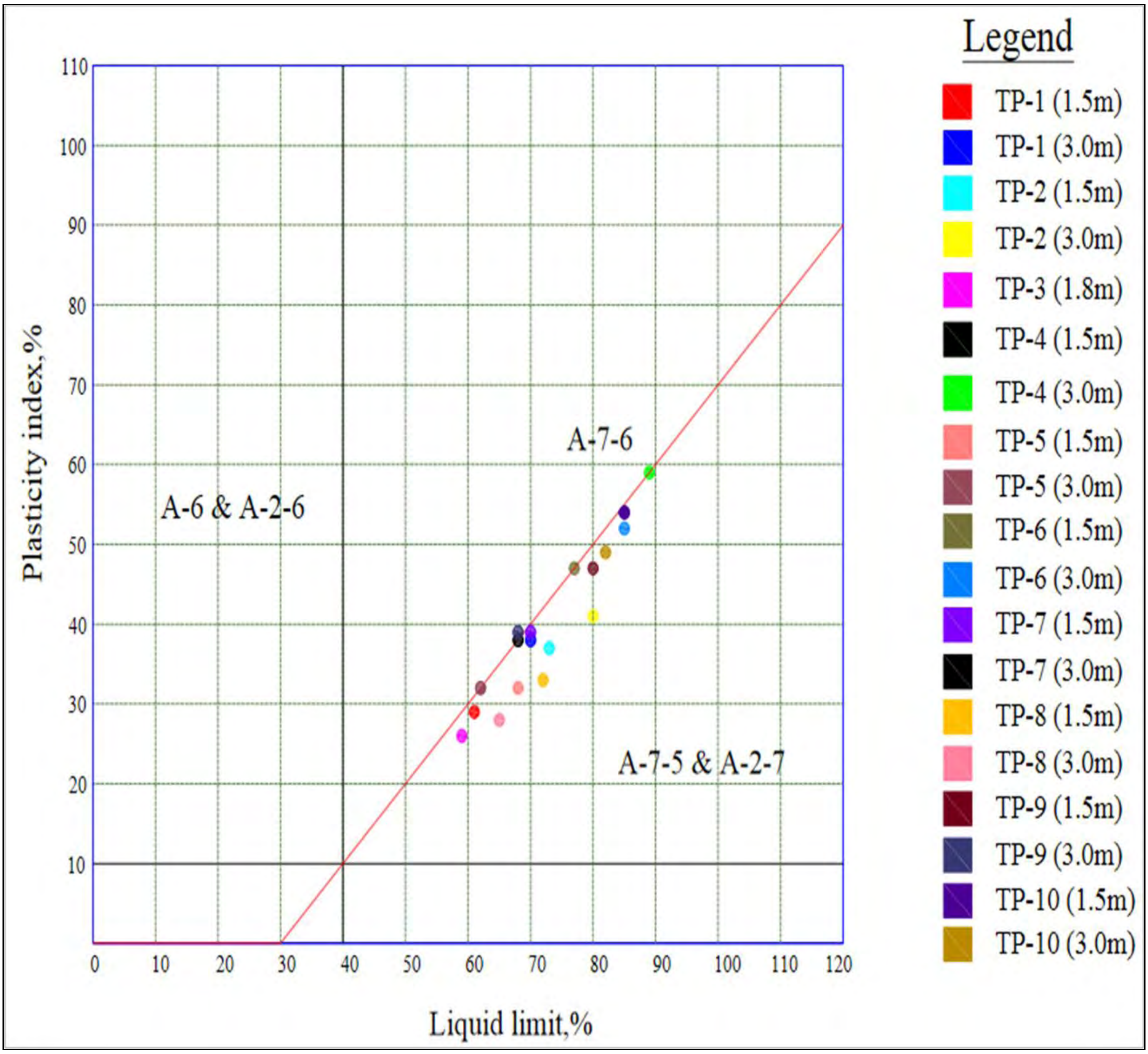


Figure 5.2: Soils of the study area according to AASHTO chart

Table 5.2.AASHTO Classification of soils in Dembecha town

Sr. No.	Test pit designation	Depth of determination	Percent Passing No. 10	Percent Passing No. 40	Percent Passing No. 200	LL, %	PI, %	AASHTO Soil classification	GI
1	TP-1	1.5 m	0.43	23.82	75.72	61	29	A-7-5	20
		3.0 m	0.71	19.46	79.83	70	38	A-7-5	20
2	TP-2	1.5 m	2.99	25.47	71.52	73	37	A-7-5	20
		3.0 m	0.54	27.07	72.39	80	41	A-7-5	20
3	TP-3	1.8 m	7.90	41.42	45.16	59	26	A-7-5	20
4	TP-4	1.5 m	10.48	36.71	45.15	68	38	A-7-5	20
		3.0 m	5.24	34.36	60.02	89	59	A-7-5	20
5	TP-5	1.5 m	0.25	26.19	73.56	68	32	A-7-5	20
		3.0 m	1.11	22.22	76.66	62	32	A-7-5	20
6	TP-6	1.5 m	4.20	37.45	58.35	77	47	A-7-5	20
		3.0 m	14.90	29.68	55.27	85	52	A-7-5	20
7	TP-7	1.5 m	2.19	34.05	63.66	70	39	A-7-5	20
		3.0 m	1.56	34.77	63.66	68	38	A-7-5	20
8	TP-8	1.5 m	0.29	23.27	76.44	72	33	A-7-5	20
		3.0 m	0.66	24.36	74.91	65	28	A-7-5	20
9	TP-9	1.5 m	9.06	38.64	52.27	80	47	A-7-5	20
		3.0 m	2.25	35.35	62.36	68	39	A-7-6	20
10	TP-10	1.5 m	3.20	34.36	62.41	85	54	A-7-5	20
		3.0 m	3.56	30.67	65.69	82	49	A-7-5	20

From table 5.3, almost all soils are classified as group A-7-5 and one soil type is group A-7-6. These soils are poor to be used as a sub grade material.

The specific gravity of soils in Dembecha town ranges from 2.73 to 2.85, which is nearly similar to the results obtained from a previous study in Dangila, Merawi and Bahir Dar [32, 33, 34] .

Based on the findings of this research, the free swell index values of a few soils of the study area show smaller values even less than 50% and more than half of the soils have marginal values, which are less than 100%.

These soils in the study area have a shared property except colour difference.

5.2 Shear strength test results

5.2.1 Unconfined compression test results

The unconfined compressive strength (UCS) of red soils in the study area at a depth of 1.5 m varies from 210.82 kPa to 250.84 kPa at moisture contents from 33.61% to 34.51% , the insitu state of these soils is found to be hard consistency and a depth of 3.0 m, UCS varies from 215.83 kPa to 250.28 kPa at moisture contents from 37.21% to 37.85% , the insitu state of these soils is found to be stiff to hard consistency.

Where as, the UCS of brown soils in the study area at a depth of 1.5 m varies from 123.99 kPa to 354.31 kPa at moisture contents from 29.72% to 36.51% , the insitu state of these soils is found to be stiff consistency and a depth of 3.0 m, UCS varies from 287.85 kPa to 424.10 kPa at moisture contents from 31.51% to 37.70% , the insitu state of these soils is found to be stiff to hard consistency.

5.3 Compressibility characteristics test results

5.3.1 Consolidation test results

Based on the most accepted standards, after classifying soils, consolidation tests were carried out and the following results obtained:

The pre consolidation pressures range from 100 kPa to 200 kPa. The brown soils have a compression indices, Cc, ranging from 0.191 to 0.197 and recompression indices ,Cs, ranging from 0.026 to 0.059 where as the red soil has a compression index, Cc of 0.176 and recompression index ,Cs of 0.015.

The values of coefficient of consolidation, Cv ,lie in the range from (0.228 to 0.263)x$10^{-3}$$cm^2$/sec in TP 4 and (0.375 to 0.873) x$10^{-3}$$cm^2$/sec in TP 10 for the brown soils and (0.48 to 1.676) x10^{-3} cm^2/sec in TP 2 for the red soil when loaded in the range of 400 kPa to 1600 kPa as shown in Figure 4.8.The rates of consolidation of soils could be recognized directly due to their permeability.

The permeability versus pressure curves of the red clay soil plots above brown clays (Figure 4.9). This indicates that there is relatively higher permeability of red soil than the brown soils. The swelling pressure determined from the swell consolidation test indicate that red soil has a swelling pressure of 20 kPa where as brown soils have swelling pressures ranging from 17 kPa to 125 kPa which can cause considerable damage to lightly loaded structures.

5.4 Comparison of Parameters of interest

Soil parameters obtained for Dembecha are compared with soils in the nearby locality, to clearly view similarities and differences (Table 5.3).

Table 5.3.Summary of comparison of parameters of interest

	Previous researches			Present research	
Location	Bahirdar [34]	Dangila [32]	Merawi [33]	Dembecha	
Soil type	Red clay	Red clay	Red clay	Red soils	Brown soils
Clay fraction, %	74-82	-	63.59-91.26	71.52-79.83	45.15-65.69
Liquid limit, LL(%)	61-68	54-77	52.30-67.80	61- 80	59 - 89
Plasticity index, PI (%)	24 - 31	22-44	27.80-39.40	28-41	26-59%
Activity	0.56	-	< 0.75	0.37- 0.57	0.58- 0.98
Free Swell Index,%	8-12	-	14.5- 20	30-50	40-93
Specific gravity,G_S	2.75-2.83	2.61-2.90	2.70-2.76	2.80 - 2.84	2.73 - 2.85
Unconfined compressive Strength, q_u (kN/ m^2)	147.47-219.95	140-220	63.67-117.81	210.82-250.84	123.99- 424.10
Swelling Pressure, P_s (kN /m^2)	-	-	-	20	17-125
Coefficient of Permeability (*10^{-6} cm/sec)	1.41-16.7	0. 23-44.41	0.38 - 2.85	0. 168- 1.375	0.083-1.237
Compression index, Cc	0.266-0.41	0.13-0.42	0.2442-0.4119	0.176	0.191-0.197
Soil Dispersivity,%	-	-	-	0- 3.34	8.32 - 78.24

6. SOIL MAP OF THE STUDY AREA

6.1 General

During road design and construction, soil engineering maps are very essential. These maps show the distribution of soils, and describe their origin, physical characteristics and engineering properties. However, national or regional based soil engineering maps do not exist in Ethiopia. Consequently, maps are often only available in association with specific road construction projects. In the absence of engineering soil maps, it is common practice to use agricultural soil classification systems of the type given in Figure 6.1 [39].

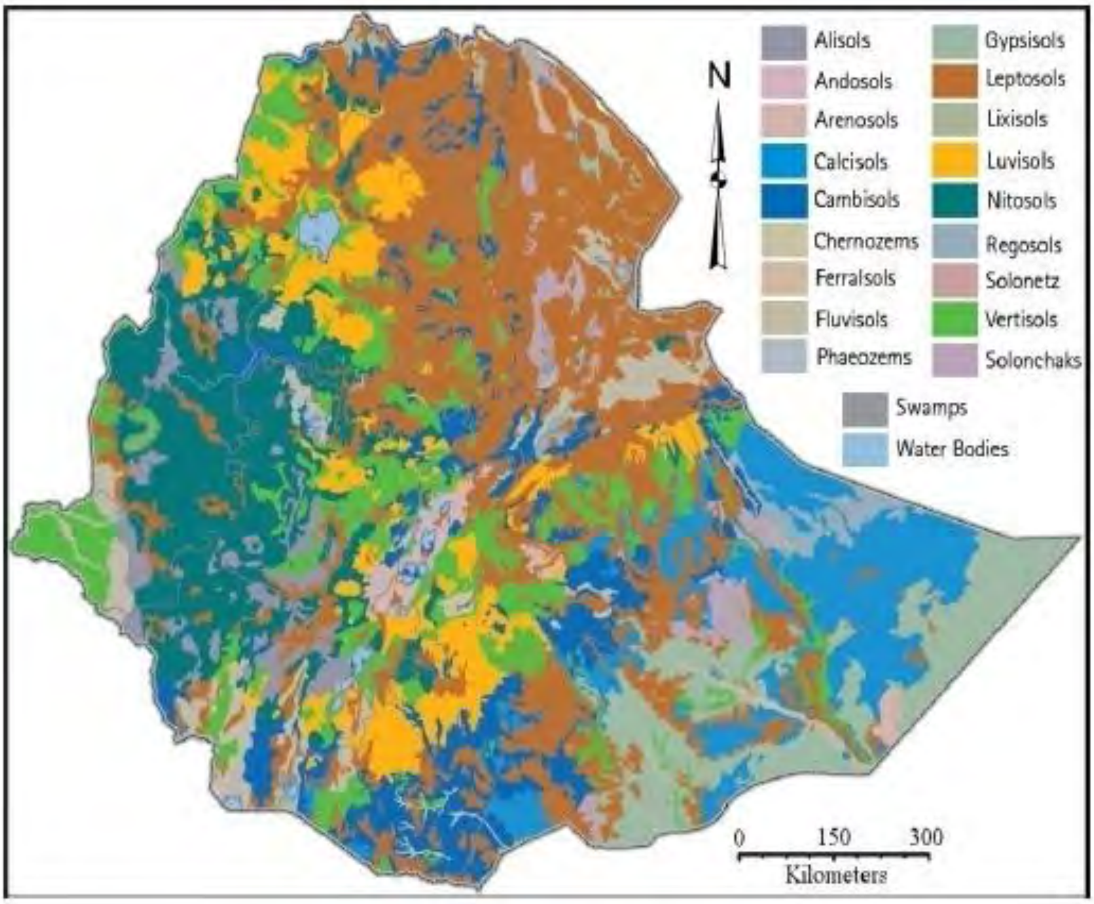


Figure 6.1 : Agricultural soil map of Ethiopia [39]

In road design, it is necessary to use maps and material categories that are useful for engineering purposes. Such maps and categories need to be comprehensive (covering all materials), meaningful in an engineering context (so that engineers will be able to understand and interpret them), and relatively descriptive. Engineering maps and categories should normally be prepared to facilitate an easy transition from field observations and descriptions made during site investigation to general classification of soil and rock properties used for design [39].

6.2 Preliminary soil map of the study area in Dembecha town

This preliminary soil map is prepared based on the results from ten representative test pits retrieved to a depth of 3.0 meters. By making use of Munsell chart, soils in the study area for a depth of 1.5 meters are well presented after interpolation of the boundaries between test pits as shown in Figure 6.2. However, the soils in the study area are mainly categorized from engineering point of view into CH (in organic clays of high plasticity) and MH (inorganic silts of high plasticity) based on 3m depth investigation. The engineering properties of soils in the study area which are distributed and delineated in the preliminary map are presented in the legend. Even though this delineation of soils serves as reference, it has to be updated based on current advanced investigation techniques to enable fellow engineers develop detailed geotechnical map. The distribution of soil is presented in Figure 6.3.

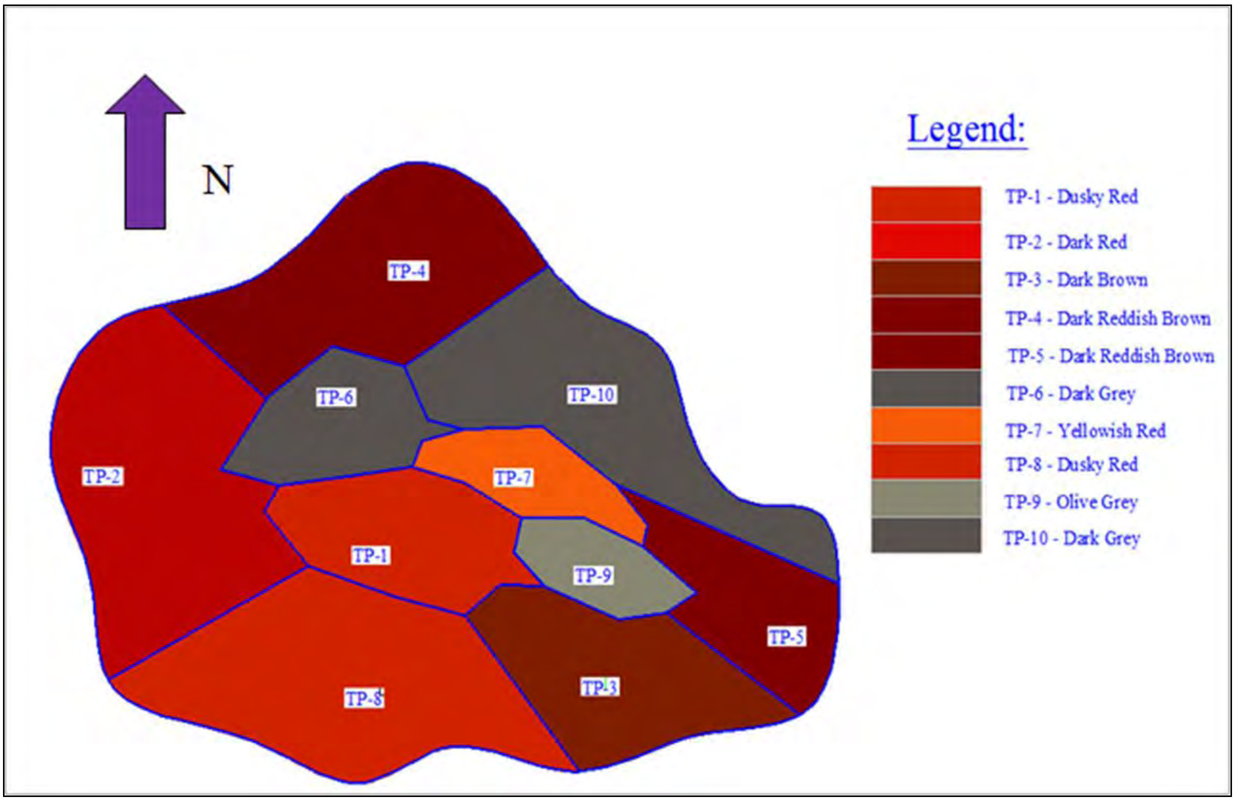


Figure 6.2: Preliminary soil map of the study area showing colours using Munsell chart

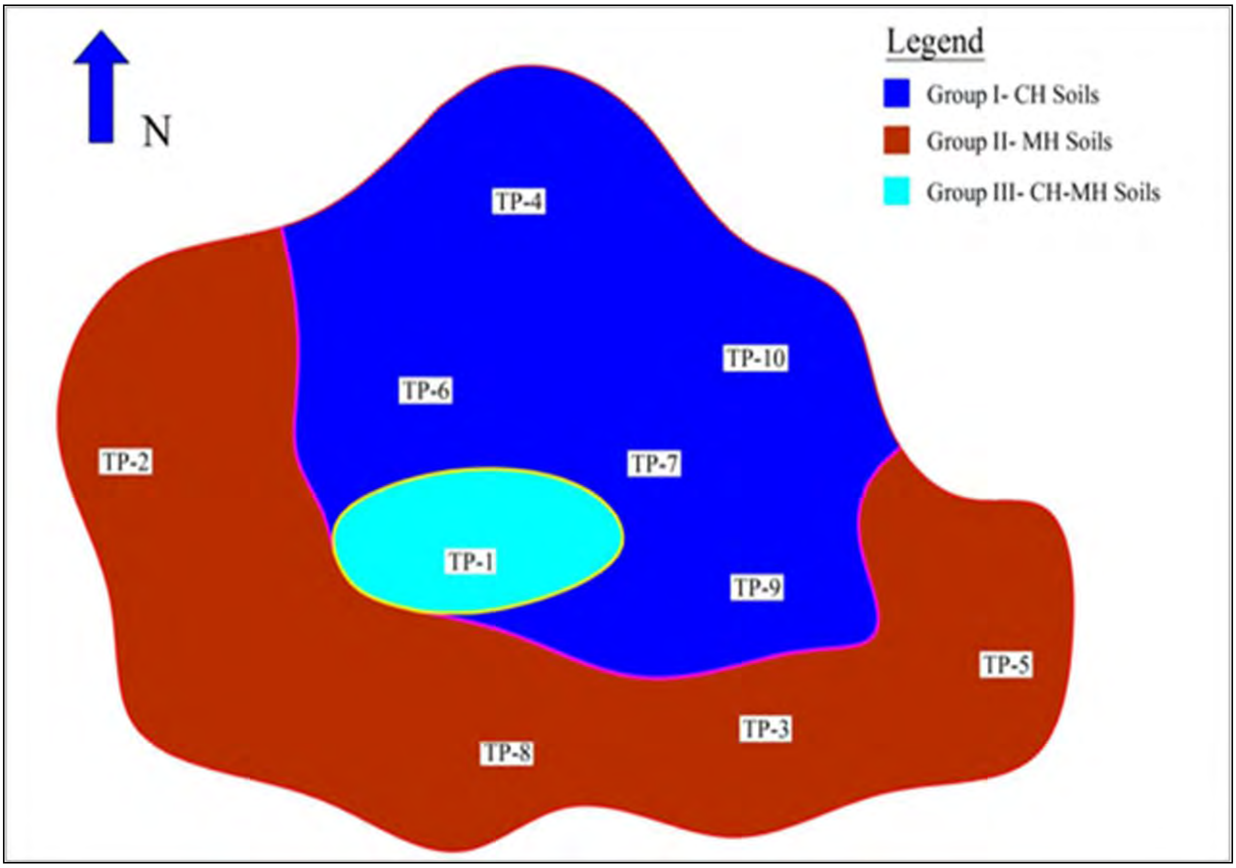


Figure 6.3: Preliminary soil map of the study area at 1.5 m depth

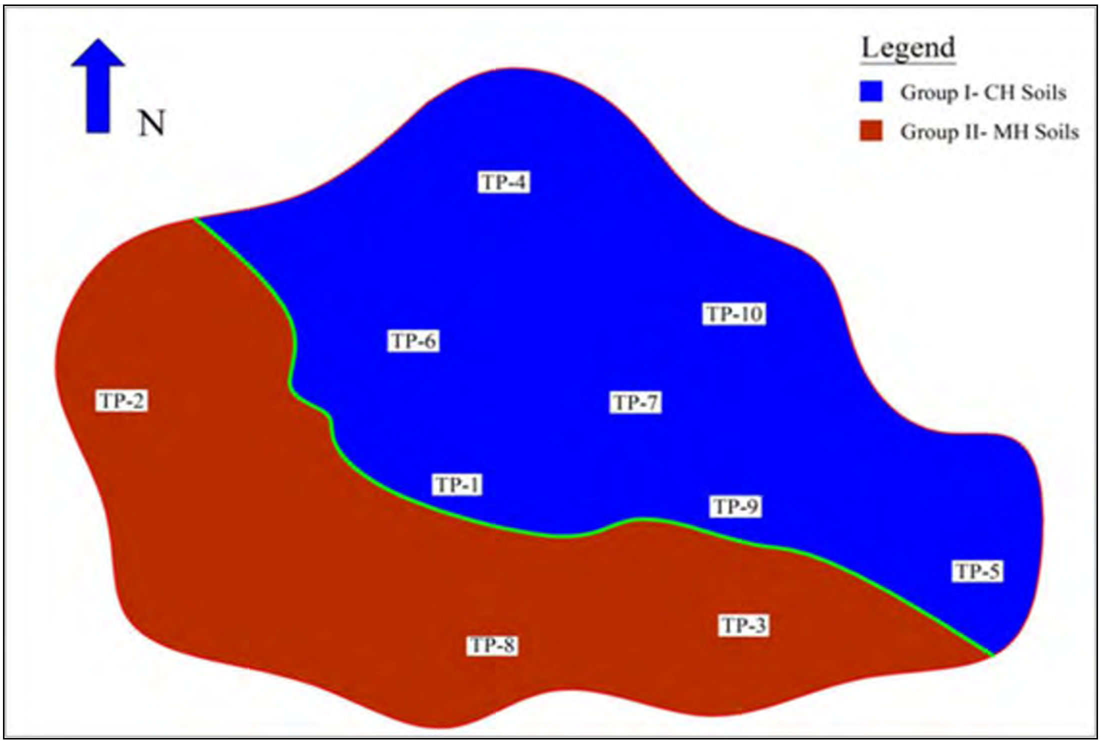


Figure 6.4: Preliminary soil map of the study area at 3.0 m depth

Table 6.1. Engineering Descriptions of soil Parameters

Descriptive Parameters	Group I CH- Soils		Group II MH- Soils	
	1.50m	3.0m	1.50m	3.0m
Colour	Ranges from brown to red.	Ranges from brown to red.	Ranges from brown to red	Ranges from brown to red
Engineering Properties	-	-	-	-
a) Index Properties	-	-	-	-
Natural moisture,%	30-44	32-48	25-35	33-38
Clay fraction,%	45.15-75.72	55.25-79.83	45.16-76.44	72.39-74.91
Liquid limit,%	61-85	62-89	59-73	65-80
Plastic limit,%	30-36	29-33	33-39	37-39
Plastic index,%	29-54	32-59	26-37	28-41
Specific gravity	2.73-2.84	2.8-2.85	2.78-2.83	2.82-2.84
Free swell,%	48-93	43-85	30-48	43-48
b) Shear strength	-	-	-	-
UCS,qu (kN/m^2)	123.99-354.31	250.28-424.10	210.82	215.83
c) Consolidation characteristics	-	-	-	-
C_c	-	0.191-0.197	-	0.176
C_s	-	0.026-0.059	-	0.015
m_v (10^{-4})	-	0.358-0.364 (for 1600 kPa)	-	0.349-0.821
C_v (10^{-3})	-	0.228-0.873	-	0.480-1.676
P_c (kN/m^2)	-	100-150	-	200
P_s (kN/m^2)	-	17-125	-	20
d) Permeability,k (10^{-9})	-	0.083-1.237	-	0.168-1.375

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

There are basically two groups of soilsin Dembecha town, namely: red soils and brown soils. Brown soils found in relatively lower elevations as compared to red soils.

