2021-10

INVESTIGATION ON SOME OF THE ENGINEERING PROPERTIES OF SOILS FOUND IN TIS ABAY TOWN

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MSc. Thesis on

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BY
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October, 2021
Bahir Dar, Ethiopia

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A Thesis Submitted to the School of Research and Graduate Studies of Bahir Dar Institute of Technology, BDU in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geotechnical Engineering

Advisor: Addiszemen Teklay (Ph.D.)

October, 2021

Bahir Dar, Ethiopia

DECLARATION

This is certify that the thesis entitled "Investigation on some of the engineering properties of soils found in Tis Abay town", submitted in partial fulfillments of the requirements for the degree of Master of Science in geotechnical engineering under faculty of civil and water resources engineering Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

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THESIS APPROVAL SHEET

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of student: Girma Molla Zegeye Signature ____ Date Sep. 18, 2021

As a member of the board of the examiners, we examined this entitled "Investigation on some of the engineering properties of soils found in Tis Abay town" by Girma Molla Zegeye. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of science in "geotechnical engineering".

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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my adviser, Dr. Addiszemen Teklay for his constructive criticism, advice and for assisting and guiding me to carry out the research work efficiently and effectively.

I wish to express my genuine appreciation to the geotechnical laboratory staffs of BIT for their support and advice during the laboratory work.

I am very grateful to Tis Abay Town administration, Bahir Dar Town administration Office and Ethiopian Metrology Agency of Bahir Dar branch that supported me by providing the necessary materials and information.

At last I want to thanks my family members in the deepest of my heart for the painstaking academic achievement in my life.

Above all I am very thankful to almighty God who is always with me in each and every step of my life. I thank God for everything. He did and made education compatible with the rest of my life.

Girma Molla Zegeye

Bahir Dar, Ethiopia; October 2021

ABSTRACT

Soil is the ultimate foundation material which supports the structure. The proper functioning of the structure, depend on the engineering properties of the underlying soil. Investigating the engineering properties of soils in Tis Abay town is the objective of this study; Since there is no systematic soil investigation works has been carried out prior to this study, so far the town needs investigation of the ground condition. Ten representative test pit points were selected and from each test pit disturbed and undisturbed samples at 1.5 m and 3.0 m were collected and brought to soil laboratory of Bahir Dar Institute of Technology and Amhara Rural Road Construction Agency for conducting different tests. Laboratory tests carried out on disturbed and undisturbed samples revealed that the natural moisture content ranges from 21 - 41 %, specific gravity of the soils ranges from 2.55 - 2.76, Atterberg limits of soils of the study area has liquid limits ranging from 60 - 98 %, plastic limit ranges from 20 - 41 % and plasticity index ranges from 28 - 78 %. The results of grain size analysis showed that soils of Tis Abay town have clay content ranging from 45 - 76 %, silt content from 20 - 60 %, sand from 1 - 5 % and gravel from 0 - 11 %. Free swell test conducted on the samples collected shows range from 43 – 164 %. Soils of the study area are classified according to AASHTO and USCS. AASHTO classification shows that soils of the study area are A-7-5 and A-7-6, which means clay soil with poor quality as a subgrade material. USCS indicates two main types of soils, which are: CH, high plastic clay soils and MH, high plastic silt soils. The results of unconfined compressive strength test of the study area range from 62 - 135 kN/m^2. Finally, one-dimensional consolidation tests were done and have Pre-consolidation Pressure, P_c range from 122 - 238 kN/m^2, Over-burden Pressure, P_o range from 52 - 56 kN/m^2, compression index, C_c range from 0.258 - 0.427 and recompression index, C_r range from 0.030 - 0.096, Over Consolidation Ratio, OCR range from 2.20 - 4.53.

Keywords: Colloidal activity, clay size fraction, plasticity, gradation, consistency, cohesion.

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LIST OF ABBREVATIONS

Designation	Description
A	Corrected Area
A_o	Initial Area
AASHTO	American Association of State Highway and Transportation Officials
A_c	Activity Number
ASTM	American Society for Testing and Materials
BIT	Bahir Dar Institute of Technology
c	Cohesion
C_c	Compression Index
CH	Inorganic Clay With High Plasticity
cm	Centimeter
C_r	Recompression Index
d	Diameter
E	Easting
E_s	Modulus of Compressibility
e	Strain/ Void Ratio
e_o	Initial Void Ratio
e_f	Final Void Ratio
Fig	Figure
GPS	Global Positioning System
G_s	Specific Gravity
g	Gram
H_i	Internal Height
hr	Hour

in.	Inch
kg	Kilo Gram
Km	Kilo Meter
kN	Kilo Newton
kPa	Kilo Pascal
LL	Liquid Limit
Log	Logarithm
M	Mass
m	Meter
MH	Inorganic Silt With High Plasticity
min	Minute
ml	Milliliter
mm	Millimeter
N	Northing
NaCl	Sodium Chloride
NMC	Natural Moisture Content
No.	Number
OCR	Over-Consolidation Ratio
ODC	One-Dimensional Consolidation
P	Pressure
P_c	Pre-Consolidation Pressure
PL	Plastic Limit
PI	Plasticity Index
q_u	Unconfined Compressive Strength
R_c	Corrected Reading
s	Relative Settlement
TP	Test Pit
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
UTM	Universal Transverse Mercator
V_s	Versus

LIST OF SYMBOLS

%	Percent
^{o}c	Degree Centigrade
Δ	Change
Σ	Summation
Ø	Angle of Internal Friction
σ	Stress
@	At

CHAPTER ONE

1. INTRODUCTION

1.1. Background

The stability of the foundation of a building, a bridge, an embankment or any other structure built on soil depends on the strength and compressibility characteristics of the subsoil. The field and laboratory investigation to obtain the essential information on the subsoil is called soil exploration or soil investigation. The successes or failure of a foundation depends essentially on the reliability of the various soil parameters obtained from the field investigation and laboratory testing, and used as an input in to the design of a foundation.

Investigations of the underground conditions at a site are prerequisite to the economical design of the substructure elements. It is also necessary to obtain sufficient information for feasibility and economic studies for a proposed project. An exploration program may be initiated on an existing structure where additions are contemplated. The current safety of an existing structure may require investigation if excessive settlements or cracks have occurred. The required remedial measures may be undertaken based on new-found information or on the damage evidence and a reinterpretation of the original data (Bowles, 1996).

1.2. Statement of the Problem

In Tis Abay town, traditional wood houses, small villa buildings (for the purpose of power house, health center and residential) are constructed and being under construction without adequate and detailed geotechnical investigation, but big structures (except the existed hydropower dam) are not constructed till now because of economic aspects, due those reasons the investigation of engineering properties of the soil are not studied well yet.

But now a day, the town includes in the metropolitans city of Bahir Dar which is the capital city of Amhara region; so the development has promising future and has a potential for expansion in all direction. Therefore, this study is intended to study engineering properties of soils of Tis Abay town by conducting index tests, shear strength test, consolidation test and it is very important for construction works as well as for further studies in the future as an input.

1.3. Objectives of the Study

1.3.1. General Objective

The primary objective of this study is investigating some of the engineering properties of soils found in Tis Abay Town.

1.3.2. Specific Objectives

This study has the following specific objectives:

A. To determine the range of the value of the index properties of soils found in Tis Abay Town.

B. To classify the soils found in Tis Abay Town based on the index properties using different classification system.

C. To determine the range of the value of the shear strength of soils found in Tis Abay Town.

D. To determine the range of the value of the consistency index at natural moisture content of soils found in Tis Abay Town.

E. To determine the consolidation characteristics of the soils found in Tis Abay Town.

1.4. Scope of the Study

In different researches, the investigation of the engineering properties of soils are done for different areas; but in this investigation some engineering properties of soils found in Tis Abay Town has been done, disturbed and undisturbed soil samples has been collected to determine index properties, shear strength determinations, consolidation parameter determinations of soils. The depth of ground investigation is limited to three meters and ten test pits were excavated since it is difficult to excavate and sampling manually beyond this depth.

1.5. Significance of the Study

Many longstanding Ethiopian structures have not soil investigation documents, simply constructed without any study of sub-grade soils, due to the lack of the expertise, advanced equipment's and carelessness.

In the construction industry of the country, earth works, sub and super structures, finishing and furnishing and others takes lot of money of the project budget. Investigation of the ground does not consider or takes small budget in many Ethiopian constructions even in mega projects. This may causes for either underestimate or overestimate the soil strength, while both cases may have negative impacts on the economy of the country in general and on the construction industry in particular.

Although the recent structures use the investigation data for their design and keep it as a documents but it is not satisfactory. So far the investigation of soils has great impact for those structures constructed without any information about the characteristics of the sub grade soils of developing country like Ethiopia.

Thus, the investigation of the characteristics of the sub grade soils of Tis Abay town is applicable to meet the objectives as mentioned above.

1.6. Description of the Study Area

1.6.1. General

Tis Abay Town is located in Amhra Region 32 km in the south east of Bahir Dar, it has been drawing the attention of tourists from different corners of the world because the town has the Blue Nile Falls (a waterfall on the Blue Nile river in Ethiopia Blue Nile, the Grand River in Africa is one of the natural wonders of Tis Abay, Ethiopia especially for its breathtaking fall. The Blue Nile Falls locally known as “Tis Abay Falls” or “smoke of fire” that the water stretched on 400 m wide surface and plunging dramatically 45 m deep creates drizzly plethora that in turn produces brilliant rainbows across the gorges of the river. The foggy downpours drive the onlookers up to a kilometer away. The curtains of the spray enthrall any visitor and will not ever vanish from memory. That is why thousands of visitors are seen streaming to this most spectacular scene.

Tis Abay Town people serving visitors with great hospitality, However in the town there is no enagh infrastractures for the guests and people of the Town for a long time. But now aday, the town includes in the metropolitans city of Bahir Dar which is the capital city of Amhara region; so the development has promising future and has a potential for expansion in all direction. However there is no systematic soil investigation workes has been carried out prior to this study, so far the Town needs investigation of the ground condition. Location of the study area has shown on Figure 1.1.

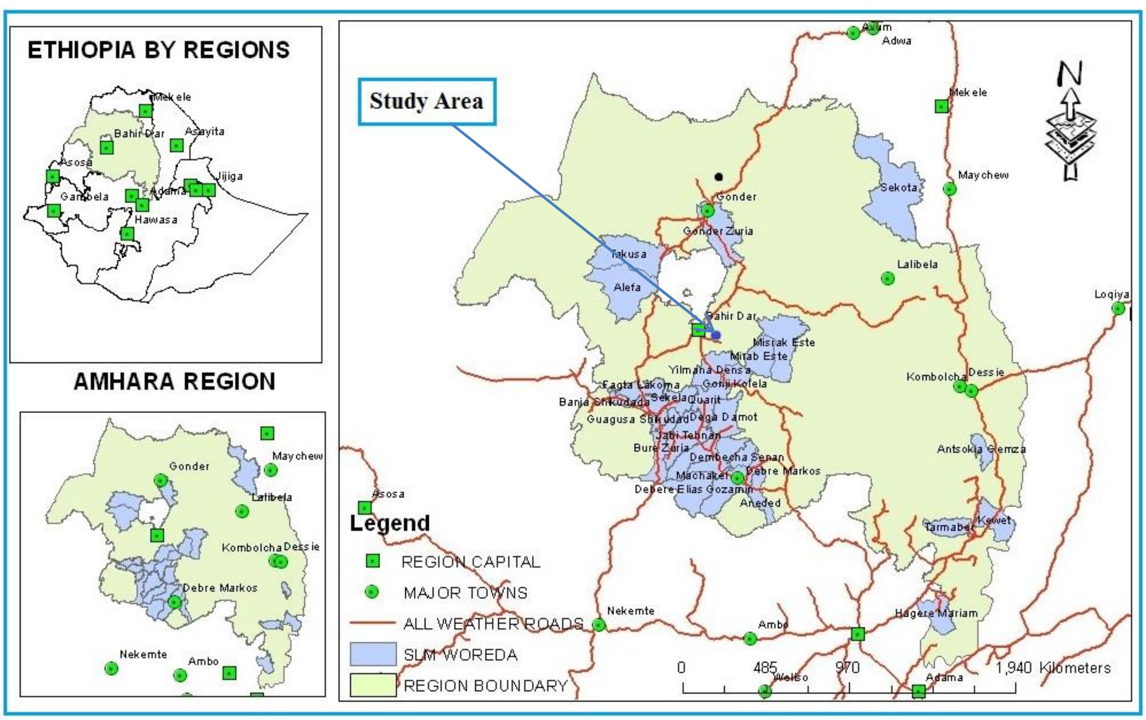

Figure 1.1. Location of the study area on the map of Ethiopia

1.6.2. Climate

1.6.2.1. Rainfall

Records of National Metrology Agency West Amhara Metrological Service Center from Tis Abay observatory substation show that the mean annual rain fall of 30 years (1990-2019) is 1237.1 mm (National Metrology Agency, 2021). There is a considerable seasonal variation of this rainfall depth in which the highest is recorded in the summer season (kiremt i.e. June, July and August) time and the lowest is recorded in the winter season (Bega i.e. December, January and February) as shown in Table 1.1 and one can also observe from Figure 1.2.

Table 1.1. Mean monthly rainfall of Tis Abay and surrounding area in mm (1990 -2019) (National Metrology Agency, 2021).

Town	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T. Abay	0.5	2.5	8.7	14.4	81.8	171.7	328.1	381.2	207.1	91.4	23.6	6.2
B.Dar	1.5	5.5	12.1	29.7	80.6	190.2	421.4	378.9	198.8	91.9	18.4	5.9
Adet	3.5	5.3	25.6	50.2	106.9	158.1	315.9	257.8	164.9	104.5	32.5	9.7
Merawi	3.7	7.3	18.1	42.8	156.1	330.4	381.8	386.9	225.6	83.5	25.7	4.7

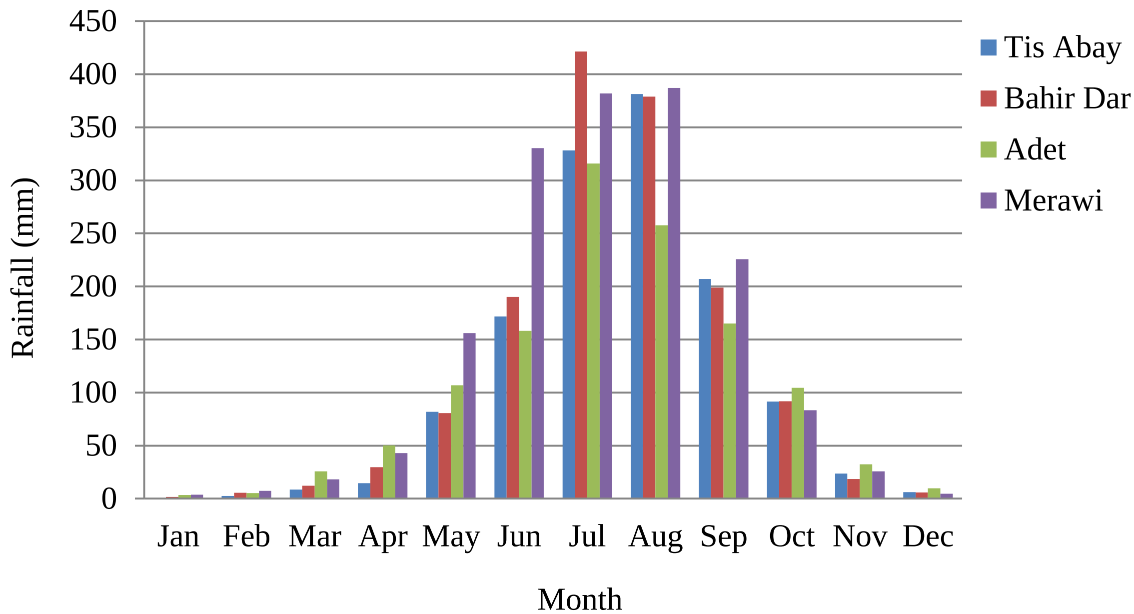

Figure 1.2. Mean monthly rainfall of Tis Abay and surrounding area in mm (1990 -2019) (National Metrology Agency, 2021).

1.2.2.2. Temperature

As data on the climatic condition of Tis Abay town the temperature data of the town is not readily available, an attempt has been made to adapt the temperature condition of the mean minimum, mean maximum and mean average monthly temperature of Bahir Dar, Adet and Merawi where the nearest metrological station of the town is tabulated for 30 years (1990-2019) as show in Table 1.2. Mean minimum and maximum monthly temperature of Bahir Dar, Adet and Merawi town shown below Figure 1.3, Figure 1.4 and figure 1.5 respectively. Mean average monthly temperature of Bahir Dar, Adet and Merawi town shown below Figure 1.6.

Table 1.2. Mean min, mean max and mean average monthly temp of the surrounding area of study area in ^{o}C (1990 -2019) (National Metrology Agency, 2021).

Mean minimum monthly temperature												
Town	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B. Dar	8.5	10.5	12.9	14.8	15.6	14.5	14.3	14.2	13.7	13.8	11.6	9.1
Adet	6.1	8.1	10.0	11.5	12.7	12.1	12.2	11.8	10.9	10.1	8.3	7.1
Merawi	7.3	8.4	10.9	12.0	13.3	12.9	12.4	12.5	11.7	11.1	9.1	7.3
Mean maximum monthly temperature												
Town	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B. Dar	27.1	28.7	29.9	30.2	29.4	27.4	24.4	24.6	25.7	26.7	26.8	26.8
Adet	26.7	28.6	29.5	29.4	28.3	25.9	23.1	22.9	24.3	24.9	25.8	26.3
Merawi	28.4	30.9	30.9	30.9	29.1	26.5	24.7	24.5	26.1	27.5	27.9	27.5
Mean average monthly temperature												
Town	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B. Dar	17.8	19.6	21.4	22.5	22.5	21.0	19.4	19.4	19.7	20.2	19.2	17.9
Adet	16.4	18.4	19.8	20.5	20.5	19.0	17.6	17.3	17.6	17.5	17.1	16.7
Merawi	17.8	19.6	20.9	21.5	21.2	19.7	18.5	18.5	18.9	19.3	18.5	17.4

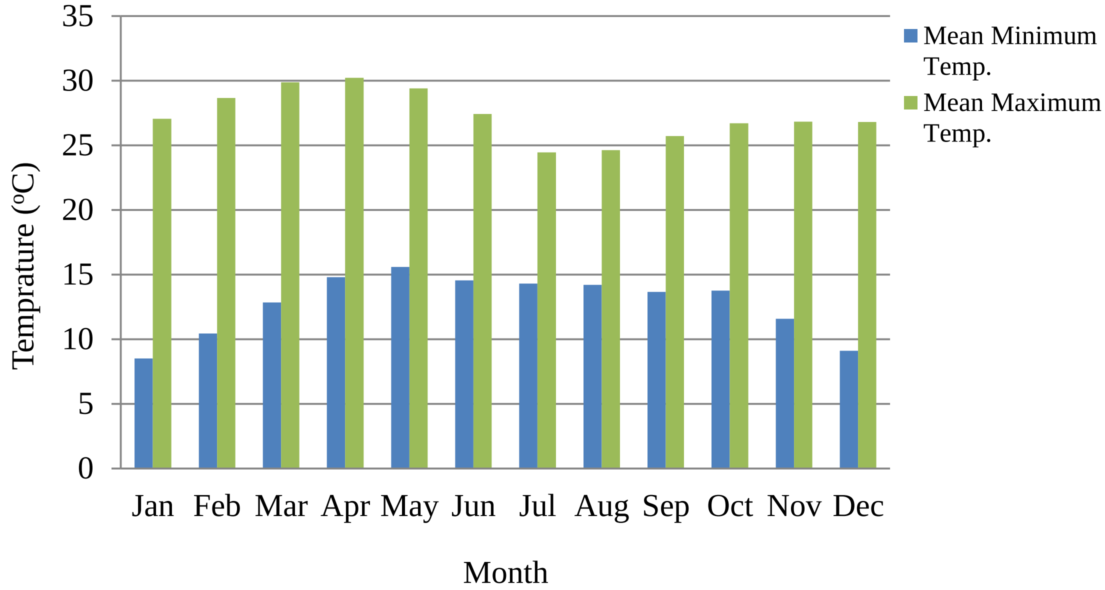

Figure 1.3. Mean minimum and maximum monthly temperature of Bahir Dar (The surrounding area of the study area) in °C (1990 -2019) (National Metrology Agency, 2021).

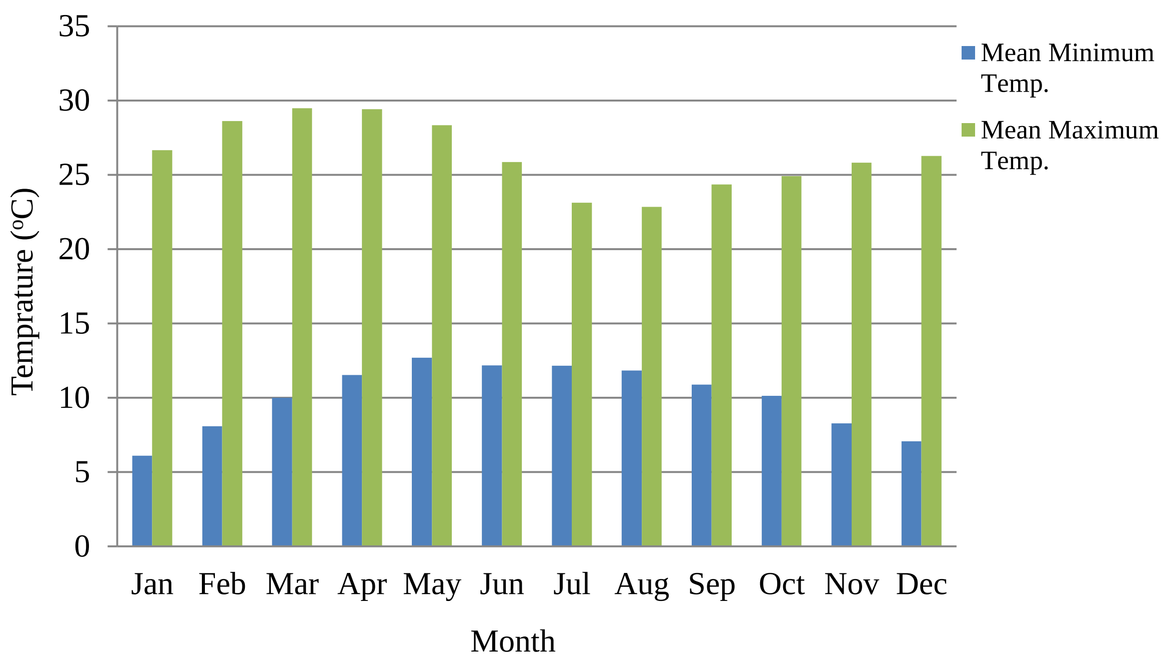

Figure 1.4. Mean minimum and maximum monthly temperature of Adet (the surrounding area of the study area) in °C (1990 -2019) (National Metrology Agency, 2021).

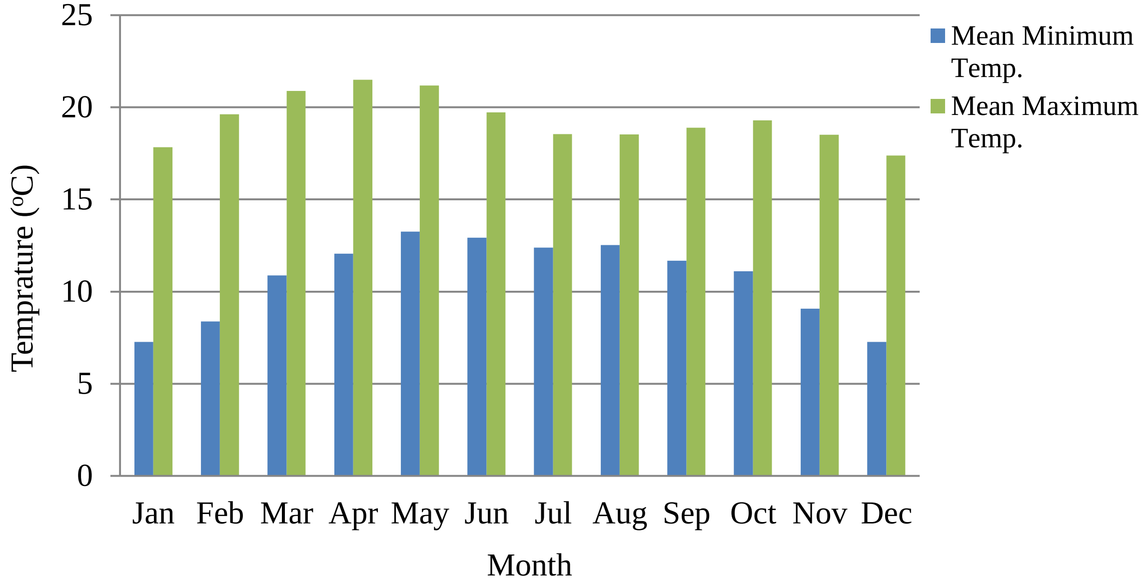

Figure 1.5. Mean minimum and maximum monthly temperature of Merawi (the surrounding area of the study area) in ^{o}C (1990 -2019) (National Metrology Agency, 2021).

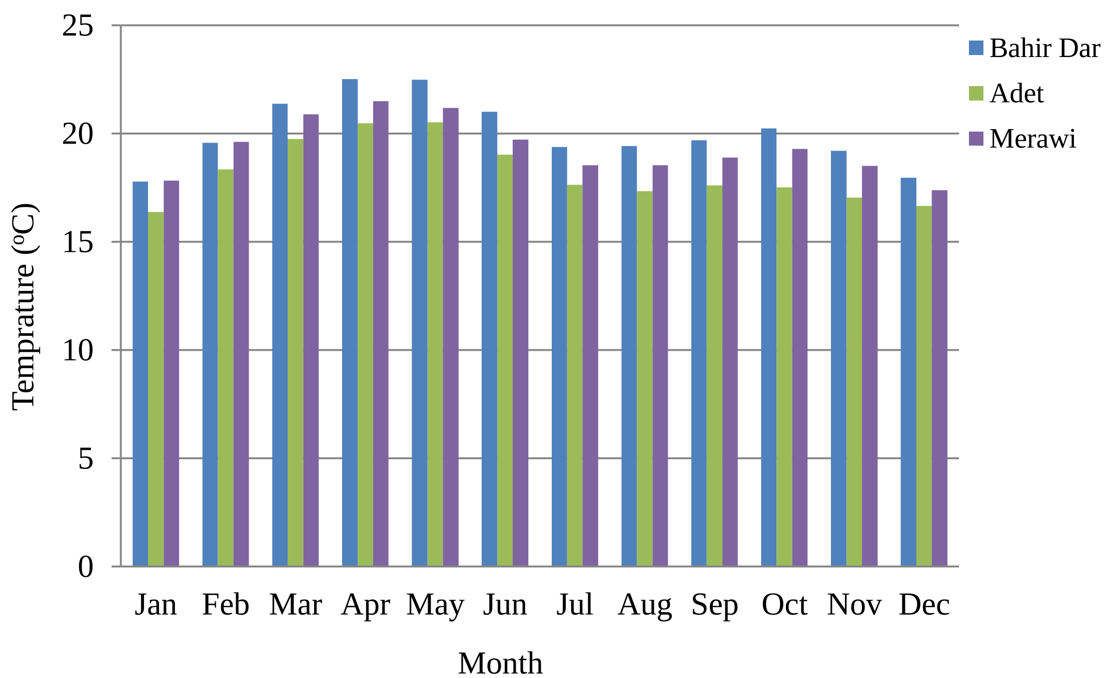

Figure 1.6. mean average monthly temperature of the surrounding area of the study area in ^{o}C (1990 -2019) (National Metrology Agency, 2021).