Red soils have clay fraction of 71.52-79.83%, specific gravity ranging from 2.80 to 2.84, liquid limit of 61- 80%, plasticity index of 28-41%, percent dispersion of 0 - 3.34%, activity of 0.37-0.57%, free swell values of 30-50 % which indicate that the soils are low to moderately expansive soils and their consistency is found to be stiff to hard as unconfined compression strength values ranging from 210.82 kPa to 250.84 kPa.Where as, brown soils have clay fraction of 45.15-65.69%, specific gravity ranging from 2.73 to 2.85, liquid limit of 59 - 89%, plasticity index of 26-59%, percent dispersion of 8.32- 78.40%, activity of 0.58- 0.98%, free swell values of 40-93% which indicate that the soils are low to moderately expansive soils and their consistency is found to be stiff to hard as unconfined compression strength values ranges from 123.99 kPa to 424.10 kPa.

The swelling pressure of brown soils was 125 kPa, which may have destabilization effect on light weight structure.

The coefficient of permeability from one dimensional consolidation test ranges from $0.083*10^{-9}$ to $1.237*10^{-9}$ cm/sec for the brown soils and $0.168*10^{-9}$ to $1.375*10^{-9}$ cm/sec for the red soils. This is not the range of values of all soils in the study area, because coefficient of permeability is dependent on many additional factors like (void ratio, degree of , saturation, composition of soil particles, soil structure, viscosity of permeant, density and concentration of permeant etc.)

Generally, based on the objective of the study, soils in the study area share nearly similar engineering properties based on available classification systems. But these shared properties have to be refined using mineralogy test.

7.2 Recommendations

1. The research pays a close attention to the engineering properties of soils without the study of mineralogical composition of soils in the study area. Hence, the study of soil mineralogy is inevitable.
2. Investigation regarding dispersive characteristics of soils should be adequately carried out since the town has critical erosion problems.
3. To come up with detailed soil map of the study area, additional samples between boudaries of test pits and from other areas are necessary.
4. Since delineated preliminary soil map for the specified soil types is not exhaustive, one should use engineering judjement in the application.

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APPENDICES

Appendix A: Meteorological data

Table A.1. Summary of monthly maximum temperature in °c
Region : Gojjam
Station : Dembecha
Element: Monthly Max. Temp. In°c
Latitude : 37°29′ , Longitude : 10°33' and Altitude : 2117m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	27.3	27.6	28.6	28.5	27.9	23.4	22.3	x	x	x	x	X
1991	29.1	30.1	29.6	30.9	23.6	23.1	20.7	21.5	23.3	24.7	25.4	25.6
1992	26.1	27.3	29.2	28	26.1	24.1	21.9	21.1	22.2	23.2	x	X
1993	26.6	26.8	28.5	24.4	25.6	23	22.2	21.8	22	24.5	26.1	27.6
1994	28.6	29.4	29.4	30.5	24.9	22.5	21.2	21.5	22.3	26.4	26	27
1995	28.8	28.9	30	26.9	25.4	25	21.6	22.9	23.1	27.2	27.8	27.3
1996	27.9	31	28.9	28.7	25.5	23.5	22.4	23.7	24.4	27	27.5	27.1
1997	28.5	x	x	x	x	x	x	x	x	x	x	X
1999	x	x	x	30.3	27.6	25	21.6	21.9	24.4	23.6	26.1	26.4
2000	28.1	29.9	30.7	27.8	28.5	23.7	21.8	22.9	23.9	24.7	26.6	X
2001	26.1	28.8	26.5	27.7	25.6	20.7	20.7	21.9	23.2	22.4	20.1	X
2003	x	29.3	29.3	30.3	31.9	25.4	22.5	22.8	23.4	25.5	26.4	26.8
2004	28.5	29.5	30.8	29.4	29.9	25.8	21.9	23	24	25.2	25.9	27.3
2005	26.5	29.1	28.2	29.4	27.8	23.9	21.6	x	23.4	23.8	x	25.8
2006	26.7	28.7	28.4	28.7	26.1	23.9	22.7	22.4	23.3	x	x	X
2007	27.4	28.6	30	28	27.4	24.2	22.1	22.4	23.5	25.7	26.9	27.4
2008	28.3	29.3	31.1	28.4	26.5	24.2	21.8	21.9	23.8	25.5	25.7	26.9
2009	27.9	29.2	29.4	29.4	29.7	26.6	22.1	23.2	24.8	25.4	27	26.8
2010	27.8	29.6	29.7	30.1	26.5	x	22.6	22.7	x	x	x	X
2011	26.8	29.6	27.7	30.1	27.2	24.5	23.5	24.1	23.9	27.3	26.8	28
2011	26.8	29.6	27.7	30.1	27.2	24.5	23.5	24.1	23.9	27.3	26.8	28
2012	28.9	29.5	30	30.9	29.6	27.9	26	24.4	25	25.8	26.1	26.4
2013	26.1	26.3	26.2	26.4	25.6	25.1	23.7	23.5	23.8	23.2	21.1	22.7
2014	26.5	26.4	x	28.3	x	x	x	x	x	x	x	X

Table A.2. Summary of monthly minimum temperature in °c
Element: Monthly Rainfall in mm
Region: Gojjam
Station: Dembecha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	8.2	10.1	10.1	10.7	12.1	11.7	12.0	x	x	x	x	X
1991	9.6	10.6	11.2	11.1	11.4	12.3	12.5	12.3	11.1	9.9	8.8	7.8
1992	9.3	9.3	12.1	12.1	13.5	11.9	11.8	12.3	11.3	11.3		
1993	7.0	9.6	11.7	11.4	11.8	11.9	12.3	11.6	10.2	10.2	8.5	7.5
1994	8.4	10.1	11.8	13.7	13.2	12.7	12.3	12.3	11.2	9.4	10.2	7.6
1995	8.8	9.9	10.4	13.6	12.7	11.9	12.5	12.4	11.4	9.7	9.8	9.3
1996	9.5	10.8	12.7	12.3	12.8	12.8	10.9	11.2	11.2	x	x	X
1997	x	x	x	13.1	13.0	11.9	12.4	12.3	10.8	11.0	8.0	8.4
1999	8.6	9.3	11.6	12.5	12.3	12.0	12.5	12.1	11.3	15.1	15.5	X
2000	7.5	10.4	14.6	16.0	16.8	12.8	11.0	11.8	10.9	9.8	7.6	X
2001	7.3	8.4	11.7	11.9	12.4	13.4	12.5	12.2	11.9	9.4	9.4	8.8
2003	9.2	10.9	13.3	12.8	14.8	12.7	13.2	13.1	12.4	10.6	10.2	10.0
2004	9.9	10.4	12.5	13.9	12.9	12.1	12.3	12.5	12.2	12.1	12.4	13.1
2005	9.1	11.4	13.0	14.5	13.3	12.8	13.4	x	12.5	11.6	9.4	7.0
2006	9.5	11.3	12.5	13.7	13.3	12.5	12.6	12.6	11.2	x	x	X
2007	9.2	10.2	11.5	12.9	13.5	12.7	12.5	11.7	11.6	9.0	8.1	6.0
2008	8.0	8.6	10.5	12.0	11.4	10.6	10.7	10.6	9.5	8.9	7.3	7.7
2009	9.4	11.9	12.6	13.1	12.8	12.7	12.6	12.6	11.5	11.5	9.1	10.2
2010	9.8	11.9	12.2	14.3	14.2	x	13.2	13.2	x	x	x	X
2011	9.7	9.0	11.8	13.0	13.3	13.2	12.4	12.7	12.2	10.4	10.7	8.7
2011	9.7	9.0	11.8	13.0	13.3	13.2	12.4	12.7	12.2	10.4	10.7	8.7
2012	8.3	8.2	10.7	10.5	10.8	9.9	6.7	7.2	7.8	6.6	6.8	7.9
2013	7.8	7.2	7.4	6.8	6.4	7.1	6.3	7.0	6.8	6.3	5.6	6.4
2014	7.0	6.4	x	11.5	x	11.3	11.3	10.7	10.4	10.6	x	X

Table A.3. Summary of monthly Rainfall Data (mm)
Element: Monthly Rainfall in mm
Region: Gojjam
Station: Dembecha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	33.3	17.1	40.3	44.1	109.5	114.5	328.5	324.7	221.4	23	21.8	0
1991	5.7	8.7	3.5	8.7	41.8	257.7	350.7	142	120.9	106	17.9	1.4
1992	19.1	x	50.1	28.4	88.2	221.1	280.5	262	156.5	170.9	x	X
1993	1.6	3.3	52.3	119	124.5	215.5	305.4	267.8	278.4	145.6	100.9	0
1994	0	0	28.3	16.7	136.3	330.3	398	274.9	177.8	25.8	52.3	0
1995	0	0	5.5	157.8	125.3	241.5	276.5	272.8	137.1	12.9	27.2	35.6
1996	18.5	7	81	72	191.3	385.5	492.9	149.9	75.9	14	70.5	4.9
1997	4.1	0	48.2	81.6	194.5	254.8	240.4	274.6	265.7	170.8	88.4	16.5
1998		0.9	63.6	0	92.7	246.2	337.5	358.1	183.3	164.3	23	0
1999	45.1	0	0	34.3	81.3	158.6	x	265.7	314	226.4	33.8	9.6
2000	2.8	0	0	69.2	23.3	211.6	x	185	280	x	140	X
2001	0	11.3	125.1	50.1	193.3	122.6	220.6	369.3	166.3	103.8	29	X
2002	25.1	7.3	57.4	13.7	11.5	198.8	263	324.4	115.9	21.9	0	72.3
2003	0	14.3	47.1	22	3.1	249.1	370.4	272.6	220.5	110.5	4.8	5.8
2004	2	2	28.5	85.3	38	210.5	316.9	188.1	159	56	55.3	3.2
2005	8	0	83.9	15.3	51	158.4	438.4		312.7	103.8	26.3	0
2006	0	4.6	46.6	12.1	121.3	237.5	421.8	320.2	238.8	x	x	X
2007	x	x	x	x	x	x	x	x	x	x	30.9	X
2008	22.2	0	0	62.6	225.4	243.6	283.3	296.1	187.3	86.4	44.6	12.9
2009	0	12.6	70.5	40.5	12.7	162.6	329.2	388.3	136.5	109.8	14.9	5.5
2010	0	6.2	x	41.3	x	x	400.5	322.7	x	x	x	X
2012	0	0	23.5	13.1	72.7	113	219.3	299.6	283.7	51.6	19.6	0
2013	0	0	0	2.2	148.9	202.6	211.4	166.9	84.7	65.6	62.4	0
2014	0	0	x	122.6	x	98.7	293.7	258	273.8	124	x	X

Appendix B: Test Pit Logging

Test Pit Log					TP. No.
Easting : 37^{0}29.160'					TP1
Northing : 10^{0}33.870'					
Elevation :2102m					
Depth to ground water : Needs Investigation					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Weak Red Silt & Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dusky Red Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Remarks
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dusky Red Silt & Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dusky Red Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
NI = Not Important NA = Not Applicable S-1 = Sample 1				Undisturbed Sample	
S-2 = Sample 2			▽	Water Level	

Test Pit Log					TP. No.
Easting : 37⁰28.529'					
Northing : 10⁰33.900'					
Elevation :2117m					
Depth to ground water : Needs Investigation					TP2
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Remarks
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Reddish Brown Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dark reddish Brown Silt	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Remarks
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dark Red Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dark Red Silt	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
NI = Not Important NA = Not Applicable S-1 = Sample 1				Undisturbed Sample	
S-2 = Sample 2			▽	Water Level	

Test Pit Log					TP. No.
Easting : 37⁰29.676'					
Northing : 10⁰33.574'					
Elevation :2076m					
Depth to ground water : Needs Investigation					TP3
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.80	S-1			Strong Brown Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
1.80+	NR		Boulders		None
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.80	S-1			Dark Brown Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
1.80+	NR		Boulders		None
NI = Not Important NA = Not Applicable S-1 = Sample 1 S-2 = Sample 2				Undisturbed Sample Water Level	

Test Pit Log					TP. No.
Easting : 37⁰29.076'					TP4
Northing : 10⁰34.440'					
Elevation :2154m					
Depth to ground water : Needs Investigation					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dark reddish Brown Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Freeswell , tests
3.00	S-2			Grayish Brown Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dark reddish Brown Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dark Brown Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
NI = Not Important NA = Not Applicable S-1 = Sample 1				Undisturbed Sample	
S-2 = Sample 2			▽	Water Level	

Test Pit Log					TP. No.
Easting : $37^{0}30.048'$					TP5
Northing : $10^{0}33.691'$					
Elevation :2083m					
Depth to ground water : Needs Investigation					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dark Red Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dusky Red Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dark Reddish Brown Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dusky Red Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
NI = Not Important NA = Not Applicable S-1 = Sample 1				Undisturbed Sample	
S-2 = Sample 2			▽	Water Level	

Test Pit Log					TP. No.
Easting : $37^{0}28.947'$					TP6
Northing : $10^{0}34.052'$					
Elevation :2112m					
Depth to ground water : Needs Investigation					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.50	NI		NA	Top Soil	_
1.50	S-1			Grey Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Freeswell , tests
3.00	S-2			Light Brownish Grey Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.50	NI		NA	Top Soil	_
1.50	S-1			Dark Grey Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Greyish Brown Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
NI = Not Important NA = Not Applicable S-1 = Sample 1				Undisturbed Sample	
S-2 = Sample 2			▽	Water Level	

Test Pit Log					TP. No.
Easting : $37^0 29.505'$					
Northing : $10^0 34.019'$					
Elevation :2086m					
Depth to ground water : Needs Investigation					TP7
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.30	NI		NA	Top Soil	_
1.50	S-1			Yellowish Red	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Freeswell , tests
3.00	S-2		▽	Yellowish Brown	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.30	NI		NA	Top Soil	_
1.50	S-1			Yellowish Red	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2		▽	Dark yellowish Brown	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
NI = Not Important NA = Not Applicable S-1 = Sample 1				Undisturbed Sample	
S-2 = Sample 2			▽	Water Level	

Test Pit Log					TP. No.
Easting : $37^0 29.167'$					TP8
Northing : $10^0 33.520'$					
Elevation :2104m					
Depth to ground water : Dry					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dusky Red Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Reddish Brown Silt	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests

Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.20	NI		NA	Top Soil	_
1.50	S-1			Dusky Red Silt	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dark Reddish Brown Silt	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests

(hatched box)	Undisturbed Sample
▽	Water Level

Test Pit Log					TP. No.
Easting : $37^0$29.740’					TP9
Northing : $10^0$33.717’					
Elevation :2078m					
Depth to ground water : Dry					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.30	NI		NA	Top Soil	_
1.50	S-1			Olive Grey Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Pale Yellow Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.30	NI		NA	Top Soil	_
1.50	S-1			Olive Grey Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Pale Olive Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
				Undisturbed Sample	
			▽	Water Level	

Test Pit Log					TP. No.
Easting : 37⁰29.539’					TP10
Northing : 10⁰34.117’					
Elevation :2091m					
Depth to ground water : Dry					
Depth (m)	Sample No.	Soil strata	Symbol	Identification when dry	Sampled for
0.00	_	_	_	_	_
0.45	NI		NA	Top Soil	_
1.50	S-1			Grey Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dark Brown Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
Depth (m)	Sample No.	Soil strata	Symbol	Identification when wet	Sampled for
0.00	_	_	_	_	_
0.45	NI		NA	Top Soil	_
1.50	S-1			Dark Grey Clay	NMC, Gs, Grain size analysis, dispersivity, Consistency limit, Free swell tests
3.00	S-2			Dark Brown Clay	NMC, Gs, Grain size analysis,dispersivity, Consistency limit, Freeswell , 1D-consolidation tests
				Undisturbed Sample	
			▽	Water Level	

Appendix C: Natural moisture content test results

C1: Natural moisture content test result of TP1 at D=1.5m

Container No	G1	G3
Mass of container, g	15.7	15.8
Mass of container + wet soil, g	57.1	57.8
Mass of container + dry soil, g	47.2	47.76
Mass of water, g	9.9	10.04
Mass of dry soil, g	31.5	31.96
Water content,%	31.40	31.41
Average water content,%	31.40	

C2: Natural moisture content test result of TP1 at D=3.0m

Container No	G3	G5
Mass of container, g	15.8	15.5
Mass of container + wet soil, g	55.41	55.4
Mass of container + dry soil, g	45.2	45.12
Mass of water, g	10.21	10.28
Mass of dry soil, g	29.4	29.62
Water content,%	34.72	34.706
Average water content,%	34.71	

C3: Natural moisture content test result of TP2 at D=1.5m

Container No	G8	G2
Mass of container, g	15.8	15.7
Mass of container + wet soil, g	72.3	72.44
Mass of container + dry soil, g	57.8	57.88
Mass of water, g	14.5	14.56
Mass of dry soil, g	42	42.18
Water content,%	34.52	34.51
Average water content,%	34.51	

C4: Natural moisture content test result of TP2 at D=3.0m

Container No	G4	G8
Mass of container, g	15.5	15.8
Mass of container + wet soil, g	62.7	62.66
Mass of container + dry soil, g	49.75	49.78
Mass of water, g	12.95	12.88
Mass of dry soil, g	34.25	33.98
Water content,%	37.81	37.90
Average water content,%	37.85	

C5: Natural moisture content test result of TP3 at D=1.80m

Container No	G1	G8
Mass of container, g	15.7	15.8
Mass of container + wet soil, g	55.23	55.2
Mass of container + dry soil, g	47.32	47.32
Mass of water, g	7.906	7.88
Mass of dry soil, g	31.62	31.52
Water content,%	25.01	25.00
Average water content,%	25.00	

C6: Natural moisture content test result of TP4 at D=1.5m

Container No	G4	G8
Mass of container, g	15.5	15.8
Mass of container + wet soil, g	48.9	48.48
Mass of container + dry soil, g	41.24	41
Mass of water, g	7.66	7.48
Mass of dry soil, g	25.74	25.2
Water content,%	29.76	29.68
Average water content,%	29.72	

C7: Natural moisture content test result of TP4 at D=3.0m

Container No	G2	G1
Mass of container, g	15.7	15.7
Mass of container + wet soil, g	64.6	64.85
Mass of container + dry soil, g	51.2	51.4
Mass of water, g	13.4	13.45
Mass of dry soil, g	35.5	35.7
Water content,%	37.74	37.67
Average water content,%	37.70	

C8: Natural moisture content test result of TP5 at D=1.5m

Container No	G5	G8
Mass of container, g	15.5	15.8
Mass of container + wet soil, g	62.4	62.52
Mass of container + dry soil, g	50.6	50.77
Mass of water, g	11.8	11.75
Mass of dry soil, g	35.1	34.97
Water content,%	33.618	33.60
Average water content,%	33.61	

C9: Natural moisture content test result of TP5 at D=3.0m

Container No	G1	G2
Mass of container, g	15.7	15.7
Mass of container + wet soil, g	65.9	66.15
Mass of container + dry soil, g	52.3	52.45
Mass of water, g	13.6	13.69
Mass of dry soil, g	36.6	36.75
Water content,%	37.16	37.26
Average water content,%	37.21	

C10: Natural moisture content test result of TP6 at D=1.5m

Container No	G8	G5
Mass of container, g	15.8	15.5
Mass of container + wet soil, g	57.4	57.6
Mass of container + dry soil, g	44.7	44.8
Mass of water, g	12.7	12.8
Mass of dry soil, g	28.9	29.3
Water content,%	43.94	43.68
Average water content,%	43.81	

C11: Natural moisture content test result of TP6 at D=3.0m

Container No	G4	G3
Mass of container, g	15.5	15.8
Mass of container + wet soil, g	54.65	55.1
Mass of container + dry soil, g	42.4	42.81
Mass of water, g	12.25	12.29
Mass of dry soil, g	26.9	27.01
Water content,%	45.54	45.50
Average water content,%	45.52	

C12: Natural moisture content test result of TP7 at D=1.5m

Container No	G8	G5
Mass of container, g	15.8	15.5
Mass of container + wet soil, g	72.2	72.26
Mass of container + dry soil, g	57.1	57.09
Mass of water, g	15.1	15.17
Mass of dry soil, g	41.3	41.59
Water content,%	36.56	36.47
Average water content,%	36.51	

C13: Natural moisture content test result of TP7 at D=3.0m

Container No	G1	G8
Mass of container, g	15.7	15.8
Mass of container + wet soil, g	72.26	71.52
Mass of container + dry soil, g	53.85	53.51
Mass of water, g	18.41	18.01
Mass of dry soil, g	38.15	37.71
Water content,%	48.25	47.75
Average water content,%	48.00	

C14: Natural moisture content test result of TP8 at D=1.5m

Container No	G5	G3
Mass of container, g	15.5	15.8
Mass of container + wet soil, g	69.3	69.52
Mass of container + dry soil, g	56.5	56.74
Mass of water, g	12.8	12.78
Mass of dry soil, g	41	40.94
Water content,%	31.21	31.21
Average water content,%	31.21	

C15: Natural moisture content test result of TP8 at D=3.0m

Container No	G2	G8
Mass of container, g	15.7	15.8
Mass of container + wet soil, g	46.75	46.79
Mass of container + dry soil, g	39.13	39.19
Mass of water, g	7.62	7.6
Mass of dry soil, g	23.43	23.39
Water content,%	32.52	32.49
Average water content,%	32.51	

C16: Natural moisture content test result of TP9 at D=1.5m

Container No	G1	G8
Mass of container, g	15.7	15.8
Mass of container + wet soil, g	65.1	65.21
Mass of container + dry soil, g	52.5	52.62
Mass of water, g	12.6	12.59
Mass of dry soil, g	36.8	36.82
Water content,%	34.23	34.19
Average water content,%	34.21	

C17: Natural moisture content test result of TP9 at D=3.0m

Container No	G8	G4
Mass of container, g	15.8	15.5
Mass of container + wet soil, g	72.21	72.38
Mass of container + dry soil, g	58.11	58.16
Mass of water, g	14.1	14.22
Mass of dry soil, g	42.31	42.66
Water content,%	33.32	33.33
Average water content,%	33.33	

C18: Natural moisture content test result of TP10 at D=1.5m

Container No	G3	G5
Mass of container, g	15.8	15.5
Mass of container + wet soil, g	57.7	57.49
Mass of container + dry soil, g	47.3	47.16
Mass of water, g	10.4	10.33
Mass of dry soil, g	31.5	31.66
Water content,%	33.015	32.62
Average water content,%	32.82	

C19: Natural moisture content test result of TP10 at D=3.0m

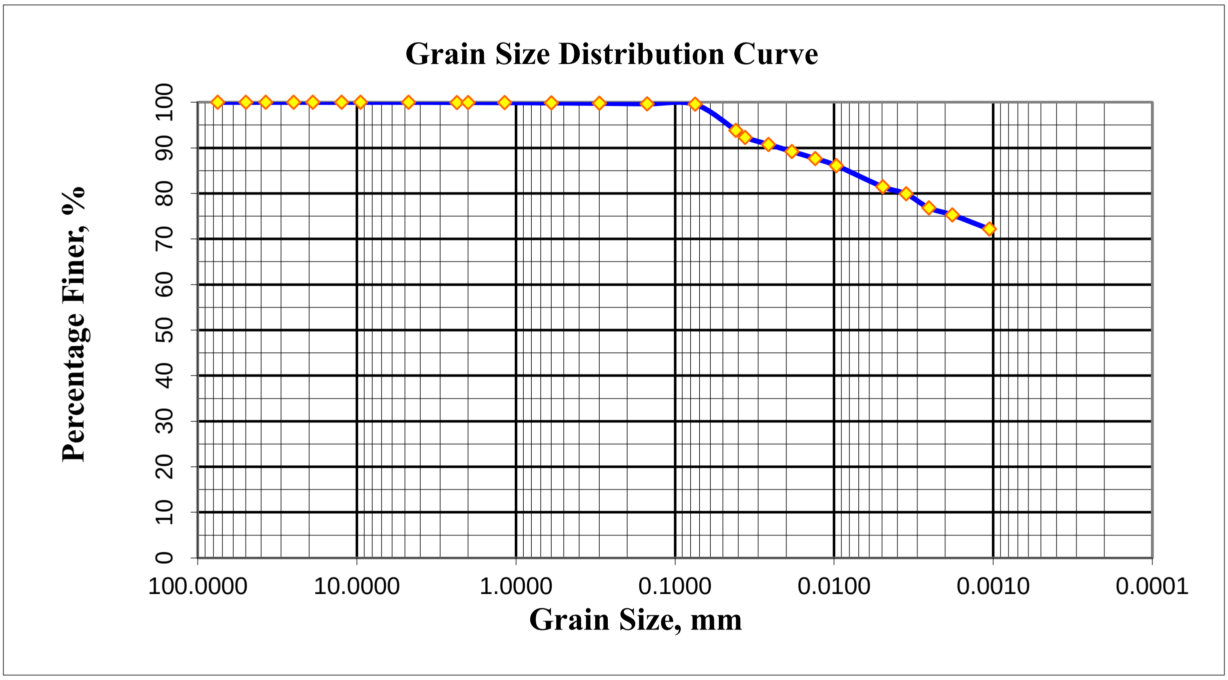
Container No	G2	G3
Mass of container, g	15.7	15.8
Mass of container + wet soil, g	68.1	67.85
Mass of container + dry soil, g	55.54	55.38
Mass of water, g	12.56	12.47
Mass of dry soil, g	39.84	39.58
Water content,%	31.52	31.50
Average water content,%	31.51	

Appendix D: Grain size analysis results (typical results)

D1: Grain size analysis result of TP1 at D=1.50m, total mass of sample = 1500 g

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.00	0.00	0.00	100.0
2"	50.0	1199.0	1199.0	0.00	0.00	0.00	100.0
1.5"	37.5	1084.0	1084.0	0.00	0.00	0.00	100.0
1"	25.0	1248.0	1248.0	0.00	0.00	0.00	100.0
3/4"	19.0	1443.0	1443.0	0.00	0.00	0.00	100.0
1/2"	12.5	1242.0	1242.0	0.00	0.00	0.00	100.0
3.8"	9.5	1211.0	1211.0	0.00	0.00	0.00	100.0
No 4	4.75	644.0	644.0	0.00	0.00	0.00	100.0
No 8	2.36	521.0	521.5	0.50	0.03	0.03	100.0
No 10	2	622.0	622.1	0.10	0.01	0.04	100.0
No 16	1.18	531.0	531.4	0.40	0.03	0.07	99.9
No 30	0.6	507.0	508.0	1.00	0.07	0.13	99.9
No 50	0.3	291.0	292.3	1.30	0.09	0.22	99.8
No 100	0.15	462.0	463.6	1.60	0.11	0.33	99.7
No 200	0.075	454.0	455.6	1.60	0.11	0.43	99.6
Elapsed Time (min)	Actual Hydro meter Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0027	1.0303	7.57	0.0415	94.27	93.86
1	1.0325	-0.0027	1.0298	7.70	0.0363	92.71	92.31
2	1.0320	-0.0027	1.0293	7.84	0.0259	91.16	90.76
4	1.0315	-0.0027	1.0288	7.97	0.0184	89.60	89.21
8	1.0310	-0.0027	1.0283	8.10	0.0132	88.04	87.66
15	1.0305	-0.0027	1.0278	8.23	0.0097	86.49	86.11
30	1.0300	-0.0027	1.0273	8.36	0.0069	84.93	84.57
60	1.0290	-0.0027	1.0263	8.63	0.0050	81.82	81.47
120	1.0285	-0.0027	1.0258	8.76	0.0035	80.27	79.92
240	1.0275	-0.0027	1.0248	9.03	0.0025	77.16	76.82
480	1.0270	-0.0027	1.0243	9.16	0.0018	75.60	75.27
1440	1.0260	-0.0027	1.0233	9.42	0.0011	72.49	72.17

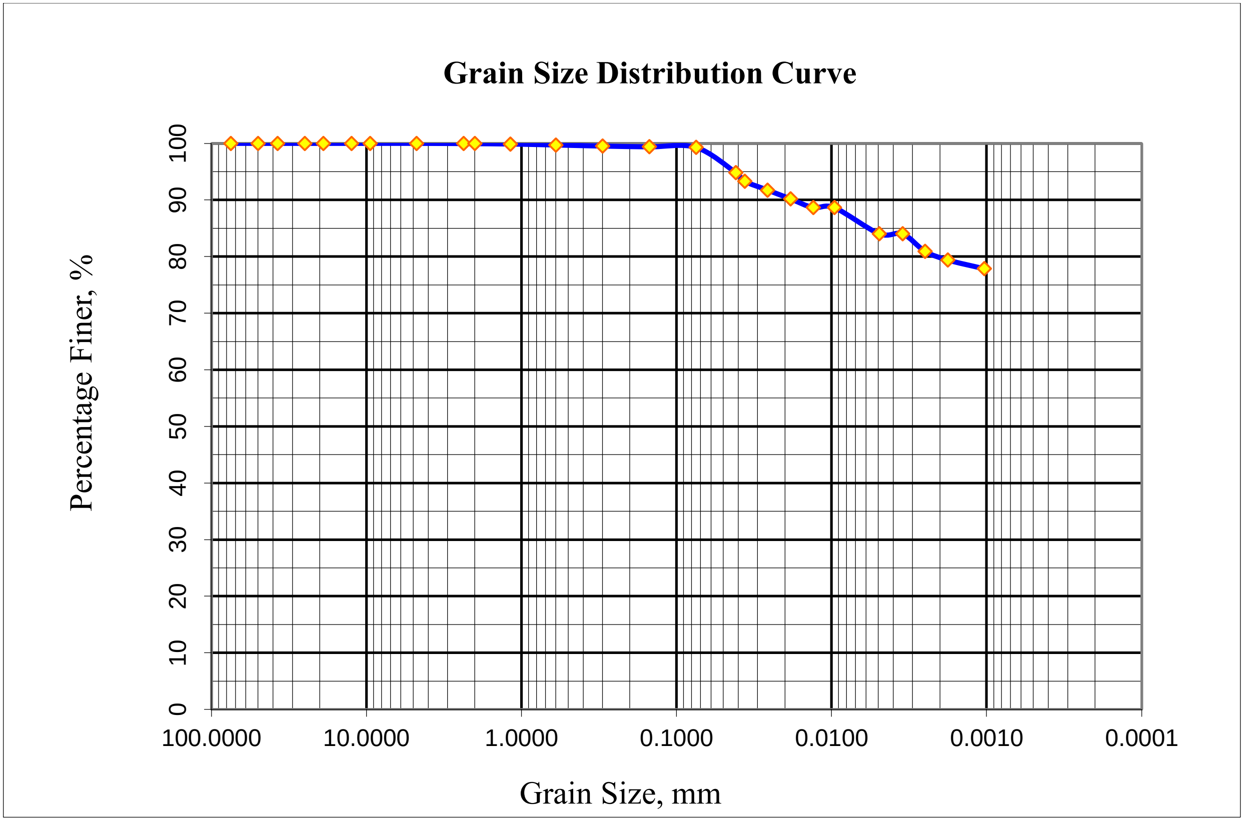
D2: Grain size distribution curve for TP1at D=1.50m



D3: Grain size analysis result of TP1 at D=3.0m, total mass of sample = 1500 g

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.00	0.00	0.00	100.0
2"	50.0	1199.0	1199.0	0.00	0.00	0.00	100.0
1.5"	37.5	1084.0	1084.0	0.00	0.00	0.00	100.0
1"	25.0	1248.0	1248.0	0.00	0.00	0.00	100.0
3/4"	19.0	1443.0	1443.0	0.00	0.00	0.00	100.0
1/2"	12.5	1242.0	1242.0	0.00	0.00	0.00	100.0
3.8"	9.5	1211.0	1211.0	0.00	0.00	0.00	100.0
No 4	4.75	644.0	644.0	0.00	0.00	0.00	100.0
No 8	2.36	521.0	521.5	0.50	0.03	0.03	100.0
No 10	2	622.0	622.3	0.30	0.02	0.05	99.9
No 16	1.18	531.0	531.9	0.90	0.06	0.11	99.9
No 30	0.6	507.0	509.6	2.60	0.17	0.29	99.7
No 50	0.3	291.0	293.9	2.90	0.19	0.48	99.5
No 100	0.15	462.0	464.0	2.00	0.13	0.61	99.4
No 200	0.075	454.0	455.4	1.40	0.09	0.71	99.3
Elapsed Time (min)	Actual Hydro meter Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0023	1.0307	7.57	0.0415	95.51	94.84
1	1.0325	-0.0023	1.0302	7.70	0.0363	93.96	93.29
2	1.0320	-0.0023	1.0297	7.84	0.0259	92.40	91.75
4	1.0315	-0.0023	1.0292	7.97	0.0184	90.84	90.20
8	1.0310	-0.0023	1.0287	8.10	0.0132	89.29	88.66
15	1.0310	-0.0023	1.0287	8.10	0.0096	89.29	88.66
30	1.0305	-0.0023	1.0282	8.23	0.0068	87.73	87.11
60	1.0295	-0.0023	1.0272	8.50	0.0049	84.62	84.02
120	1.0295	-0.0023	1.0272	8.50	0.0035	84.62	84.02
240	1.0285	-0.0023	1.0262	8.76	0.0025	81.51	80.94
480	1.0280	-0.0023	1.0257	8.89	0.0018	79.96	79.39
1440	1.0275	-0.0023	1.0252	9.03	0.0010	78.40	77.85

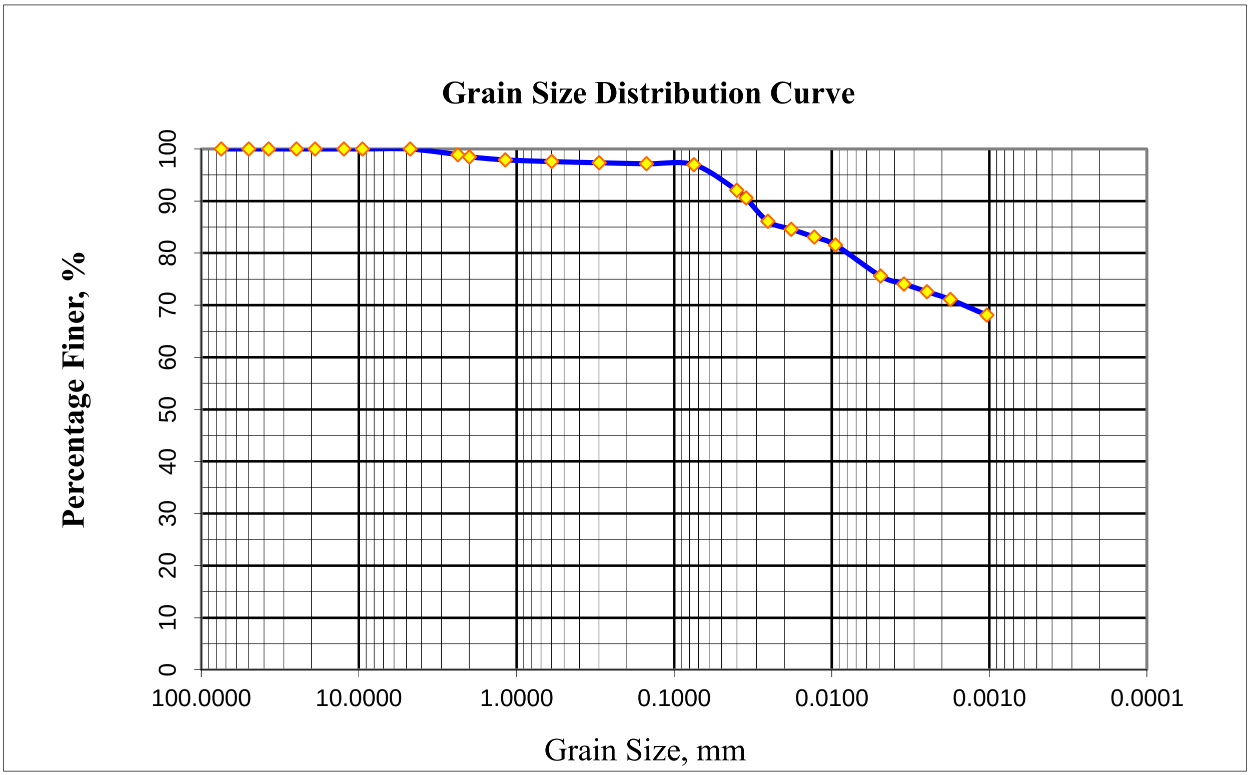
D4: Grain size distribution curve for TP1at D=3m



D5: Grain size analysis result of TP2 at D=1.50m, total mass of sample = 1500 g

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.00	0.00	0.00	100.0
2"	50.0	1199.0	1199.0	0.00	0.00	0.00	100.0
1.5"	37.5	1084.0	1084.0	0.00	0.00	0.00	100.0
1"	25.0	1248.0	1248.0	0.00	0.00	0.00	100.0
3/4"	19.0	1443.0	1443.0	0.00	0.00	0.00	100.0
1/2"	12.5	1242.0	1242.0	0.00	0.00	0.00	100.0
3.8"	9.5	1211.0	1211.0	0.00	0.00	0.00	100.0
No 4	4.75	644.0	644.3	0.30	0.02	0.02	100.0
No 8	2.36	521.0	537.1	16.10	1.07	1.09	98.9
No 10	2	622.0	628.4	6.40	0.43	1.52	98.5
No 16	1.18	531.0	539.7	8.70	0.58	2.10	97.9
No 30	0.6	507.0	511.9	4.90	0.33	2.43	97.6
No 50	0.3	291.0	294.4	3.40	0.23	2.65	97.3
No 100	0.15	462.0	465.0	3.00	0.20	2.85	97.1
No 200	0.075	454.0	456.4	2.40	0.16	3.01	97.0
Elapsed Time (min)	Actual Hydro meter Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0023	1.0307	7.57	0.0402	94.95	92.09
1	1.0325	-0.0023	1.0302	7.70	0.0351	93.41	90.59
2	1.0310	-0.0023	1.0287	8.10	0.0255	88.77	86.09
4	1.0305	-0.0023	1.0282	8.23	0.0181	87.22	84.59
8	1.0300	-0.0023	1.0277	8.36	0.0129	85.67	83.09
15	1.0295	-0.0023	1.0272	8.50	0.0095	84.13	81.59
30	1.0290	-0.0023	1.0267	8.63	0.0068	82.58	80.09
60	1.0275	-0.0023	1.0252	9.03	0.0049	77.94	75.59
120	1.0270	-0.0023	1.0247	9.16	0.0035	76.39	74.09
240	1.0265	-0.0023	1.0242	9.29	0.0025	74.85	72.59
480	1.0260	-0.0023	1.0237	9.42	0.0018	73.30	71.09
1440	1.0250	-0.0023	1.0227	9.69	0.0010	70.21	68.09

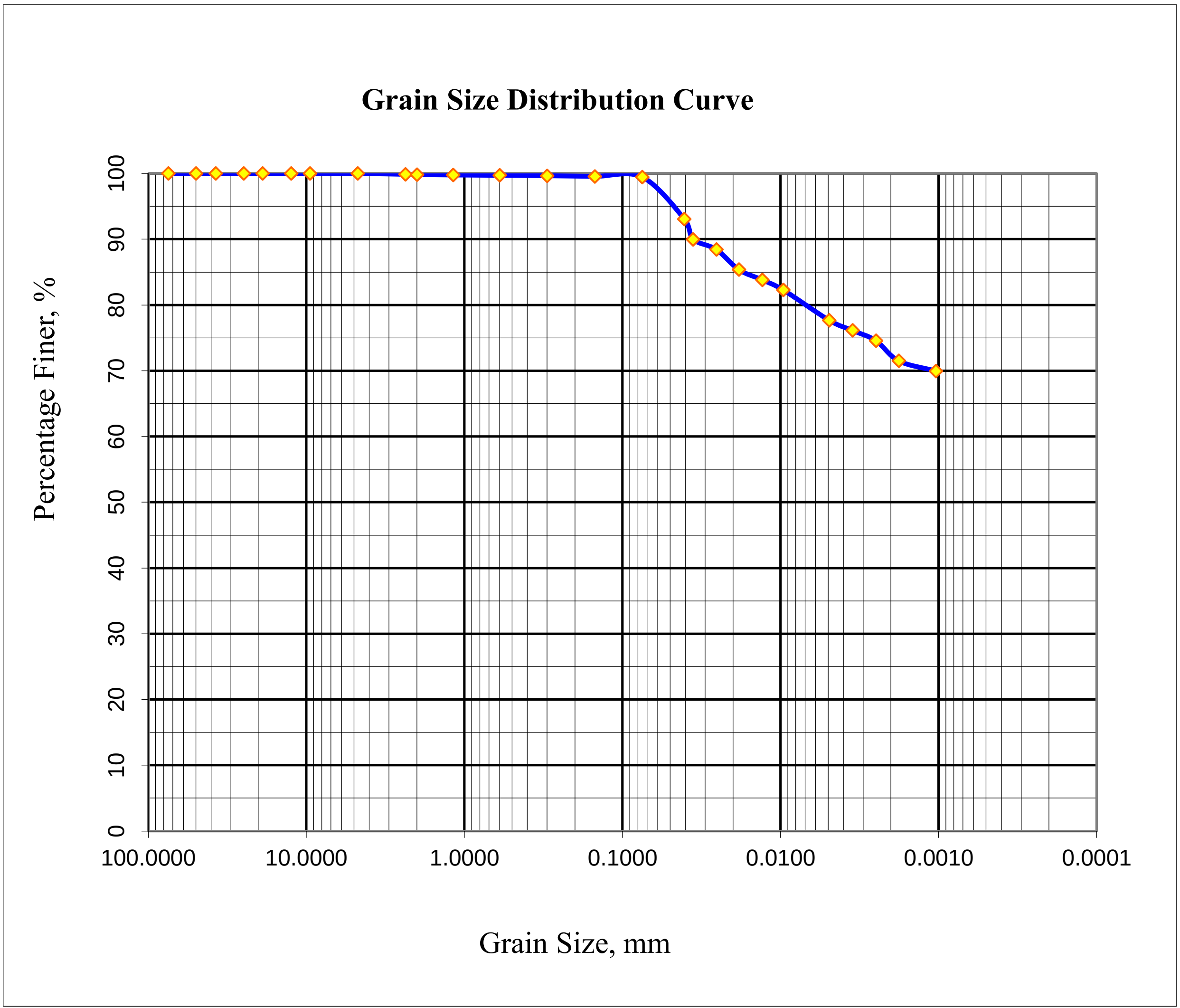
D6: Grain size distribution curve for TP2 at D=1.50m



D7: Grain size analysis result of TP2 at D=3.0m, total mass of sample = 1500 g

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.00	0.00	0.00	100.0
2"	50.0	1199.0	1199.0	0.00	0.00	0.00	100.0
1.5"	37.5	1084.0	1084.0	0.00	0.00	0.00	100.0
1"	25.0	1248.0	1248.0	0.00	0.00	0.00	100.0
3/4"	19.0	1443.0	1443.0	0.00	0.00	0.00	100.0
1/2"	12.5	1242.0	1242.0	0.00	0.00	0.00	100.0
3.8"	9.5	1211.0	1211.0	0.00	0.00	0.00	100.0
No 4	4.75	644.0	644.0	0.00	0.00	0.00	100.0
No 8	2.36	521.0	522.8	1.80	0.12	0.12	99.9
No 10	2	622.0	622.6	0.60	0.04	0.16	99.8
No 16	1.18	531.0	531.9	0.90	0.06	0.22	99.8
No 30	0.6	507.0	507.8	0.80	0.05	0.27	99.7
No 50	0.3	291.0	292.0	1.00	0.07	0.34	99.7
No 100	0.15	462.0	463.4	1.40	0.09	0.43	99.6
No 200	0.075	454.0	455.6	1.60	0.11	0.54	99.5
Elapsed Time (min)	Actual Hydro meter Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0023	1.0302	7.70	0.0406	93.59	93.08
1	1.0315	-0.0023	1.0292	7.97	0.0358	90.49	90.00
2	1.0310	-0.0023	1.0287	8.10	0.0255	88.94	88.46
4	1.0300	-0.0023	1.0277	8.36	0.0183	85.84	85.38
8	1.0295	-0.0023	1.0272	8.50	0.0131	84.29	83.83
15	1.0290	-0.0023	1.0267	8.63	0.0096	82.74	82.29
30	1.0285	-0.0023	1.0262	8.76	0.0069	81.19	80.75
60	1.0275	-0.0023	1.0252	9.03	0.0049	78.09	77.67
120	1.0270	-0.0023	1.0247	9.16	0.0035	76.54	76.13
240	1.0265	-0.0023	1.0242	9.29	0.0025	74.99	74.59
480	1.0255	-0.0023	1.0232	9.55	0.0018	71.89	71.51
1440	1.0250	-0.0023	1.0227	9.69	0.0010	70.35	69.97

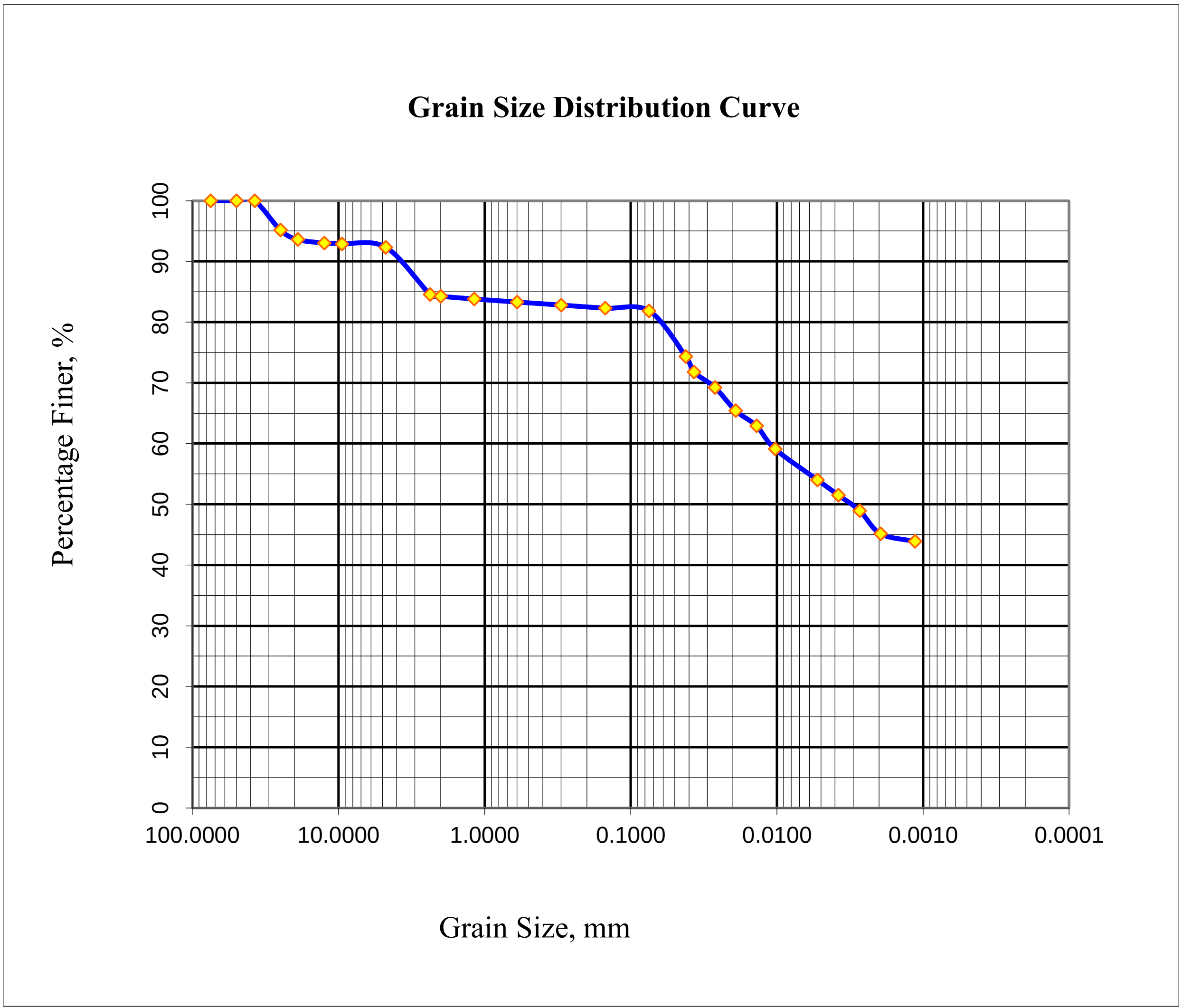
D8: Grain size distribution curve for TP2 at D=3.0m



D9: Grain size analysis result of TP4 at D=1.50m, total mass of sample = 3000 g

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.00	0.00	0.00	100.0
2"	50.0	1199.0	1199.0	0.00	0.00	0.00	100.0
1.5"	37.5	1084.0	1084.0	0.00	0.00	0.00	100.0
1"	25.0	1248.0	1393.0	145.00	4.83	4.83	95.2
3/4"	19.0	1443.0	1490.1	47.10	1.57	6.40	93.6
1/2"	12.5	1242.0	1259.2	17.20	0.57	6.98	93.0
3.8"	9.5	1211.0	1215.0	4.00	0.13	7.11	92.9
No 4	4.75	644.0	660.6	16.60	0.55	7.66	92.3
No 8	2.36	521.0	754.5	233.50	7.78	15.45	84.6
No 10	2	622.0	630.8	8.80	0.29	15.74	84.3
No 16	1.18	531.0	544.5	13.50	0.45	16.19	83.8
No 30	0.6	507.0	522.2	15.20	0.51	16.70	83.3
No 50	0.3	291.0	305.9	14.90	0.50	17.19	82.8
No 100	0.15	462.0	477.5	15.50	0.52	17.71	82.3
No 200	0.075	454.0	466.9	12.90	0.43	18.14	81.9
Elapsed Time (min)	Actual Hydro meter Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0320	-0.0027	1.0293	7.84	0.0420	90.80	74.33
1	1.0310	-0.0027	1.0283	8.10	0.0370	87.70	71.79
2	1.0300	-0.0027	1.0273	8.36	0.0266	84.60	69.25
4	1.0285	-0.0027	1.0258	8.76	0.0192	79.95	65.45
8	1.0275	-0.0027	1.0248	9.03	0.0138	76.85	62.91
15	1.0260	-0.0027	1.0233	9.42	0.0103	72.20	59.11
30	1.0250	-0.0027	1.0223	9.69	0.0074	69.11	56.57
60	1.0240	-0.0027	1.0213	9.95	0.0053	66.01	54.03
120	1.0230	-0.0027	1.0203	10.22	0.0038	62.91	51.50
240	1.0220	-0.0027	1.0193	10.48	0.0027	59.81	48.96
480	1.0205	-0.0027	1.0178	10.88	0.0020	55.16	45.15
1440	1.0200	-0.0027	1.0173	11.01	0.0011	53.61	43.89