1.6.3. Identification of Soil Sample in the Study Area

Visual site investigation and information from the area were collected in order to consider the different soil types and to take the representative sample evenly. Accordingly, Ten test pit pointes were selected from different locations of the town. Pits were excavated to a maximum depth of three meters. Disturbed and undisturbed samples were collected and brought to the geotechnical laboratory for conducting different types of soil tests. The global coordinates of sampling location i.e. northing, easting and altitude shown in Table 1.3. The location of test pits under Tis Abay town map shows under Figure 1.7.

Table 1.3. Global coordinates of test pits

Test Pit	GPS Data (UTM)		Altitude (m)
	Northing	Easting	
TP-1	342298	1271628	1655
TP-2	341490	1270538	1672
TP-3	343599	1270235	1665
TP-4	342455	1268454	1676
TP-5	345165	1271853	1668
TP-6	346063	1270859	1623
TP-7	347290	1270561	1617
TP-8	346167	1267551	1644
TP-9	348479	1268551	1637
TP-10	345795	1269787	1612

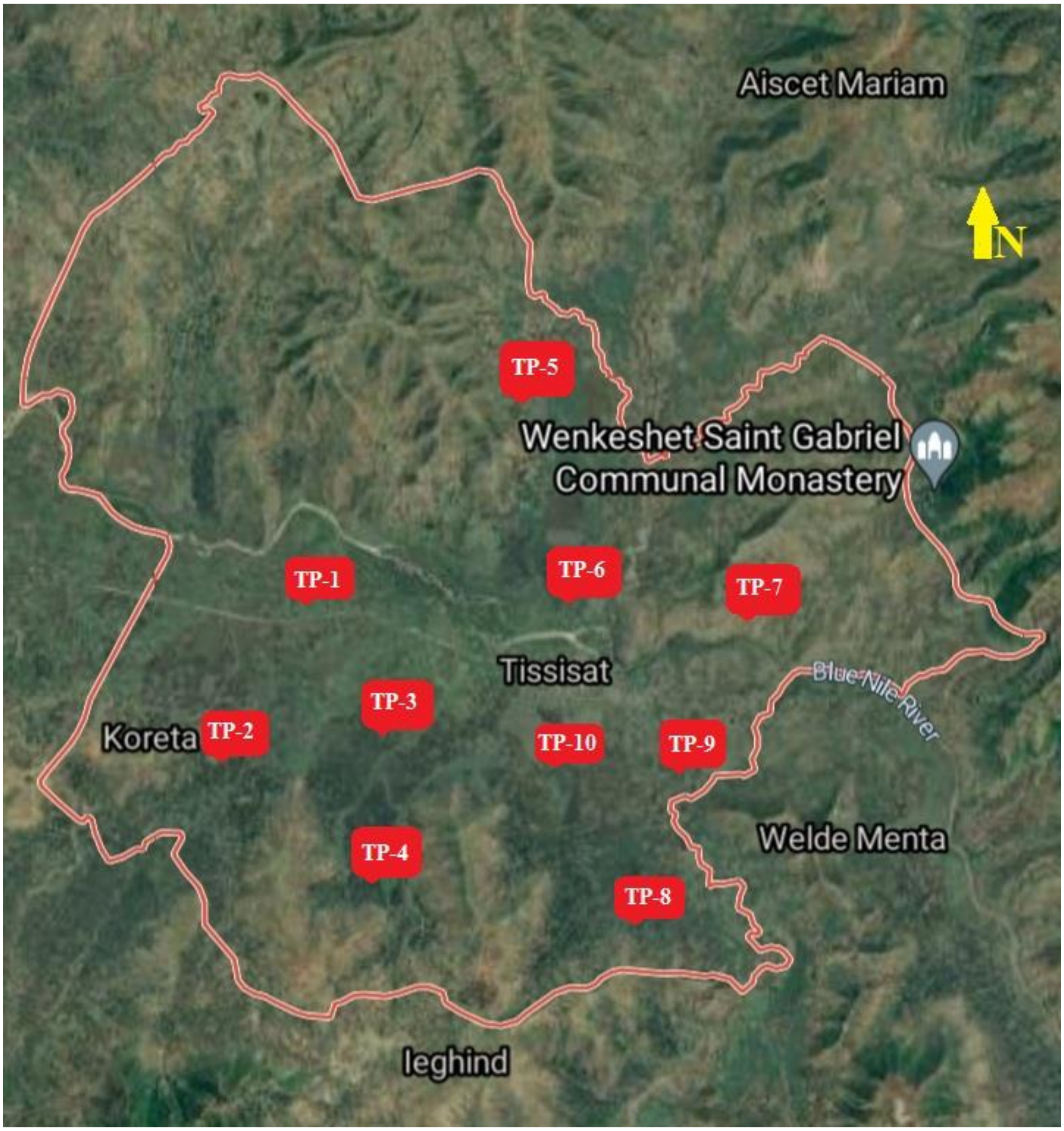

Figure 1.7. Location of test pits

CHAPTER TWO

2. LITERATURE REVIEW

2.1. General

Every civil engineering work involves the determination of soil type and its associated engineering application; certain properties are more significant than others. The common problems faced by civil engineers are related to bearing capacity and compressibility of soil and seepage through the soil. The possible solution to these problems is arrived at based on the study of the physical and index properties of the soil.

“In nature, soils occur in a large variety. However, soils exhibiting similar behavior can be grouped together to form a particular group. Engineers are continually searching for simplified tests that will increase their knowledge of soils beyond that which can be gained from visual examination without having to resort to the expense, detail, and precision required with engineering properties tests. These simplified tests provide indirect information about the engineering properties of soils and are, therefore, called index tests” (Venkatramaiah, 2006).

2.2. Soil Formation

“Soils are formed by the process of weathering of the parent rock. The process of weathering of rock decreases the cohesive force binding the mineral grains and leads to the disintegration of bigger masses to smaller and smaller particles. Soil is defined as a natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water. By contrast rock is considered to be a natural aggregate of mineral grains connected by strong and permanent cohesive force” (Terzaghi and Ralph,1996).

“Soils are formed from the physical and chemical weathering of rocks. Physical weathering involves reduction of size without any change in the original composition of the parent rock. The main agent responsible for this processes are exfoliation, unloading, erosion, freezing and thawing. Chemical weathering causes both reduction in size and chemical alteration of the original parent rock. The main agents responsible for chemical weathering are hydration, carbonation and oxidation. Often chemical and physical weathering takes place in concert" (Budhu, 2000).

"Chemical weathering is much more important than physical weathering in soil formation. Soils at a particular site can be residual (that is weathered in place) or transported (moved by water, wind, glacier, etc.) and the geologic history of a particular deposit significantly affects its engineering behavior" (Holtz and Kovaks, 1981).

"Chemical decomposition of rocks results in the formation of clay minerals. These clay minerals impart plastic properties to soils. Clayey soils are formed by chemical decomposition" (Das, 2006). The main factors affecting the formations of soil are: Parent materials i.e. geology of the area, topography and drainage, climate and vegetation cover.

2.2.1. Parent Materials

"There are two main variables in parent materials that affect soils: grain size and composition. Grain size is the main determinant of soil texture. Texture influences the soil structure, consistency, cation exchange capacity, profile drainage, moisture retaining capacity and organic content" (Girma, 1962).

2.2.2. Topography and Drainage

"Topography has a major influence on drainage characteristics which in turn is known to have major effect on soil mineralogy. Its control over soil properties is particularly strong in tropical environment reflecting the importance of lateral movement of water and soil materials" (Taylor, 1990).

2.2.3. Climate

Climate is the principal factor governing the rate and type of soil formation. The two important components of climate are the amount and distribution of precipitation, and temperature. The temperature variable is adequately represented by mean annual temperature, which doesn't differ greatly from the nearly constant temperature in the lower part of the regolith.

The two main rain fall parameters most widely available are the mean annual total and the length of the dry season. The amount and distribution of precipitation affects the availability of moisture and the relative humidity of the soil atmosphere; it influences the concentration or chemical activities of solutions in the system (Dagnachew, 2011).

2.3. General Types of Soils

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

"On the basis of origin of their constituents, soils can be divided in to two large groups: residual and transported soils. Residual soils are those that remain at the place of their formation as a result of the weathering of parent rock. Transported soils are that are found at location far from their place of formation. Transported soils are mixed with soils of different origin in the course of transportation. They also disintegrate and alter still further. With the decreasing velocity of water, or wind transporting them coarser particles are deposited first followed by fine particles. Thus transported soils are sorted out according to grain sizes. Soils of organic origin are formed chiefly in situ, either by the growth and subsequent decay of plants such as peat mosses or by the accumulation of fragments of the inorganic skeletons or shells of organism. Hence a soil of organic origin can be either organic or inorganic. The term organic soil ordinarily refers to a transported soils consisting of the products of rock weathering with a more or less conspicuous admixture of decayed vegetable matter" (Murthy, 1990).

2.3.1. Soil Particle Size and Shape

The size of particles may range from gravel to the finest size possible. Their characteristics vary with the size. Soil particles coarser than 0.075 mm are visible to the naked eye or may be examined by means of a hand lens. They constitute the coarser fractions of the soils. The coarser fractions of soils consist of gravel and sand. "The individual particles of gravel, which are fragments of rock, are composed of one or more minerals, whereas sand grains contain mostly one mineral which is usually quartz. The individual grains of gravel and sand may be angular, sub angular, sub-rounded, rounded or well-rounded. Gravel may contain grains which may be flat. Some sands contain a fairly high percentage of mica flakes that give them the property of elasticity. Silt and clay constitute the finer fractions of the soil. Any one grain of this fraction generally consists of only one mineral. The particles may be angular, flake-shaped or sometimes needle-like" (Morin and Parry, 1971).

2.3.2. Soil Mineralogical Composition

"Mineral particles are inorganic materials derived from rocks and minerals. They are extremely variable in size and composition. Primary minerals: present in original rock from which soil is formed. These occur predominantly in sand and silt fractions, and are weathering resistant (quartz, feldspars). Secondary minerals: formed by decomposition of primary minerals, and their subsequent weathering and re-composition into new ones (clay minerals). Humus or organic matter (decomposed organic materials)" (Dagnachew, 2011).

2.4. Soil Structure

The structure of 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, also may be included in the study of soil structure, which is typical for transported or sediments soils. Structural composition of sediment soils influences many of their important engineering properties such as permeability, compressibility and shear strength.

2.4.1. Single Grained Structure

Budhu (2000) expressed that single grained structure is characteristics of coarse grained soils, with a particle greater than 0.02 mm. Gravitational force pre dominate the surface force and hence grain to grain contact results. The deposition may occur in a loose state with large voids or in a dense state with less of voids.

2.4.2. Honey-Comp Structure

Budhu (2000) elaborated that honey-comp structure can occur only in fine-grained soils especially in silt and rock flour. Due to the relatively smaller size of grains, besides gravitational forces, inter-particle surface force also play an important role in the process of settling down. Miniature arches are formed which bridge over relatively large void spaces. This results in the formation of a honey comp structure each cell of a honey comp being made up of numerous individual soil grains. The structure has a large void space and may carry high loads without a significant volume change. The structure can be broken down by external disturbances.

2.4.3. Flocculent Structure

"Flocculent structure is characteristics of fine grained soils such as clays. Inter particle forces play a predominant role in the deposition. Mutual repulsion of the particles may be eliminated by means of an appropriate chemical; this will result in grains coming closer together to form 'a floc'. The formation of floc is flocculation" (Budhu, 2000).

2.5. Clay Minerals

"The minerals of clays are formed by the weathering of rocks. Most clay minerals of interest to geotechnical engineers are composed of oxygen and silicon which are the two most abundant elements on earth. Silicates are a group of minerals with a structural unit called the silica tetrahedron. A central silica cat-ion is surrounded by four oxygen anions, one at each corner of the tetrahedron. Silica tetrahedrons combine to form sheets, called silicate sheets. Silicate sheets may contain other structural units such as alumina sheets. Alumina sheets are formed by a combination of alumina minerals, which consist of an aluminum ion surrounded by six oxygen or hydroxyl atoms in an octahedron" (Budhu, 2000).

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

2.5.1. Kaolinite

"Kaolinite has a structure that consists of one silica sheet and one alumna sheet bonded together in to a layer about 0.72 nm (nm = 10^{-9} m) thick and stacked repeatedly. The layers are held together by hydrogen bonds" (Budhu, 2000). "Kaolinite has a few or no exchangeable cat-ion, and the interlayer bonds are relatively strong preventing any hydration between layers and allowing many layers to build up. Kaolinite is relatively stable and water is unable to penetrate between the layers. Consequently Kaolinite shows little swelling on wetting" (Taylor, 1990). 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. In contrast to most other clays, which are flaky, halloysite particles are tabular or rod likes (Samuel, 2017).

2.5.2. Illite

The illites are somewhat similar to montmorillonites in the structural units, but are different in their chemical composition. In illite, the layers are separated by potassium ion, where as in montmorillonite the layers are separated by loosely held water and exchangeable metallic ions. Unlike montmorillonite particles, which are extremely small and have a great affinity for water, the illite particles will normally aggregate and there by develop less affinity for water than montmorillonites. Correspondingly,their expansion properties are less. The cat-ion exchange capacity of illite is less than that of montmorillonite. The inner layer bonding by the potassium ions is sufficiently strong. Illites usually occur as a very small, flaky particles mixed with other clay and non-clay materials (Samuel, 2017).

2.5.3. Montmorillonite

Montmorillonites are made up of sheet like unit comprising an alumna octahedral sheet between two silica tetrahedral sheets. As the electrons rotate around the nucleus of an atom there will be times when there are more electrons on one side of the atom than the other, giving rise to a weak instantaneous dipole. Weak Vander Waals forces hold layers together and the bonding of these sheets is rather weak, resulting in a rather unstable mineral, especially when wet. In fact, montmorillonite display a significant affinity for water, with subsequent swelling and expansion. Its excessive swelling capacity may seriously endanger the stability of overlying structures and road pavements. Bentonite is part of the montmorillonite clay family, usually formed from the weathering of volcanic ash (Samuel, 2017).

2.6. Review of Previous Researches

Investigation of soils is very important in providing necessary data or information that can be used in designing civil engineering structures. Many investigators have studied on soils of Ethiopia.

Morin and Perry (1971) studied the origin and mineralogical composition of Ethiopian red clay soils. According to their study Ethiopian red clay soils are principally residual, derived from the weathering of volcanic rocks. The parent rock for black and red clays in Ethiopia is mainly olivine basalt, basalt and trachyte.

Ethiopian red clay soils have developed where rain fall is plentiful and drainage is good, and contain Kaolinite and Halloysite as the principal clay minerals, but Montmorillonite is also frequently present in significant amounts. The red color of the Ethiopian soils indicates the presence of iron.

Hailemariam (1992) has studied about investigation into shear strength characteristics of red clay soils of Addis Ababa. Based on experimental results of index property test soil under investigation are not expansive and no significant variations in the investigated depths as well as in different pits were found. The comparison of Addis Ababa red clay soil and lateritic soils of West Africa shows that the red clay soils investigated are not lateritic.

Mesfin (2004) has studied about investigation on index properties of expansive soils of Ethiopia. Based on experimental results from 125 samples shows high clay content, high to extremely high plasticity ranges. From the test result, the expansive soil of Ethiopia is classified as to extremely high swelling potential. Hence, these soils are unsuitable as construction material and should be considered as problematic foundation soils.

Ayenew (2004) has studied about investigation into shear strength characteristics of expansive soil of Ethiopia. Based on experimental results the shear strength of expansive soil ranges from 30 - 150 kPa in cohesion and 3 - 25 degree in angle of internal frication in UU test on unsaturated soil. For saturated soil sample in UU test the cohesion ranges from 55 - 94 kPa. There is a decrease in strength in saturated samples, which shows that the degree of saturation and the suction pressure can have major influence on the shear strength of expansive soil.

Behaylu (2014) has studied about investigation on some of engineering properties of soils found in Ambo town, Ethiopia. Based on experimental results that soils of the study area are highly plastic with the predominant proportion of clay size fraction. Black and gray soils have higher plasticity index than reddish brown and brown soils. The test results indicates that the black and gray soils of the study area are expansive soil having the free swell value of ranges from 35 - 155 %. The black and gray soils of Ambo town are active with activity number > 1.25. This indicates that they have poor quality and unsuitable for using as a sub grade material.

Tadesse (2014) has studied about investigation into some of the engineering properties of soil in woldiya town, Ethiopia. According to his experimental results the study area is partially non expansive and partially expansive. Especially the soil in the south-west of the town is covered by thick black clay soil which is expansive. Therefore, Woldiya soil is partly active and inactive as compared to the swelling characteristic of other fine grained soil.

Adem (2014) has studied about investigation into some of the engineering properties of soils in Debre Markos town, Ethiopia. From the index property test results the majority soil type of the study area is red clay. All the samples have free swell value of less than 50 % except sample from one test pit. This implies large area of the town cover by non-expansive red clay soil and only small areas covered with expansive soil following Wiseta river.

Eyasu (2015) has studied about investigation some of the engineering properties of soil in Merawi town, Ethiopia. From the laboratory test performed, it can be observed that the soils in Merawi has no significant variations of engineering properties within the investigated depths as well as in different pits which were found in the research work. The coefficient of permeability values shows that the soil is naturally impervious clay soil that will take a long period of time to consolidate. the consistency index values of range of the soil indicates that the natural consistency of soil is soft to stiff clay soil and the soil in the town is compressible clay soil for the pressure intensity above pre-consolidation pressure. Similarly the recompression index values indicate that the consolidation of the soil for the pressure intensity between the overburden pressure and pre-consolidation pressure is very small.

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1. Test Methods and Procedures

The method of performing the intended research work includes, review of literatures have been done for revising the accepted theories and practices in the topic areas, reconnaissance of the area, sampling and data collection and series of laboratory tests were conducted and the engineering properties of the soils of the study area were detrmined.

3.1.1. Reconnaissance of the Area

The engineer visually should inspect the site and the surrounding area. In many cases, the information gathered from such a trip is invaluable for future planning. The type of vegetation at a site, in some instances, may indicate the type of subsoil that will be encountered. Open cuts near the site provide an indication about the subsoil stratification. Cracks in the walls of nearby structure(s) may indicate settlement from the possible existence of soft clay layers or the presence of expansive clay soils.

3.1.2. Sampling and Data Collection

To achieve the objective of the study, ten test pits in the representative area were selected and disturbed and undisturbed samples were taken at varying soil profile by direct excavation manually at the depths of 1.5 m and 3.0 m. After careful sampling, samples brought to soil laboratory of Bahir Dar Institute of Technology and Amhara Rural Road Construction Agency.

3.1.3. Laboratory Tests

After transportation of the disturbed samples to the laboratory, The following tests were performed

1. Natural moisture content
2. Specific gravity
3. Free Swell
4. Atterberg Limit (Plastic and Liquid Limit)
5. Grain Size Distribution (Sieve and Hydrometer analysis)

Similarly, after careful transportation of the undisturbed samples to the laboratory, the following tests were performed

1. Unconfined compression strength (UCS)
2. One dimensional consolidation

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

3.2. Material Used

Soil samples collected from the representative test pits are the material used for this study.

3.3. Apparatus and Tools

The apparatus and tools used for the research work include:

- For Natural moisture content test

  Drying oven, Balance, Moisture can, Gloves, Spatula.
- For Specific gravity test

  Pycno-meter, Balance, Vacuum pump, Funnel, Spoon, Porcelain dish.
- For Atterberg Limit test

  Liquid limit device (Casagrande apparatus), Porcelain dish, Flat grooving tool with gage, Moisture cans, Balance, Glass plate, Spatula, Wash bottle, Drying oven.
- For Grain Size distribution test

  Balance, Set of sieves, Cleaning brush, Sieve shaker, Mixer (blender), 151H Hydrometer, Sedimentation cylinder, Control cylinder, Thermometer, Beaker, Timing device.

- For Unconfined compression strength (UCS) test

  Core cuter, Compression device, Load and deformation dial gauges, Sample trimming equipment, Balance, Moisture can.

- For One dimensional consolidation test

  Core cuter, Consolidation device (including ring, porous stones, water reservoir, and load plate), Dial gauge, Sample trimming device, glass plate, Metal straight edge, Clock, Moisture can, Filter paper.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Index Properties

4.1.1. General

“The properties of soils are complex and variable. Every civil engineering work involves the determination of soil type and its associated engineering application; certain properties are more significant than others. The common problems faced by civil engineers are related to bearing capacity and compressibility of soil and seepage through the soil. The possible solution to these problems is arrived at based on the study of the physical and index properties of the soil” (Arora, 1997).

4.1.2. Natural Moisture Content

The water content of the soil is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids. For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil (Venkatramaiah, 2006). The water content of a soil is quantitative measure of the wetness of a soil mass. The water content of a soil can be determined to a high degree of precision, as it involves only mass which can be determined more accurately than volumes (Arora, 1997).

Natural moisture content of soils of the study area shows in Table 4.1 based on ASTM D 2216-98 test procedure and the values ranges from 21.67 - 41.24 %. Analysis of the test results are presented in Appendix_A1.

Table 4.1. Natural moisture content of soil samples of the study area

Test Pit	Depth (m)	NMC (%)
TP-1	1.5	32.42
	3	36.72
TP-2	1.5	30.48
	3	36.61
TP-3	1.5	35.15
	3	36.24
TP-4	1.5	37.4
	3	41.24
TP-5	1.5	34.15
	3	37.76
TP-6	1.5	21.67
	3	22.93
TP-7	1.5	27.25
	3	29.04
TP-8	1.5	38.11
	3	39.61
TP-9	1.5	40.43
	3	39.39
TP-10	1.5	37.61
	3	37.21

4.1.3. Specific gravity

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil. Particle density or specific gravity is a measure of the actual particles which make up the soil mass and is defined as the ratio of the mass of the particles to the mass of the water they displace. Knowledge of the particle density is essential in relation to other soil tests. It is used when calculating porosity and voids ratio and is particularly important when compaction and consolidation properties are being investigated. The majority of apparatus used for the various tests is general laboratory equipment (Reddy, 2002).

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

Feldspars) and 2.65 (Quartz) to 3.5 (Augite or Olivine). Gypsum has a smaller value of 2.3 and salt (NaCl) has 2.1. Some iron minerals may have higher values, for instance, Magnetite has 5.2 (Morin and Parry, 1971).

The Specific Gravity of soils of the study area shows in Table 4.2 based on ASTM D 854-00 test procedure and the values ranges from 2.55 - 2.76 %. Analysis of the test results are presented in Appendix_A2.

Table 4.2. Specific gravity of the soil samples of the study area

Test Pit	Depth (m)	Specific Gravity
TP-1	1.5	2.67
	3	2.7
TP-2	1.5	2.74
	3	2.62
TP-3	1.5	2.71
	3	2.73
TP-4	1.5	2.67
	3	2.7
TP-5	1.5	2.65
	3	2.68
TP-6	1.5	2.57
	3	2.59
TP-7	1.5	2.63
	3	2.55
TP-8	1.5	2.73
	3	2.76
TP-9	1.5	2.72
	3	2.73
TP-10	1.5	2.67
	3	2.68

4.1.4. Atterberg's Limit

4.1.4.1. General

The condition of a soil can be altered by changing the moisture content. Atterberg Limits are defined as water contents at certain limiting or critical stages in soil behavior. They, along with the natural water content, are the most important items in the description of fine grained soils.

The Liquid Limit, Plastic Limit, and the Plasticity Index of soils are used extensively to correlate a soil with engineering behavior such as compressibility, hydraulic conductivity, shrink-swell, and shear strength. Atterberg defined four possible states of consistency for soils: liquid, plastic, semi-solid and solid. The Liquid Limit divides the plastic and liquid states and is defined as the water content at which the soil flows to close a standard size groove when shaken in a standardized device. The Plastic Limit separates plastic and semi-solid states. At water contents below the Plastic Limit the soil cannot be molded without cracking (Reddy, 2002).

4.1.4.2. Liquid Limit and Plastic Limit

The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a pat of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.

The Swedish soil scientist Albert Atterberg originally defined seven “limits of consistency” to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit, is used occasionally.) The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system (Reddy, 2002).

4.1.4.3. Test Procedure and Results

Atterberg Limits were determined for air-dried samples. The air- dried samples were prepared by spreading the specimen in the air until it dried. The sample of soil passing sieve No 40 (0.425 mm) is used to determine the Atterberg Limits. The moisture content, in percent, required to close a distance of 12.7 mm. along the bottom of the groove after 25 blows is defined as the liquid limit. It is difficult to adjust the moisture content in the soil to meet the required 12.7 mm closure of the groove in the soil pat at 25 blows. Hence, at least three tests for the same soil are conducted at varying moisture contents, with the number of blows, N, required to achieve closure varying between 15 and 35 (Das, 1997).

About 15 g of soil passing through sieve No. 40 (ASTM), mixed thoroughly with water. The soil is rolled on a glass plate with the hand, until it is about 3 mm in diameter. This procedure of mixing and rolling is repeated till the soil shows signs of crumbling when the diameter is 3 mm. The water content of the crumbled portion of the thread is determined. This is called as plastic limit (Das, 1997).

Atterberg limits of soils of the study area are summarized in Table 4.4. Liquid limit sample determination for test pit 1 at 1.5 m shown in Table 4.3 and Figure 4.1 using ASTM D 4318-00 test procedure. Liquid limit of soils of the study area ranges from 60.59 - 98.98 %, plastic limit ranges from 20.48 -41.51 % and plasticity index ranges from 28.36 - 78.50 %.

Analysis of the test results are presented in Appendix_A3.