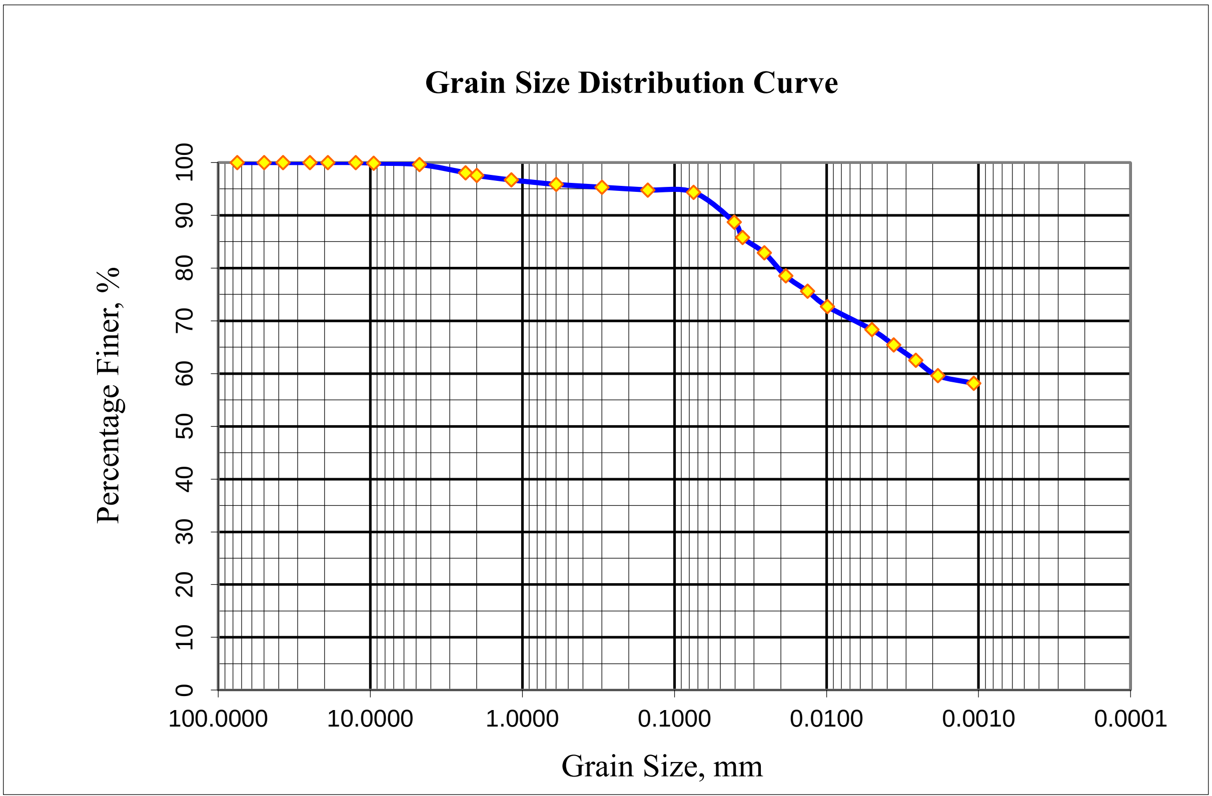
D10: Grain size distribution curve for TP4 at D=1.50m



D11: Grain size analysis result of TP4 at D=3.0m, total mass of sample = 3000 g

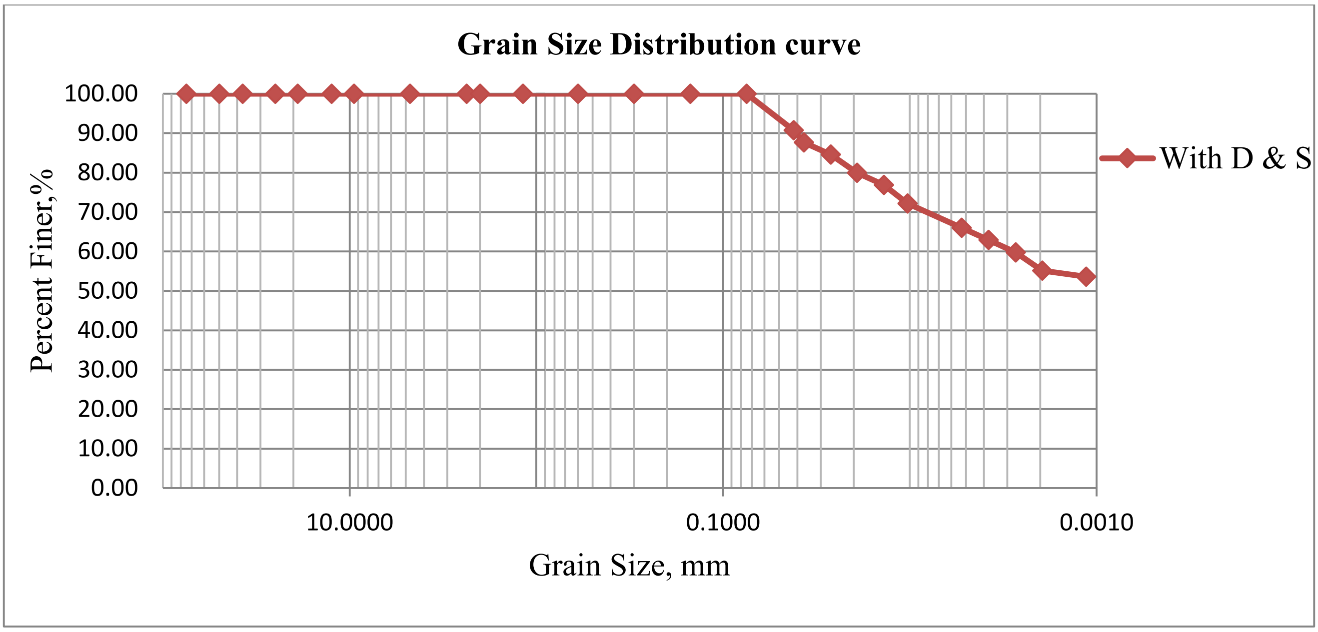
Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.00	0.00	0.00	100.0
2"	50.0	1199.0	1199.0	0.00	0.00	0.00	100.0
1.5"	37.5	1084.0	1084.0	0.00	0.00	0.00	100.0
1"	25.0	1248.0	1248.0	0.00	0.00	0.00	100.0
3/4"	19.0	1443.0	1443.0	0.00	0.00	0.00	100.0
1/2"	12.5	1242.0	1242.0	0.00	0.00	0.00	100.0
3.8"	9.5	1211.0	1212.7	1.70	0.11	0.11	99.9
No 4	4.75	644.0	648.0	4.00	0.27	0.38	99.6
No 8	2.36	521.0	544.4	23.40	1.56	1.94	98.1
No 10	2	622.0	629.8	7.80	0.52	2.46	97.5
No 16	1.18	531.0	543.7	12.70	0.85	3.31	96.7
No 30	0.6	507.0	519.5	12.50	0.83	4.14	95.9
No 50	0.3	291.0	299.2	8.20	0.55	4.69	95.3
No 100	0.15	462.0	469.7	7.70	0.51	5.20	94.8
No 200	0.075	454.0	460.3	6.30	0.42	5.62	94.4
Elapsed Time (min)	Actual Hydro meter Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0025	1.0305	7.57	0.0404	93.97	88.69
1	1.0320	-0.0025	1.0295	7.84	0.0356	90.89	85.78
2	1.0310	-0.0025	1.0285	8.10	0.0256	87.81	82.88
4	1.0295	-0.0025	1.0270	8.50	0.0186	83.19	78.51
8	1.0285	-0.0025	1.0260	8.76	0.0133	80.11	75.61
15	1.0275	-0.0025	1.0250	9.03	0.0099	77.03	72.70
30	1.0265	-0.0025	1.0240	9.29	0.0071	73.95	69.79
60	1.0260	-0.0025	1.0235	9.42	0.0050	72.41	68.34
120	1.0250	-0.0025	1.0225	9.69	0.0036	69.32	65.43
240	1.0240	-0.0025	1.0215	9.95	0.0026	66.24	62.52
480	1.0230	-0.0025	1.0205	10.22	0.0019	63.16	59.61
1440	1.0225	-0.0025	1.0200	10.35	0.0011	61.62	58.16

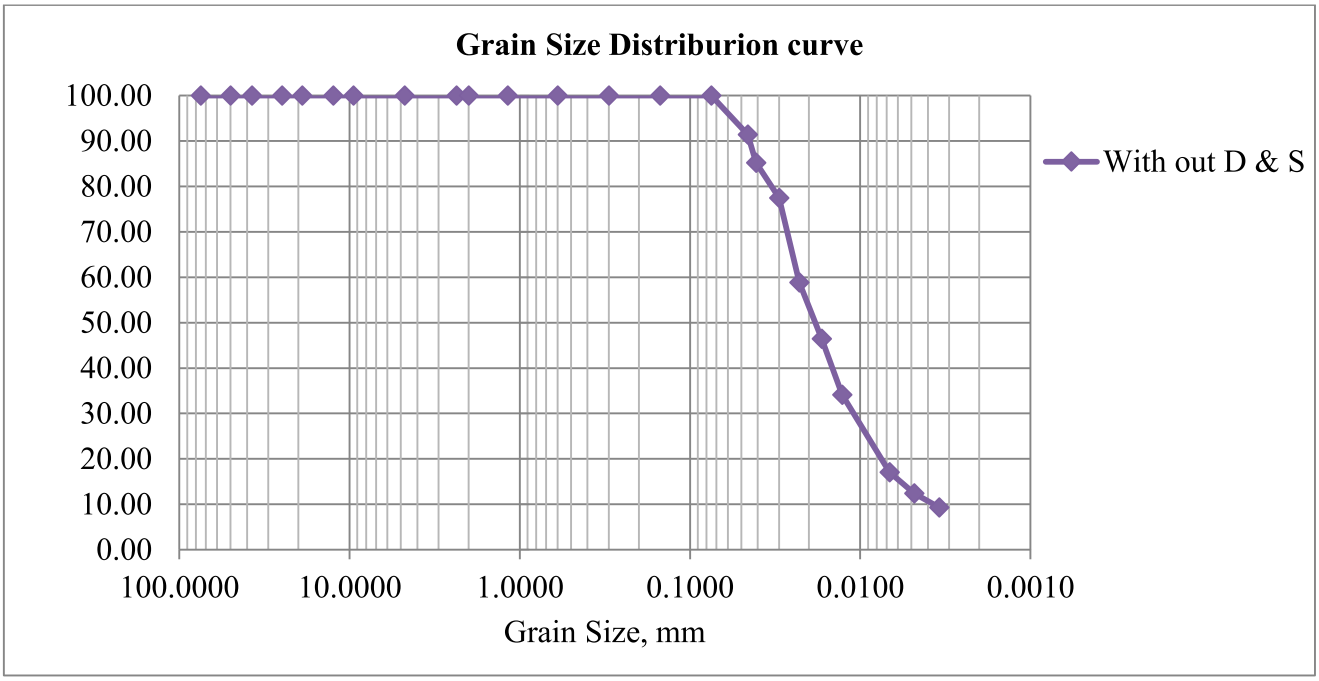
D12: Grain size distribution curve for TP4 at D=3.0m



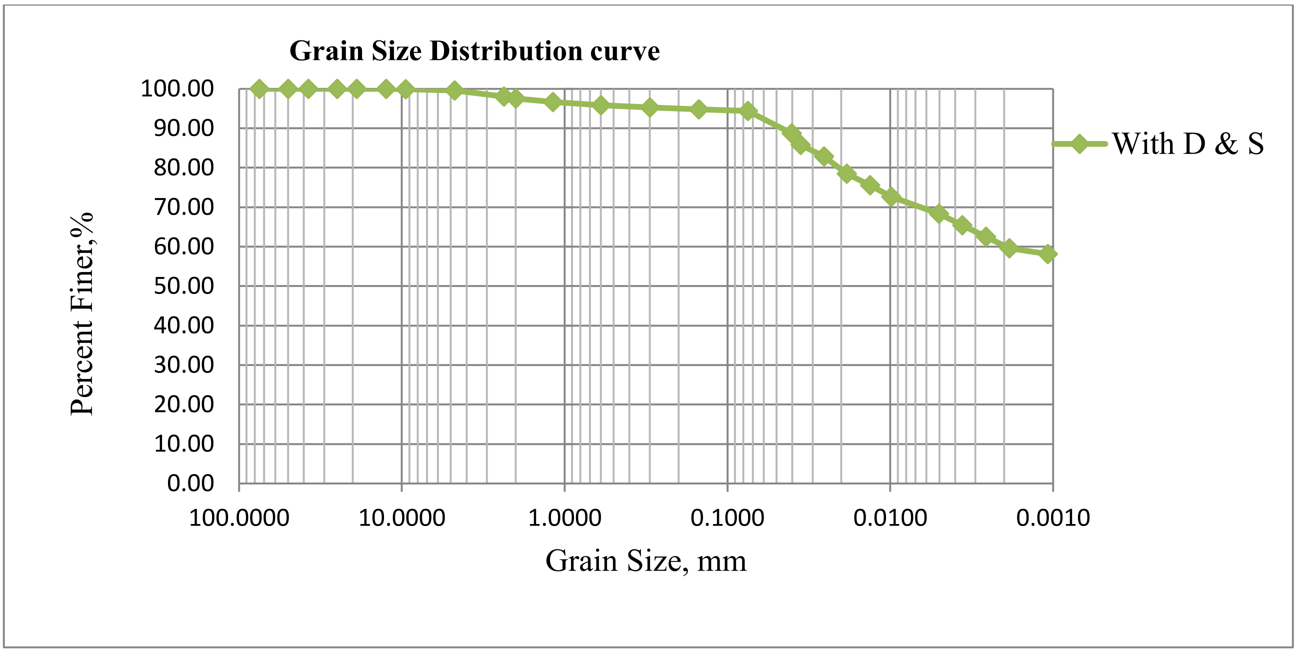
Appendix E: Dispersivity Test Curves

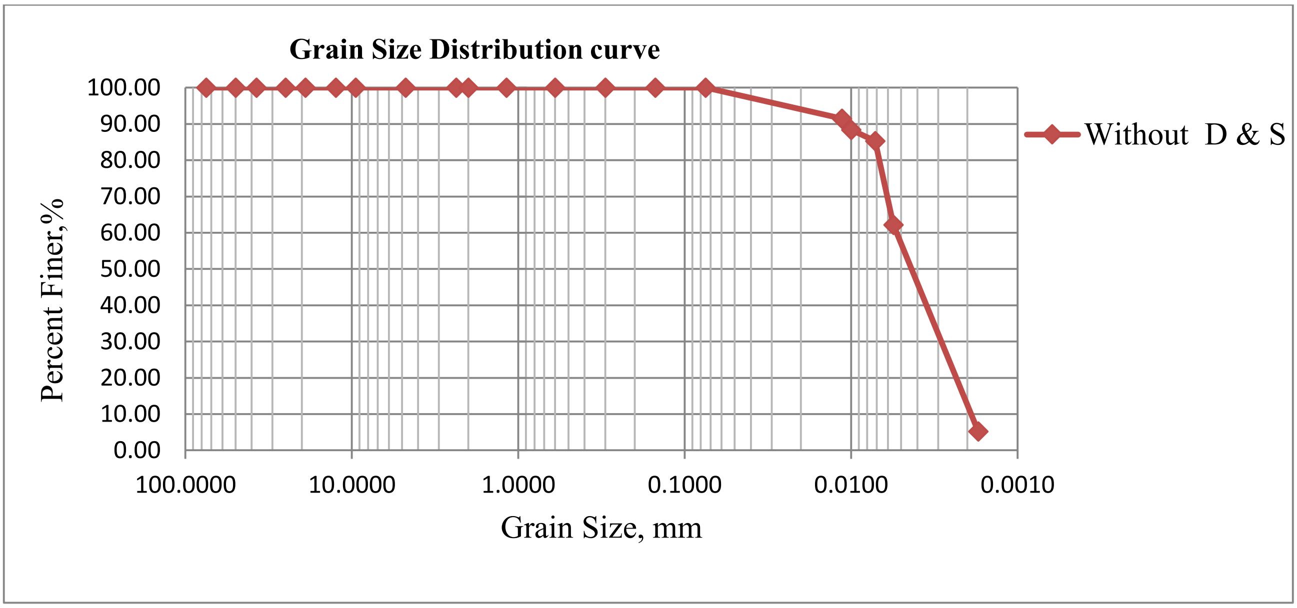
E1: Dispersivity Test Curves of TP4 at 1.50m



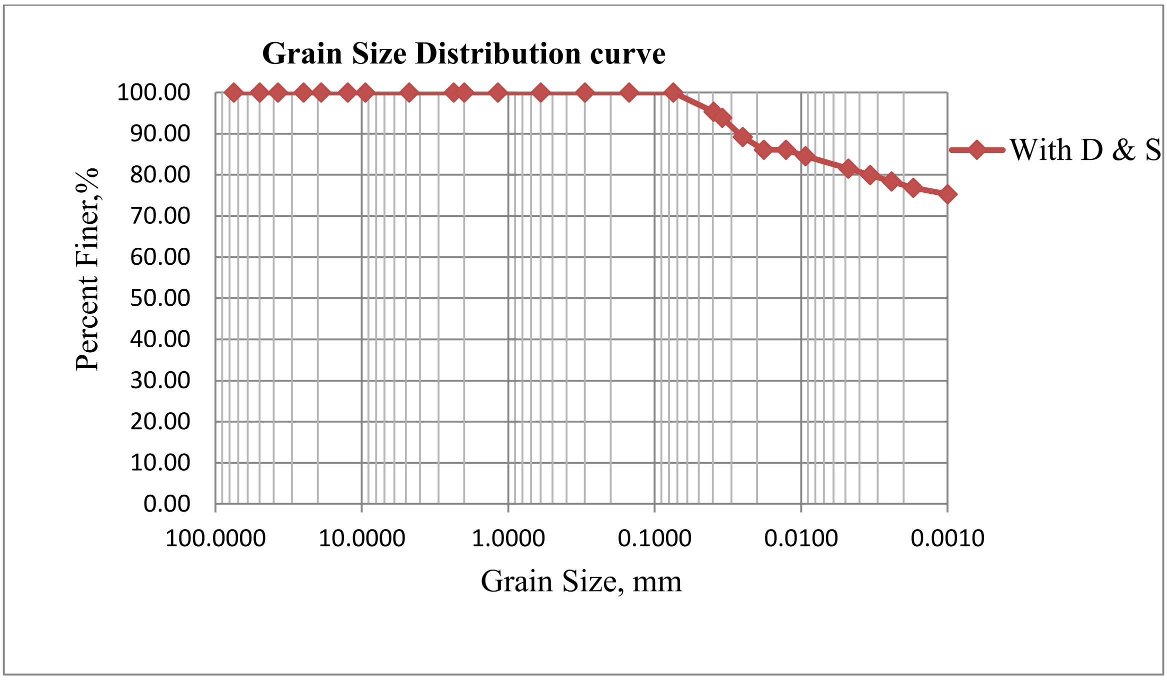


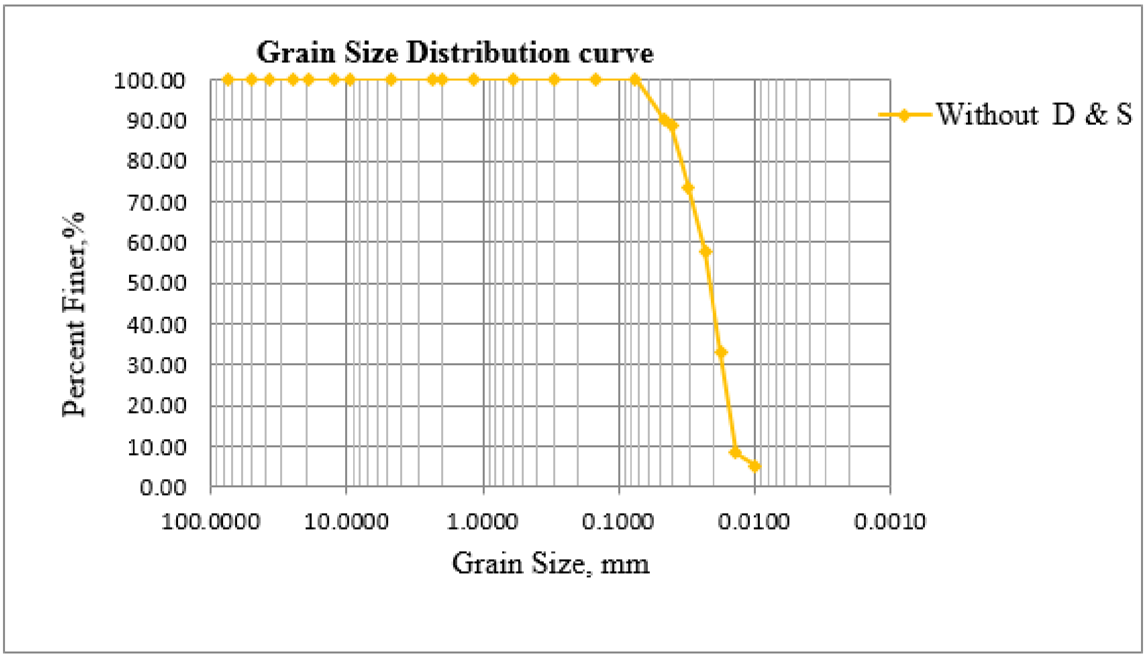
E2: Dispersivity Test Curves of TP4 at 3.0m



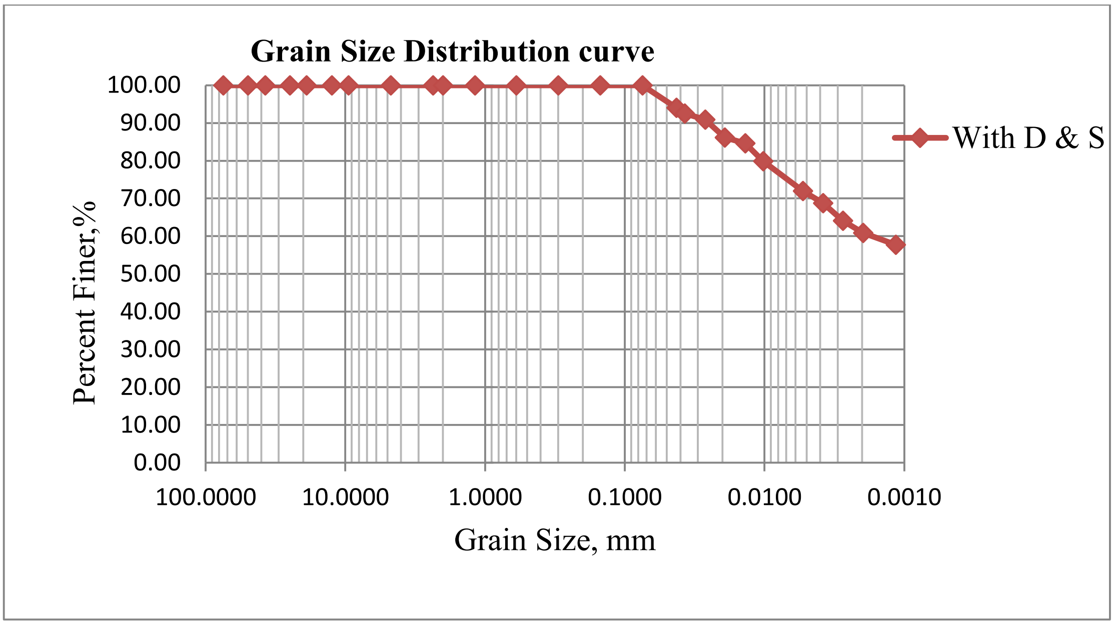


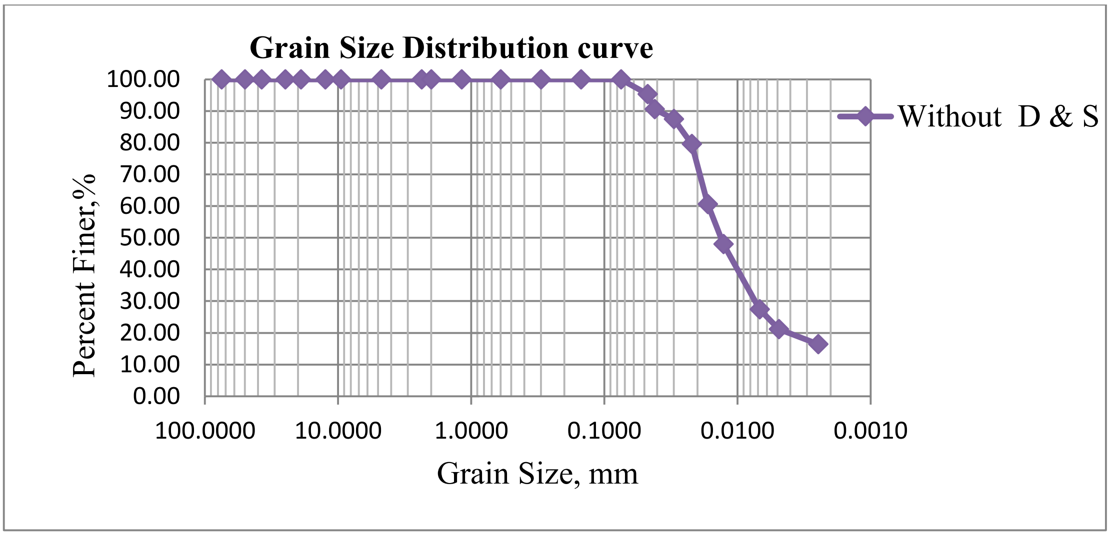
E3: Dispersivity Test Curves of TP5at 3.0m



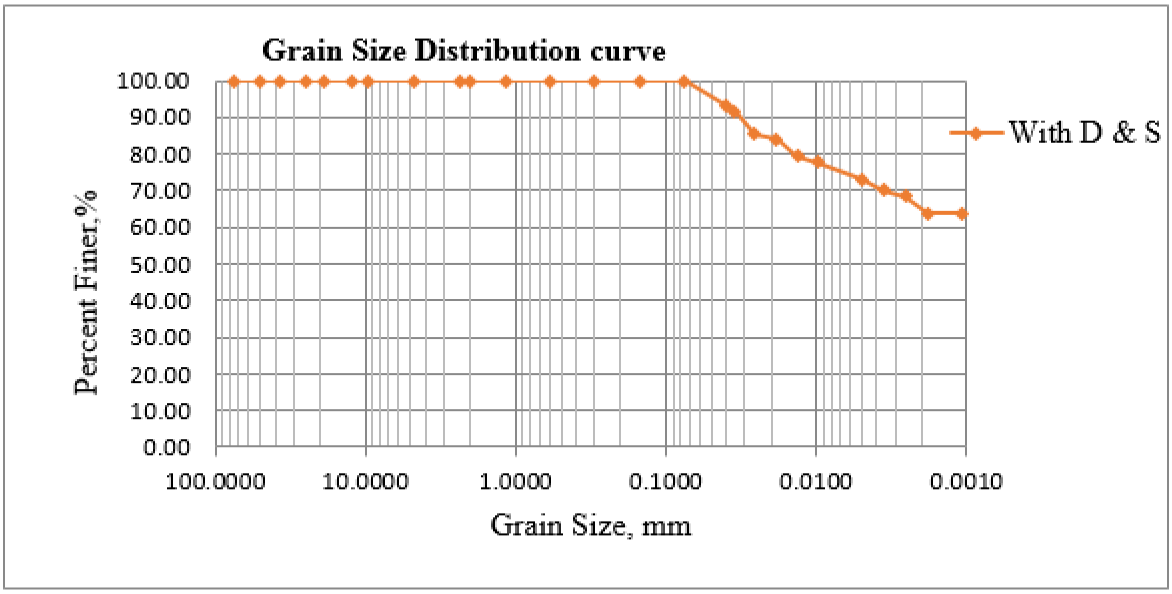


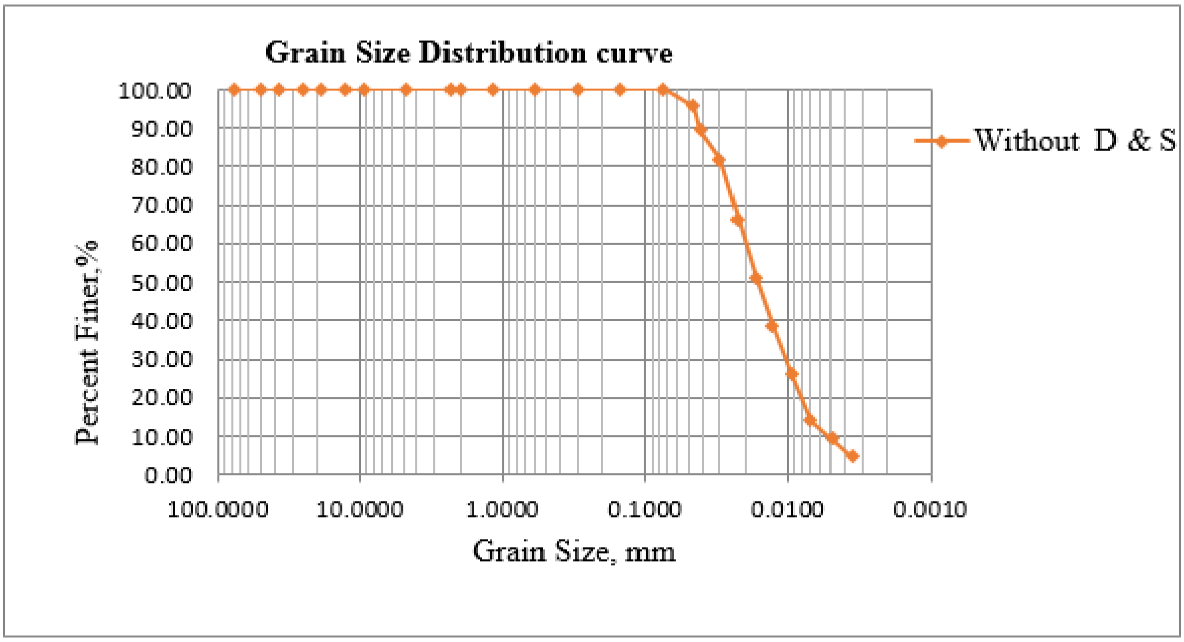
E4: Dispersivity Test Curves of TP6 at 1.50m



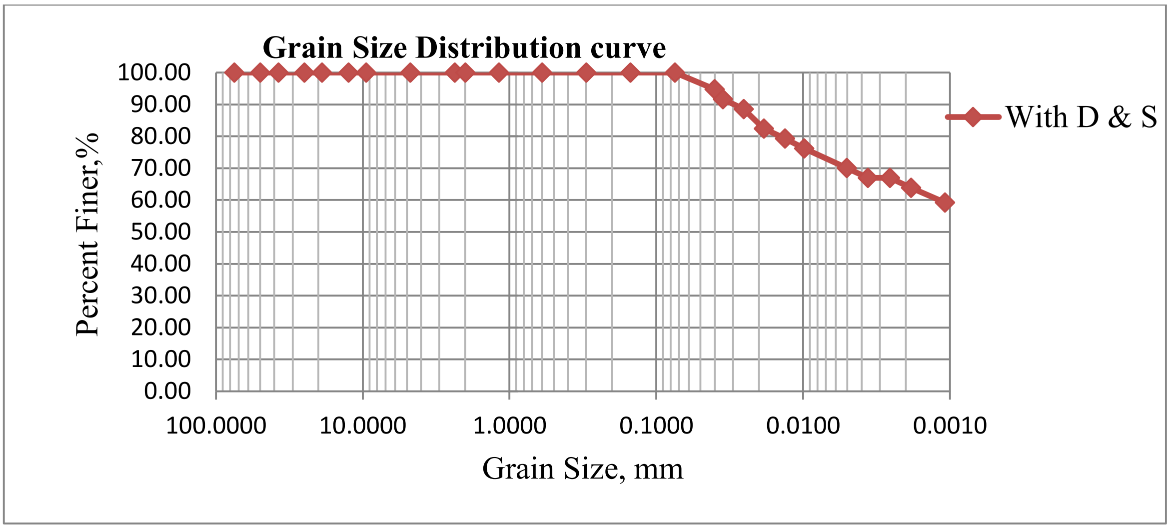


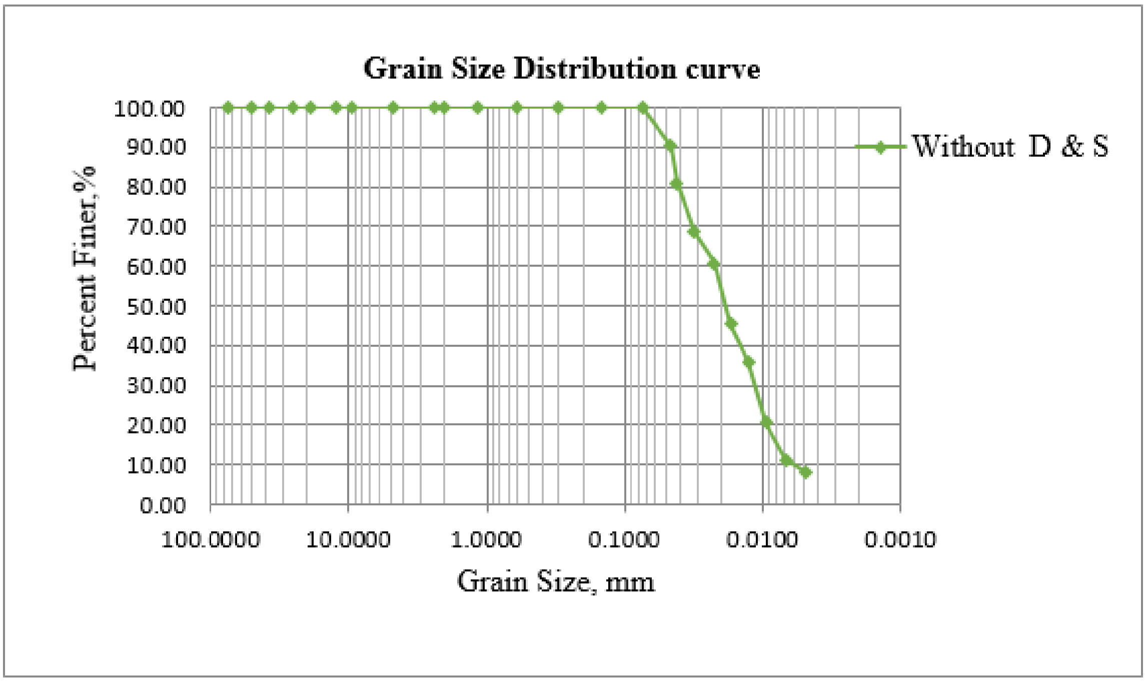
E5: Dispersivity Test Curves of TP6 at 3.0m



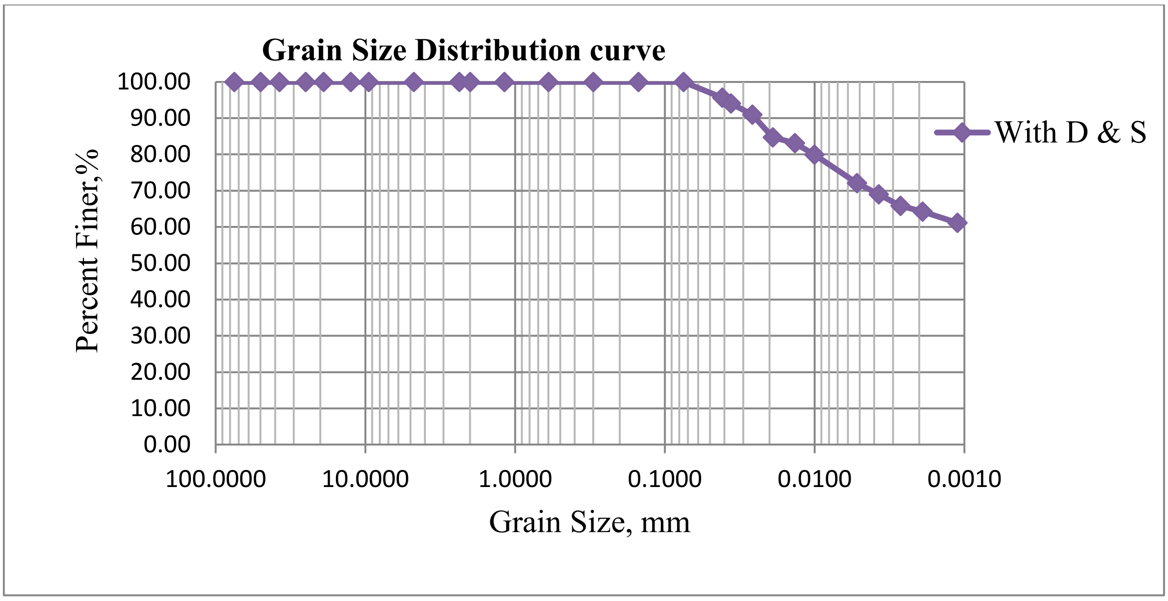


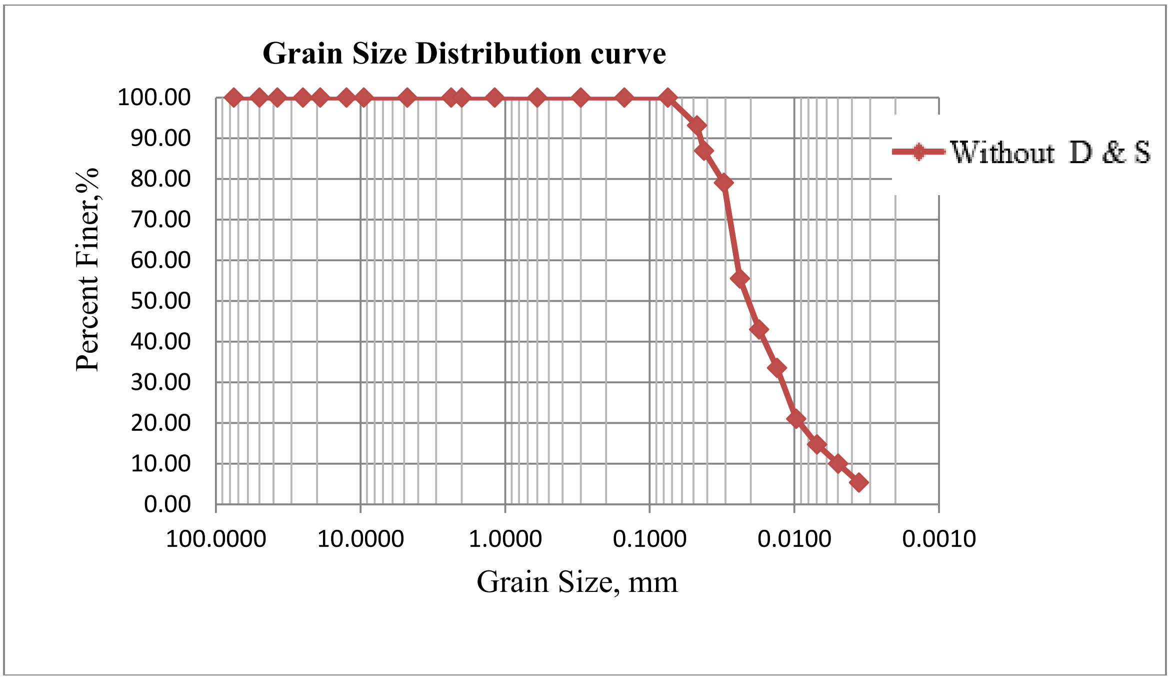
E6: Dispersivity Test Curves of TP7 at 3.0m



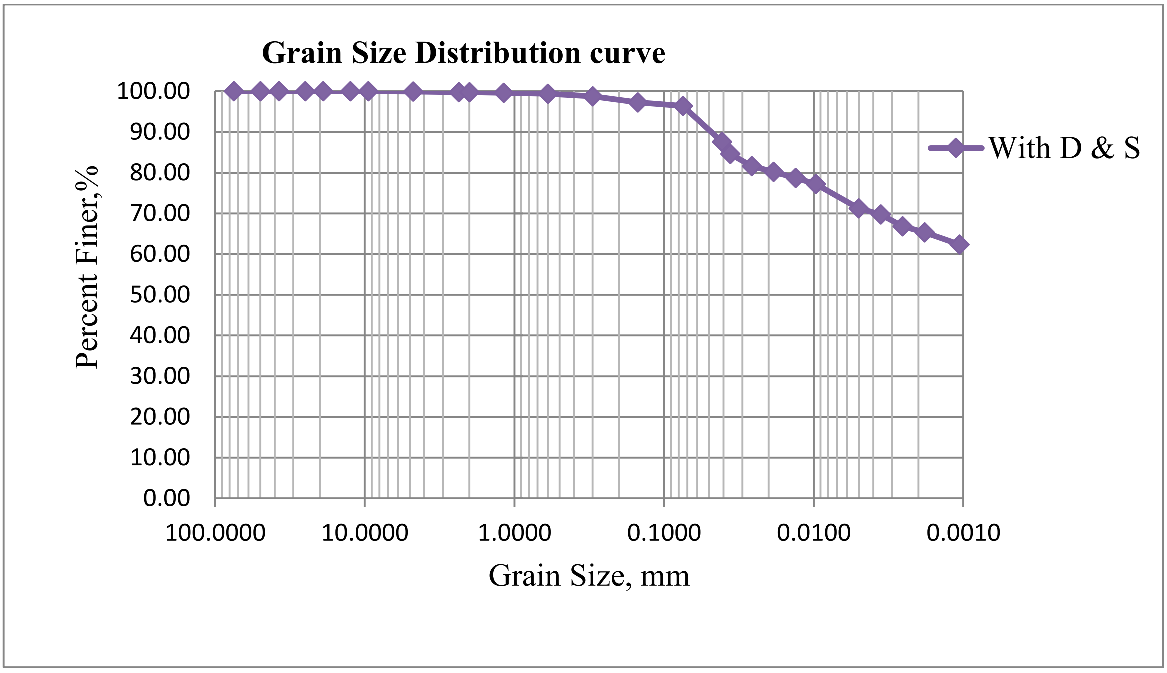


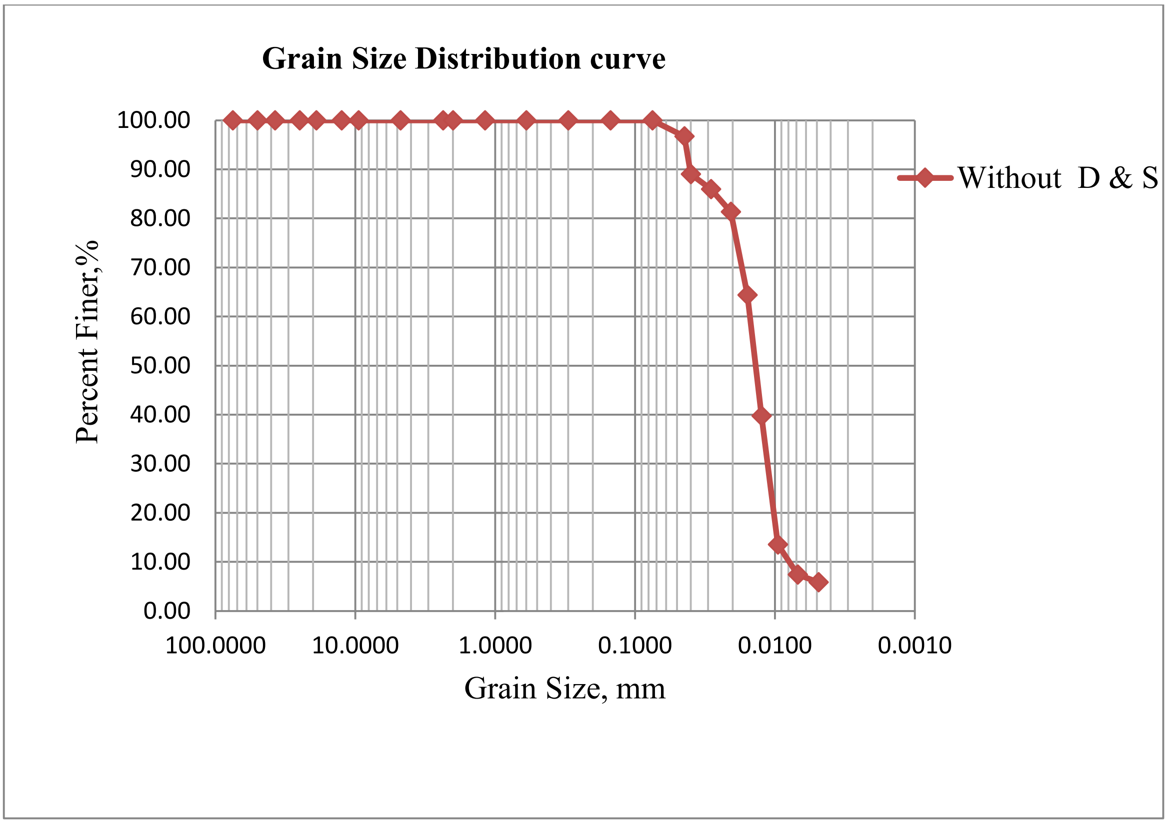
E7: Dispersivity Test Curves of TP8 at 1.50m





E8: Dispersivity Test Curves TP8 at 3.0m



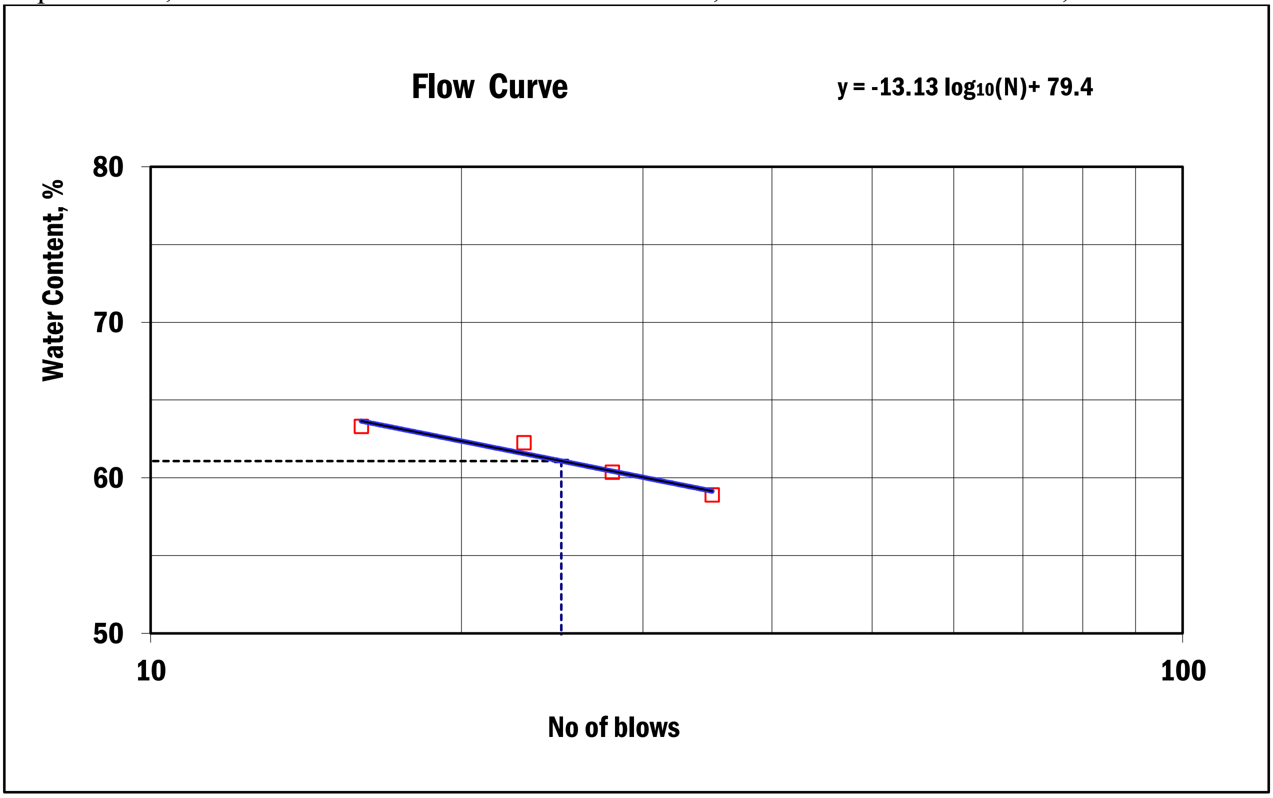


Appendix F: Atterberg Limits (Liquid limit and Plastic limit test results) but (typical results)

F1: Liquid limit and Plastic limit test result of TP1 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	E5	CA	3M	DAS3	H5	G5
Mass of container, g	15.60	29.90	10.50	15.50	15.50	15.50
Mass of container + Wet soil, g	29.90	48.50	26.40	33.30	21.70	21.80
Mass of container + Dry soil, g	24.60	41.50	20.30	26.40	20.20	20.30
Mass of water, g	5.30	7.00	6.10	6.90	1.50	1.50
Mass of dry soil, g	9.00	11.60	9.80	10.90	4.70	4.80
Water content, %	58.89	60.34	62.24	63.30	31.91	31.25
No of blows	35	28	23	16	------	------