Table 4.3. Liquid limit determinations for test pit 1@1.5 m

-Sample No: 1 - depth: 1.5 m	LL				PL			PI=LL -PL
Container no.	1	2	3	4	1	2	3	
Mc= Mass of empty, clean can + lid (g)	36.3	34.6	28.2	33.7	28.2	34.6	34.2	
Mcms= Mass of can, lid, and moist soil (g)	97.5	120.4	111	109.6	38	40.2	40.33	
Mcds = Mass of can, lid, and dry soil (g)	70.5	81.6	73.4	75.8	35.7	38.9	38.9	
Mw=(Mcms-Mcds)=Mass of pore water(g)	27	38.8	37.6	33.8	2.3	1.3	1.43	
MS=(Mcds- Mc)= Mass of soil solids (g)	34.2	47	45.2	42.1	7.5	4.3	4.7	
Water content, W%= ((Mw)/(Ms))*100%	78.95	82.55	83.19	80.29	30.67	30.23	30.43	
Number of Blows (No.)	33	23	17	28				
Average (%)	81.38				30.45			50.93

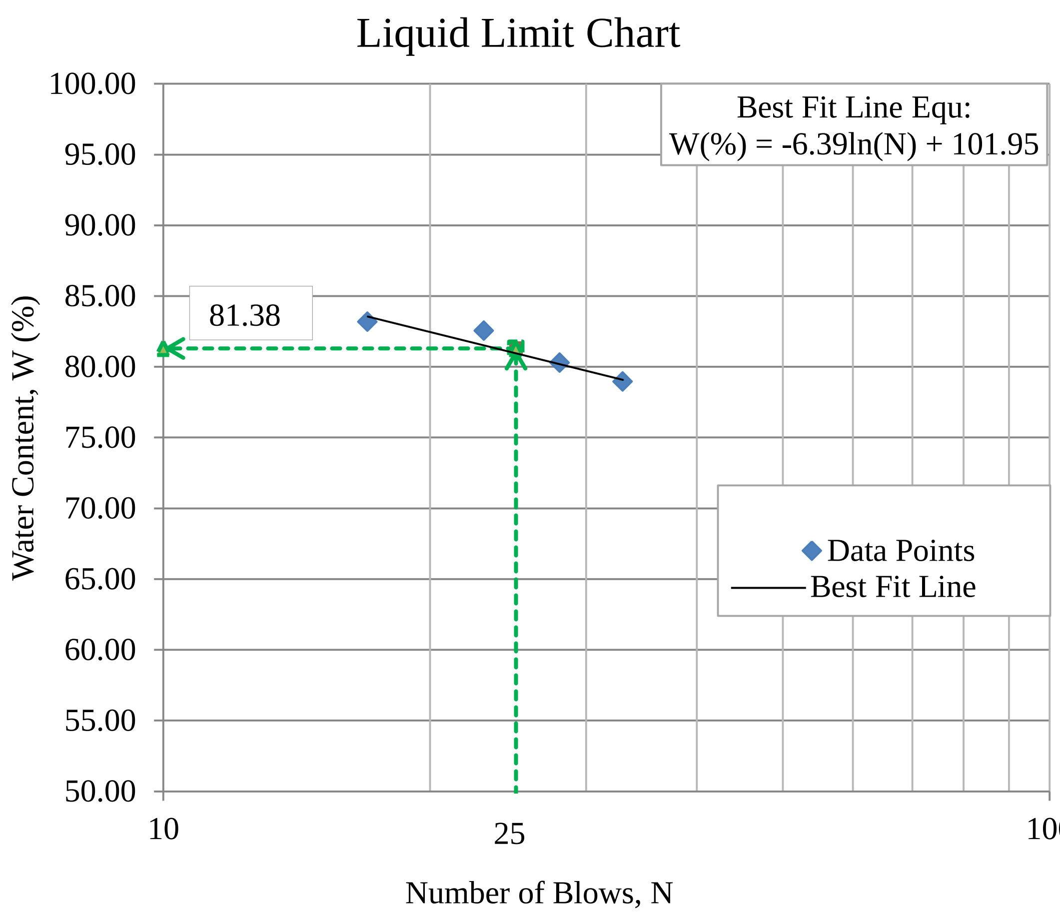

Figure 4.1. Liquid limit determinations for test pit 1@1.5 m

Table 4.4. Summary of Atterberg Limits of soil samples of the study area

Test Pit	Depth (m)	Liquid Limit (%)	Plastic Limit (%)	PI (%)
TP-1	1.5	81.38	30.45	50.93
	3	94.21	30.81	63.40
TP-2	1.5	79.64	31.76	47.88
	3	76.21	32.37	43.84
TP-3	1.5	92.71	31.23	61.48
	3	98.98	20.48	78.50
TP-4	1.5	89.95	30.56	59.39
	3	83.25	31.09	52.16
TP-5	1.5	94.03	31.68	62.35
	3	98.23	20.70	77.53
TP-6	1.5	60.59	31.70	28.89
	3	64.70	31.99	32.71
TP-7	1.5	64.15	35.79	28.36
	3	87.67	39.97	47.70
TP-8	1.5	88.17	37.60	50.57
	3	90.79	41.51	49.28
TP-9	1.5	93.33	38.36	54.97
	3	98.68	33.70	64.98
TP-10	1.5	92.46	31.69	60.77
	3	89.64	32.60	57.04

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4.1.5. Grain-Size Distribution of Soil

4.1.5.1. General

To classify a soil properly, its grain size distribution must be known. In any soil mass, the sizes of the grains vary greatly. The grain-size distribution of coarse-grained soil is generally determined by means of sieve analysis. For a fine-grained soil, the grain-size distribution can be obtained by means of hydrometer analysis. The analysis of soils by particle size provides a useful engineering classification system from which a considerable amount of empirical data can be obtained.

Two separate and different procedures are used. Sieving is used for gravel and sand size particles and sedimentation procedures are used for the finer soils. For soil containing a range of coarse and fine particles it is usual to employ a composite test of sieving and sedimentation procedures (Fasil, 2003). The distribution of particle sizes larger then 0.075 mm (retained on the No. 200 sieve) is determined by sieving, while distribution of particles sizes smaller then 0.075 mm is determined by sedimentation process using a hydrometer. The size of the sample (i.e., the amount of soil) will depend on the maximum size of the particles present in the sample itself, according to the following table (Giovanna, 2007). Grain size distribution ranges shown in Table 4.5.

Table 4.5. Grain size distribution ranges (ASTM D422, 2007)

SOIL GRAIN SIZES

Soil Type	USCS Symbol	Grain Size Range (mm)			
		USCS	AASHTO	USDA	MIT
Gravel	G	76.2 to 4.75	76.2 to 2	>2	>2
Sand	S	4.75 to 0.075	2 to 0.075	2 to 0.05	2 to 0.06
Silt	M	Fines < 0.075	0.075 to 0.002	0.05 to 0.002	0.06 to 0.002
Clay	C		< 0.002	< 0.002	< 0.002

4.1.5.2. Sieve Analysis

A sieve analysis is conducted by taking a measured amount of dry, well-pulverized soil and passing it through a stack of progressively finer sieves with a pan at the bottom. The amount of soil retained on each sieve is measured, and the cumulative percentage of soil passing through each is determined. This percentage is generally referred to as percent finer. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

4.1.5.3. Hydrometer Analysis

Hydrometer analysis is based on the principle of sedimentation of soil grains in water. When a soil specimen is dispersed in water, the particles settle at different velocities, depending on their shape, size, and weight, and the viscosity of the water. Soil particle sizes smaller than 0.075 mm (passing 200 mesh sieves) are determined by hydrometer method. It is based on the process of sedimentation of soil particles in water by gravity. The steady fall of soil particles through a liquid at rest is called sedimentation. The hydrometer method is based on Stokes equation that relates the velocity of free falling spherical particle through a liquid to the diameter of the particle, the specific gravity of the particle and the viscosity of the liquid. The hydrometer analysis assume that, the soil particles are spheres, the soil suspension is sufficiently low concentration to permit individual settling of grains without interference by others.

The gradation of soils in the study area varies considerably as sown in Table 4.6, Figure 4.2 and Figure 4.3 using ASTM D 422-98 test procedure. From the grain size analysis result clay content ranging from 45.23 - 76.38 %, Silt faction 20.33 - 60.47 %, sand fraction 1.28 - 5.30 % and gravel ranges from 0.0 - 11.08.

The detail tests are presented in Appendix_ A4.

Table 4.6. Summary of grain size distribution of soil samples of the study area

Test Pit	Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
TP-1	1.5	2.50	3.00	36.48	58.02
	3	1.00	3.00	20.68	75.32
TP-2	1.5	0.00	5.30	34.45	60.25
	3	2.10	2.31	39.32	56.27
TP-3	1.5	10.94	2.95	39.17	46.94
	3	6.63	1.28	30.47	61.62
TP-4	1.5	0.35	2.94	20.33	76.38
	3	0.00	2.94	28.62	68.44
TP-5	1.5	7.71	1.39	42.32	48.88
	3	7.77	1.58	28.91	61.74
TP-6	1.5	11.08	2.13	25.13	61.66
	3	7.72	4.11	35.89	52.28
TP-7	1.5	1.66	3.59	45.45	49.30
	3	0.80	2.21	29.84	67.15
TP-8	1.5	0.00	3.88	30.29	65.83
	3	0.00	3.50	41.42	55.08
TP-9	1.5	0.00	3.86	40.80	55.34
	3	0.35	4.09	28.61	66.95
TP-10	1.5	0.00	2.69	29.79	67.52
	3	0.34	3.23	51.2	45.23

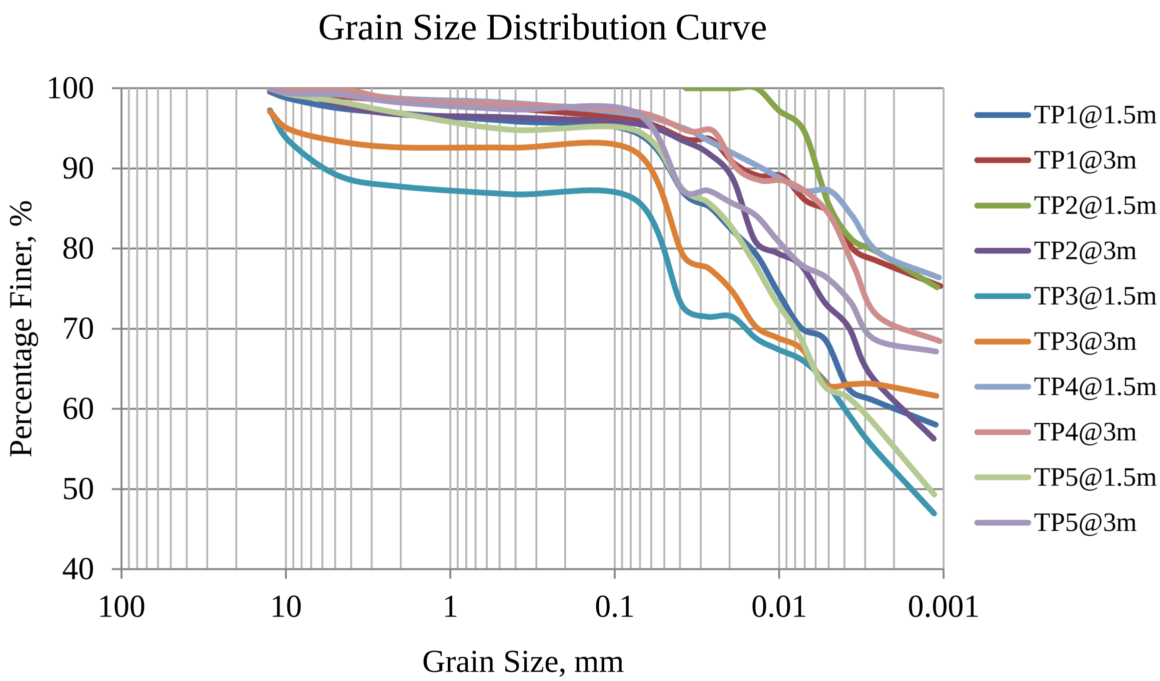


Figure 4.2. Grain size distribution curve for sample from test pit 1-5

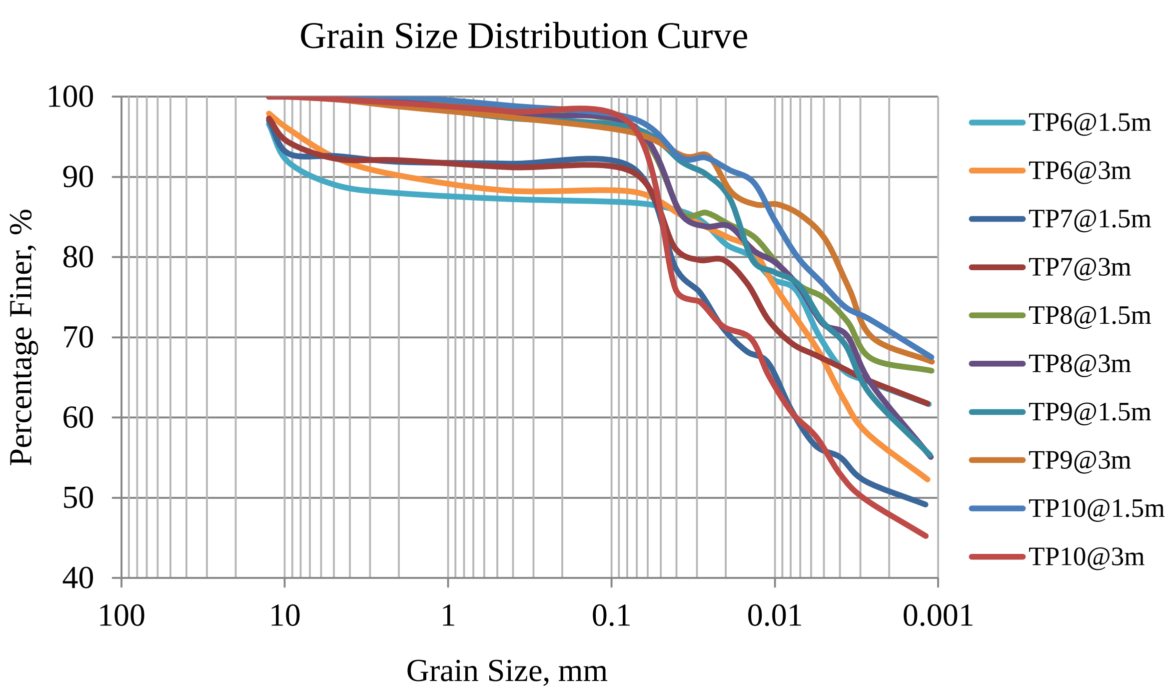


Figure 4.3. Grain size distribution curve for sample from test pit 6-10

4.1.6. Free-Swell

Both the amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several physico-chemical aspects of the soil. Among clay minerals Montimorillonite influence the magnitude of swelling maximally as compared to Illites and Kaolinites (Murthy, 1990).

To study the swelling property of the soils, the simplest test conducted is free swell test. This test is performed by slowly pouring 10 ml of oven dry soil which has passed the No. 40 (0.425 mm) sieve in to 100 ml graduated cylinder filled with water. After 24 hours, final volume of the suspension being read (Teferra and Leikun.1999). Hence, free swell is defined as shown below on equation 4.1:

$$Free\ swell\ = \frac{\text{Final volume } - \text{Initial volume of the soil}}{\text{Initial Volum}} * 100\ \% \ldots\ldots .Eqn\ (4.1)$$

Free swell < 50 %, Non expansive

Free swell between 50 - 100 %, Marginal

Free swell > 100 %, Expansive

From the test result one can see that the free swell of the soil under investigation ranges from 43 - 164 % and summarized in Table 4.7. Free swell of the study area is ranging from non-expansive soil to expansive soil.

Analysis of the test results are presented in Appendix-A5.

Table 4.7. Free swell of soil samples of the study area

Test Pit	Depth (m)	Free Swell (%)
TP-1	1.5	130
	3	122
TP-2	1.5	155
	3	135.5
TP-3	1.5	115
	3	119
TP-4	1.5	164
	3	156
TP-5	1.5	132
	3	123.5
TP-6	1.5	44
	3	42.5
TP-7	1.5	48.5
	3	43
TP-8	1.5	140
	3	129.5
TP-9	1.5	125
	3	115.5
TP-10	1.5	105
	3	120

4.2. Classification of the Soils

4.2.1. General Considerations for Classification of Soils

Soil classification system is an arrangement of different soils in to groups having similar properties. The purpose of soil classification is to make possible the estimation of soil properties by association with soils of the same class whose properties are known and to provide the engineer with accurate method of soil description (Teferra and Leikun.1999).

The behavior of a soil mass under load depends upon many factors such as the properties of the various constituents present in the mass, the density, the degree of saturation, the environmental conditions etc. If soils are grouped on the basis of certain definite principles and rated according to their performance, the properties of a given soil can be understood to a certain extent, on the basis of some simple tests. The systems that are quite popular amongst engineers are the AASHTO Soil Classification System and the Unified Soil Classification System (USCS) (Morin and Parry, 1971).

4.2.2. AASHTO Classification System

The AASHTO classification system, also called public roads administration (PRA) classification, is based on grain size distribution, liquid limit and plasticity index. There are seven groups of inorganic soils, A-l to A-7 with 12 subgroups in all. The AASHTO system uses similar techniques as that of USC but the dividing line has an equation of the form PI = LL-30. It generally classifies a soil broadly into granular material and silt-clay material. The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7.

Classification of soil and soil-aggregate mixtures according to ASTM D3282 shown on Table 4.8 and Liquid Limit and Plasticity Index Ranges for Silt-Clay Materials according to AASHTO M-145-12 shows under Figure 4.4.

AASHTO classification for soil samples of the study area summarized in Table 4.9 and Plasticity chart of soils of the study area according to AASHTO M-145-12 soil classification test procedure shows under Figure 4.5.

Table 4.8. Classification of soil and soil-aggregate mixtures (ASTM D3282, 2009)

Organic	Granular Materials (35% Or Less Passing No. 200)							Silt-Clay Materials (More than 35% Passing No. 200)				Organic
Group	A-1		A-3	A-2				A-4	A-5	A-6	A-7	A-8
Subgroup	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6	
Sieve Analysis, % Passing												
No. 10	50 max.	—	—	—	—	—	—	—	—	—	—	
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—	
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.	
LL and PI of Fraction Passing No. 40												
LL	—		N.P	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	
PI	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.	
Types of Significant Materials	Stone Fragments, Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils		Peat
Subgrade Rating	Excellent to Good			Fair to Poor								Unsuitable

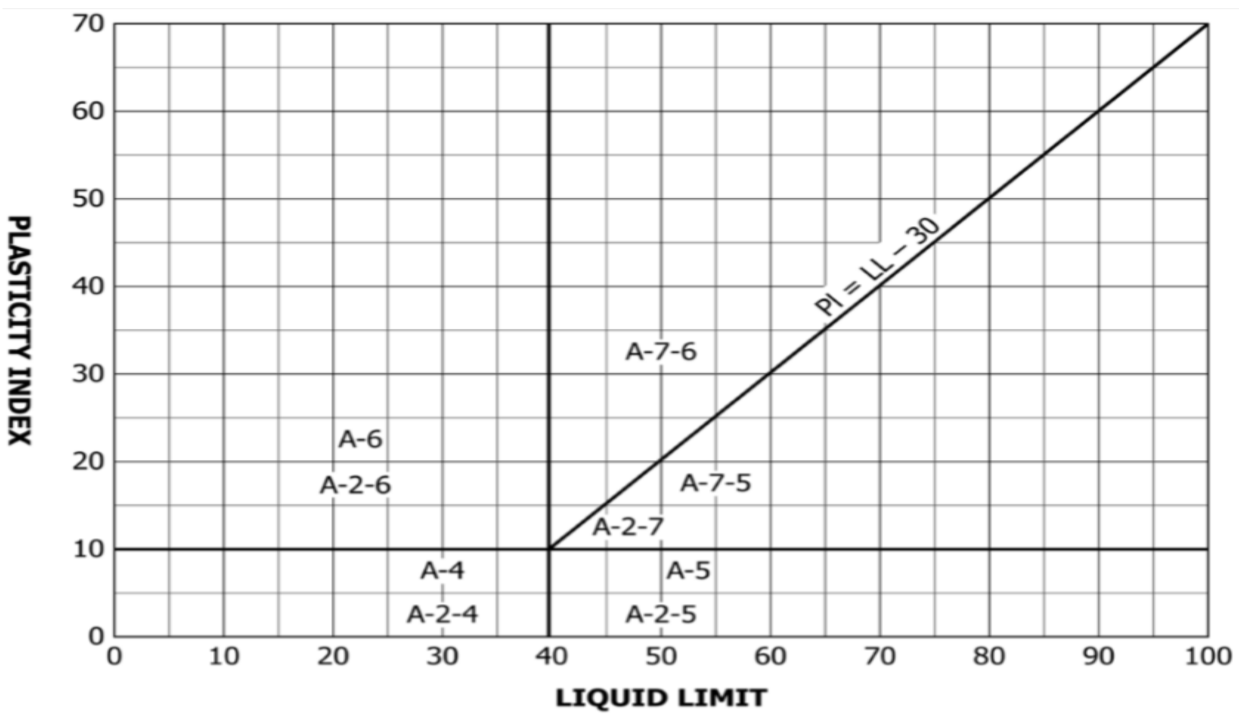


Figure 4.4. Liquid Limit and Plasticity Index Ranges for Silt-Clay Materials (AASHTO M145, 2012)

Table 4.9. AASHTO classification for soil samples of the study area

Test Pit	Depth (m)	% Passing On Sieve #200	LL (%)	PL (%)	PI (%)	Group Classification	Usual Types of Significant Constituent Material
TP-1	1.5	94.50	81.38	30.45	50.93	A-7-5	Clayey Soil
	3	96.00	94.21	30.81	36.87	A-7-5	Clayey Soil
TP-2	1.5	94.70	79.64	31.76	47.88	A-7-5	Clayey Soil
	3	95.59	76.21	32.37	43.84	A-7-5	Clayey Soil
TP-3	1.5	86.11	92.71	31.23	61.48	A-7-5	Clayey Soil
	3	92.09	98.98	20.48	78.5	A-7-6	Clayey Soil
TP-4	1.5	96.71	89.95	30.56	59.39	A-7-5	Clayey Soil
	3	97.06	83.25	31.09	52.16	A-7-5	Clayey Soil
TP-5	1.5	91.20	94.03	31.68	62.35	A-7-5	Clayey Soil
	3	90.65	72.66	20.70	38.31	A-7-5	Clayey Soil
TP-6	1.5	86.79	60.83	31.70	29.13	A-7-5	Clayey Soil
	3	88.17	64.21	31.99	32.22	A-7-5	Clayey Soil
TP-7	1.5	94.75	63.68	35.79	27.89	A-7-5	Clayey Soil
	3	96.99	87.67	39.97	47.70	A-7-5	Clayey Soil
TP-8	1.5	96.12	88.17	37.60	50.57	A-7-5	Clayey Soil
	3	96.50	90.79	41.51	49.28	A-7-5	Clayey Soil
TP-9	1.5	96.14	93.33	38.36	54.97	A-7-5	Clayey Soil
	3	95.59	98.68	33.70	64.98	A-7-5	Clayey Soil
TP-10	1.5	97.31	92.46	31.69	60.77	A-7-5	Clayey Soil
	3	96.43	89.64	32.6	57.04	A-7-5	Clayey Soil

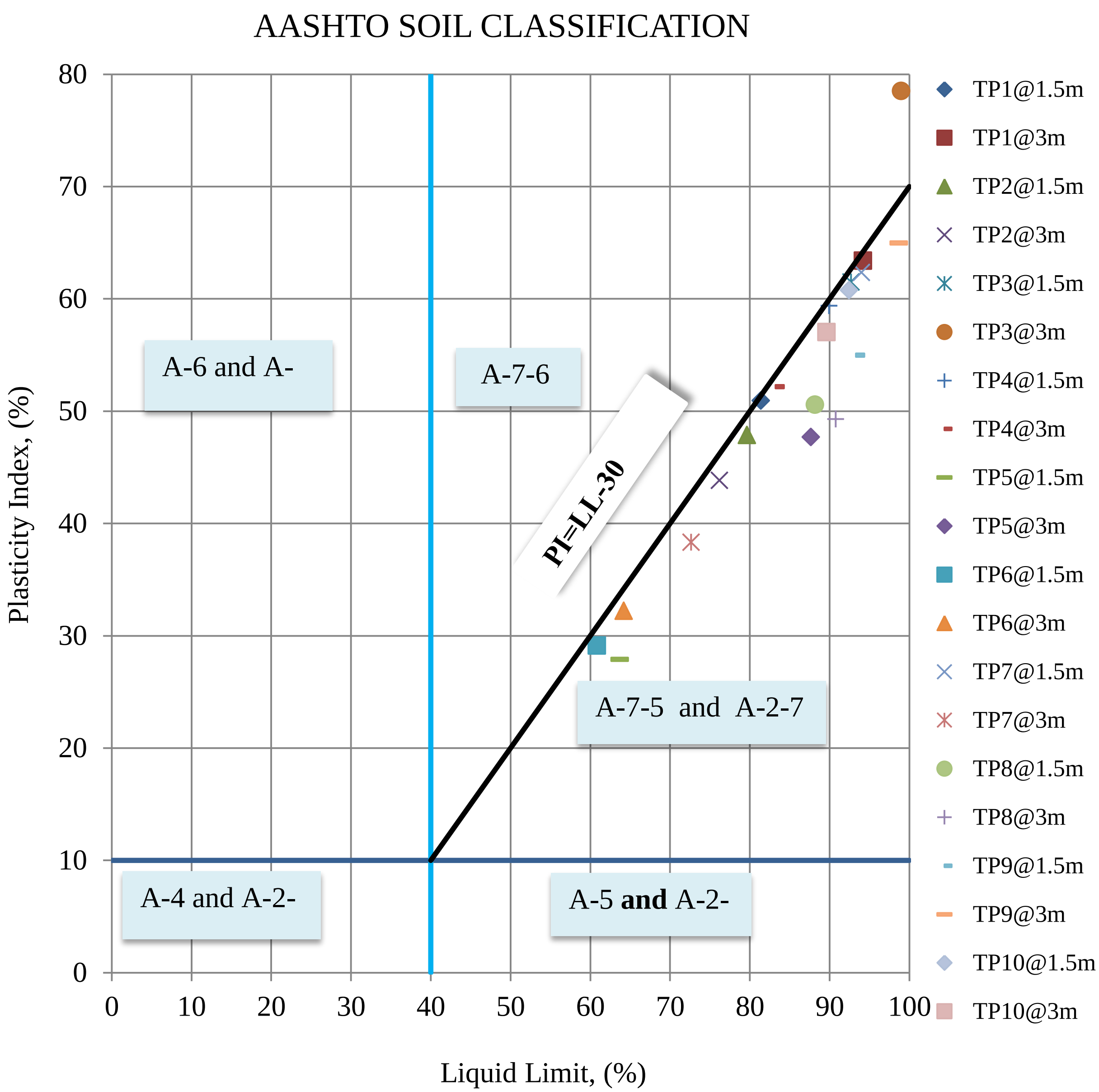


Figure 4.5. Plasticity chart of soils of the study area according to AASHTO classification

4.2.3. Unified Soil Classification System (USCS)

The Unified Soil Classification System is based on the recognition of the type and predominance of the constituents considering grain-size, gradation, plasticity and compressibility. In the laboratory, the grain-size curve and the Atterberg limits can be used (Morin and Parry, 1971).