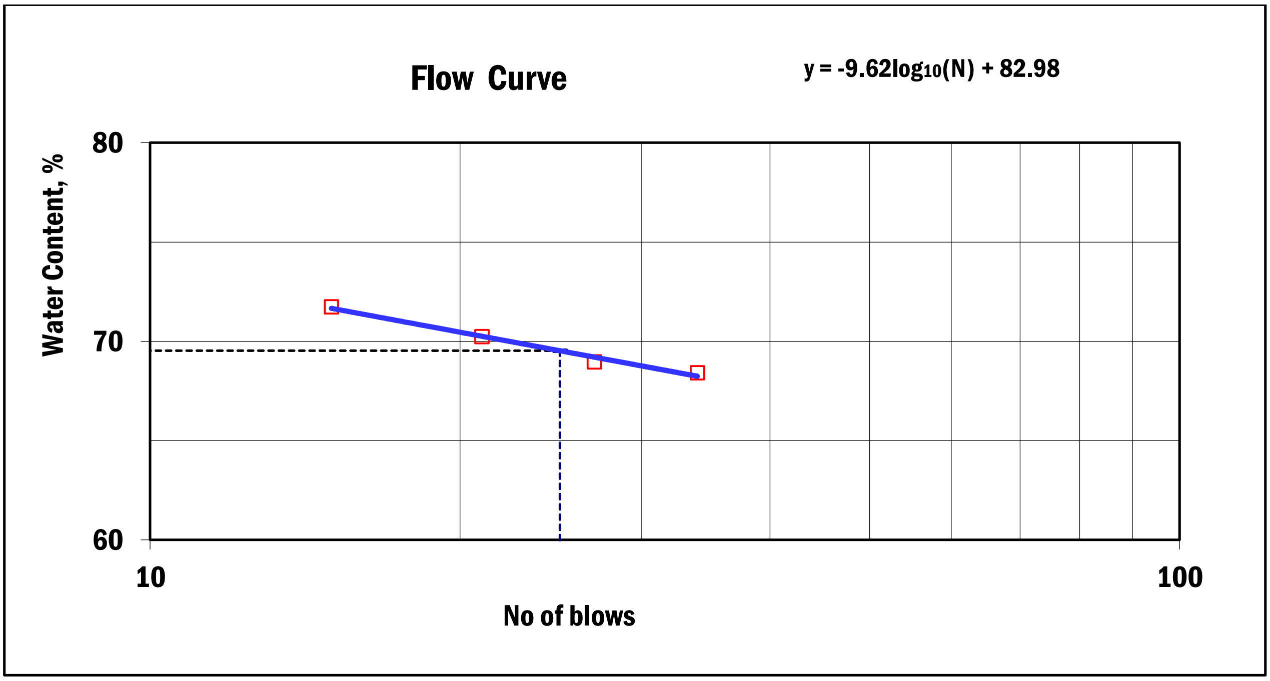
Liquid Limit, % = 61 Plastic Limit, % = 32 PI, %= 29



F2: Liquid limit and Plastic limit test result of TP1 at D=3.0 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	SM1	T-12	MO3	T-7	T-3	T-5
Mass of container, g	15.60	15.70	15.70	15.50	15.50	15.80
Mass of container + Wet soil, g	31.60	30.40	30.00	31.30	21.50	21.90
Mass of container + Dry soil, g	25.10	24.40	24.10	24.70	20.04	20.40
Mass of water, g	6.50	6.00	5.90	6.60	1.46	1.50
Mass of dry soil, g	9.50	8.70	8.40	9.20	4.54	4.60
Water content, %	68.42	68.97	70.24	71.74	32.16	32.61
No of blows	34	27	21	15	------	------

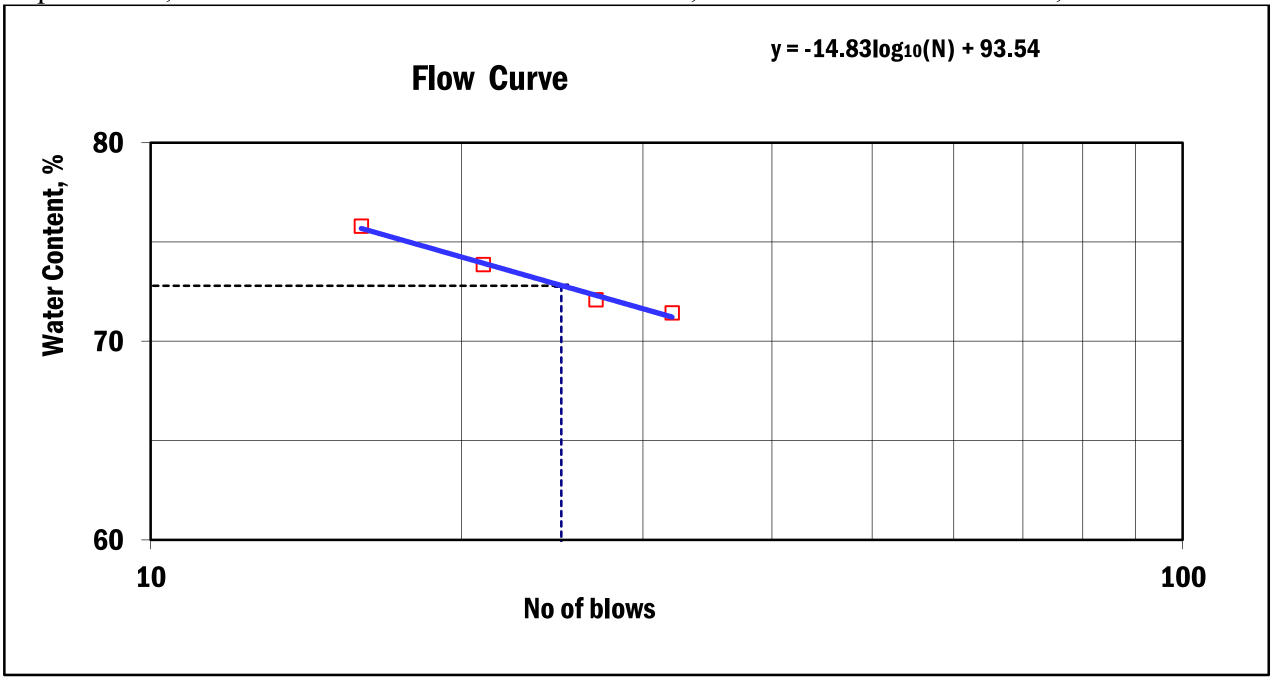
Liquid Limit, % = 70 Plastic Limit, % = 32 PI, %= 38



F3: Liquid limit and Plastic limit test result of TP2 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	A201	R59	LL	G3-4	A7	A5
Mass of container, g	15.60	15.40	15.50	15.70	15.60	15.50
Mass of container + Wet soil, g	32.40	33.40	28.80	32.40	22.40	21.50
Mass of container + Dry soil, g	25.40	25.86	23.15	25.20	20.60	19.90
Mass of water, g	7.00	7.54	5.65	7.20	1.80	1.60
Mass of dry soil, g	9.80	10.46	7.65	9.50	5.00	4.40
Water content, %	71.43	72.08	73.86	75.79	36.00	36.36
No of blows	32	27	21	16	------	------

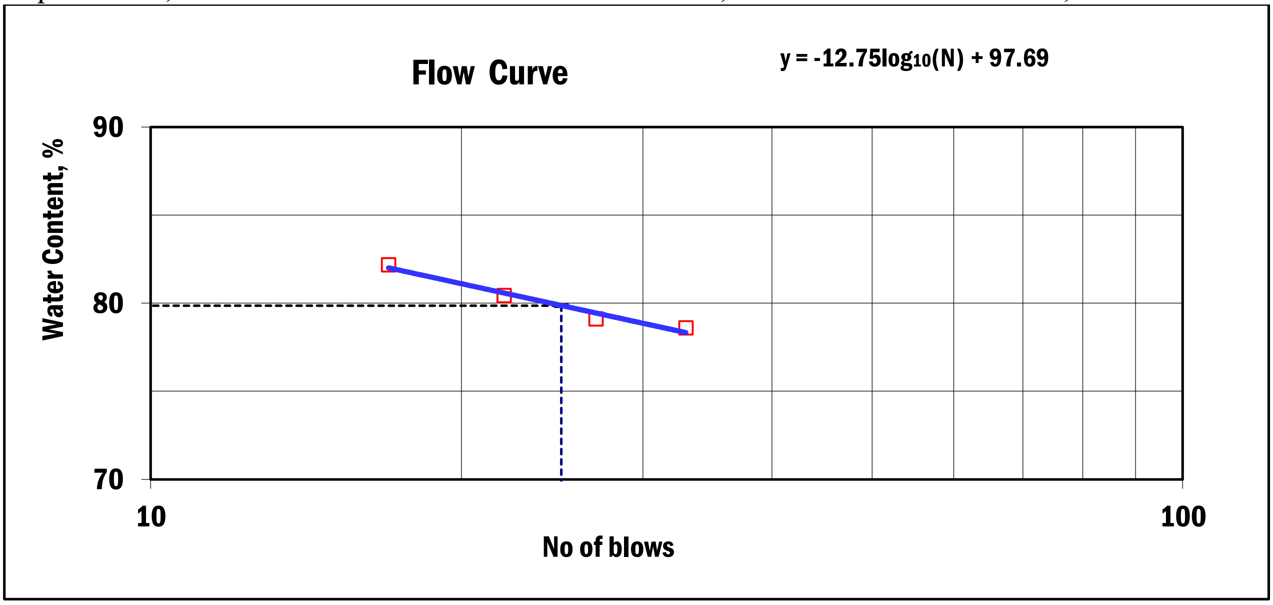
Liquid Limit, % = 73 Plastic Limit, % = 36 PI, %= 37



F4: Liquid limit and Plastic limit test result of TP2 at D=3.0 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	TA2	A27	M2	J7	J43	C290
Mass of container, g	15.30	15.60	15.80	15.80	15.80	14.10
Mass of container + Wet soil, g	32.50	31.90	32.40	29.10	21.90	20.60
Mass of container + Dry soil, g	24.93	24.70	25.00	23.10	20.20	18.79
Mass of water, g	7.57	7.20	7.40	6.00	1.70	1.81
Mass of dry soil, g	9.63	9.10	9.20	7.30	4.40	4.69
Water content, %	78.61	79.12	80.43	82.19	38.64	38.59
No of blows	33	27	22	17	------	------

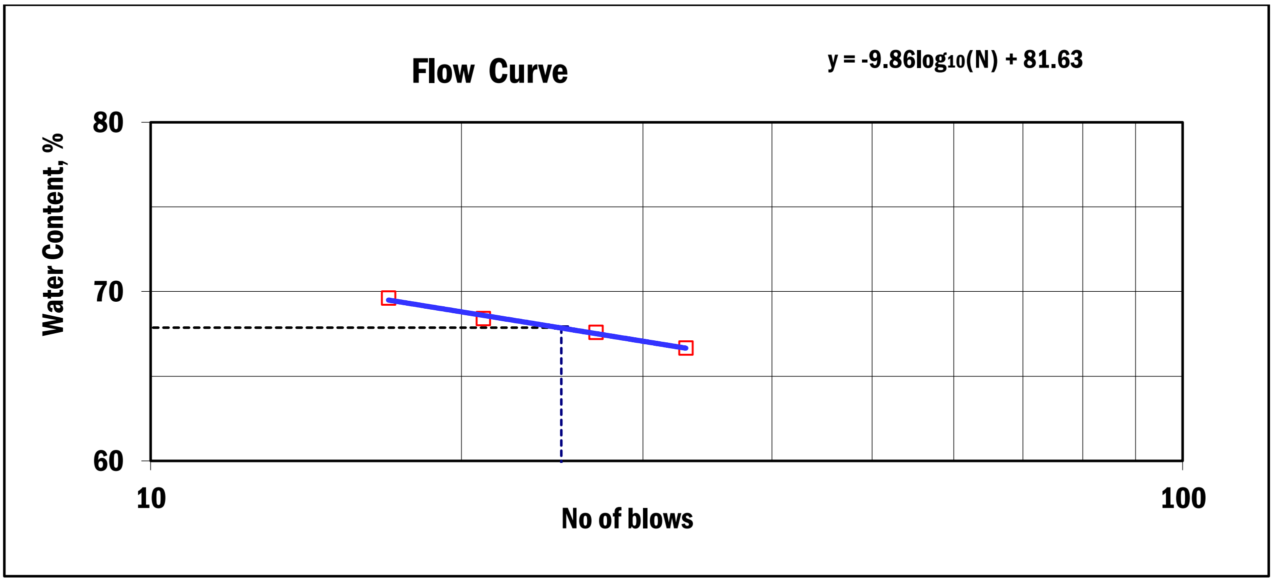
Liquid Limit, % = 80 Plastic Limit, % = 39 PI, %= 41



F5: Liquid limit and Plastic limit test result of TP4 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	MF	23	11	19	60	D25
Mass of container, g	15.70	15.40	15.70	15.50	15.50	15.90
Mass of container + Wet soil, g	34.70	33.50	33.50	32.80	22.10	22.00
Mass of container + Dry soil, g	27.10	26.20	26.27	25.70	20.60	20.60
Mass of water, g	7.60	7.30	7.23	7.10	1.50	1.40
Mass of dry soil, g	11.40	10.80	10.57	10.20	5.10	4.70
Water content, %	66.67	67.59	68.40	69.61	29.41	29.79
No of blows	33	27	21	17	------	------

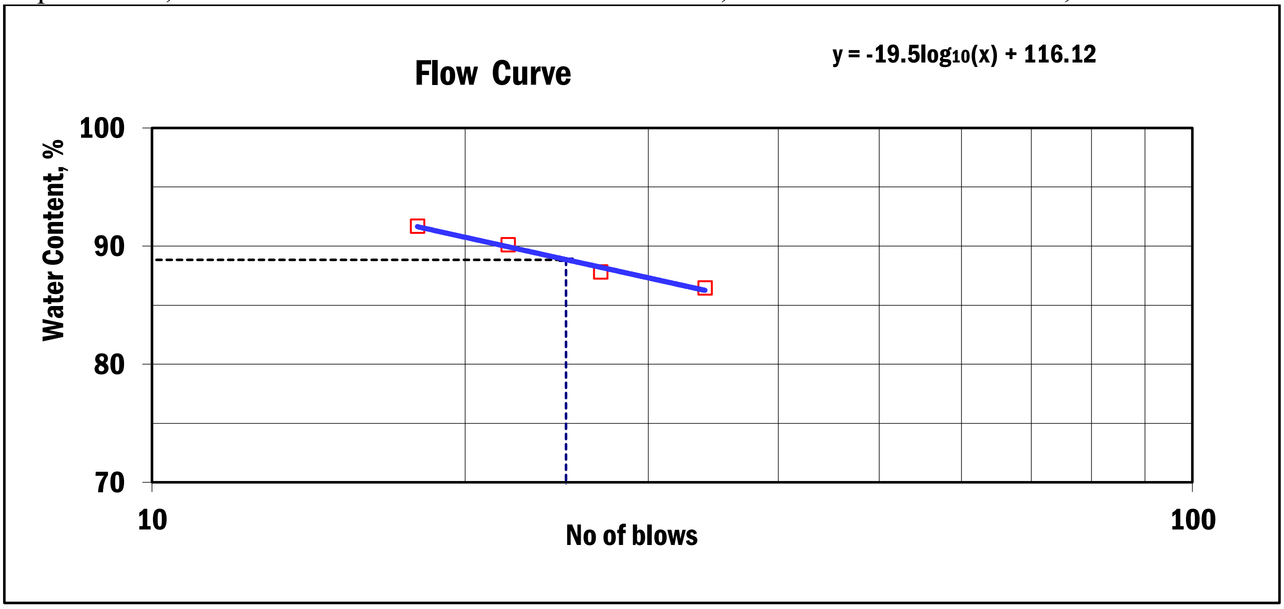
Liquid Limit, % = 68 Plastic Limit, % = 30 PI, %= 38



F6: Liquid limit and Plastic limit test result of TP4 at D=3.0 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	A8	15	TT	G-3	9	R1
Mass of container, g	15.50	15.60	15.60	15.70	15.20	15.80
Mass of container + Wet soil, g	33.40	31.60	32.90	31.80	21.30	22.20
Mass of container + Dry soil, g	25.10	24.12	24.70	24.10	19.89	20.70
Mass of water, g	8.30	7.48	8.20	7.70	1.41	1.50
Mass of dry soil, g	9.60	8.52	9.10	8.40	4.69	4.90
Water content, %	86.46	87.79	90.11	91.67	30.06	30.61
No of blows	34	27	22	18	------	------

Liquid Limit, % = 89 Plastic Limit, % = 30 PI, %= 59



Appendix G: Specific gravity test results

G1: Specific gravity test results of TP1 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.8	160.9
Temperature, T_x(°c)	20.3	19.9
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.69	144.84
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9999	1.0001
Specific gravity of soil at 20°c.	2.81	2.80
Average specific gravity of soil .		2.80

G2: Specific gravity test results of TP1 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.7	160.7
Temperature, T_x(°c)	23.6	23.5
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.64	144.62
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9992	0.9992
Specific gravity of soil at 20°c.	2.79	2.80
Average specific gravity of soil .		2.80

G3: Specific gravity test results of TP2 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.8
Temperature, T_x(°c)	21.2	20.8
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.67	144.68
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9997	0.9999
Specific gravity of soil at 20°c.	2.85	2.81
Average specific gravity of soil .		2.83

G4: Specific gravity test results of TP2 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.8	160.8
Temperature, T_x(°c)	21.8	22.5
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.66	144.65
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9995	0.9994
Specific gravity of soil at 20°c.	2.82	2.82
Average specific gravity of soil .		2.82

G5: Specific gravity test results of TP3 at D=1.80m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.7	160.7
Temperature, T_x(°c)	22	22
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.70	144.70
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9996	0.9996
Specific gravity of soil at 20°c.	2.78	2.78
Average specific gravity of soil .		2.78

G6: Specific gravity test results of TP4 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.8
Temperature, T_x(°c)	21.9	23.6
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.73	144.69
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9996	0.9992
Specific gravity of soil at 20°c.	2.83	2.81
Average specific gravity of soil .		2.82

G7: Specific gravity test results of TP4 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.9
Temperature, T_x(°c)	22.3	22.5
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.67	144.65
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9995	0.9994
Specific gravity of soil at 20°c.	2.85	2.86
Average specific gravity of soil .		2.85

G8: Specific gravity test results of TP5 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.8	160.8
Temperature, T_x(°c)	27.2	24.1
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.58	144.66
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9982	0.9990
Specific gravity of soil at 20°c.	2.84	2.82
Average specific gravity of soil .		2.83

G9: Specific gravity test results of TP5 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.9
Temperature, T_x(°c)	23.1	22.1
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.69	144.71
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9992	0.9995
Specific gravity of soil at 20°c.	2.84	2.84
Average specific gravity of soil .		2.84

G10: Specific gravity test results of TP6 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.6	160.5
Temperature, T_x(°c)	20	21.3
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.71	144.68
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9993	0.9993
Specific gravity of soil at 20°c.	2.74	2.72
Average specific gravity of soil .		2.73

G11: Specific gravity test results of TP6 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.9
Temperature, T_x(°c)	19.9	19.9
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.70	144.70
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	1.0001	1.0001
Specific gravity of soil at 20°c.	2.84	2.84
Average specific gravity of soil .		2.84

G12: Specific gravity test results of TP7 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.8	160.85
Temperature, T_x(°c)	20.3	20.8
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.69	144.68
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9999	0.9998
Specific gravity of soil at 20°c.	2.81	2.83
Average specific gravity of soil .		2.82

G13: Specific gravity test results of TP7 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.8	160.9
Temperature, T_x(°c)	24.6	24.2
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.64	144.65
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.999	0.9990
Specific gravity of soil at 20°c.	2.83	2.85
Average specific gravity of soil .		2.84

G14: Specific gravity test results of TP8 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.8	160.7
Temperature, T_x(°c)	21.6	23.7
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.70	144.66
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9995	0.9994
Specific gravity of soil at 20°c.	2.81	2.79
Average specific gravity of soil .		2.80

G15: Specific gravity test results of TP8 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.85
Temperature, T_x(°c)	21	19.9
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	144.67	144.69
Weight of dry soil , w_s (gm)	25	25
Conversion factor , K	0.9998	1.0001
Specific gravity of soil at 20°c.	2.85	2.83
Average specific gravity of soil .		2.84

G16: Specific gravity test results of TP9 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.8
Temperature, T_x(°c)	23.2	24.6
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.66	144.62
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9992	0.9990
Specific gravity of soil at 20°c.	2.85	2.83
Average specific gravity of soil .		2.84

G17: Specific gravity test results of TP9 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	160.9
Temperature, T_x(°c)	22.8	23
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.66	144.68
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9993	0.9993
Specific gravity of soil at 20°c.	2.85	2.85
Average specific gravity of soil .		2.85

G18: Specific gravity test results of TP10 at D=1.50m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.7	160.6
Temperature, T_x(°c)	21.3	20.7
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.68	144.70
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9996	0.9994
Specific gravity of soil at 20°c.	2.78	2.75
Average specific gravity of soil .		2.76

G19: Specific gravity test results of TP10 at D=3.0m

Pycnometer No.	P1	P2
Weight of dry, clean pycnometer, Wp (g)	45.3	45.3
Weight of pycnometer + soil + water, W_{pws} (g)	160.89	160.9
Temperature, T_x(°c)	23.8	22.3
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	144.66	144.69
Weight of dry soil , W_s (gm)	25	25
Conversion factor , K	0.9991	0.9995
Specific gravity of soil at 20°c.	2.85	2.84
Average specific gravity of soil .		2.85

Appendix H: Free swell test results (typical results)

H1: Free swell test result of TP1 at D=1.5m

Methods used	Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
		Sample No.1 (cc)	Sample No.2 (cc)		
Oven dry	10.0	14.8	14.8	14.8	44
Kerosene	10.0	12.5	12.5	12.5	Not needed

H2: Free swell test result of TP1 at D=3.0m

Methods used	Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
		Sample No.1 (cc)	Sample No.2 (cc)		
Oven dry	10.0	14.3	14.3	14.3	43
Kerosene	10.0	11.7	11.7	11.7	Not needed

H3: Free swell test result of TP2 at D=1.50m

Methods used	Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
		Sample No.1 (cc)	Sample No.2 (cc)		
Oven dry	10.0	14.5	15.0	14.8	48
Kerosene	10	12	12	12	Not needed

H4: Free swell test result of TP2 at D=3.0m

Methods used	Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
		Sample No.1 (cc)	Sample No.2 (cc)		
Oven dry	10.0	14.0	14.5	14.3	43
Kerosene	10	11	11.5	11.3	Not needed

H5: Free swell test result of TP3 at D=1.80m

Methods used	Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
Oven dry	10.0	14.0	14.0	14.0	40
Kerosene	10.0	12.5	12.5	12.5	Not needed

H6: Free swell test result of TP4 at D=1.50m

Methods used	Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
Oven dry	10.0	14.5	15.0	14.8	48
Kerosene	10.0	12.0	12.0	12.0	Not needed

H7: Free swell test result of TP5 at D=1.50m

Methods used	Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
Oven dry	10.0	13.0	13.0	13.0	30
Kerosene	10.0	11.5	12.0	11.8	Not needed

H8: Free swell test result of TP5 at D=3.0m

Methods used	Initial Volume (cc)	Final Volume Sample No.1 (cc)	Final Volume Sample No.2 (cc)	Average Final Volume (cc)	Free Swell Index (%)
Oven dry	10.0	15.0	15.0	15.0	50
Kerosene	10.0	11.8	12.2	12.0	Not needed

H9: Free swell test result of TP8 at D=1.50m

Methods Used	Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
		Sample No.1 (cc)	Sample No.2 (cc)		
Oven dry	10.0	14.5	14.5	14.5	45
Kerosene	10.0	11.8	11.76	11.8	Not needed

H10: Free swell test result of TP8 at D=3.0m

Methods Used	Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
		Sample No.1 (cc)	Sample No.2 (cc)		
Oven dry	10.0	14.5	15.0	14.8	48
Kerosene	10.0	12.5	12.7	12.6	Not needed