Coarse grained soils are those having 50 % or more materials retained on sieve No 200. Fine grained soils are those having more than 50 % passing through sieve No 200. USCS uses symbols for the particle size groups. These symbols and their representations are: G-gravel, S-sand, M-silt and C-clay. ‘’W’’ for well graded and ‘’P ‘’for poorly graded and plasticity characteristics ‘’H’’ for high and ‘’L’’ for low and symbol ‘’O’’ indicating the presence of organic material (Budhu, 2000).

Plasticity charts of the soils for Unified Soil Classification System according to ASTM D2487-00 shows under Figure 4.6.

USCS classification for soil samples of the study area summarized in Table 4.10 using ASTM D 2487-00 test procedure and Plasticity chart of soils of the study area according to USCS classification shows under Figure 4.7.

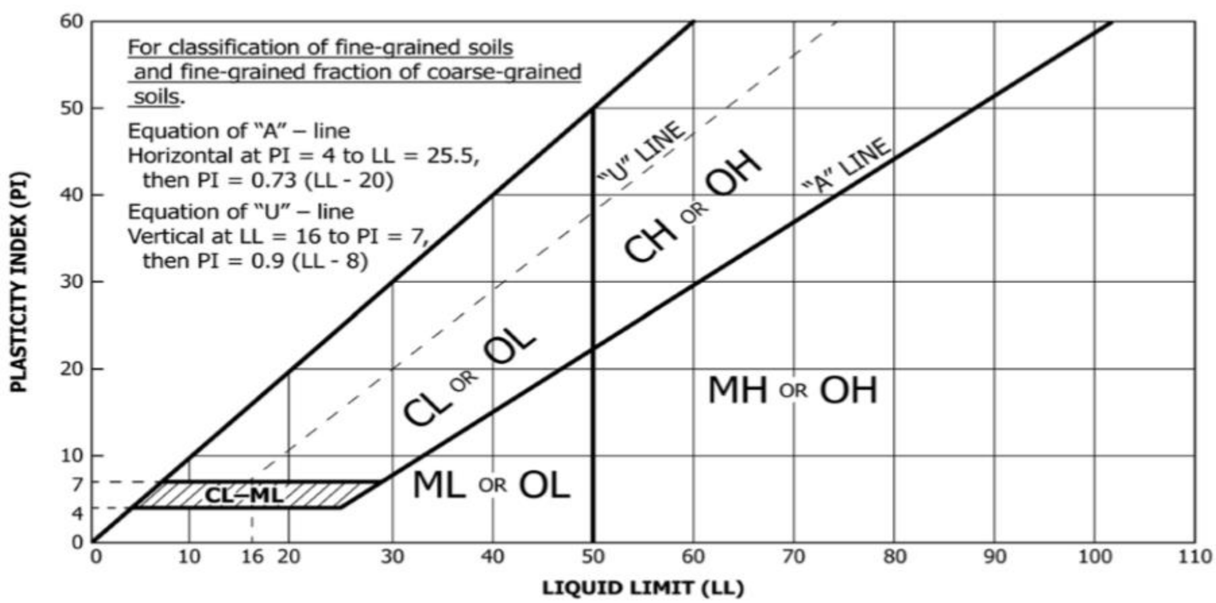


Figure 4.6. Plasticity charts of the soils for Unified Soil Classification System (ASTM D2487, 2000)

Table 4.10. USCS classification for soil samples of the study area

Test Pit	Depth (m)	% Passing On Sieve #200	LL (%)	PL (%)	PI (%)	Classification According to USCS	Descriptions
TP-1	1.5	94.50	81.38	30.45	50.93	CH	Clay with High Plasticity
	3	96.00	94.21	30.81	36.87	CH	Clay with High Plasticity
TP-2	1.5	94.70	79.64	31.76	47.88	CH	Clay with High Plasticity
	3	95.59	76.21	32.37	43.84	CH	Clay with High Plasticity
TP-3	1.5	86.11	92.71	31.23	61.48	CH	Clay with High Plasticity
	3	92.09	98.98	20.48	78.5	CH	Clay with High Plasticity
TP-4	1.5	96.71	89.95	30.56	59.39	CH	Clay with High Plasticity
	3	97.06	83.25	31.09	52.16	CH	Clay with High Plasticity
TP-5	1.5	91.20	94.03	31.68	62.35	CH	Clay with High Plasticity
	3	90.65	72.66	20.70	38.31	MH	Silt with High Plasticity
TP-6	1.5	86.79	60.83	31.70	29.13	MH	Silt with High Plasticity
	3	88.17	64.21	31.99	32.22	MH	Silt with High Plasticity
TP-7	1.5	94.75	63.68	35.79	27.89	MH	Silt with High Plasticity
	3	96.99	87.67	39.97	47.70	MH	Silt with High Plasticity
TP-8	1.5	96.12	88.17	37.60	50.57	CH	Clay with High Plasticity
	3	96.50	90.79	41.51	49.28	MH	Silt with High Plasticity
TP-9	1.5	96.14	93.33	38.36	54.97	CH	Clay with High Plasticity
	3	95.59	98.68	33.70	64.98	CH	Clay with High Plasticity
TP-10	1.5	97.31	92.46	31.69	60.77	CH	Clay with High Plasticity
	3	96.43	89.64	32.6	57.04	CH	Clay with High Plasticity

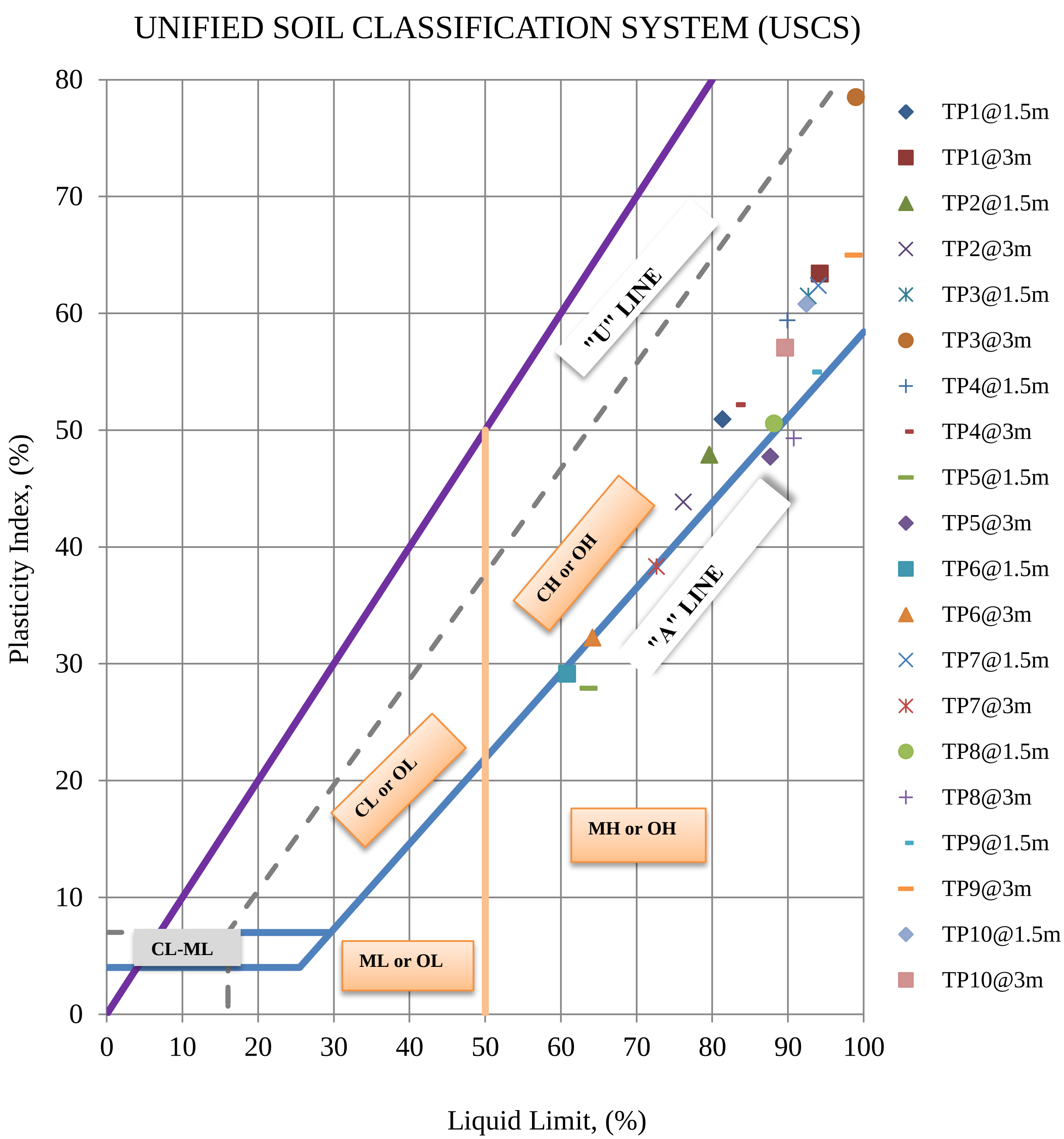


Figure 4.7. Plasticity chart of the study area according to unified soil classification system

4.2.4. Classification Based on Activity

Skempton's colloidal activity is determined as the ratio of the plasticity index of the clay content to fines. He observed that, for a given soil, the plasticity index is directly proportional to the percent of clay-size fraction (i.e., percent by weight finer than 0.002 mm in size). Activity designated by "A_c" is defined as shown on equation 4.2.

$$A_c = \frac{\text{Plastic Index (\%)}}{\text{Clay Fraction (\%)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ (4.2)$$

Activity has been used as an index property to determine the swelling potential of clays [Das, 1997). It is a measure of the water holding capacity of clayey soils. The changes in the volumes of a clayey soil during swelling or shrinkage depend upon the activity (Budhu, 2000). Classification of soils based on activity presented in Table 4.11.

Table 4.11. Classification of soils based on activity (Budhu, 2000).

No.	Activity	Soil Type
1	<0.75	In active
2	0.75-1.25	Normal
3	>1.25	Active

Activities of soils of the study area are computed based on results obtained from hydrometer analysis (percentage of clay fraction) and Atterberg's Limit (PI).

Colloidal activity values for the soils under investigation are calculated and summarized below in Table 4.12 and activity chart of the soils of the study area shown under Figure 4.8.

Table 4.12. Activity of the soil in the study area

Test Pit	Depth (m)	PI (%)	Percentage of clay	A_c	Remark
TP-1	1.5	50.93	58.02	0.88	Normal
	3	63.4	75.32	0.84	Normal
TP-2	1.5	47.88	60.25	0.79	Normal
	3	43.84	56.27	0.78	Normal
TP-3	1.5	61.48	46.94	1.31	Active
	3	78.5	61.62	1.27	Active
TP-4	1.5	59.39	76.38	0.78	Normal
	3	52.16	68.44	0.76	Normal
TP-5	1.5	62.35	48.88	1.28	Active
	3	77.53	61.74	1.26	Active
TP-6	1.5	28.89	61.66	0.47	In active
	3	32.71	52.28	0.63	In active
TP-7	1.5	28.36	49.30	0.58	In Active
	3	47.7	67.15	0.58	In Active
TP-8	1.5	50.57	65.83	0.77	Normal
	3	49.28	55.08	0.89	Normal
TP-9	1.5	54.97	35.34	1.56	Active
	3	64.98	46.95	1.38	Active
TP-10	1.5	60.77	47.52	1.28	Active
	3	57.04	45.23	1.26	Active

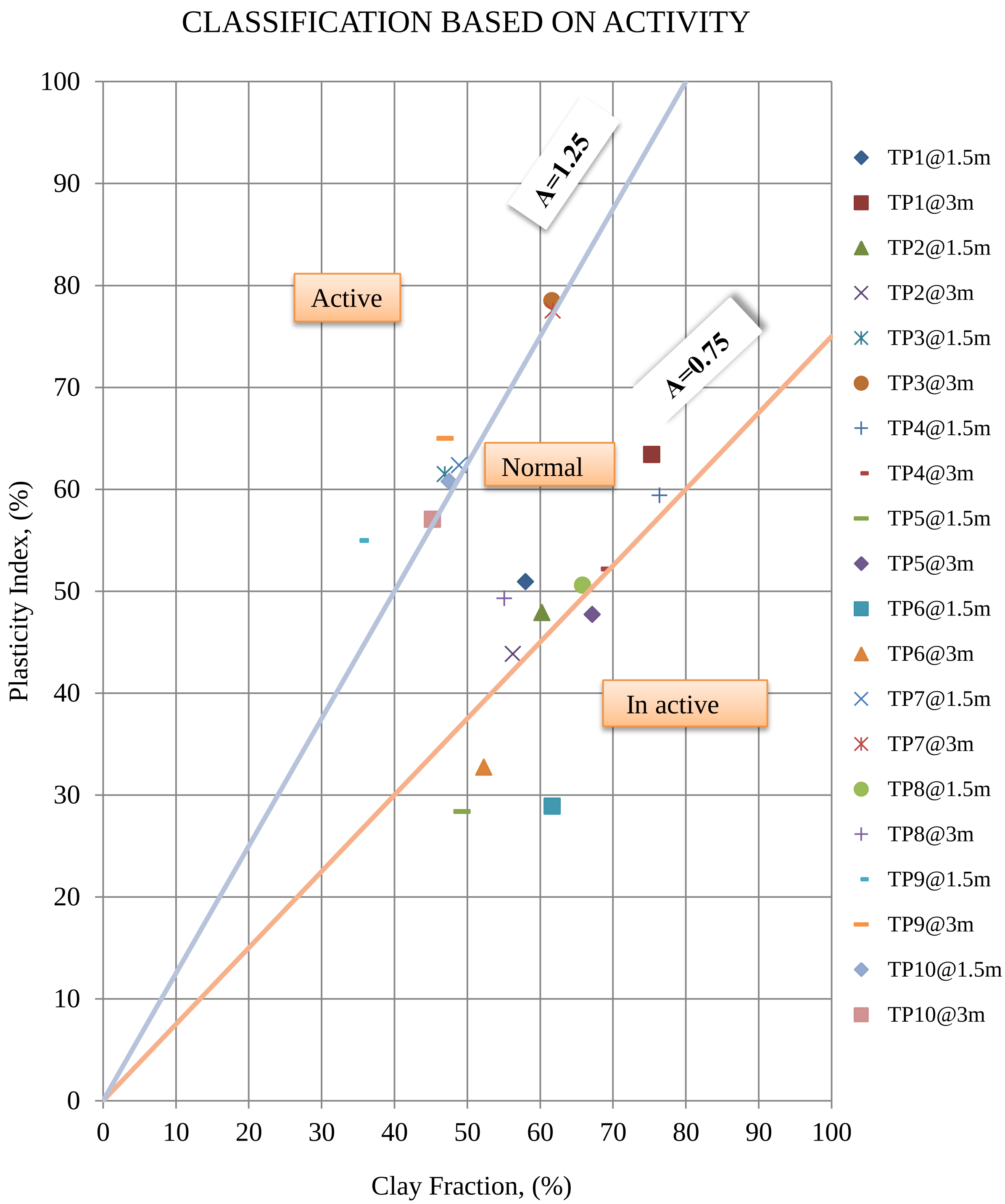


Figure 4.8. Activity chart of soils of the study area

4.3. Shear Strength of Soil

4.3.1. General

The shear strength of a soil is its maximum resistance to shear stresses just before the failure. It is the principal engineering property which controls the stability of a soil mass under loads. It governs the bearing capacity of soils, the stability of slopes in soils, the earth pressure against retaining structure and many other problems. All the problem of soils engineering are related in one way or the other with the shear strength of the soil (Arora, 1986).

The most common laboratory methods employed to obtain shear strength parameters are direct shear test (for cohesion less soils), unconfined compression, UCS test (for cohesive soils) and triaxial compression test (for both cohesive and non- cohesive soils).

For this thesis UCS test are conducted because of its simplicity and the soils of the study area being cohesive soils. .

4.3.2. Unconfined Compression Strength (UCS) Test

Unconfined compression test is a special case of triaxial compression test in which the all-round pressure (the minor principal stress, σ_3 is zero; the major principal stress, σ_1 is the deviator stress. The test is carried out only on saturated sample which can stand without any lateral support. This test is applicable to cohesive soils only. The test is un-drained test and is based on the assumption that there is no moisture loss during the test. This test is one of the simplest and quickest tests used for the determination of shear strength of cohesive soils (Murthy, 1990).

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated un-drained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (q_u) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15 % axial strain, whichever occurs first during the performance of a test (Reddy, 2002).

For soils, the un-drained shear strength (s_u) is necessary for the determination of the bearing capacity of foundations, dams, etc. The un-drained shear strength (s_u) of clays is commonly determined from an unconfined compression test. The un-drained shear strength (s_u) of a cohesive soil is equal to one-half the unconfined compressive strength (q_u) when the soil is under the $\emptyset = 0$ condition ($\emptyset$ = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents un-drained conditions, when the un-drained shear strength is basically equal to the cohesion (c), This is expressed as shown below on equation 4.3.

$$s_u = c_u = \frac{q_u}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots.\ldots\ldots\ldots\ldots.. Eqn\ (4.3)$$

The consistency of clay soils and other cohesive soils is usually described as soft, medium, stiff or hard. The most direct quantitative measure of consistency is the load per unit area at which unconfined cylindrical samples of the soil fails in compression test. This quantity is known as the unconfined compressive strength of the soil (Terzaghi and Ralph.1996).

Table: 4.13 show the general relation between Consistency and unconfined strength of clay soil.

Table 4.13. Consistency and unconfined strength of clay soil

Consistency	q_u (kN/m^2)
Very soft	< 25
Soft	25 – 50
Medium	50 – 100
Stiff	100 – 200
Very stiff	200 – 400
Hard	> 400

Compressive strength of soils of the study area ranges from 62.75 - 135 kN/m^2, which fall in the range of medium-stiff state. The remaining test pits have similar soil texture with either of these test pits. Table: 4.14, Figure 9 and Figure 10 shows UCS test result of soil samples of the study area based on ASTM D 2166-00 test procedure. The detail tests are presented in Appendix-B.

Table 4.14. UCS test result of soil samples of the study area

Test Pit	Depth (m)	UCS, q_u (kPa)	Un-drained Shear Strength, c_u (kPa)	Consistency
TP-1	1.5	85.43	42.72	Medium
	3	104.45	52.23	Stiff
TP-2	1.5	68.48	34.24	Medium
	3	78.65	39.33	Medium
TP-3	1.5	70.39	35.19	Medium
	3	106.34	53.17	Stiff
TP-4	1.5	80.07	40.04	Medium
	3	99.15	49.58	Medium
TP-5	1.5	115.8	57.90	Stiff
	3	132.60	66.30	Stiff
TP-6	1.5	118.02	59.01	Stiff
	3	135.08	67.54	Stiff
TP-7	1.5	75.31	37.66	Medium
	3	111.26	55.63	Stiff
TP-8	1.5	62.75	31.38	Medium
	3	94.99	47.49	Medium
TP-9	1.5	83.32	41.66	Medium
	3	102.94	51.47	Stiff
TP-10	1.5	65.81	32.91	Medium
	3	63.66	31.83	Medium

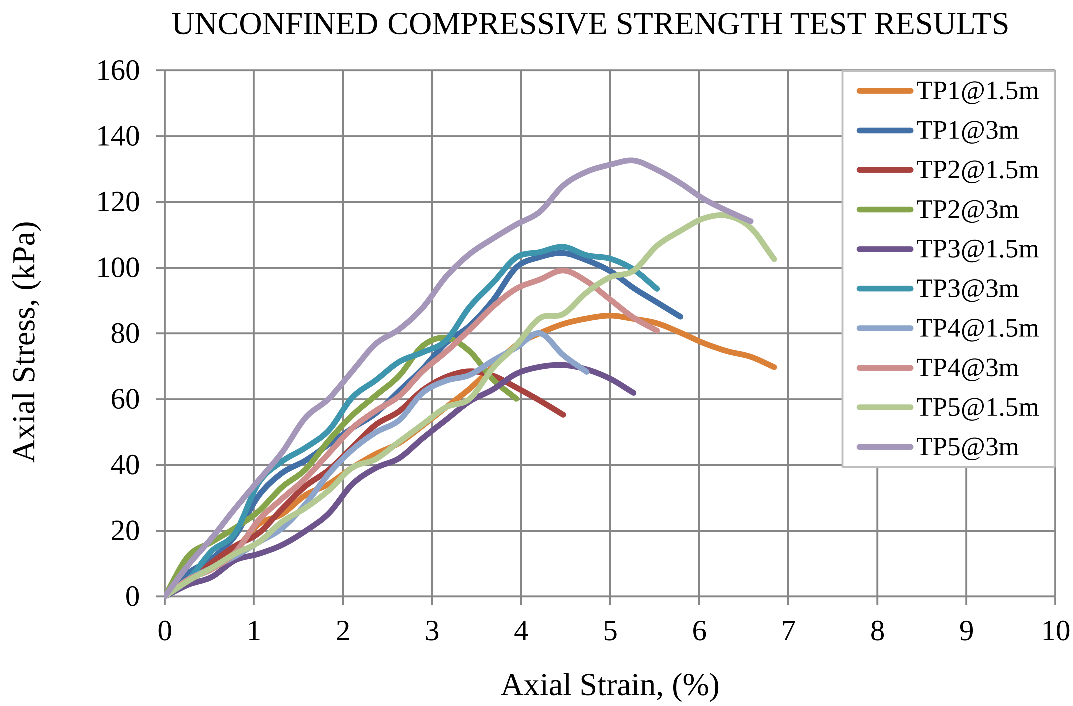


Figure 4.9. Axial stress Vs. Axial Strain of the study area

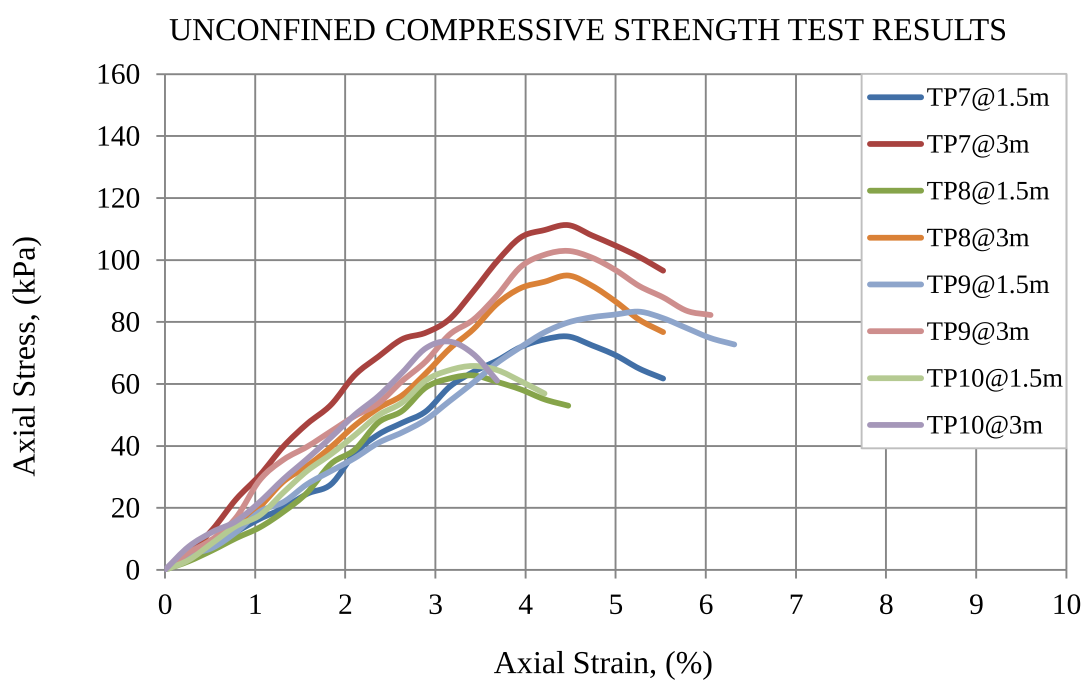


Figure 4.10. Axial stress Vs. Axial Strain of the study area

4.4. Consolidation Test

4.4.1. General

Structures are built on soils and transfer loads to the subsoil through the foundation, it results in increased stresses in the underlying soils. The increase in stress generally causes settlements. When the soils are fine grained and saturated the increase in total stress is carried by the water, as excess pore pressure. Since these soils have low hydraulic conductivity the excess pore pressure will dissipate slowly and the settlement will be delayed in time. The consolidation test, also called Odometer test, is used to determine the parameters that can be used to estimate both the magnitude and the time rate of the settlements (Giovanna, 2007).

The change in volume of the mass under imposed stress must be due to the escape of water if the soil is saturated. But, if the soil is partly saturated, the change in volume of the mass is partly due to the compression and escapes of air from the voids and partly due to the dissolution of air in the pore water. Deformation may continue for months, years, or even decades. This is the fundamental and only difference between the compression of granular material and the consolidation of cohesive soils. Compression of sand occurs almost instantly, whereas consolidation is a very time-dependent process. The difference in settlement rates depends on the difference in permeability (Holtz and Kovaks, 1981).

Terzaghi theory of one-dimensional consolidation is based on the assumption that the soil is laterally confined and the consolidation takes place only in the vertical direction. In field, as the layers are not laterally confined, the consolidation takes place in all the three-dimensions. In general, the consolidation in the horizontal direction is small and, therefore, neglected. However, in some special cases, such as in sand drains, there is significant radial drainage, in additional to the vertical drainage. For such cases, three-dimensional consolidation equation is required to determine the rate of consolidation. But in this thesis one-dimensional consolidation test are used for the soils of the study area which is cohesive soil.

4.4.2. One-Dimensional Consolidation Test

This test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures.

From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the pre-consolidation pressure (or maximum past pressure) of the soil.