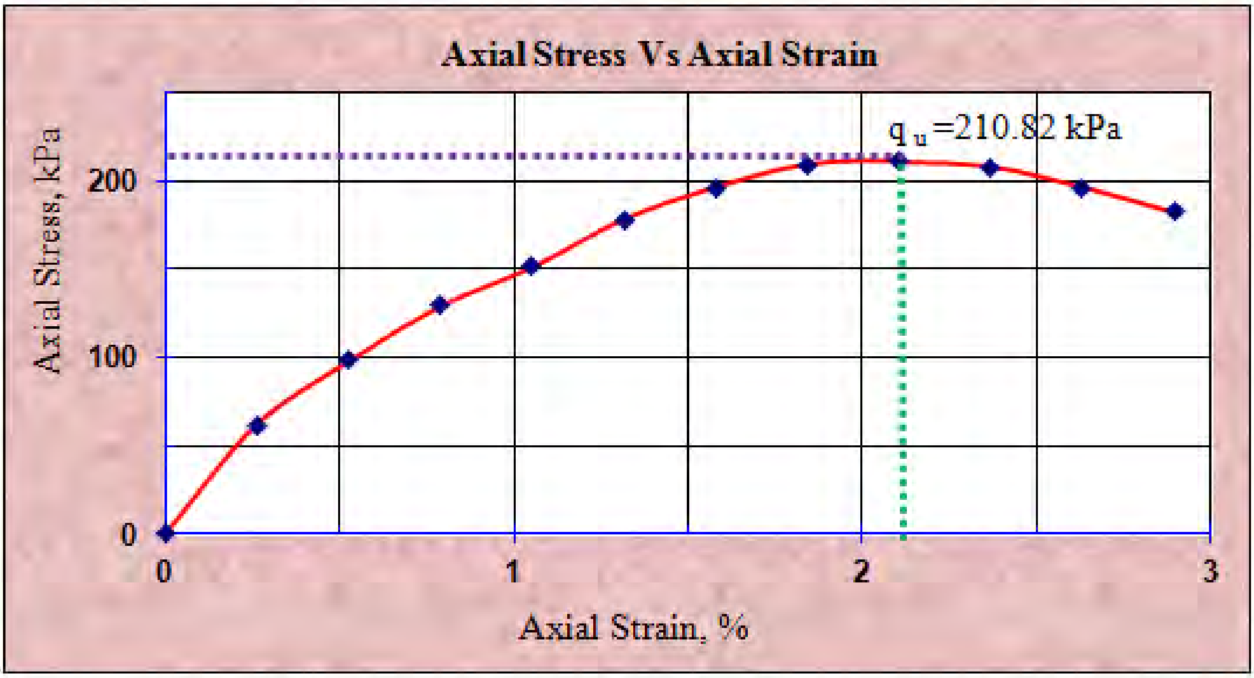
Appendix I: Unconfined compression test results

I1: Unconfined compression test result of TP2 at D=1.50m

Test Pit No	2	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	1.50	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight,kN/m^3	17.47
Diameter of sample , mm	38	Moisture Content	34.5%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m^2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	49	0.0696	0.001137	61.19
0.40	0.53	79	0.1122	0.001140	98.39
0.60	0.79	104	0.1477	0.001143	129.19
0.80	1.05	122	0.1732	0.001146	151.15
1.00	1.32	144	0.2045	0.001149	177.93
1.20	1.58	159	0.2258	0.001152	195.94
1.40	1.84	170	0.2414	0.001155	208.93
1.60	2.11	172	0.2442	0.001159	210.82
1.80	2.37	170	0.2414	0.001162	207.81
2.00	2.63	161	0.2286	0.001165	196.28
2.20	2.89	150	0.2130	0.001168	182.37

I2: Unconfined compression test result curve of TP2 at D=1.50m

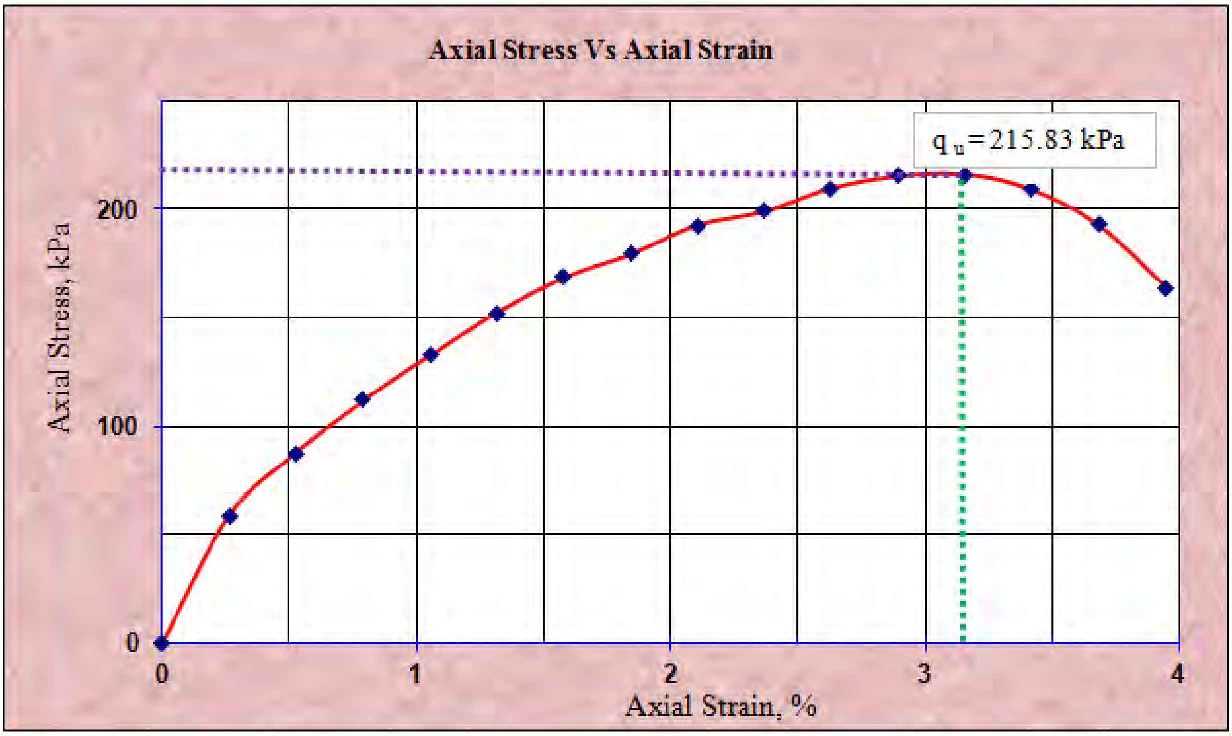


I3: Unconfined compression test result of TP2 at D=3.0m

Test Pit No	2	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	3.0	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m^3	16.76
Diameter of sample , mm	38	Moisture Content	37.85%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m^2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	47	0.0667	0.001137	58.69
0.40	0.53	70	0.0994	0.001140	87.18
0.60	0.79	90	0.1278	0.001143	111.80
0.80	1.05	107	0.1519	0.001146	132.56
1.00	1.32	123	0.1747	0.001149	151.98
1.20	1.58	137	0.1945	0.001152	168.83
1.40	1.84	146	0.2073	0.001155	179.44
1.60	2.11	157	0.2229	0.001159	192.44
1.80	2.37	163	0.2315	0.001162	199.25
2.00	2.63	172	0.2442	0.001165	209.69
2.20	2.89	177	0.2513	0.001168	215.20
2.40	3.16	178	0.2528	0.001171	215.83
2.60	3.42	173	0.2457	0.001174	209.20
2.80	3.68	160	0.2272	0.001177	192.95
3.00	3.95	136	0.1931	0.001181	163.56

I4: Unconfined compression test result curve of TP2 at D=3.0m

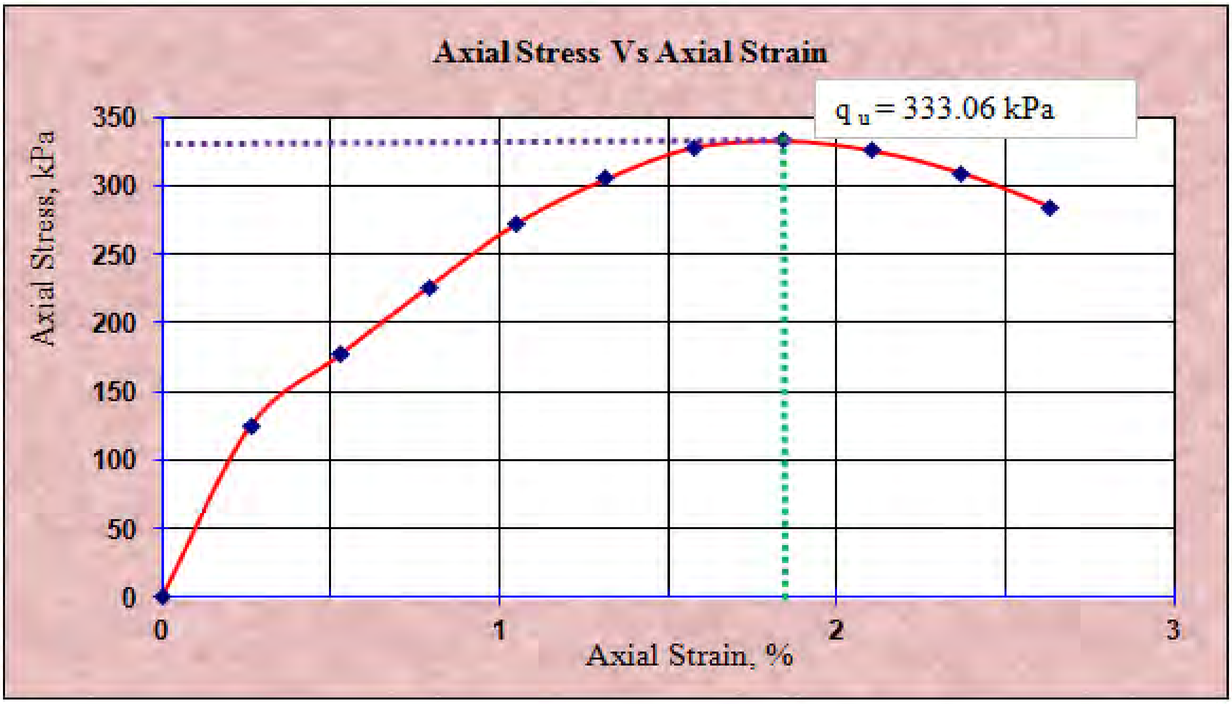


I5: Unconfined compression test result of TP4 at D=1.50m

Test Pit No	4	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	1.50	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m^3	16.86
Diameter of sample , mm	38	Moisture Content	29.72%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	100	0.1420	0.001137	124.88
0.40	0.53	142	0.2016	0.001140	176.86
0.60	0.79	182	0.2584	0.001143	226.08
0.80	1.05	220	0.3124	0.001146	272.56
1.00	1.32	247	0.3507	0.001149	305.19
1.20	1.58	266	0.3777	0.001152	327.79
1.40	1.84	271	0.3848	0.001155	333.06
1.60	2.11	266	0.3777	0.001159	326.04
1.80	2.37	253	0.3593	0.001162	309.27
2.00	2.63	233	0.3309	0.001165	284.06

I6: Unconfined compression test result curve of TP4 at D=1.50m

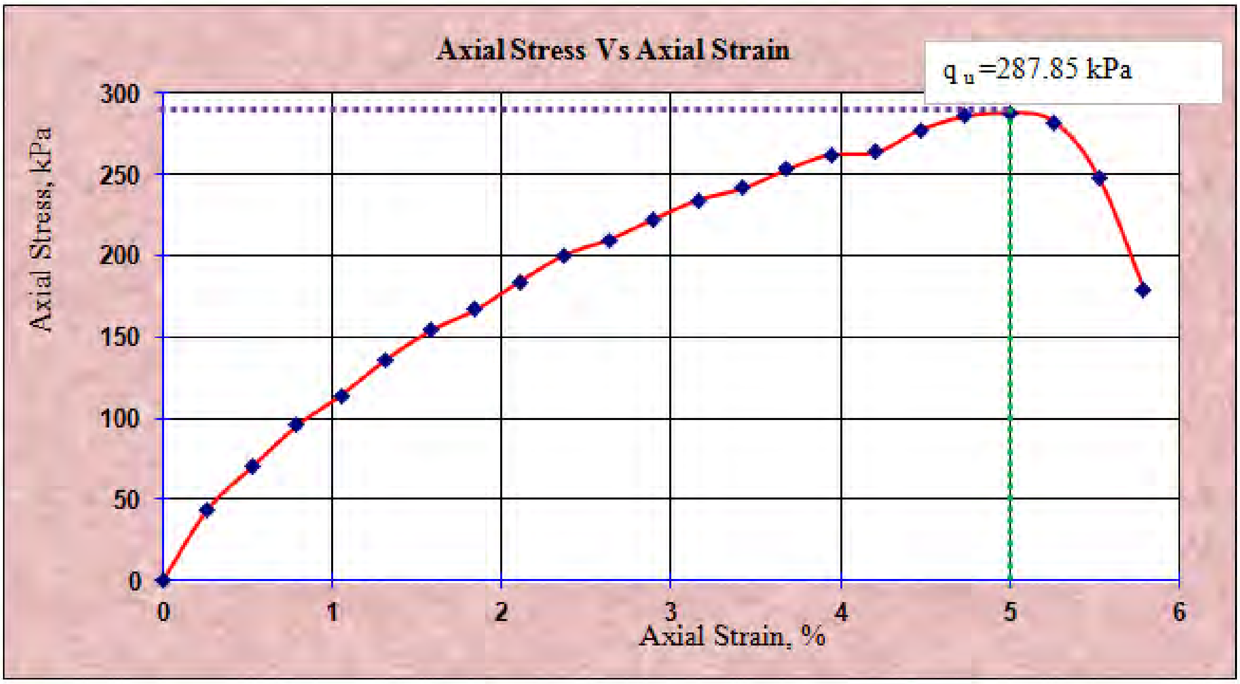


I7: Unconfined compression test result of TP4 at D=3.0m

Test Pit No	4	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	3.0	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m^3	17.24
Diameter of sample , mm	38	Moisture Content	37.70%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m^2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	35	0.0497	0.001137	43.71
0.40	0.53	56	0.0795	0.001140	69.75
0.60	0.79	77	0.1093	0.001143	95.65
0.80	1.05	92	0.1306	0.001146	113.98
1.00	1.32	110	0.1562	0.001149	135.92
1.20	1.58	125	0.1775	0.001152	154.04
1.40	1.84	136	0.1931	0.001155	167.15
1.60	2.11	150	0.2130	0.001159	183.86
1.80	2.37	164	0.2329	0.001162	200.48
2.00	2.63	172	0.2442	0.001165	209.69
2.20	2.89	183	0.2599	0.001168	222.50
2.40	3.16	193	0.2741	0.001171	234.02
2.60	3.42	200	0.2840	0.001174	241.85
2.80	3.68	210	0.2982	0.001177	253.25
3.00	3.95	218	0.3096	0.001181	262.18
3.20	4.21	220	0.3124	0.001184	263.86
3.40	4.47	232	0.3294	0.001187	277.49
3.60	4.74	240	0.3408	0.001191	286.26
3.80	5.00	242	0.3436	0.001194	287.85
4.00	5.26	238	0.3380	0.001197	282.31
4.20	5.53	210	0.2982	0.001200	248.41
4.40	5.79	152	0.2158	0.001204	179.30

I8: Unconfined compression test result curve of TP4 at D=3.0m

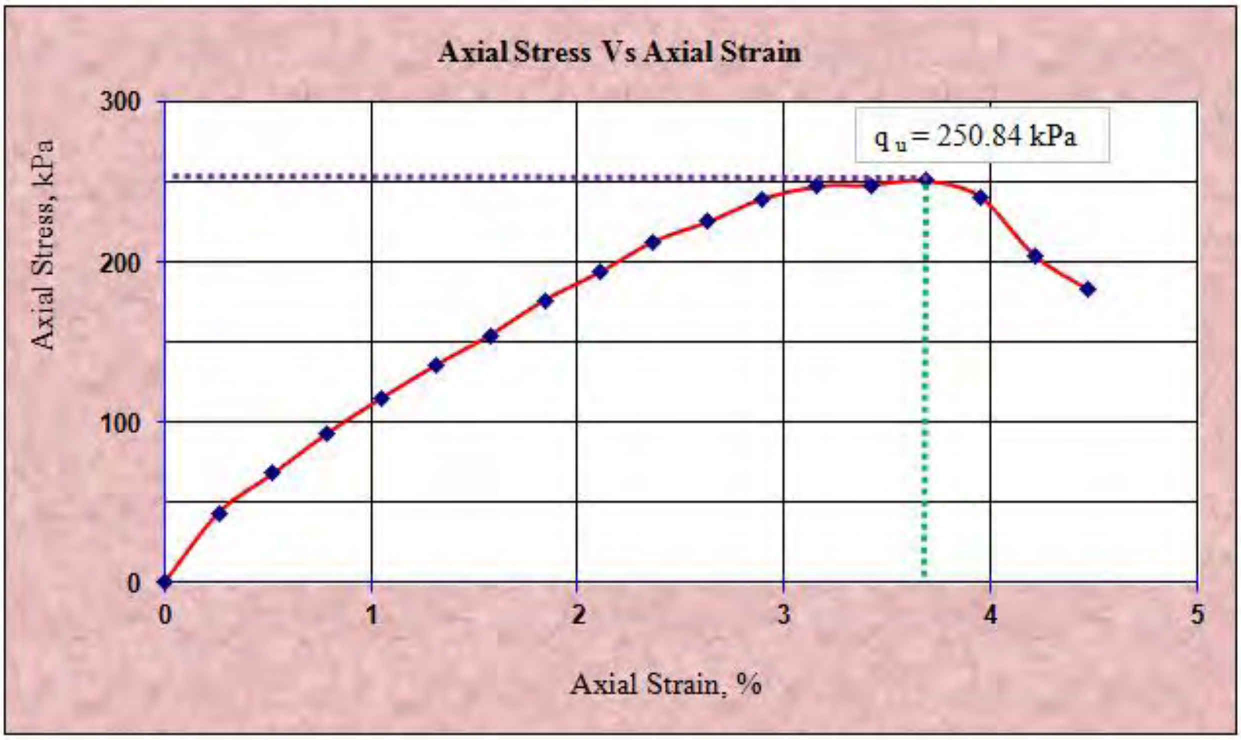


I9: Unconfined compression test result of TP5 at D=1.50m

Test Pit No	5	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	1.50	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m^3	16.32
Diameter of sample , mm	38	Moisture Content	33.61%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m^2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	35	0.0497	0.001137	43.71
0.40	0.53	55	0.0781	0.001140	68.50
0.60	0.79	75	0.1065	0.001143	93.16
0.80	1.05	93	0.1321	0.001146	115.22
1.00	1.32	110	0.1562	0.001149	135.92
1.20	1.58	125	0.1775	0.001152	154.04
1.40	1.84	143	0.2031	0.001155	175.75
1.60	2.11	158	0.2244	0.001159	193.66
1.80	2.37	174	0.2471	0.001162	212.70
2.00	2.63	185	0.2627	0.001165	225.54
2.20	2.89	197	0.2797	0.001168	239.52
2.40	3.16	204	0.2897	0.001171	247.36
2.60	3.42	205	0.2911	0.001174	247.89
2.80	3.68	208	0.2954	0.001177	250.84
3.00	3.95	200	0.2840	0.001181	240.53
3.20	4.21	170	0.2414	0.001184	203.89
3.40	4.47	153	0.2173	0.001187	183.00

I10: Unconfined compression test result curve of TP5 at D=1.50m

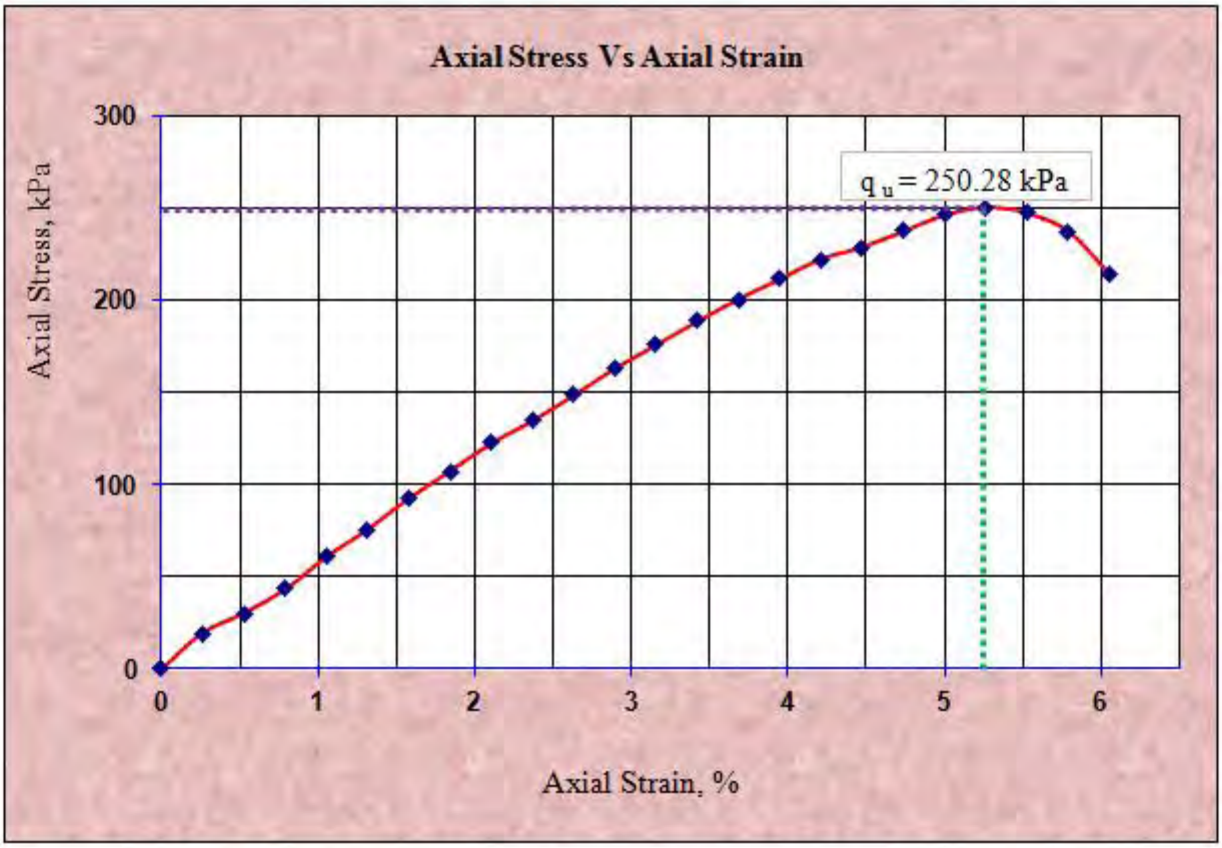


I11: Unconfined compression test result of TP5 at D=3.0m

Test Pit No	5	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	3.0m	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m3	18.15
Diameter of sample , mm	38	Moisture Content	37.21%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

xial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m^2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	15	0.0213	0.001137	18.73
0.40	0.53	24	0.0341	0.001140	29.89
0.60	0.79	35	0.0497	0.001143	43.48
0.80	1.05	49	0.0696	0.001146	60.71
1.00	1.32	61	0.0866	0.001149	75.37
1.20	1.58	75	0.1065	0.001152	92.42
1.40	1.84	87	0.1235	0.001155	106.92
1.60	2.11	100	0.1420	0.001159	122.57
1.80	2.37	110	0.1562	0.001162	134.47
2.00	2.63	122	0.1732	0.001165	148.73
2.20	2.89	134	0.1903	0.001168	162.92
2.40	3.16	145	0.2059	0.001171	175.82
2.60	3.42	156	0.2215	0.001174	188.64
2.80	3.68	166	0.2357	0.001177	200.19
3.00	3.95	176	0.2499	0.001181	211.67
3.20	4.21	185	0.2627	0.001184	221.88
3.40	4.47	191	0.2712	0.001187	228.45
3.60	4.74	199	0.2826	0.001191	237.36
3.80	5.00	207	0.2939	0.001194	246.22
4.00	5.26	211	0.2996	0.001197	250.28
4.20	5.53	209	0.2968	0.001200	247.22
4.40	5.79	201	0.2854	0.001204	237.10
4.60	6.05	182	0.2584	0.001207	214.09

I12: Unconfined compression test result curve of TP5 at D=3.0m

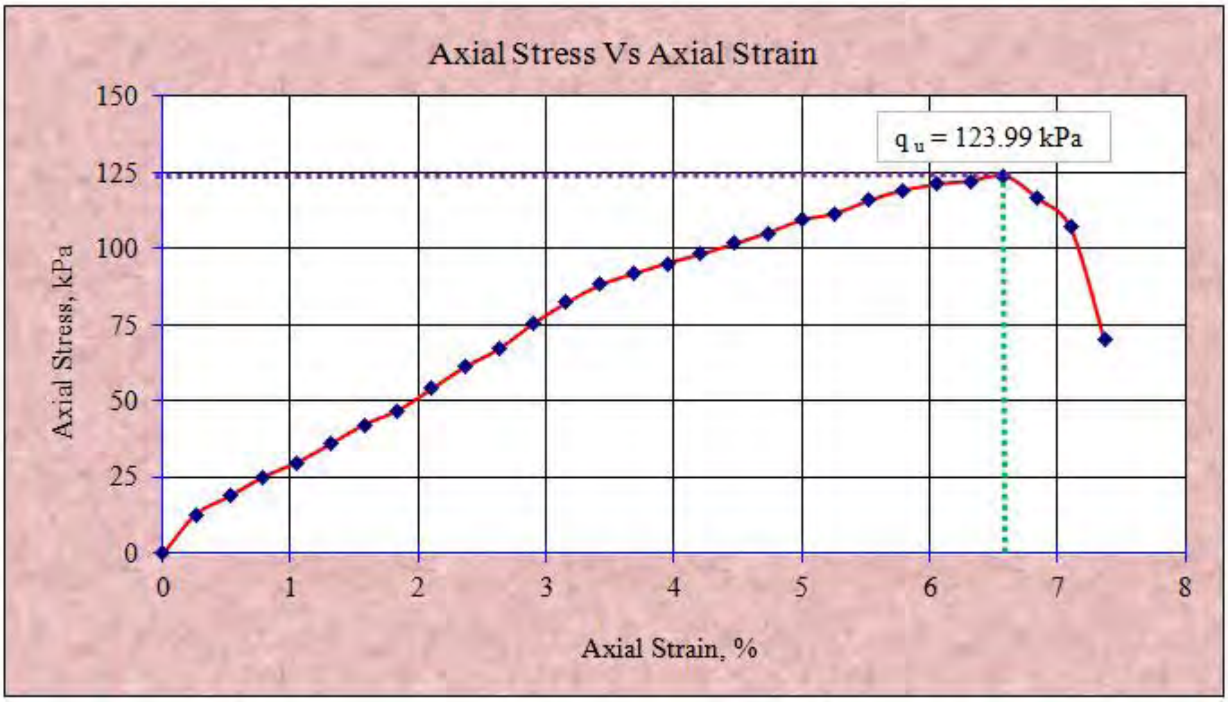


I13: Unconfined compression test result of TP7 at D=1.50m

Test Pit No	7	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	1.50	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m3	17.55
Diameter of sample , mm	38	Moisture Content	36.51%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	10	0.0142	0.001137	12.49
0.40	0.53	15	0.0213	0.001140	18.68
0.60	0.79	20	0.0284	0.001143	24.84
0.80	1.05	24	0.0341	0.001146	29.73
1.00	1.32	29	0.0412	0.001149	35.83
1.20	1.58	34	0.0483	0.001152	41.90
1.40	1.84	38	0.0540	0.001155	46.70
1.60	2.11	44	0.0625	0.001159	53.93
1.80	2.37	50	0.0710	0.001162	61.12
2.00	2.63	55	0.0781	0.001165	67.05
2.20	2.89	62	0.0880	0.001168	75.38
2.40	3.16	68	0.0966	0.001171	82.45
2.60	3.42	73	0.1037	0.001174	88.27
2.80	3.68	76	0.1079	0.001177	91.65
3.00	3.95	79	0.1122	0.001181	95.01
3.20	4.21	82	0.1164	0.001184	98.35
3.40	4.47	85	0.1207	0.001187	101.67
3.60	4.74	88	0.1250	0.001191	104.96
3.80	5.00	92	0.1306	0.001194	109.43
4.00	5.26	94	0.1335	0.001197	111.50
4.20	5.53	98	0.1392	0.001200	115.92
4.40	5.79	101	0.1434	0.001204	119.14
4.60	6.05	103	0.1463	0.001207	121.16
4.80	6.32	104	0.1477	0.001211	121.99
5.00	6.58	106	0.1505	0.001214	123.99
5.20	6.84	100	0.1420	0.001217	116.64
5.40	7.11	92	0.1306	0.001221	107.01
5.60	7.37	85	0.1207	0.001224	70.00

I14: Unconfined compression test result curve of TP7 at D=1.50m

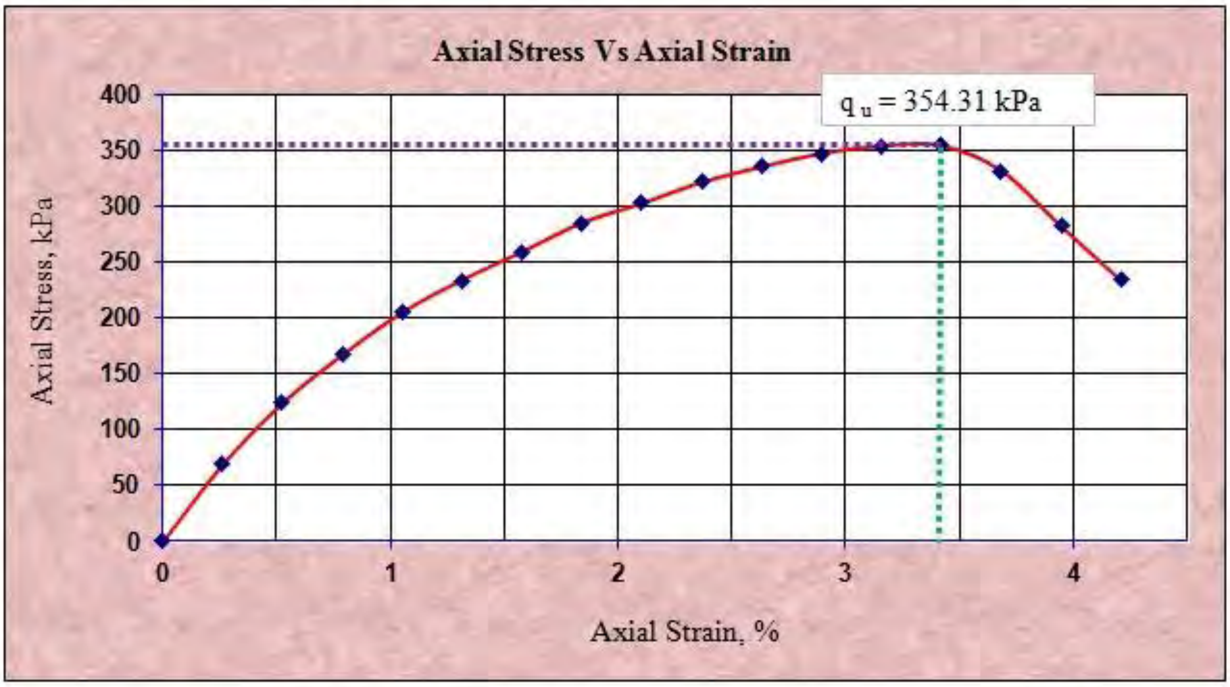


I15: Unconfined compression test result of TP10 at D=1.50m

Test Pit No	10	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	1.50	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m3	18.11
Diameter of sample , mm	38	Moisture Content	32.82%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	55	0.0781	0.001137	68.68
0.40	0.53	99	0.1406	0.001140	123.30
0.60	0.79	134	0.1903	0.001143	166.45
0.80	1.05	165	0.2343	0.001146	204.42
1.00	1.32	189	0.2684	0.001149	233.53
1.20	1.58	210	0.2982	0.001152	258.78
1.40	1.84	232	0.3294	0.001155	285.13
1.60	2.11	247	0.3507	0.001159	302.75
1.80	2.37	263	0.3735	0.001162	321.50
2.00	2.63	275	0.3905	0.001165	335.26
2.20	2.89	285	0.4047	0.001168	346.51
2.40	3.16	292	0.4146	0.001171	354.06
2.60	3.42	293	0.4161	0.001174	354.31
2.80	3.68	275	0.3905	0.001177	331.64
3.00	3.95	235	0.3337	0.001181	282.62
3.20	4.21	195	0.2769	0.001184	233.87

I16: Unconfined compression test result curve of TP10 at D=1.50m

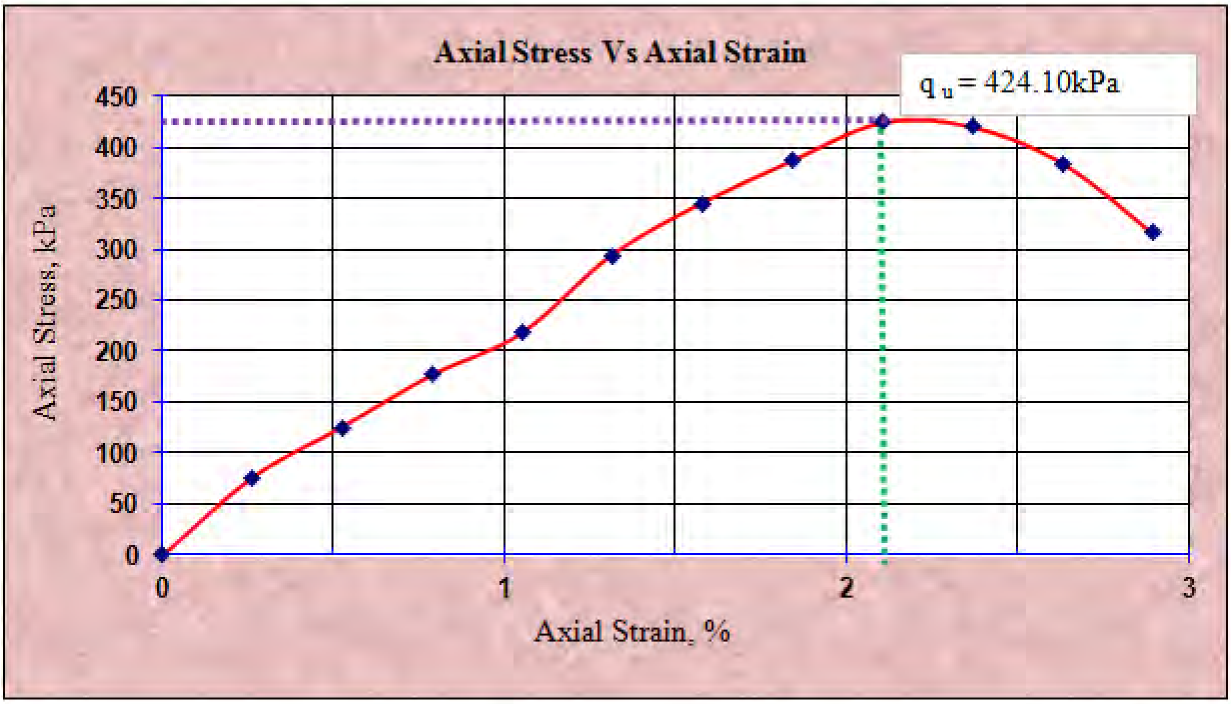


I17: Unconfined compression test result of TP10 at D=3.0m

Test Pit No	10	Cross- Sectional Area , m^2	0.001134
Test Pit Depth , m	3.0	Ring Calibration Factor, kN/div	0.00142
Sampling	Undisturbed	Wet unit Weight, kN/m3	17.94
Diameter of sample , mm	38	Moisture Content	31.51%
Length of sample , mm	76	Rate of Strain, mm/min	1.70

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m2]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001134	0
0.20	0.26	60	0.0852	0.001137	74.93
0.40	0.53	100	0.1420	0.001140	124.55
0.60	0.79	142	0.2016	0.001143	176.39
0.80	1.05	176	0.2499	0.001146	218.05
1.00	1.32	238	0.3380	0.001149	294.07
1.20	1.58	280	0.3976	0.001152	345.05
1.40	1.84	315	0.4473	0.001155	387.14
1.60	2.11	346	0.4913	0.001159	424.10
1.80	2.37	344	0.4885	0.001162	420.51
2.00	2.63	315	0.4473	0.001165	384.03
2.20	2.89	260	0.3692	0.001168	316.12

I18: Unconfined compression test result curve of TP10 at D=3.0m

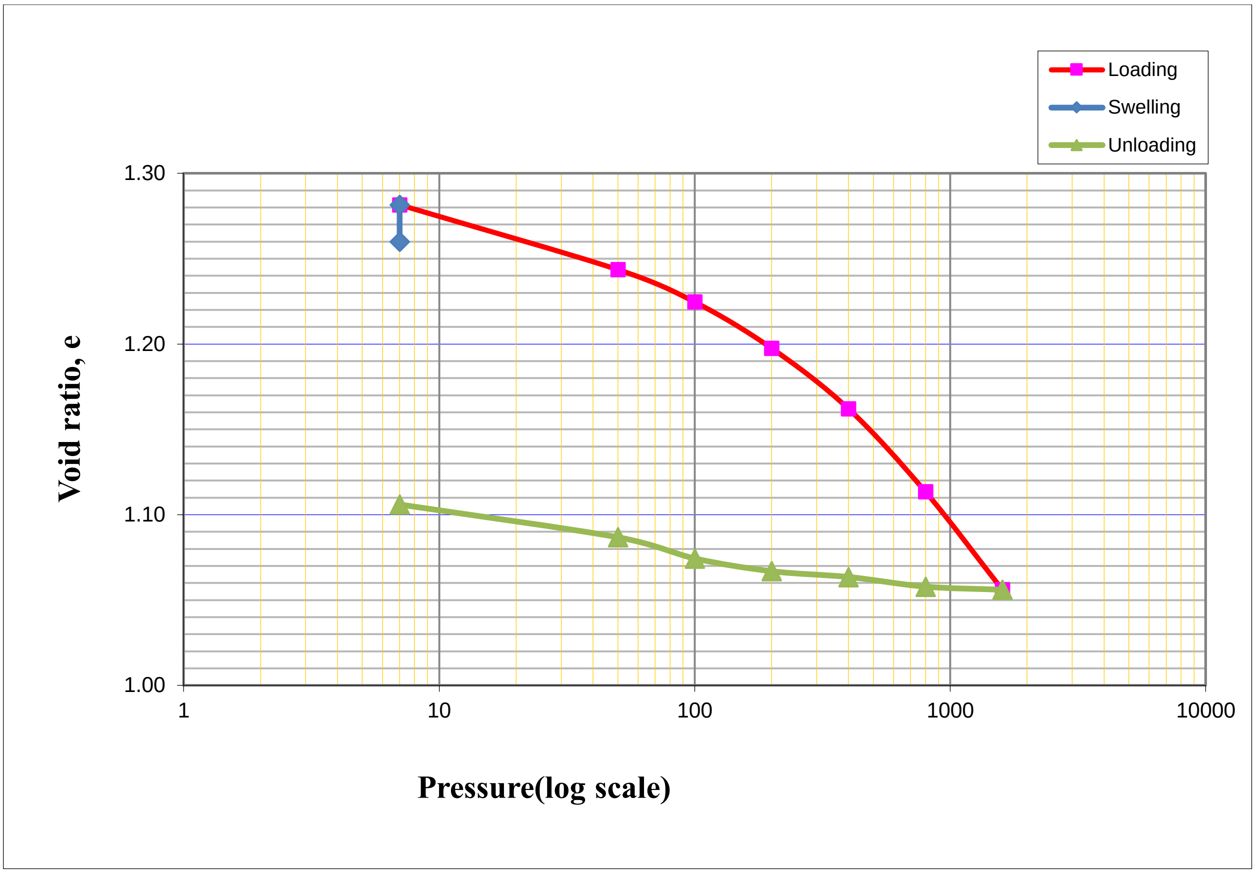


Appendix J: Consolidation and swell consolidation test results

J1: Consolidation test result of Technic & Vocational School(TP-2)

Sample type:	Un isturbed	Initial void ratio:	1.26
Sample height:	2cm	Wet density ,g/cm^3	1.676
Sample area	19.635cm^2	Seating Load:	7Kpa
Initial moisture content:	28.91%		

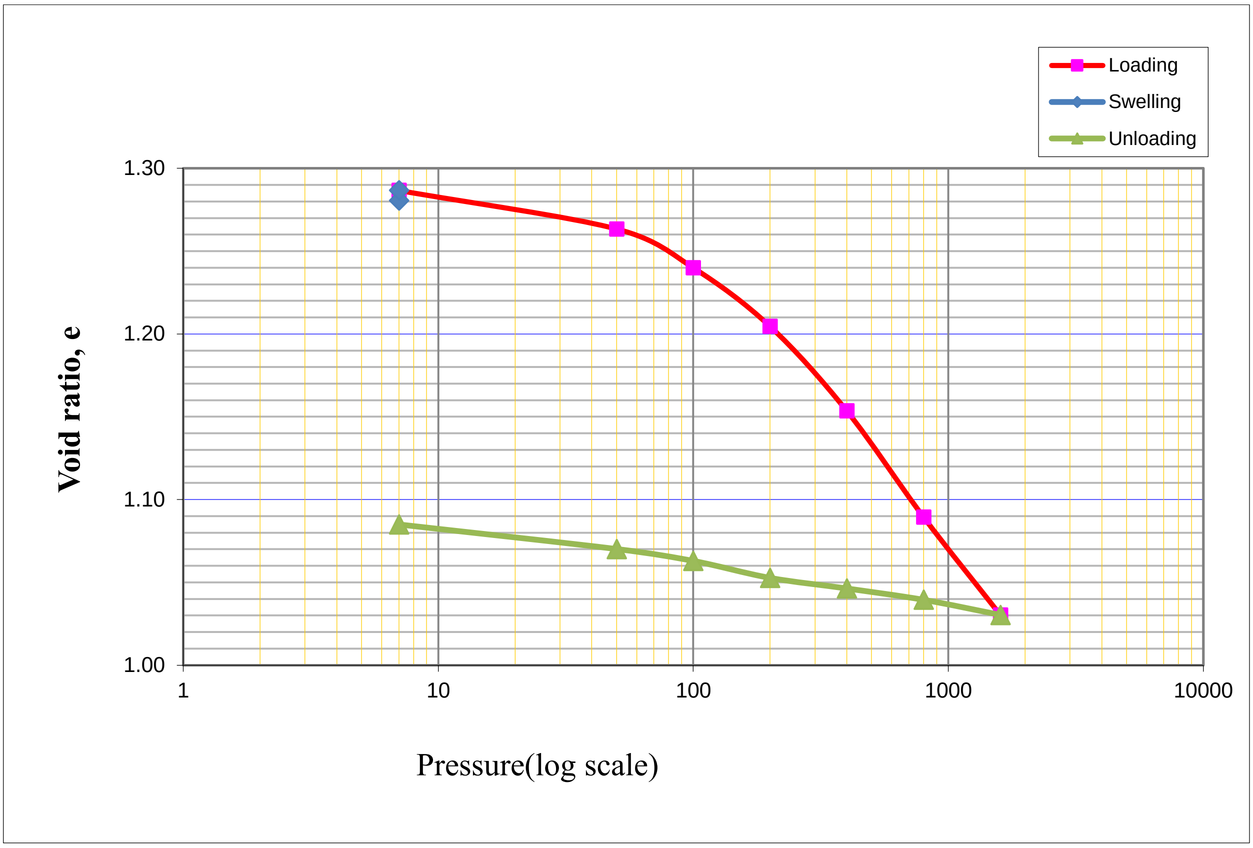
Applied pressure P (kPa)	Final dial reading (mm)	Change in specimen height (mm)	Final specimen height (mm)	Void height (mm)	Void ratio
Loading					
7	2.000	0.00	20.00	11.15	1.260
7	2.192	0.19	20.19	11.34	1.282
50	1.856	-0.14	19.86	11.01	1.244
100	1.688	-0.31	19.69	10.84	1.225
200	1.448	-0.55	19.45	10.60	1.198
400	1.134	-0.87	19.13	10.28	1.162
800	0.704	-1.30	18.70	9.85	1.113
1600	0.196	-1.80	18.20	9.35	1.056
Unloading					
1600	0.196	-1.80	18.20	9.35	1.056
800	0.212	-1.79	18.21	9.36	1.058
400	0.262	-1.74	18.26	9.41	1.064
200	0.292	-1.71	18.29	9.44	1.067
100	0.358	-1.64	18.36	9.51	1.074
50	0.468	-1.53	18.47	9.62	1.087
7	0.638	-1.36	18.64	9.79	1.106


Loading
Swelling
Unloading
Void ratio, e
1.30
1.20
1.10
1.00
1
10
100
1000
10000
Pressure(log scale)

J2: Consolidation test result of saint Michael(TP-4)

Sample type: Un isturbed
Initial void ratio: 1.28
Sample height: 2cm
Wet density ,g/cm^3 1.72
Sample area 19.635cm^2
Seating Load: 7Kpa
Initial moisture content: 38.00%

Applied pressure P (kPa)	Final dial reading (mm)	Change in specimen height (mm)	Final specimen height (mm)	Void height (mm)	Void ratio
Loading					
7	2.200	0.00	20.00	11.23	1.281
7	2.254	0.05	20.05	11.28	1.287
50	2.050	-0.15	19.85	11.08	1.263
100	1.844	-0.36	19.64	10.87	1.240
200	1.534	-0.67	19.33	10.56	1.205
400	1.086	-1.11	18.89	10.12	1.153
800	0.524	-1.68	18.32	9.55	1.089
1600	0.006	-2.19	17.81	9.04	1.030
Unloading					
1600	0.006	-2.19	17.81	9.04	1.030
800	0.086	-2.11	17.89	9.12	1.039
400	0.146	-2.05	17.95	9.18	1.046
200	0.202	-2.00	18.00	9.23	1.053
100	0.292	-1.91	18.09	9.32	1.063
50	0.355	-1.85	18.16	9.39	1.070
7	0.485	-1.72	18.29	9.52	1.085

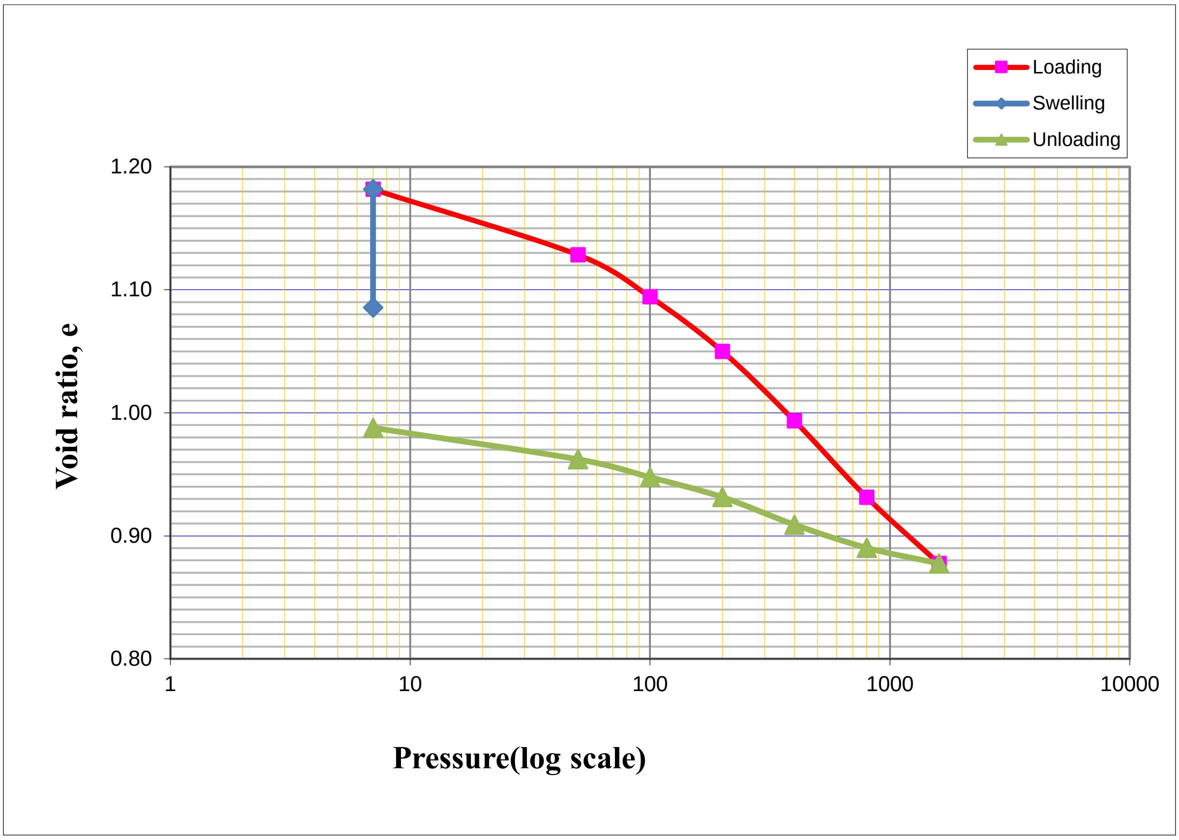


Loading
Swelling
Unloading
Void ratio, e
1.30
1.20
1.10
1.00
1
10
100
1000
10000
Pressure(log scale)

J3: Consolidation test result of sisomesk (TP-10)

Sample type:	Un isturbed	Initial void ratio:	1.09
Sample height:	2cm	Wet density ,g/cm^3	1.79
Sample area	19.635cm^2	Seating Load:	7Kpa
Initial moisture content:	31.23%		

Applied pressure P (kPa)	Final dial reading (mm)	Change in specimen height (mm)	Final specimen height (mm)	Void height (mm)	Void ratio
Loading					
7	2.000	0.00	20.00	10.41	1.086
7	2.922	0.92	20.92	11.33	1.182
50	2.412	0.41	20.41	10.82	1.128
100	2.084	0.08	20.08	10.49	1.094
200	1.660	-0.34	19.66	10.07	1.050
400	1.118	-0.88	19.12	9.53	0.994
800	0.522	-1.48	18.52	8.93	0.931
1600	0.006	-1.99	18.01	8.42	0.878
Unloading					
1600	0.006	-1.99	18.01	8.42	0.878
800	0.128	-1.87	18.13	8.54	0.890
400	0.308	-1.69	18.31	8.72	0.909
200	0.523	-1.48	18.52	8.93	0.931
100	0.678	-1.32	18.68	9.09	0.948
50	0.818	-1.18	18.82	9.23	0.962
7	1.063	-0.94	19.06	9.47	0.988


Loading
Swelling
Unloading
1.20
1.10
1.00
0.90
0.80
Void ratio, e
1
10
100
1000
10000
Pressure(log scale)

DECLARATION

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

Name:	Tenaw Workie
Signature:	_____________
Place:	Addis Ababa Institute of Technology,
	Addis Ababa University,
	Addis Ababa.
Date of submission:	September, 2015