The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earth-fill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

4.4.2.1. Test Procedure

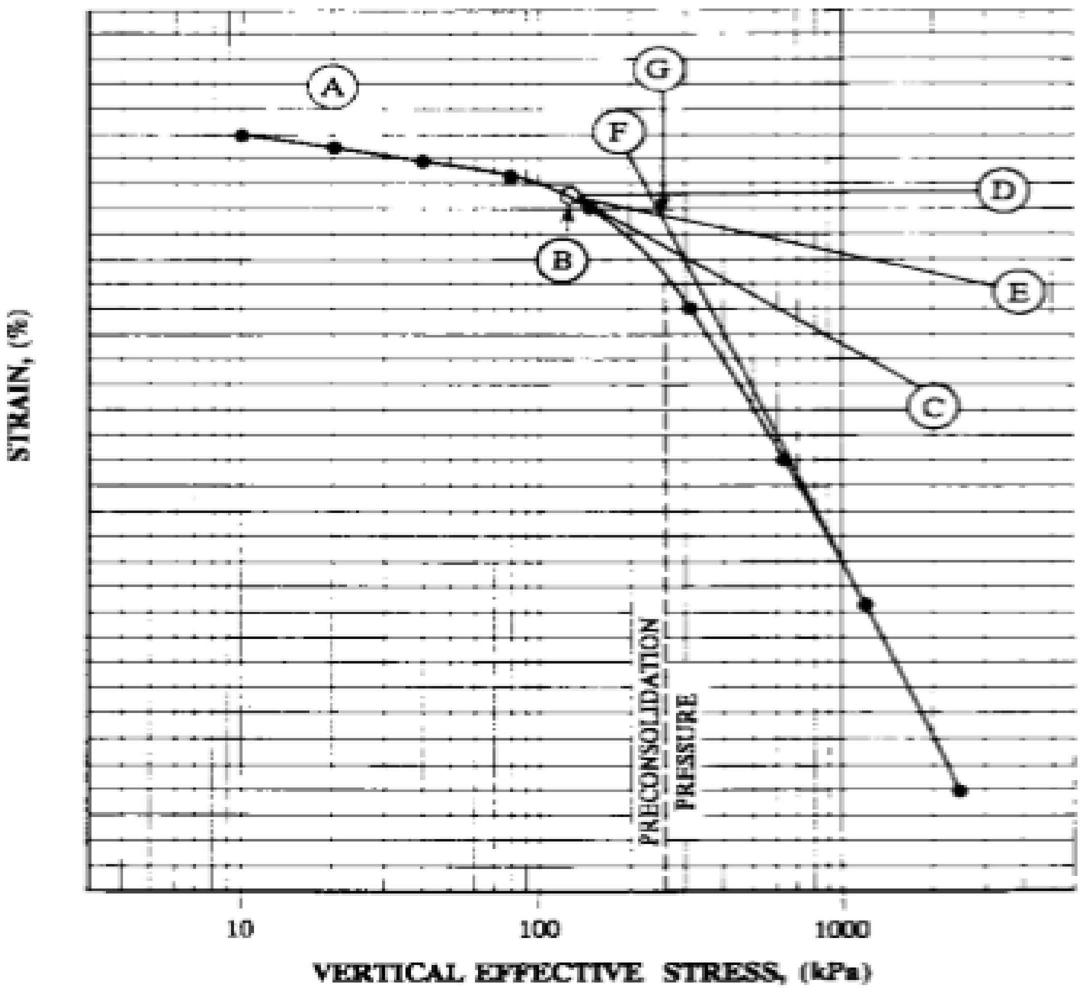
The test is performed on a cylindrical specimen, constrained laterally by a ring and allowed to compress under a constant load. The seating load (7 kPa) is held on the sample for 24 hours or until all excess pore pressure is dissipated. During this time the change in height is measured. The load is usually doubled at the end of the 24 hour period and the process repeated. Usually 5 or 6 load increments are applied and then data are taken during one unloading step. The measurements are used to determine the relationship between the effective stress and void ratio or strain, and the rate at which consolidation can occur (Giovanna, 2007).

Record the height or change in height, d, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 min, and 1, 2, 4, 8 and 24 hr. Take sufficient readings near the end of the pressure increment period to verify that primary consolidation is completed. The load was doubled every 24 hours starting from 50 kPa to 1600 kPa. This procedure was followed for all the samples. Unloading was also done by steps to examine the unloading behavior.

4.4.2.2. Pre-Consolidation Pressure

The maximum pressure to which an over consolidated soil had been subjected in the past is known as the pre-consolidation pressure or over consolidation pressure (P_c). When a soil specimen is taken from a natural deposit, the weight of the overlying material (over-burden) is removed. This causes an expansion of the soil due to a reduction in pressure (Arora, 1986).

Several methods have been proposed for determining the value of the maximum consolidation pressure. There are a few graphical methods for determining the pre-consolidation pressure based on laboratory test data. No suitable criteria exist for appraising the relative merits of the various methods. The earliest and the most widely used method was the one proposed by Casagrande (1936). The method involves locating the point of maximum curvature, B, on the laboratory e-log p curve of an undisturbed sample as shown in Figure 4.11. From B, a tangent is drawn to the curve and a horizontal line is also constructed. The angle between these two lines is then bisected. The abscissa of the point of intersection of this bisector with the upward extension of the inclined straight part corresponds to the pre-consolidation pressure (P_c) (Budhu, 2000). Figure 4.12 shows the plot of void ratio V_s pressure curve used to determine P_c and Summary of the consolidation test results of soil samples of the study area Presented in Table 4.15 and Table 4.16 using ASTM D 2435-96 test procedure.



A	STRESS STRAIN CURVE FROM DATA POINTS
B	POINT OF MAXIMUM CURVATURE
C	TANGENT LINE TO CURVE AT POINT B
D	HORIZONTAL LINE THROUGH POINT B
E	LINE BISECTING ANGLE BETWEEN LINES C AND D
F	TANGENT TO LINEAR PORTION OF CURVE IN VIRGIN COMPRESSION RANGE
G	INTERSECTION OF LINES E AND F (VERTICAL EFFECTIVE STRESS AT POINT G EQUALS THE PRECONSOLIDATION PRESSURE)

Figure 4.11. Evaluation for Pre-consolidation Pressure From Casagrande Method (ASTM D 2435)

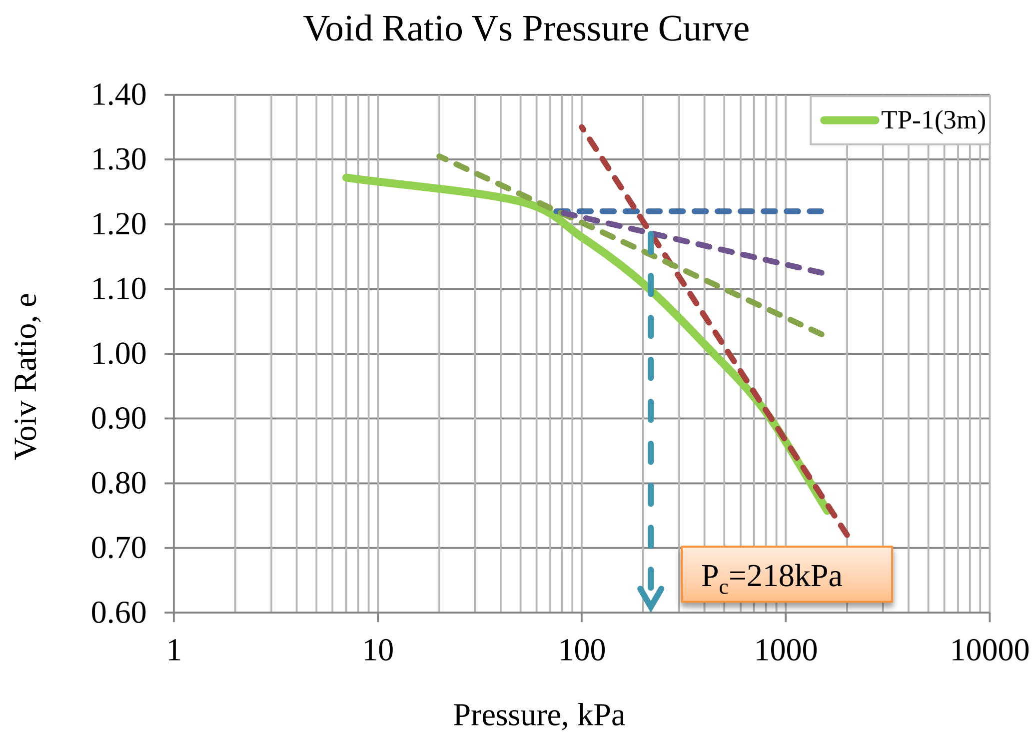


Figure 4.12. Plot of void ratio Vs pressure curve used to determine P_c

4.4.2.3. Compression (C_c) and Recompression Index (C_r)

The compression index, C_c will be the slope of loading curve and recompression index, C_r will be the slope of unloading curve. Figure 4.13, Figure 4.14 and Figure 4.15 shows the plot of loading unloading curve to calculate compression and recompression index. Therefore, by taking any two points on the straight portions for both loading and unloading curves, C_c and C_r can be estimate using Equation 4.4 and Equation 4.5 respectively.

$$\text{Compression Index } = \frac{e_1 - e_2}{\log P_2 - \log P_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn}(4.4)$$

$$\text{Recompression Index } = \frac{e_1 - e_2}{\log P_2 - \log P_1} \ldots\ldots\ldots.\ldots\ldots\ldots\ldots \text{Eqn}(4.5)$$

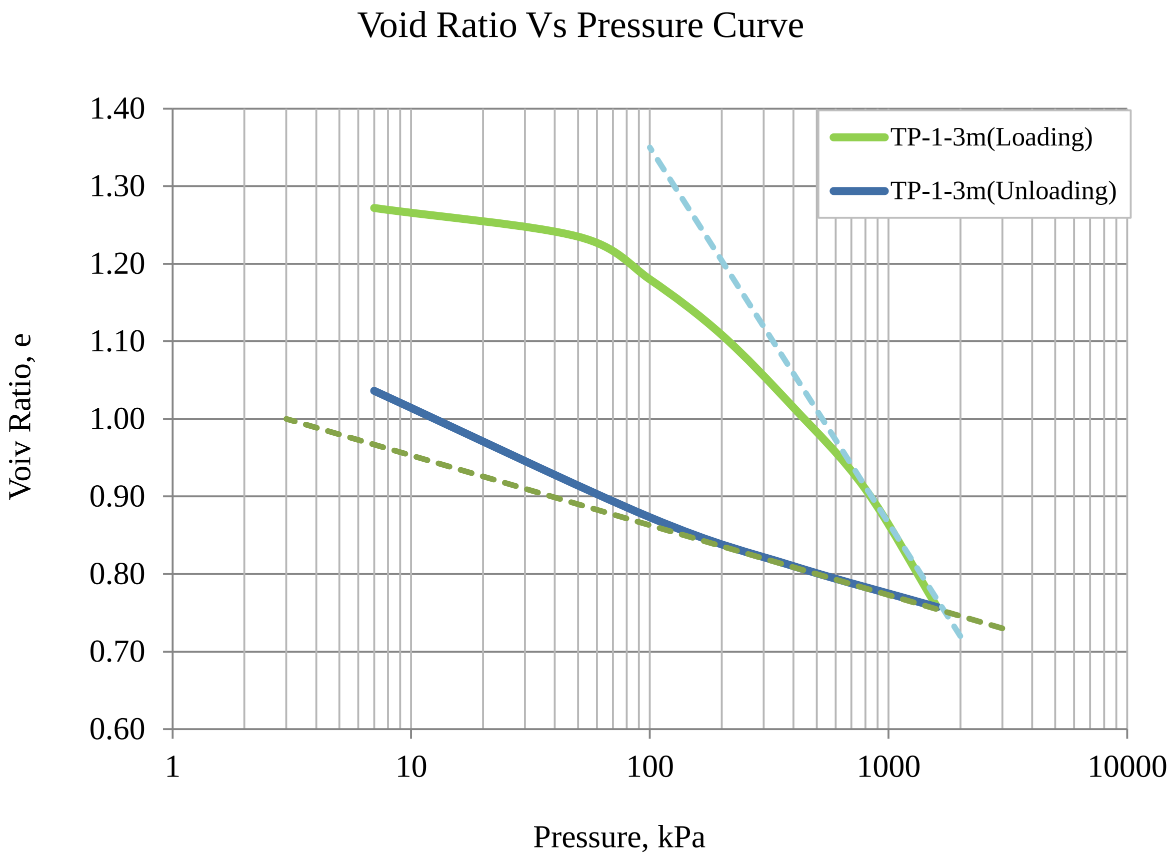


Figure 4.13. Plot of loading unloading curve to calculate compression and recompression index

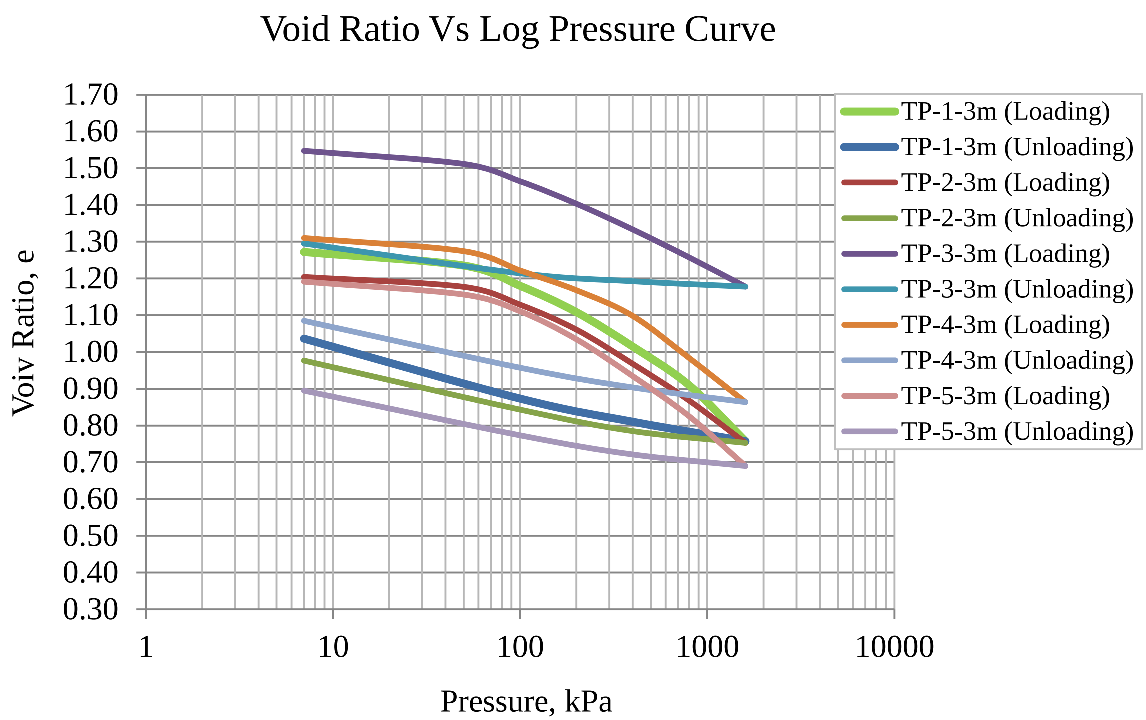


Figure 4.14. Plot of vertical effective stress V_s void ratio on semi-log scale for TP 1-5

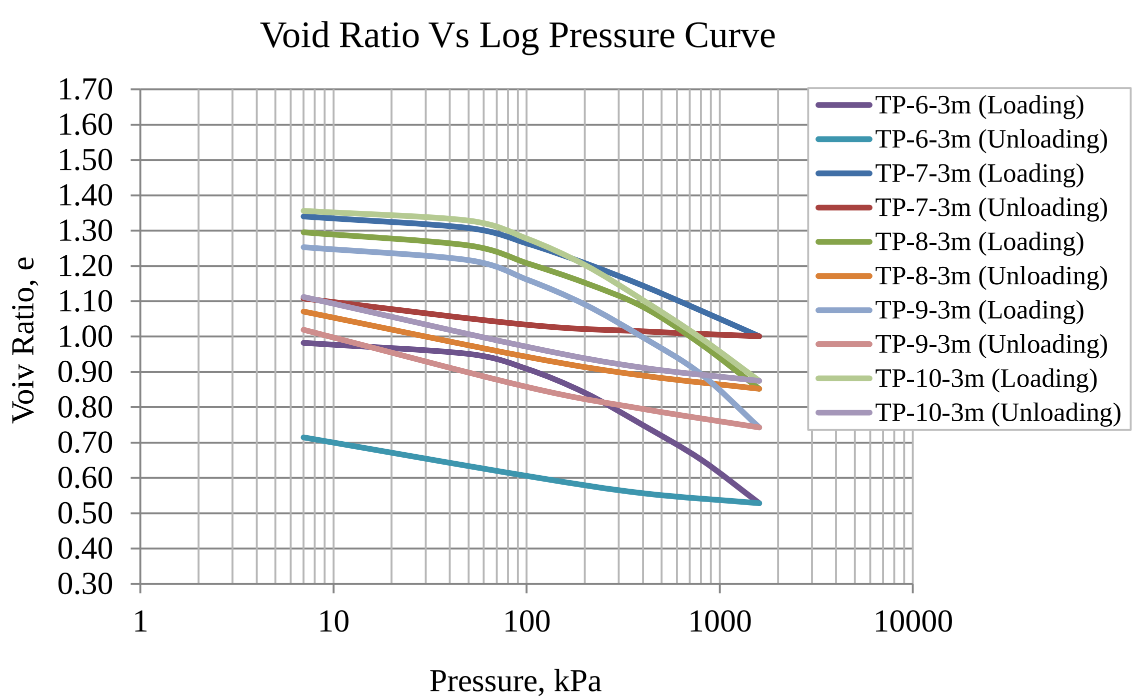


Figure 4.15. Plot of vertical effective stress V_s void ratio on semi-log scale for TP 6-10

Table 4.15. Summary of the consolidation test results of soil samples of the study area

Test Pit	Depth (m)	Total Unit Weight (kN/m^3)	Incremetal Load, P (kPa)	Void Ratio, e_f	Compression Index, C_c	Re-Compression Index, C_s	Pre-consolidation Pressure, P_c (kPa)	Over-burden Pressure, P_o (kPa)	Over Consolidation Ratio, OCR
TP-1	3	18.7	7	1.27	0.427	0.096	218.00	56.10	3.89
			50	1.24					
			100	1.18					
			200	1.11					
			400	1.01					
			800	0.91					
			1600	0.76					
			1600	0.76					
			400	0.81					
			100	0.87					
			7	1.04					
TP-2	3	18.5	7	1.20	0.357	0.075	145.00	55.50	2.61
			50	1.18					
			100	1.13					
			200	1.06					
			400	0.97					
			800	0.87					
			1600	0.75					
			1600	0.75					
			400	0.78					
			100	0.84					
			7	0.98					
TP-3	3	18.1	7	1.55	0.258	0.030	145.00	54.30	2.67
			50	1.51					
			100	1.46					
			200	1.40					
			400	1.33					
			800	1.26					
			1600	1.18					
			1600	1.18					
			400	1.19					
			100	1.21					
			7	1.29					
TP-4	3	18.2	7	1.31	0.389	0.078	204.00	54.60	3.74
			50	1.27					
			100	1.22					
			200	1.17					
			400	1.10					
			800	0.98					
			1600	0.86					
			1600	0.86					
			400	0.90					
			100	0.96					
			7	1.08					
TP-5	3	17.6	7	1.19	0.406	0.069	168.00	52.80	3.18
			50	1.16					
			100	1.11					
			200	1.03					
			400	0.93					
			800	0.83					
			1600	0.69					
			1600	0.69					
			400	0.72					
			100	0.77					
			7	0.89					

Table 4.16. Summary of the consolidation test results of soil samples of the study area

Test Pit	Depth (m)	Total Unit Weight (kN/m^3)	Incremental Load, P (kPa)	Void Ratio, e_f	Compression Index, C_c	Re-Compression Index, C_s	Pre-consolidation Pressure, P_c (kPa)	Over-burden Pressure, P_o (kPa)	Over Consolidation Ratio, OCR
TP-6	3	17.5	7	0.98	0.367	0.064	238.00	52.50	4.53
			50	0.95					
			100	0.91					
			200	0.84					
			400	0.75					
			800	0.65					
			1600	0.53					
			1600	0.53					
			400	0.56					
			100	0.61					
			7	0.71					
TP-7	3	18.4	7	1.34	0.238	0.027	120.00	55.20	2.17
			50	1.31					
			100	1.26					
			200	1.21					
			400	1.14					
			800	1.07					
			1600	1.00					
			1600	1.00					
			400	1.01					
			100	1.03					
			7	1.11					
TP-8	3	18.8	7	1.30	0.385	0.075	176.00	56.40	3.12
			50	1.26					
			100	1.21					
			200	1.15					
			400	1.08					
			800	0.98					
			1600	0.85					
			1600	0.85					
			400	0.89					
			100	0.94					
			7	1.07					
TP-9	3	18.6	7	1.25	0.424	0.095	190.00	55.80	3.41
			50	1.22					
			100	1.16					
			200	1.09					
			400	1.00					
			800	0.89					
			1600	0.74					
			1600	0.74					
			400	0.80					
			100	0.86					
			7	1.02					
TP-10	3	18.5	7	1.36	0.380	0.080	122.00	55.50	2.20
			50	1.33					
			100	1.28					
			200	1.20					
			400	1.10					
			800	1.00					
			1600	0.87					
			1600	0.87					
			400	0.91					
			100	0.97					
			7	1.11					

4.4.2.4. Relative Settlement

Relative settlement versus effective stress, σ' or the void ratio against effective stress, σ' plot is used to determine the coefficients (v and w) of the equation of modulus of compressibility; For soils, whose behavior is typically non-linear, modulus of compressibility (E_s) is not constant.

The coefficient v depends on the void ratio, water content and consistency of the sample, it could have values ranging from 50 to 3000 kN/m^2. While as w depends on soil type. It could assume values ranging from 0 to 1 (Jumikis, 1962).

On the data obtained from one dimensional consolidation test, relative settlement versus pressure (effective stress) was plotted on log-log scale as shown in Figure 4.16 and Figure 4.17. For further study, one can be formulate the equation of modulus of compressibility and can be observe that the relationship between the effective stress, σ' and the modulus of compressibility (E_s). Summary of total compression and relative settlement values of the samples presented in Table 4.17 and Table 4.18.

Table 4.17 Summary of total compression and relative settlement

Test Pit	Depth, (m)	Effective Stress, P (kPa)	Total Compression, ΔH (mm)	Relative Settlement, $s = \Delta H/H_i$
TP-1	3	7	0.000	0.000
		50	0.325	0.016
		100	0.485	0.024
		200	0.630	0.032
		400	0.825	0.041
		800	0.925	0.046
		1600	1.340	0.067
TP-2	3	7	0.000	0.000
		50	0.245	0.012
		100	0.440	0.022
		200	0.615	0.031
		400	0.845	0.042
		800	0.905	0.045
		1600	1.045	0.052
TP-3	3	7	0.000	0.000
		50	0.280	0.014
		100	0.370	0.019
		200	0.480	0.024
		400	0.550	0.028
		800	0.595	0.030
		1600	0.625	0.031
TP-4	3	7	0.000	0.000
		50	0.310	0.016
		100	0.455	0.023
		200	0.465	0.023
		400	0.605	0.030
		800	0.990	0.050
		1600	1.040	0.052
TP-5	3	7	0.000	0.000
		50	0.320	0.016
		100	0.415	0.021
		200	0.695	0.035
		400	0.915	0.046
		800	0.995	0.050
		1600	1.235	0.062

Table 4.18. Summary of total compression and relative settlement

Test Pit	Depth, (m)	Effective Stress, P (kPa)	Total Compression, ΔH (mm)	Relative Settlement, $s = \Delta H/H_i$
TP-6	3	7	0.000	0.000
		50	0.315	0.016
		100	0.425	0.021
		200	0.685	0.034
		400	0.925	0.046
		800	0.985	0.049
		1600	1.245	0.062
TP-7	3	7	0.000	0.000
		50	0.280	0.014
		100	0.370	0.019
		200	0.480	0.024
		400	0.545	0.027
		800	0.605	0.030
		1600	0.620	0.031
TP-8	3	7	0.000	0.000
		50	0.325	0.016
		100	0.435	0.022
		200	0.485	0.024
		400	0.595	0.030
		800	0.920	0.046
		1600	1.100	0.055
TP-9	3	7	0.000	0.000
		50	0.325	0.016
		100	0.485	0.024
		200	0.630	0.032
		400	0.825	0.041
		800	0.925	0.046
		1600	1.340	0.067
TP-10	3	7	0.000	0.000
		50	0.235	0.012
		100	0.430	0.022
		200	0.635	0.032
		400	0.845	0.042
		800	0.915	0.046
		1600	1.025	0.051

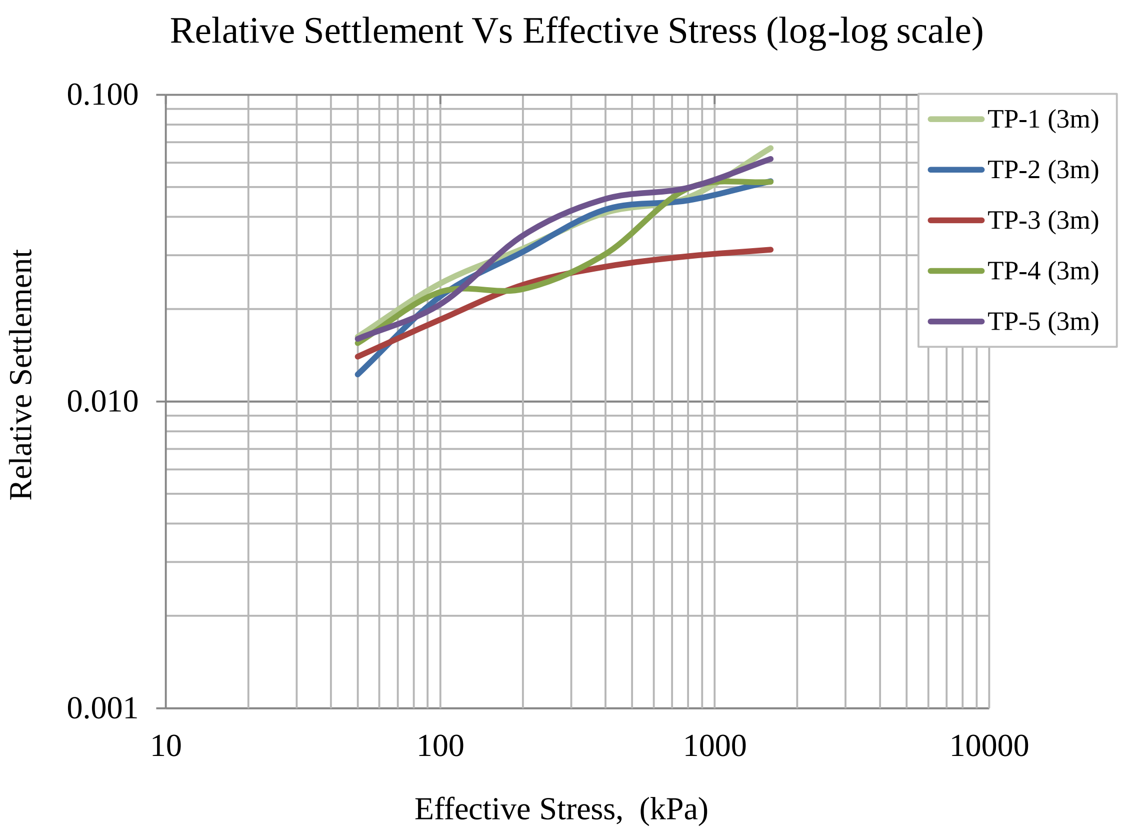


Figure 4.16. Effective stress Vs relative settlement for TP 1-5

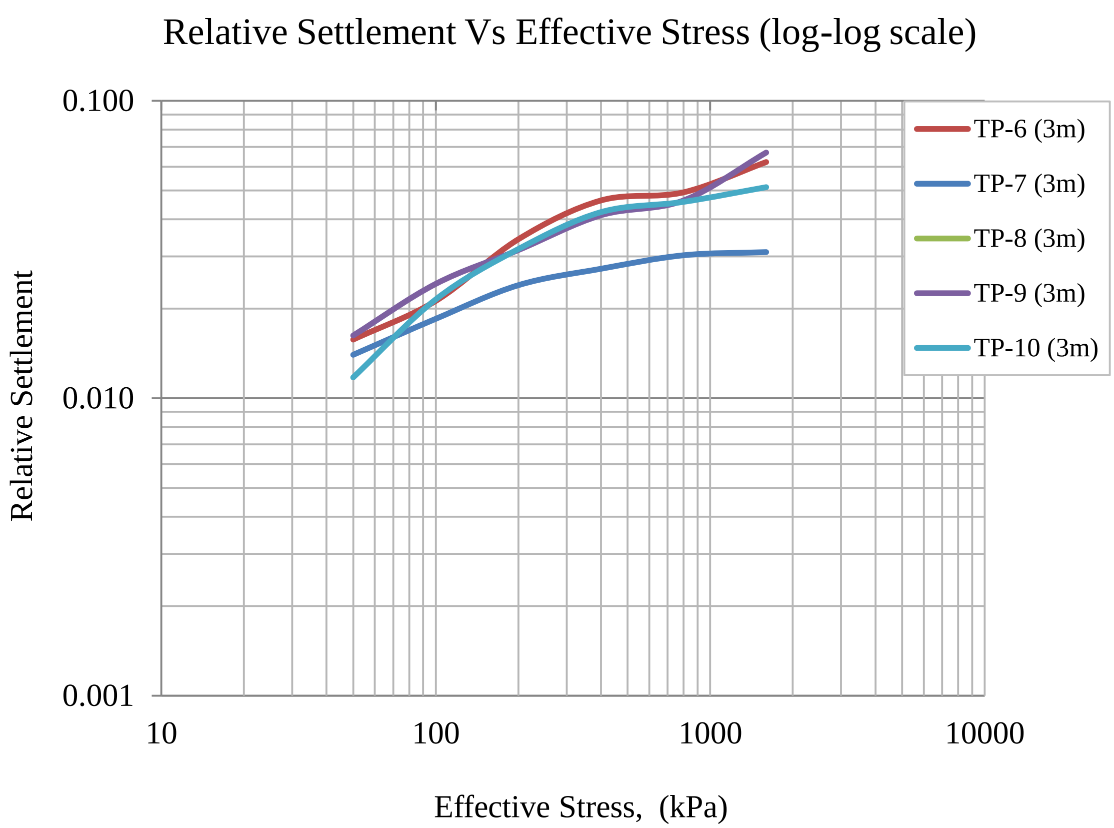


Figure 4.17. Effective stress Vs relative settlement for TP 6-10

4.5. Discussions of the Laboratory Test Results

The specific gravity of soils of the study area ranges from 2.55 - 2.76; Which indicate that the range of typical specific gravity values of inorganic soils (Arora, 1986).

Test results of Atterberg's limits indicate that soils of the study are have Liquid limit ranging from 60.59 - 98.98 %, plastic limit 20.48 - 41.51 % and PI ranging from 28.36 - 78.50 %. Based on the test results the plasticity chart shows us, the soils have clay with high plasticity and also silt with high plasticity.

The Grain Size analysis result is shown in Figure 4.2 and Figure 4.3 and the summary of grain size analysis result is shown on Table 4.6. From the figure, more than 65 % of the soil particles passes on Sieve no. 200 in all test pits. This means the soil in the study area is fine-grained soils (silt and clayey soils). The results indicate that the predominant proportion of soil particles in the study area is clay and silt, which have clay content ranging from 45.23 - 76.38 %, silt content ranging from 20.33 - 60.47 %, sand content ranging from 1.28 - 5.30 % and gravel content ranging from 0.00 - 11.08 %. This shows that soils of the study area consists of a wide range of grain sizes ranging from clay to gravel.

Free swell test results are summarized in Table 4.7. From the test result one can see that the free swell of the soil under investigation ranges from 43 – 164 %. This shows that the degree of expansiveness of the soils is ranging from non-expansive to expansive.

Table 4.9 and Figure 4.5 indicate classifications of soils of the study area according to AASHTO soil classification system. Accordingly soils of the study area are grouped in A-7-5 and A-7-6. The higher group index (i.e. greater than 20) of the soils indicate that soils of the study area are clayey soil with poor quality as a subgrade material.

Table 4.10 and Figure 4.7 show classification of soils of the study area according to Unified Soil Classification System (USCS). Figure 4.7 shows plasticity chart of the study area according to USCS. This chart shows that the soil under investigation lies below the A-line in the region of inorganic silt with high plasticity. This chart also shows that samples located above A-line, which is inorganic clay with high plasticity. Accordingly soils of the study area are classified as highly plastic clay (CH) and highly plastic silt (MH).

The unconfined compressive strength, q_u results of the study area conducted on undisturbed representative samples range from 62.75 – 135 kN/m^2 at natural moisture content of 21.67 - 39.61 %; the un-drained shear strength, C_u ranges from 31.38 - 67.54 kN/m^2. This indicates that the consistency index of the soil ranges from medium to stiff clay soil. The characteristics of such soils can be pressed into or with pressure by thump to soft and medium soil, respectively as observed in the field.

Figure 4.13 show the ten- representative undisturbed sample plot of vertical effective stress V_s void ratio on semi-log. Except their variation in initial void ratio the plot shows similar curvature for all the samples. The soil has a Pre-consolidation Pressure, P_c range from 122 - 238 kN/m^2 and Over-burden Pressure, P_o range from 52.5 - 56.4 kN/m^2. Over Consolidation Ratio, OCR of the soil samples range from 2.20 - 4.53 which are more than one, so the soil in the study area is over consolidated in its natural state. The compression and recompression index of the soils is calculated from the straight portions of the loading and unloading e-log p curve (Fiure4.13), the typical loading-unloading curve as shown in Figure 4.12. This calculation shows that the compression index, C_c, ranges from 0.258 – 0.427 and recompression index, C_r range from0.030 - 0.096.

4.6. Comparison of Test Results with Previously Done Researches

The soil in Tis Abay must be compared with silt and clay soils. For the soil under investigation Index property, UCS and one dimensional consolidation tests were studied and comparisons were made with known black and red clay soils found in the different part of the country. Results of the current research are summarized and compared to with range of values of soils found in the different part of the country. A comparison of the study area soils with other parts of the country is given in the Table 4.19.

Table 4.19. Comparison of test results in different parts of the country

Description	Morin and Perry, (1971)	Previous research (Haile mariam, 1992)	Previous research (Tadesse, 2014)	Previous research (Adiszem en,2005)	Previous research (Adem, 2014)	Current research
Soil Type	Red clay	Red clay	Silty and Black Clay	Black Clay	Red clay	Red and Black clay
Location	Ethiopia	A.Ababa	Woldiya	Gondar	D.Markos	Tis Abay
Clay Content (%)	34 - 76	48 - 73	6 - 50	41 - 82	50 - 73	45 - 76
Activity	-	-	0.89-1.27	0.76-1.47	-	0.47-1.56
LL (%)	44 - 66	60 - 68	34 - 97	68 - 110	45 - 68	60 - 98
PL (%)	-	14 - 18	28 - 35	-	18 - 38	20 - 41
PI (%)	14 - 30	25 - 30	5 - 63	45 - 78	15 - 40	28 - 78
Gs	2.61 -2.9	2.7-2.83	2.65-3.0	-	2.69-2.84	2.55-2.76
Free swell (%)	-	8 - 13	39 - 130	-	30 - 180	43 - 164
plasticity chart	-	-	CH,ML	-	MH,CH,CL	CH,MH
q_u (kPa)	-	-	64 - 91	-	320 - 382	62 - 135

As shown in the Table 4.19 the soils of Tis Abay town have considerable similarities with clay content, activity, atterberg's limit, specific gravity and classification when compared with the previously tested soils found in the different part of the country. More similarity is observed with respect to the index tests and physical properties. Moreover, the test result shows that the value of plasticity is high as these soils due to the mode of formation. Generally, the ranges of values for the present study are close to the results obtained by previous researchers; So that, the soils are more or less in same range that have similar properties.

4.7. Soil Map of Tis Abay Town

The soil map of the study area was prepared using laboratory test results and visual observation of the area. Visual observation of the study area made during reconnaissance survey for selection of the test pit location and shows that most parts of Tis Abay town are covered with black cotton soil and some part of the town covered with reddish color soil as shown Figure 4.18. Test pits are excavated to a maximum depth of 3 m and the vertical layer of the soil is similar from the surface to the bottom except test pit number 3, 9 and 10; the vertical soil profiles i.e. bore hole log in details are presented below in Table 4.20 for the ten test pits. Based on the laboratory test results the soil of the study area has two main types of soils which are highly plastic clay soils (CH) and highly plastic silt soils (MH).

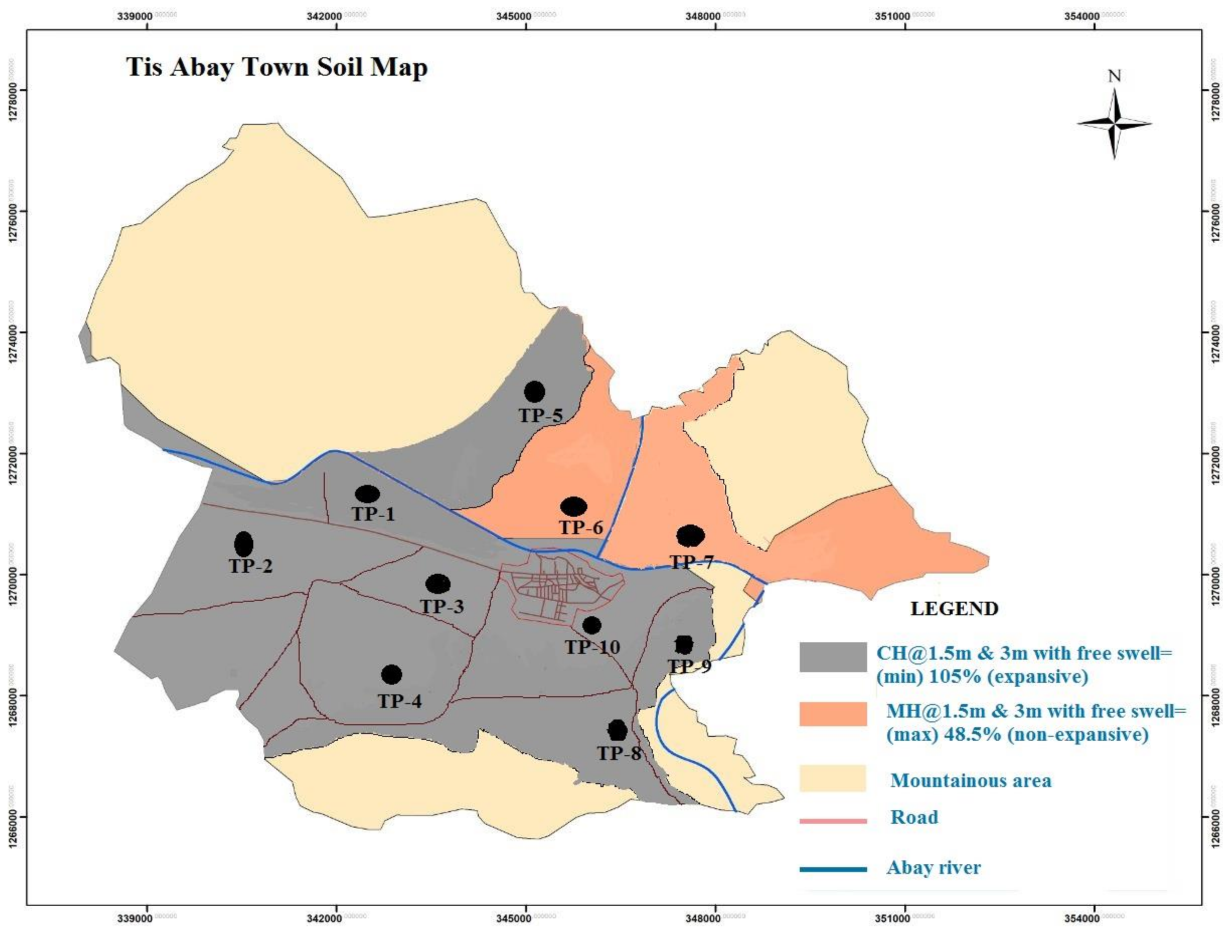


Figure 4.18 Soil map of Tis Abay town

Table 4.20 Bore hole profile

Test Pit-1	**Coordinates (UTM) N: 342298 E: 1271628**		**Elevation (m): 1655**
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test
Test Pit-2	**Coordinates (UTM) N: 341490 E: 1270538**		**Elevation (m): 1672**
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test
Test Pit-3	**Coordinates (UTM) N: 343599 E: 1270235**		**Elevation (m): 1665**
Depth (m)	Vertical Profile	Description	Conducted Tests
-0.3	-	Fill	-
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test
Test Pit-4	**Coordinates (UTM) N: 342455 E: 1268454**		**Elevation (m): 1676**
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test
Test Pit-5	**Coordinates (UTM) N: 345165 E: 1271853**		**Elevation (m): 1668**
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test

Test Pit-6	Coordinates (UTM) N: 346063 E: 1270859		Elevation (m): 1623
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Reddish Silt Soil	Index and UCS Test
-3		Reddish Silt Soil	Index, UCS and ODC Test
Test Pit-7	**Coordinates (UTM) N: 347290 E: 1270561**		**Elevation (m): 1617**
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Reddish Silt Soil	Index and UCS Test
-3		Reddish Silt Soil	Index, UCS and ODC Test
Test Pit-8	**Coordinates (UTM) N: 346167 E: 1267551**		**Elevation (m): 1644**
Depth (m)	Vertical Profile	Description	Conducted Tests
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test
Test Pit-9	**Coordinates (UTM) N: 348479 E: 1268551**		**Elevation (m): 1637**
Depth (m)	Vertical Profile	Description	Conducted Tests
-0.25	-	Fill	-
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test
Test Pit-10	**Coordinates (UTM) N: 345795 E: 1269787**		**Elevation (m): 1612**
Depth (m)	Vertical Profile	Description	Conducted Tests
-0.35	-	Fill	-
-1.5		Black Clay Soil	Index and UCS Test
-3		Black Clay Soil	Index, UCS and ODC Test

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From the laboratory tests results which were done for this research work, the following conclusion can be drawn.

- Since pit excavation method of exploration is used, the outcomes would be applicable only for structures which under lie their foundation up to depth of 3 m.
- From the laboratory test performed, it can be observed that there no significant variations of engineering properties within the investigated depths unlike for different pits which were found in the study area.
- The test results show that the soils in the study area are black and red clay soils. The North-East part of Tis Abay town is covered by Reddish clay soil which is not-expansive; the other part of the town covered by black clay soil which is expansive.
- Test results of Atterberg's limits indicate that soils of the study are have Liquid limit ranging from 60.59 - 98.98 %, plastic limit 20.48 - 41.51 % and PI ranging from 28.36 - 78.50 %. This indicates that soils of the study area are highly plastic.
- Grain size analysis tests revealed that from 1.5 m and 3 m depths, the soil found in Tis Abay town have clay soil which is the dominant proportion of soil particle according to USCS and AASHTO classifications. Percentage of clay content ranges from 45.23 - 76.38, silt content from 20.33 - 60.47 %, sand from 1.28 - 5.30 % and gravel from 0.00 - 11.08 %.
- The specific gravity of soils of the study area ranges from 2.55 - 2.76; Which indicate that the range of typical specific gravity values of inorganic soils.
- The free swell values in the study area ranges from 43 – 164 %. This shows the soil in the study area is partially non expansive and partially expansive.

- The Activity also showed that, the soil under investigation has activity number of greater and less than 1.25 and analogously the free swell tests gives free swell of greater and less than 100 %. Therefore, Tis Abay soil is partly active and inactive as compared to the swelling characteristic of other fine grained soil.
- USCS soil classification system indicates two main types of soils, which are: CH, high plastic clay soils and MH, high plastic silt soils whereas AASHTO soil classification system shows that soils of the study area are grouped in A-7-5 and A-7-6, this indicate that they have poor quality and unsuitable for using as a sub grade material.
- The results of unconfined compressive strength test of the study area range from 62.75 – 135 kN/m^2 at natural moisture content of 21.67 - 39.61 %.
- As determined from the one-dimensional consolidation test conducted on undisturbed soil samples, Pre-consolidation Pressure, P_c range from 122 – 238 kN/m^2, Over-burden Pressure, P_o range from 52.5 - 56.4 kN/m^2, compression index, C_c range from 0.258 - 0.427 and recompression index, C_r range from0.030 - 0.096, Over Consolidation Ratio, OCR range from 2.20 - 4.53.

5.2. Recommendations

- Obviously, soils may have different characteristics with in a small depth or distance difference; by increasing the number of test pits more detail and accurate results can be obtained.
- Correlations that relate index proprieties with shear strength parameters were not done. Further studies can shade light on this aspect of the problem.

5.3. Limitation

- Due to shortage of budget and time limitation only ten test pits were excavated to the maximum depth of 3 m. Ten test pits are not enough to generalize the engineering properties of soils found in Tis Abay town.
- And also due to the above reason all engineering properties were not studied.

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APPENDIX

Appendix-A: Index Properties

Appendix A1. Natural moisture content determination

Table A1 - 1. Natural Moisture Content Determination

Test Pit	Depth	M_c = Mass of empty, clean can + lid (g)	M_{cms} = Mass of can, lid, and moisture (g)	M_{cds} = Mass of can, lid, and dry soil (g)	M_s =(M_{cds}-M_c) = Mass of soil solids (g)	M_w = (M_{cms}-M_{cds}) = Mass of pore water (g)	W = (M_w*100/ M_s) = Water content, w (%)
TP-1	1.5m	29.3	106.5	87.6	58.3	18.9	32.42
	3m	24.8	97.4	77.9	53.1	19.5	36.72
TP-2	1.5m	19.4	98.6	80.1	60.7	18.5	30.48
	3m	31.2	102.1	83.1	51.9	19	36.61
TP-3	1.5m	32.3	76.9	65.3	33	11.6	35.15
	3m	26.5	115.6	91.9	65.4	23.7	36.24
TP-4	1.5m	18.2	135.4	103.5	85.3	31.9	37.4
	3m	20.5	143.1	107.3	86.8	35.8	41.24
TP-5	1.5m	29.8	89.9	74.6	44.8	15.3	34.15
	3m	26.5	98	78.4	51.9	19.6	37.76
TP-6	1.5m	24.8	135.4	115.7	90.9	19.7	21.67
	3m	30.1	144.3	123	92.9	21.3	22.93
TP-7	1.5m	19.7	145.3	118.4	98.7	26.9	27.25
	3m	23.1	136.4	110.9	87.8	25.5	29.04
TP-8	1.5m	32.3	80.5	67.2	34.9	13.3	38.11
	3m	31.2	116.5	92.3	61.1	24.2	39.61
TP-9	1.5m	34.5	120.5	96.2	60.1	24.3	40.43
	3m	30.1	140.5	109.3	79.2	31.2	39.39
TP-10	1.5m	32.3	110.6	89.2	56.9	21.4	37.61
	3m	31.2	112.6	90.5	59.3	22.1	37.27

Appendix A2. Specific Gravity Determination

Table A2 - 1.Specific Gravity Determination

Test Pit	Depth	W_P = Mass of empty, clean pycnometer (g)	W_{PS} = Mass of empty pycnometer + dry soil (g)	W_B = Mass of pycnometer + dry soil + water (g)	W_A = Mass of pycnometer + water (g)	$W_0 = (W_{PS} - W_P)$ = weight of sample of oven-dry soil (g)	Specific Gravity, $G_S = W_o/W_o + (W_A - W_B)$
TP-1	1.5m	54.6	79.4	179.6	164.1	24.8	2.67
	3m	60.3	85.7	184.9	168.9	25.4	2.7
TP-2	1.5m	62.5	81.7	167.4	155.2	19.2	2.74
	3m	59.9	87.1	177	160.2	27.2	2.62
TP-3	1.5m	65.6	94.1	179.6	161.6	28.5	2.71
	3m	52.4	84.6	193.3	172.9	32.2	2.73
TP-4	1.5m	51.1	73.3	161.4	147.5	22.2	2.67
	3m	64.6	89.7	178.4	162.6	25.1	2.7
TP-5	1.5m	59.9	79.5	179.6	167.4	19.6	2.65
	3m	65.6	89.2	175.6	160.8	23.6	2.68
TP-6	1.5m	54.6	78.8	169.4	154.6	24.2	2.57
	3m	52.4	73.4	165.4	152.5	21	2.59
TP-7	1.5m	64.6	90.4	180.4	164.4	25.8	2.63
	3m	54.6	80.6	176.9	161.1	26	2.55
TP-8	1.5m	65.6	97.5	175.3	155.1	31.9	2.73
	3m	52.4	79.2	180.6	163.5	26.8	2.76
TP-9	1.5m	64.6	91.3	160.5	143.6	26.7	2.72
	3m	51.1	76.5	171.6	155.5	25.4	2.73
TP-10	1.5m	65.6	90.4	177.9	162.4	24.8	2.67
	3m	59.9	85.6	174.6	158.5	25.7	2.68

Appendix A3. Atterberg Limits Determination

Table A3 - 1. Atterberg Limit Determination

-Sample No: 1 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	36.3	34.6	28.2	33.7	28.2	34.6	34.2	
M_{cms}= Mass of can, lid, and moist soil (g)	97.5	120.4	111	109.6	38	40.2	40.33	
M_{cds} = Mass of can, lid, and dry soil (g)	70.5	81.6	73.4	75.8	35.7	38.9	38.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	27	38.8	37.6	33.8	2.3	1.3	1.43	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	34.2	47	45.2	42.1	7.5	4.3	4.7	
Water content, W %= ((M_w)/(M_s))*100%	78.95	82.55	83.19	80.29	30.67	30.23	30.43	
Number of Blows, N	33	23	17	28				
Average (%)	81.38				30.45			50.93

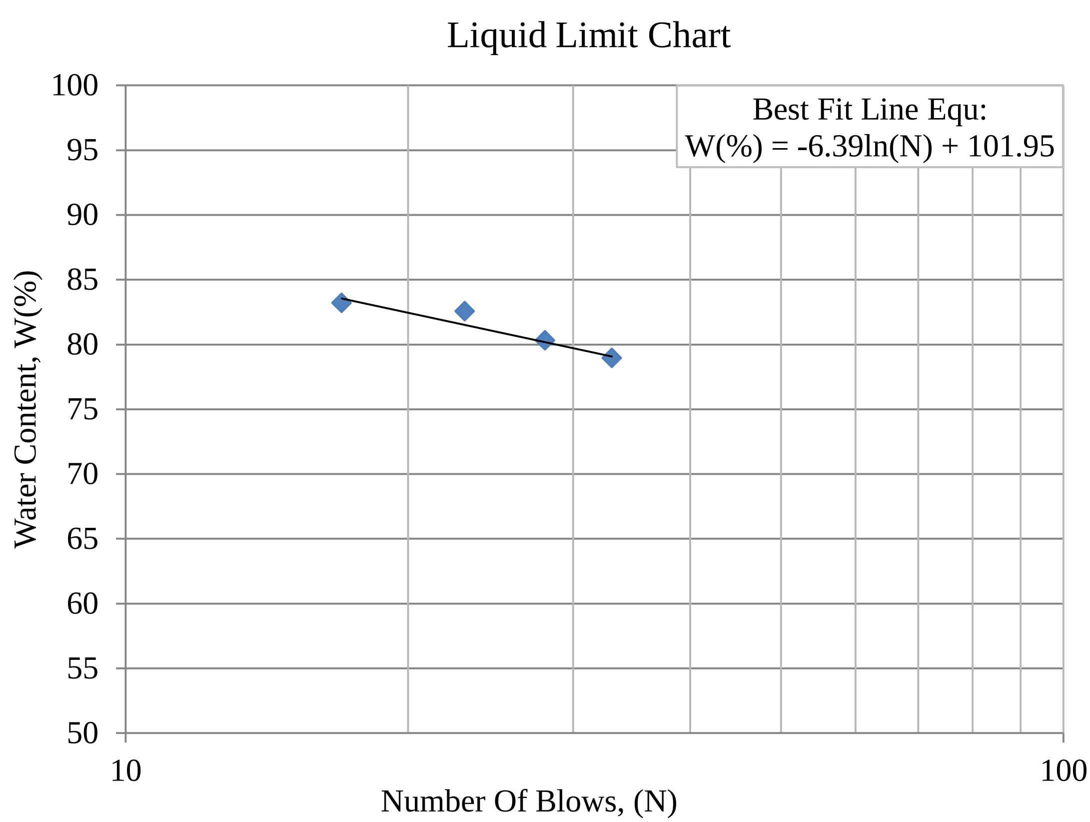

Figure A3-1 Liquid Limit determination for TP-1@1.5 m

Table A3-2 Atterberg Limit Determination

-Sample No: 1 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	19.4	24.8	29.3	26.5	31.2	34.6	33.5	
M_{cms}= Mass of can, lid, and moist soil (g)	103	100.1	105	102.3	42.5	52.1	51.3	
M_{cds} = Mass of can, lid, and dry soil (g)	63	63.5	67.8	65.6	39.7	48.2	47.1	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	40	36.6	37.2	36.7	2.8	3.9	4.2	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	43.6	38.7	38.5	39.1	8.5	13.6	13.6	
Water content, W %= ((M_w)/(M_s))*100%	91.74	94.57	96.62	93.86	32.94	28.68	30.88	
Number of Blows, N	34	22	18	28				
Average (%)	94.21				30.81			63.40

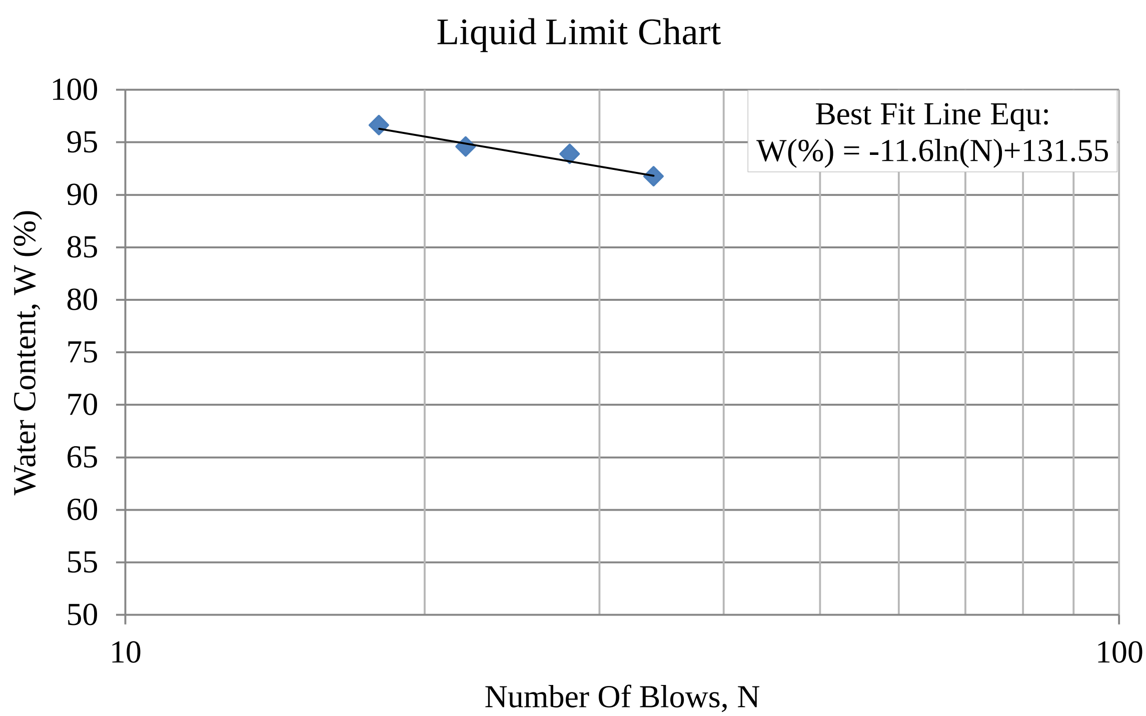

Figure A3-2 Liquid Limit determination for TP-1@3 m

Table A3-3 Atterberg Limit Determination

-Sample No: 2 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	29.3	31.2	19.4	30.2	34.6	24.8	33.5	
M_{cms}= Mass of can, lid, and moist soil (g)	98.6	109.1	115.6	98.8	41.5	41.2	42.2	
M_{cds} = Mass of can, lid, and dry soil (g)	68.4	74.5	72.2	68.6	39.9	37.1	40.1	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	30.2	34.6	43.4	30.2	1.6	4.1	2.1	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	39.1	43.3	52.8	38.4	5.3	12.3	6.6	
Water content, W %= ((M_w)/(M_s))*100%	77.24	79.91	82.20	78.65	30.19	33.33	31.82	
Number of Blows, N	31	24	19	27				
Average (%)	79.64				31.76			47.88

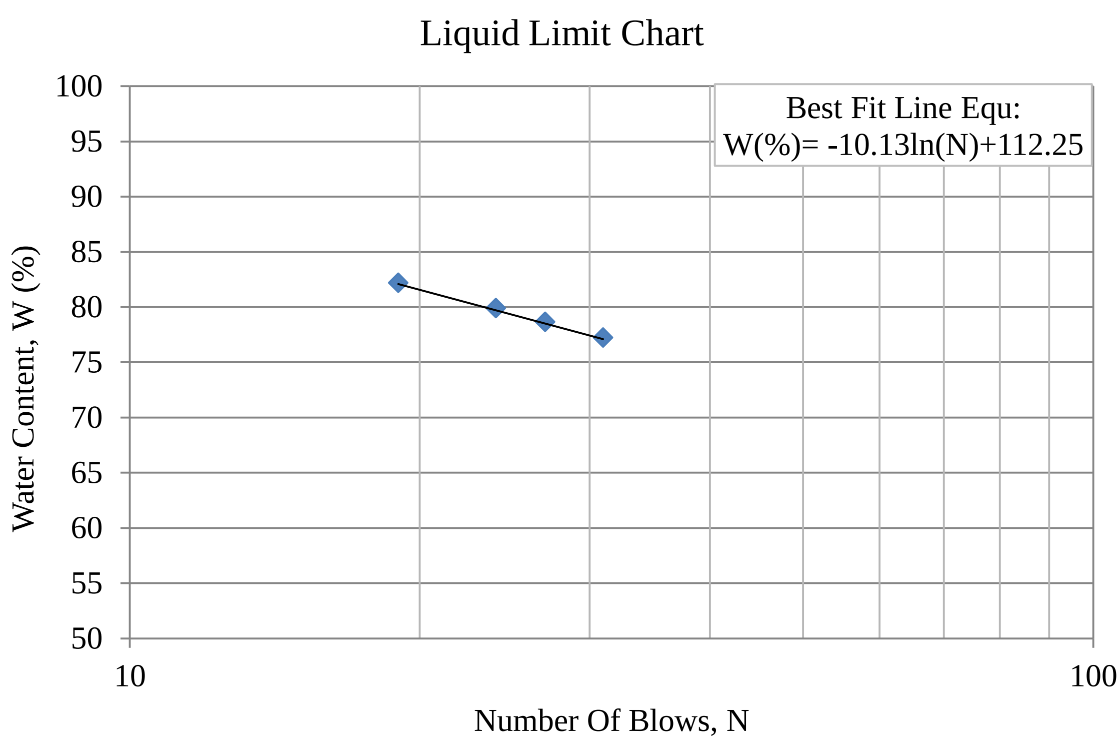

Figure A3-3 Liquid Limit determination for TP-2@1.5 m

Table A3-4 Atterberg Limit Determination

-Sample No: 2 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	34.3	31.2	24.8	33.3	28.2	36.3	34.5	
M_{cms}= Mass of can, lid, and moist soil (g)	98.6	121	115.8	96.6	44.1	41.1	41.4	
M_{cds} = Mass of can, lid, and dry soil (g)	71.5	81.6	73.4	70.1	40.3	39.9	39.7	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	27.1	39.4	42.4	25.9	3.8	1.2	1.7	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	37.2	50.4	48.6	36.8	12.1	3.6	5.2	
Water content, W %= ((M_w)/(M_s))*100%	72.85	78.17	87.24	70.38	31.40	33.33	32.69	
Number of Blows, N	28	23	16	35				
Average (%)	76.21				32.37			43.84

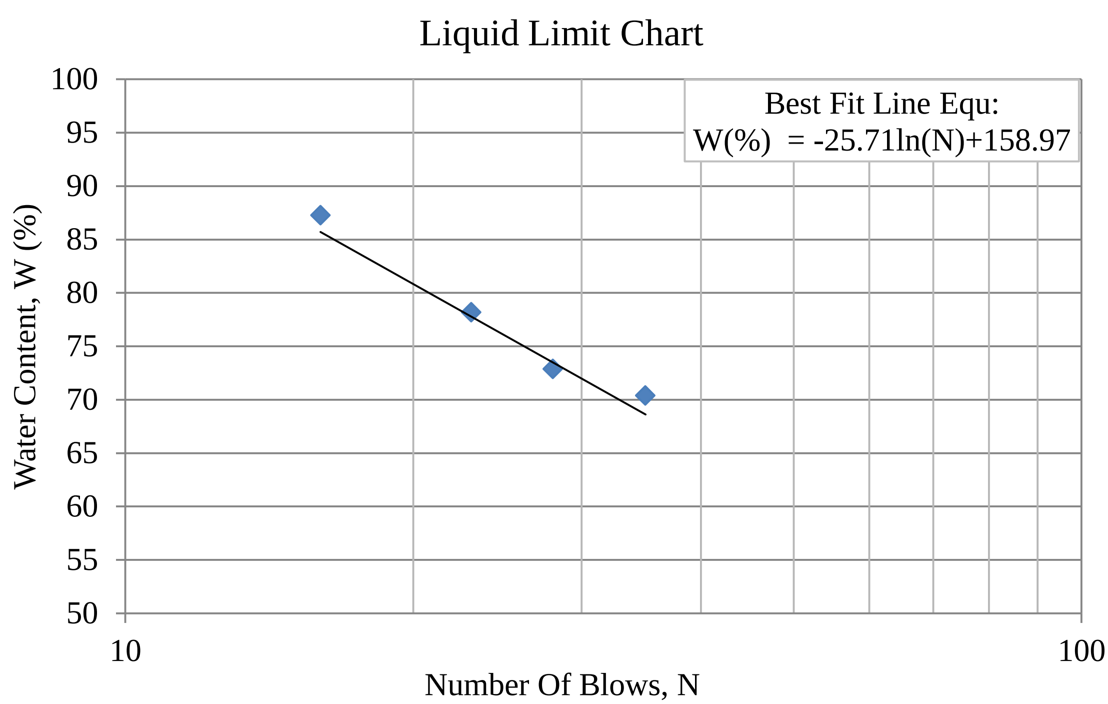

Figure A3-4 Liquid Limit determination for TP-2@3 m

Table A3-5 Atterberg Limit Determination

-Sample No: 3 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	36.3	34.6	28.2	35.5	28.2	34.6	35.5	
M_{cms}= Mass of can, lid, and moist soil (g)	98.9	122.5	115.4	97.5	39.1	41.5	40.1	
M_{cds} = Mass of can, lid, and dry soil (g)	69.1	80.1	73	68.2	36.6	39.8	39	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	29.8	42.4	42.4	29.3	2.5	1.7	1.1	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	32.8	45.5	44.8	32.7	8.4	5.2	3.5	
Water content, W %= ((M_w)/(M_s))*100%	90.85	93.19	94.64	89.60	29.76	32.69	31.43	
Number of Blows, N	31	24	18	35				
Average (%)	92.71				31.23			61.48

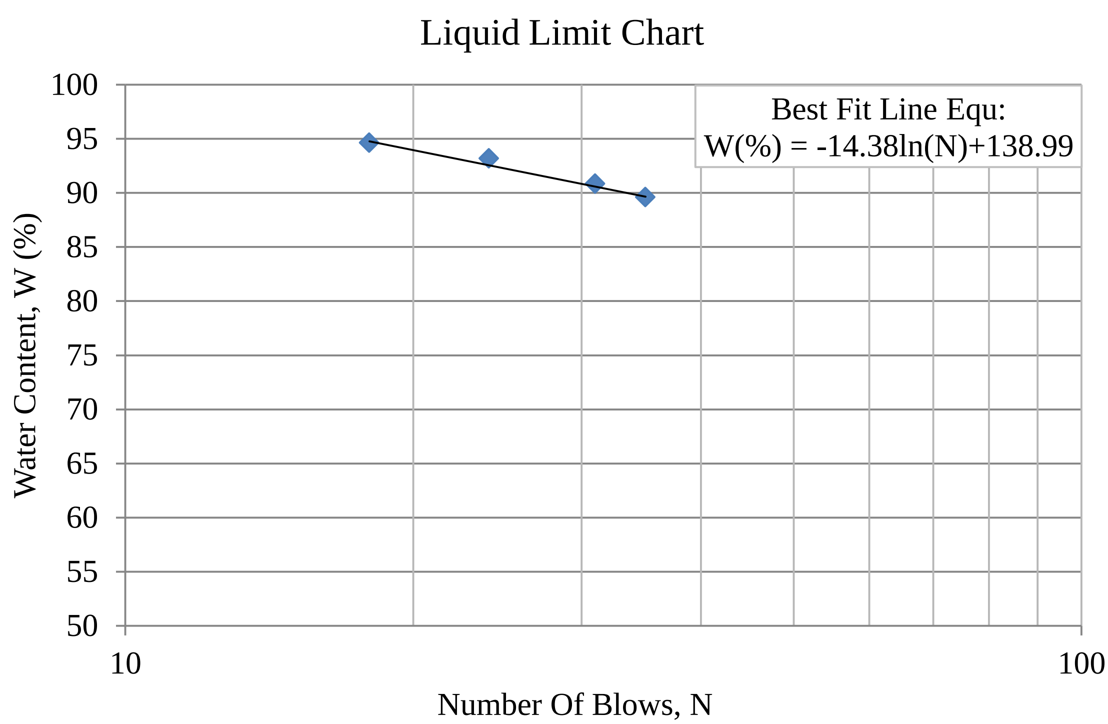

Figure A3-5 Liquid Limit determination for TP-3@1.5 m

Table A3-6 Atterberg Limit Determination

-Sample No: 3 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	34.6	24.8	29.3	29.5	31.2	19.4	34.6	
M_{cms}= Mass of can, lid, and moist soil (g)	94.5	119.8	111.5	93.2	47.5	42	47	
M_{cds} = Mass of can, lid, and dry soil (g)	64.8	72.5	70.5	61.6	44.7	38.2	44.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	29.7	47.3	41	31.6	2.8	3.8	2.1	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	30.2	47.7	41.2	32.1	13.5	18.8	10.3	
Water content, W %= ((M_w)/(M_s))*100%	98.34	99.16	99.51	98.44	20.74	20.21	20.39	
Number of Blows, N	33	24	17	29				
Average (%)	98.98				20.48			78.50

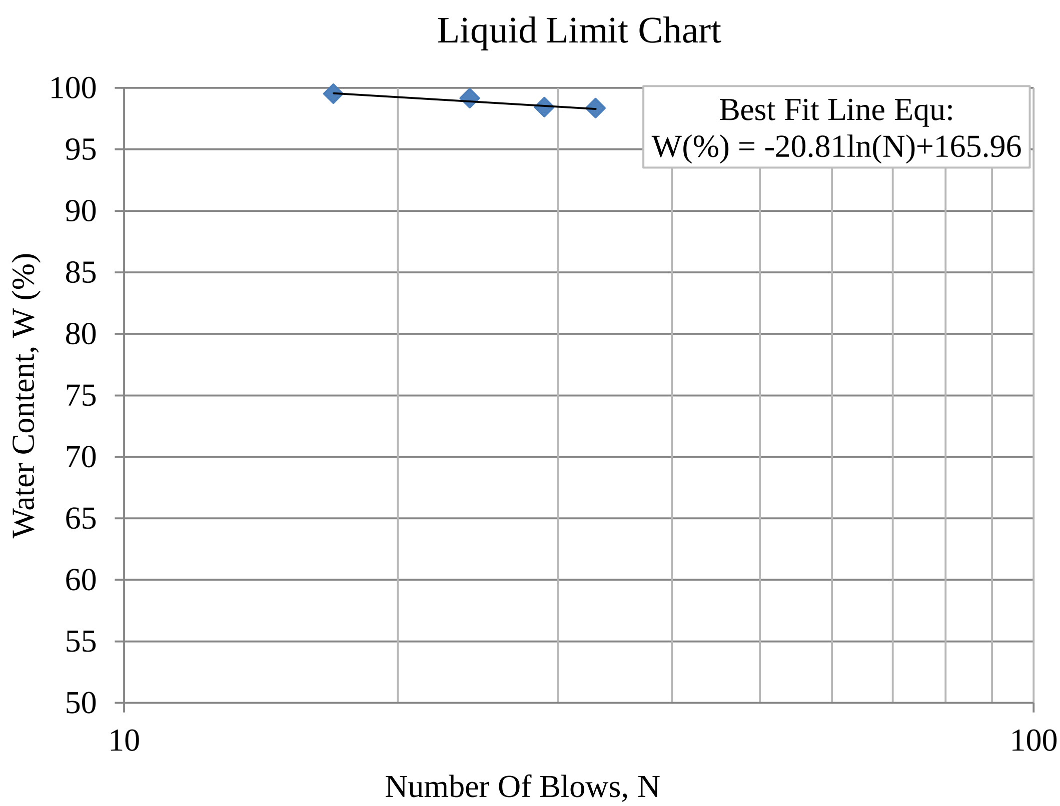

Figure A3-6 Liquid Limit determination for TP-3@3 m

Table A3-7 Atterberg Limit Determination

-Sample No: 4 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	34.6	24.8	29.3	37.5	31.2	19.4	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	114.9	109.3	119.9	123.2	46.7	47.8	46.5	
M_{cds} = Mass of can, lid, and dry soil (g)	77.5	69.2	76.4	83	43.1	41.1	42.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	37.4	40.1	43.5	40.2	3.6	6.7	3.6	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	42.9	44.4	47.1	45.5	11.9	21.7	11.7	
Water content, W %= ((M_w)/(M_s))*100%	87.18	90.32	92.36	88.35	30.25	30.88	30.77	
Number of Blows, N	34	24	17	28				
Average (%)	89.95				30.56			59.39

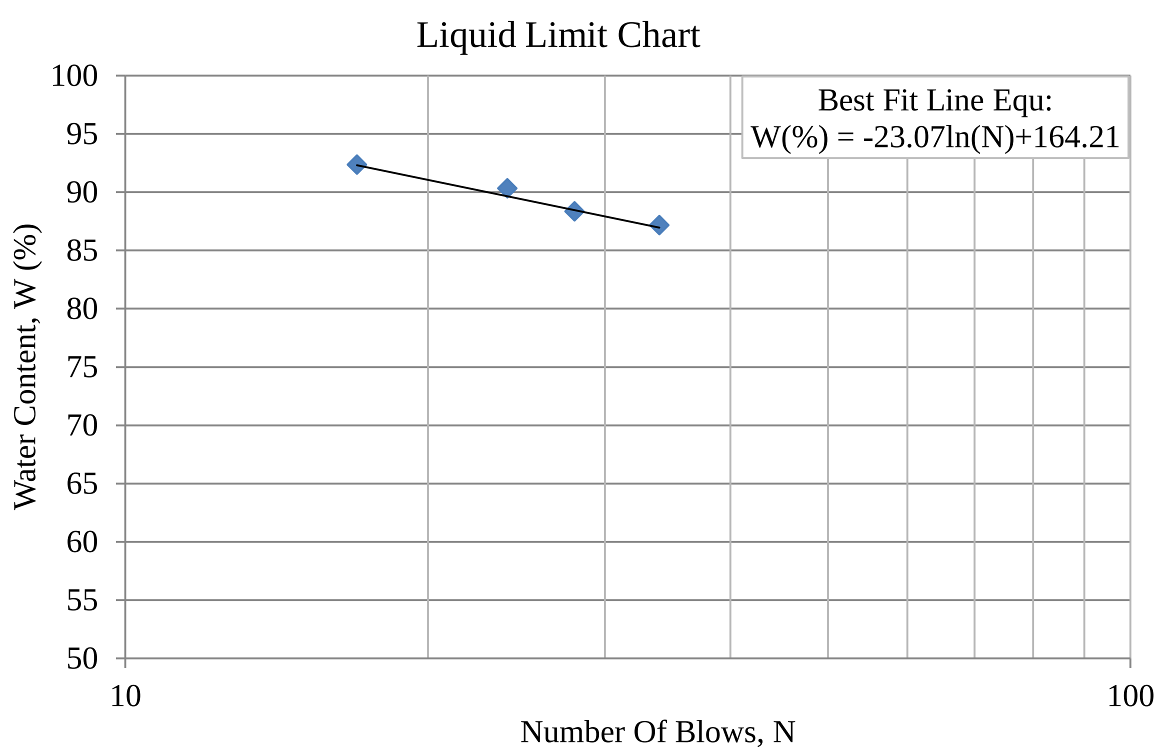

Figure A3-7 Liquid Limit determination for TP-4@1.5 m

Table A3-8 Atterberg Limit Determination

-Sample No: 4 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	28.2	34.6	28.2	34.6	28.2	34.6	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	94	116.5	99	115	36.5	37.6	38.7	
M_{cds} = Mass of can, lid, and dry soil (g)	64.5	79.2	66.5	78.8	34.5	36.9	36.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	29.5	37.3	32.5	36.2	2	0.7	1.8	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	36.3	44.6	38.3	44.2	6.3	2.3	5.7	
Water content, W %= ((M_w)/(M_s))*100%	81.27	83.63	84.86	81.90	31.75	30.43	31.58	
Number of Blows, N	33	24	18	30				
Average (%)	83.25				31.09			52.16

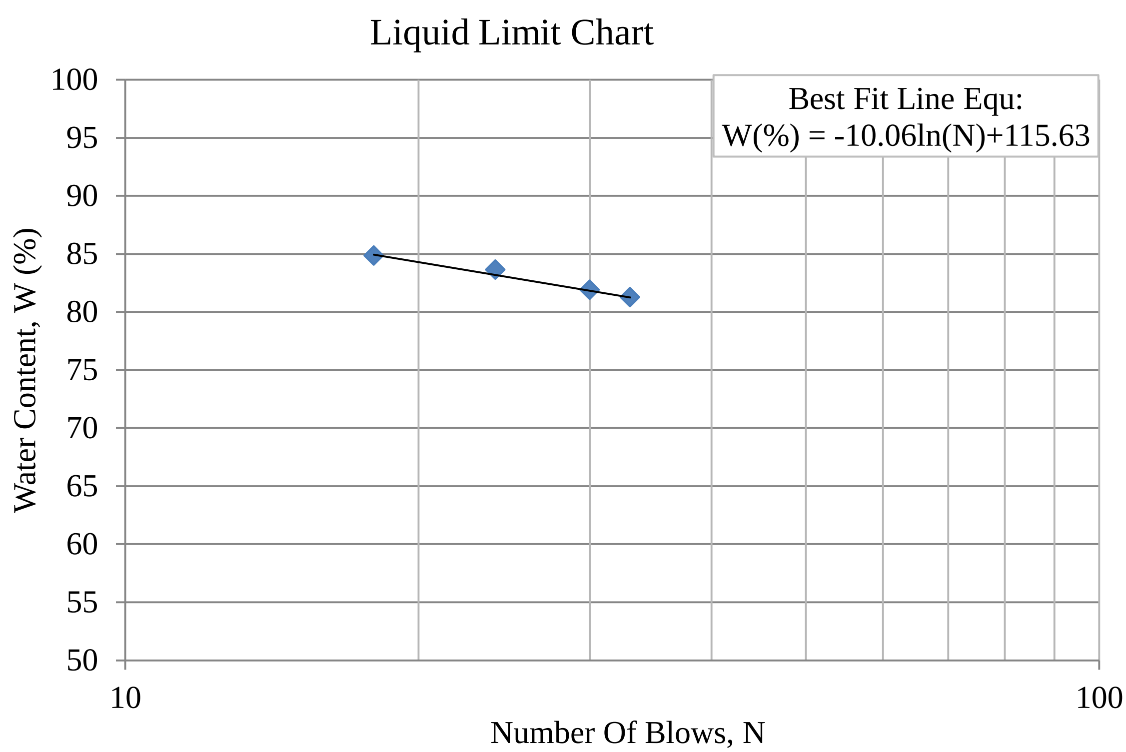

Figure A3-8 Liquid Limit determination for TP-4@3 m

Table A3-9 Atterberg Limit Determination

-Sample No: 5 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	36.3	34.6	28.2	36.3	24.8	29.3	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	103	108.6	109.3	100.2	52.2	50.6	47.7	
M_{cds} = Mass of can, lid, and dry soil (g)	77.7	79.3	76.6	76.2	45.5	44.6	43.4	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	25.3	29.3	32.7	24	6.7	6	4.3	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	41.4	44.7	48.4	39.9	20.7	15.3	12.2	
Water content, W %= ((M_w)/(M_s))*100%	61.11	65.55	67.56	60.15	32.37	39.22	35.25	
Number of Blows, N	30	23	19	35				
Average (%)	64.15				35.79			28.36

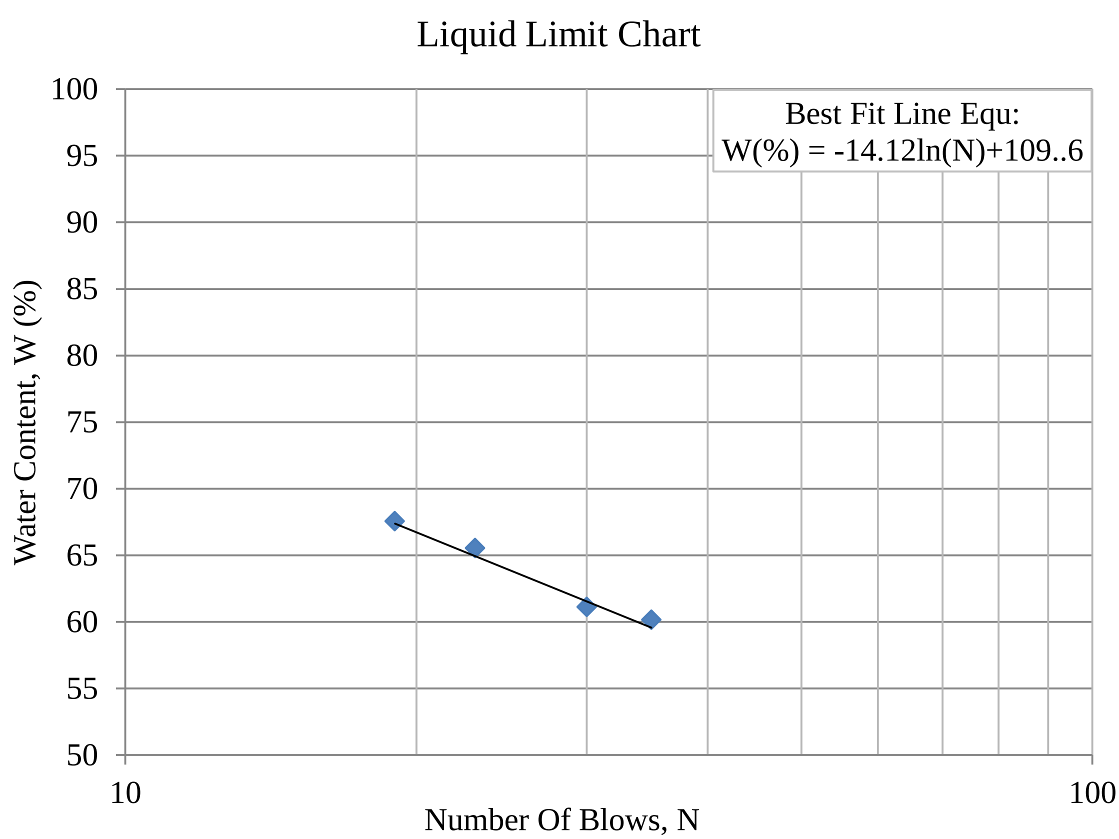

Figure A3-9 Liquid Limit determination for TP-5@1.5 m

Table A3-10 Atterberg Limit Determination

-Sample No: 5 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	31.2	19.4	34.6	34.6	24.8	29.3	34.6	
M_{cms}= Mass of can, lid, and moist soil (g)	113.6	118.6	129.3	125.4	41.2	44.1	45.6	
M_{cds} = Mass of can, lid, and dry soil (g)	76.4	69.8	82.4	86.2	36.6	39.8	42.5	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	37.2	48.8	46.9	39.2	4.6	4.3	3.1	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	45.2	50.4	47.8	51.6	11.8	10.5	7.9	
Water content, W %= ((M_w)/(M_s))*100%	82.30	96.83	98.12	75.97	38.98	40.95	39.24	
Number of Blows, N	27	22	17	33				
Average (%)	87.67				39.97			47.70

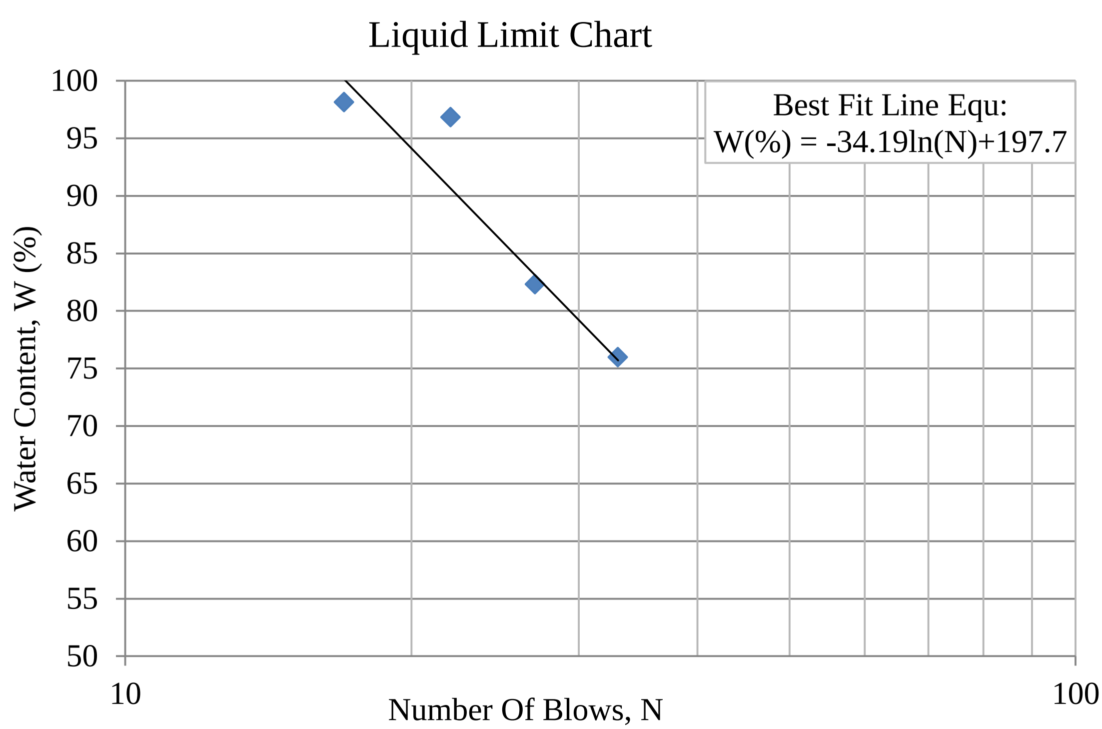

Figure A3-10 Liquid Limit determination for TP-5@3 m

Table A3-11 Atterberg Limit Determination

-Sample No: 6 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	36.3	34.6	28.2	34.6	24.8	29.3	24.8	
M_{cms}= Mass of can, lid, and moist soil (g)	106.2	99.9	94.6	95.6	41	40.5	38.2	
M_{cds} = Mass of can, lid, and dry soil (g)	80.6	75.8	68.8	72.3	36.7	38.1	35.0	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	25.6	24.1	25.8	23.3	4.3	2.4	3.2	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	44.3	41.2	40.6	37.7	11.9	8.8	10.2	
Water content, W %= ((M_w)/(M_s))*100%	57.79	58.50	63.55	61.80	36.13	27.27	31.37	
Number of Blows, N	34	27	19	23				
Average (%)	60.59				31.70			28.87

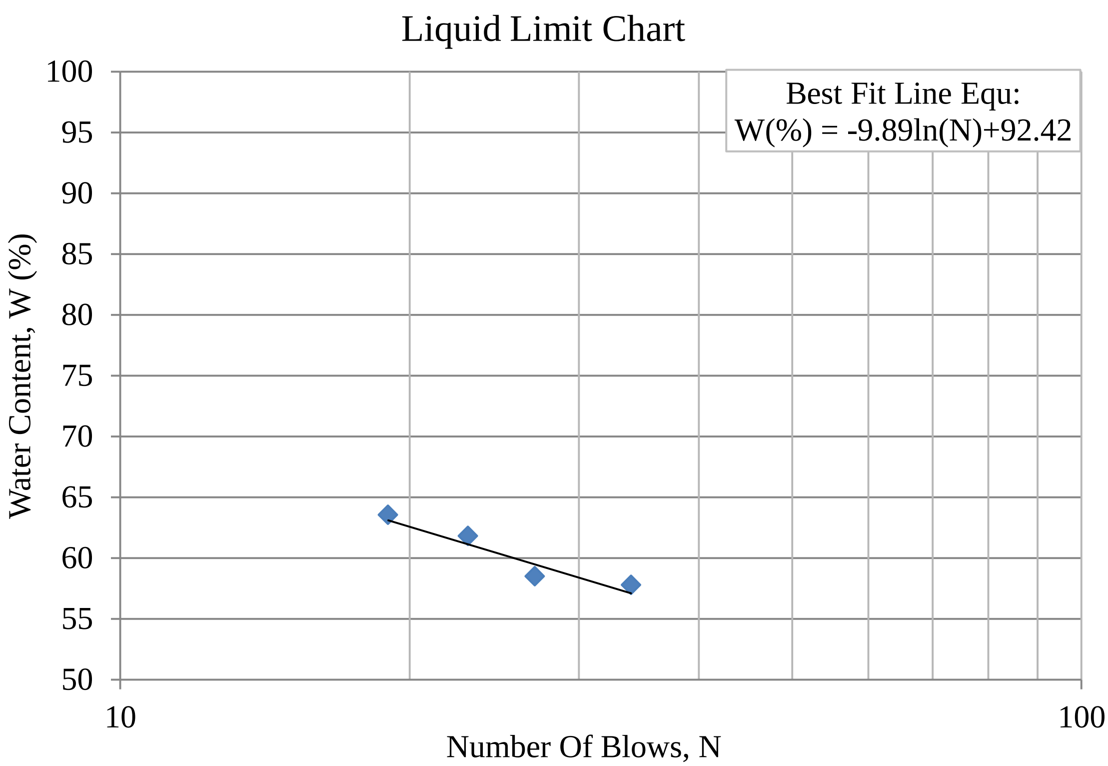

Figure A3-11 Liquid Limit determination for TP-6@1.5 m

Table A3-12 Atterberg Limit Determination

-Sample No: 6 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	36.3	34.6	28.2	34.6	28.2	34.6	32.0	
M_{cms}= Mass of can, lid, and moist soil (g)	89.1	110	100.2	108.5	36.5	39.3	38.2	
M_{cds} = Mass of can, lid, and dry soil (g)	69.2	80.3	70.9	80.2	34.6	38.1	36.7	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	19.9	29.7	29.3	28.3	1.9	1.2	1.5	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	32.9	45.7	42.7	45.6	6.4	3.5	4.7	
Water content, W %= ((M_w)/(M_s))*100%	60.49	64.99	68.62	62.06	29.69	34.29	31.91	
Number of Blows, N	33	24	18	28				
Average (%)	64.70				31.99			32.71

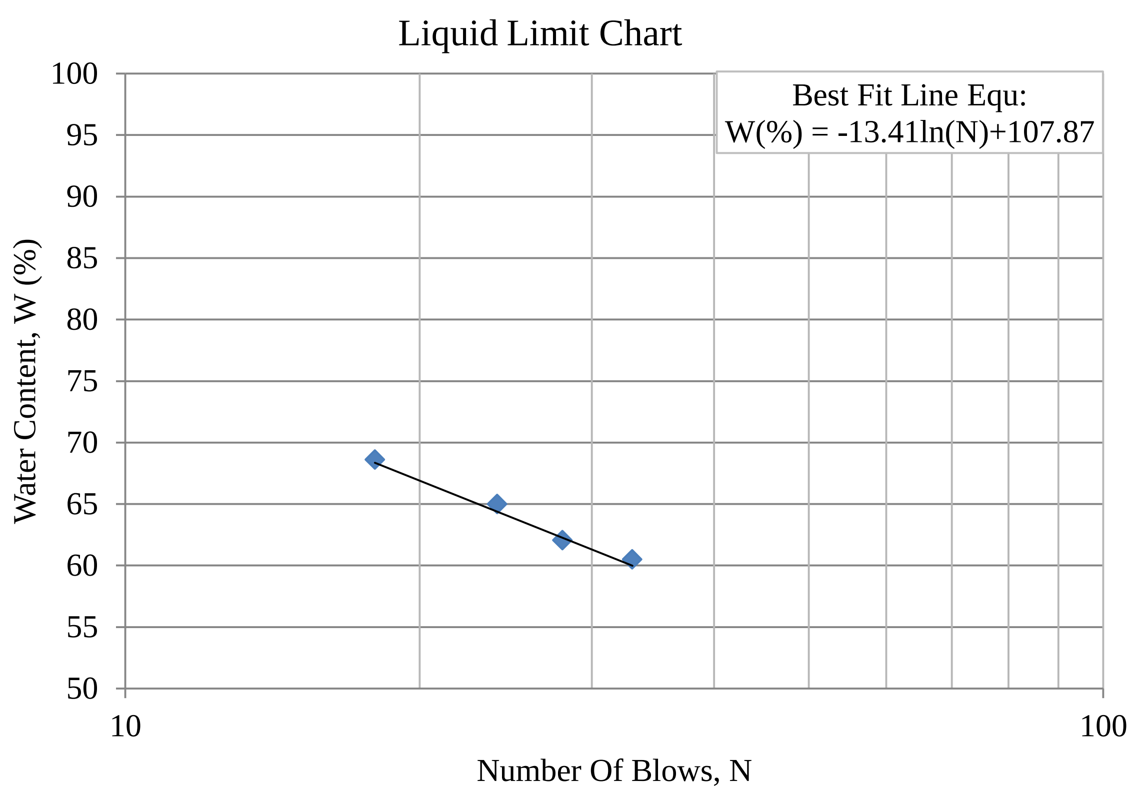

Figure A3-12 Liquid Limit determination for TP-6@3 m

Table A3-13 Atterberg Limit Determination

-Sample No: 7 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	24.8	29.3	31.2	31.2	19.4	25.5	32.0	
M_{cms}= Mass of can, lid, and moist soil (g)	112.5	115	113.5	111.5	38	39	38.6	
M_{cds} = Mass of can, lid, and dry soil (g)	70.4	73.5	73.4	72.4	33.2	36	37.0	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	42.1	41.5	40.1	39.1	4.8	3	1.6	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	45.6	44.2	42.2	41.2	13.8	10.5	5	
Water content, W %= ((M_w)/(M_s))*100%	92.32	93.89	95.02	94.90	34.78	28.57	32.00	
Number of Blows, N	35	26	19	23				
Average (%)	94.03				31.68			62.35

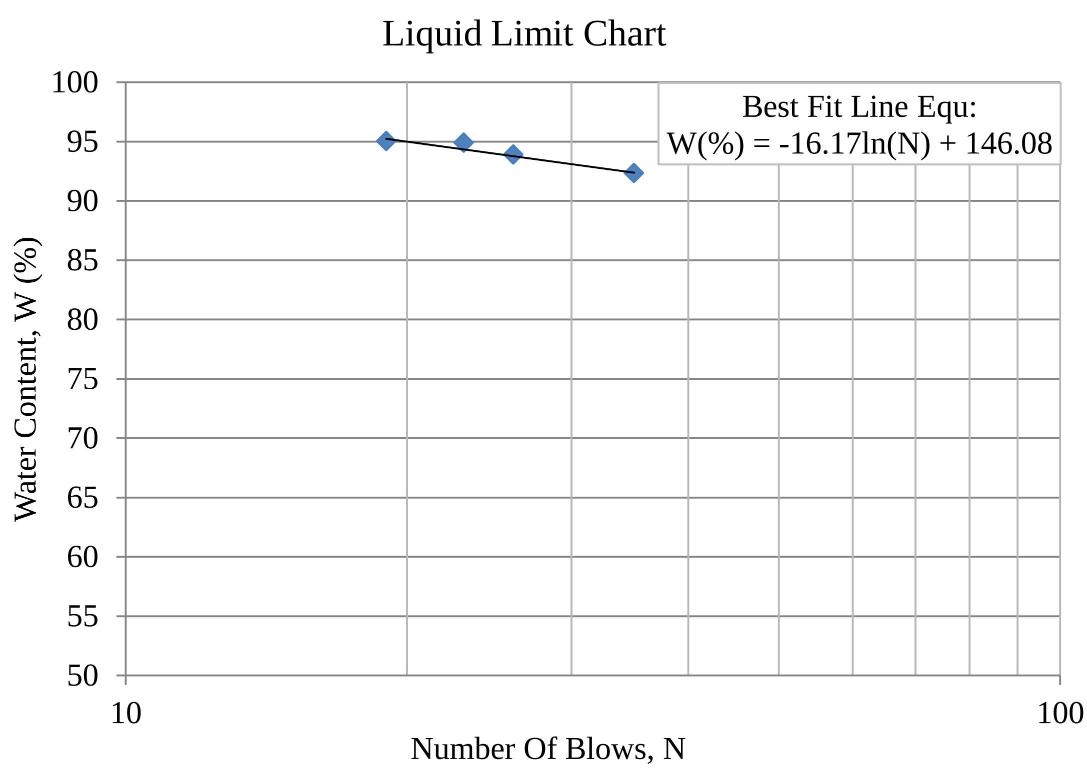

Figure A3-13 Liquid Limit determination for TP-7@1.5 m

Table A3-14 Atterberg Limit Determination

-Sample No: 7 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	28.2	31.2	19.4	37.6	28.2	28.2	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	113.6	120.4	114.5	125.6	38	40	39.3	
M_{cds} = Mass of can, lid, and dry soil (g)	71.4	76.2	67.2	82.1	36.3	38	37.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	42.2	44.2	47.3	43.5	1.7	2	1.4	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	43.2	45	47.8	44.5	8.1	9.8	6.7	
Water content, W %= ((M_w)/(M_s))*100%	97.69	98.22	98.95	97.75	20.99	20.41	20.90	
Number of Blows, N	31	24	18	29				
Average (%)	98.23				20.70			77.53

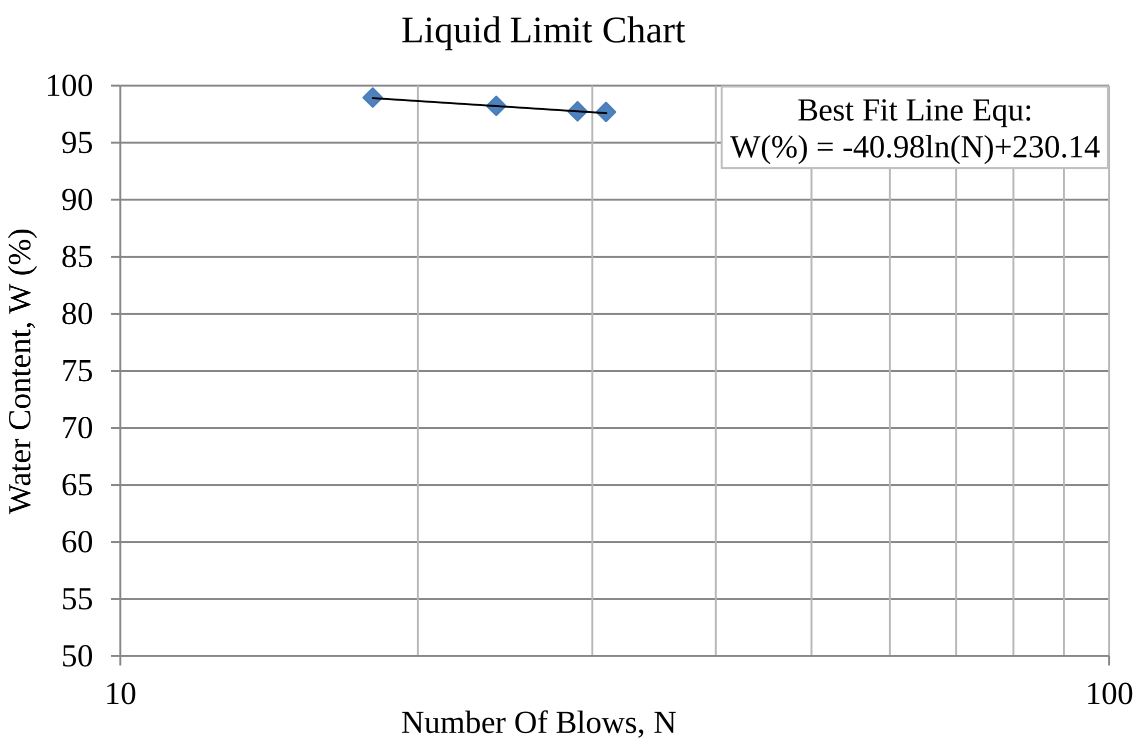

Figure A3-14 Liquid Limit determination for TP-7@3 m

Table A3-14 Atterberg Limit Determination

-Sample No: 8 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	28.2	34.6	24.8	34.6	36.3	31.2	36.3	
M_{cms}= Mass of can, lid, and moist soil (g)	98	122	115.5	118.6	43.5	37.9	46.5	
M_{cds} = Mass of can, lid, and dry soil (g)	65.5	80.5	71.5	80.1	41.5	36.1	43.7	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	32.5	41.5	44	38.5	2	1.8	2.8	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	37.3	45.9	46.7	45.5	5.2	4.9	7.4	
Water content, W %= ((M_w)/(M_s))*100%	87.13	90.41	94.22	84.62	38.46	36.73	37.84	
Number of Blows, N	27	21	16	34				
Average (%)	88.17				37.60			50.57

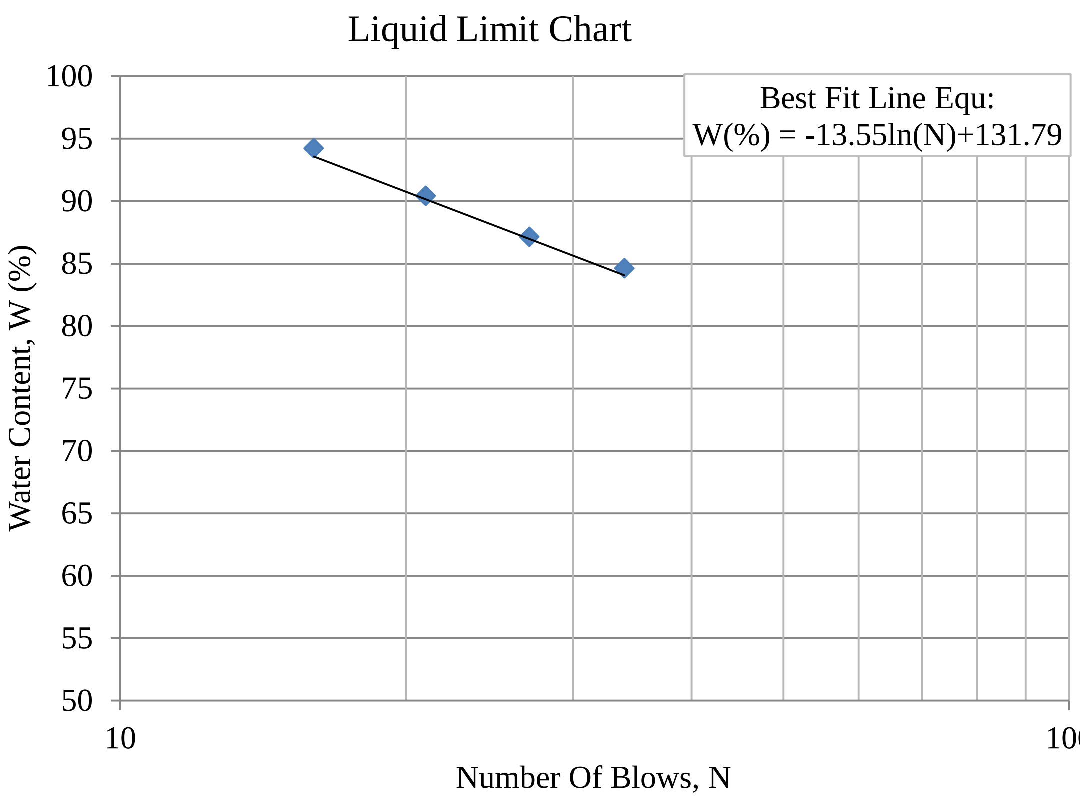

Figure A3-15 Liquid Limit determination for TP-8@1.5 m

Table A3-16 Atterberg Limit Determination

-Sample No: 8 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	34.3	31.2	24.8	34.3	28.2	36.3	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	100.5	117.5	117	101.5	43.5	42.5	43.8	
M_{cds} = Mass of can, lid, and dry soil (g)	69.2	75.5	70.5	70.6	39.5	40.5	40.1	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	31.3	42	46.5	30.9	4	2	3.7	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	34.9	44.3	45.7	36.3	11.3	4.2	8.9	
Water content, W %= ((M_w)/(M_s))*100%	89.68	94.81	101.7	85.12	35.40	47.62	41.57	
Number of Blows, N	26	21	17	33				
Average (%)	90.79				41.51			49.28

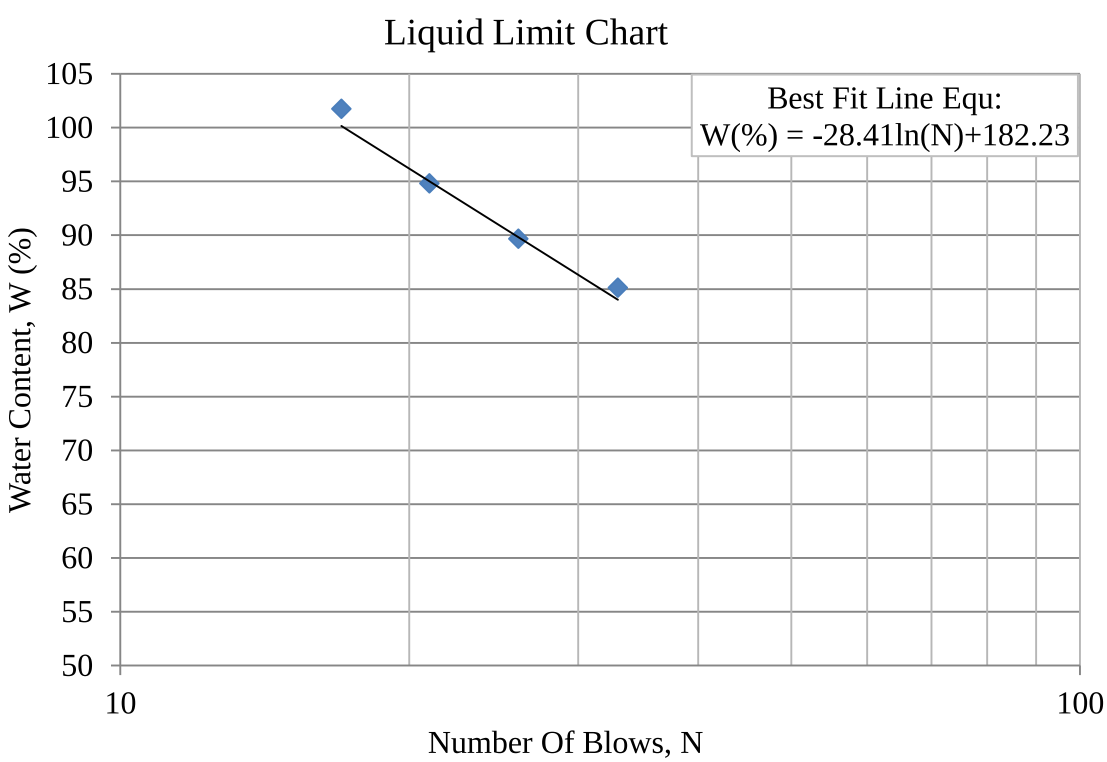

Figure A3-16 Liquid Limit determination for TP-8@3 m

Table A3-17 Atterberg Limit Determination

-Sample No: 9 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	34.6	29.3	31.2	34.6	24.8	19.4	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	113	119.5	126.5	110.3	42	43	42.8	
M_{cds} = Mass of can, lid, and dry soil (g)	75.6	75.5	79.2	75.0	37.2	36.5	39.6	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	37.4	44	47.3	35.3	4.8	6.5	3.2	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	41	46.2	48	40.4	12.4	17.1	8.4	
Water content, W %= ((M_w)/(M_s))*100%	91.22	95.24	98.54	87.38	38.71	38.01	38.10	
Number of Blows, N	29	21	16	34				
Average (%)	93.33				38.36			54.97

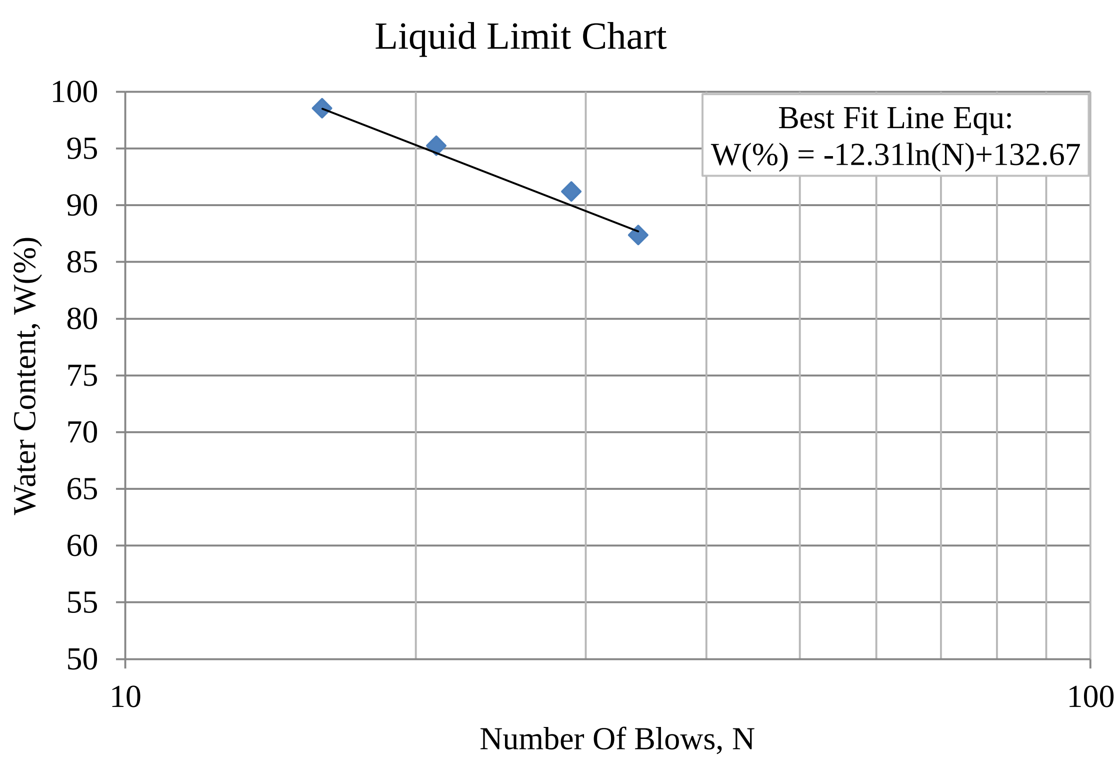

Figure A3-17 Liquid Limit determination for TP-9@1.5 m

Table A3-18 Atterberg Limit Determination

-Sample No: 9 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	29.3	36.3	28.2	36.3	31.2	34.6	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	99.5	115	115.5	117.6	40.5	42	41.5	
M_{cds} = Mass of can, lid, and dry soil (g)	64.7	75.9	72.1	77.2	38.2	40.1	38.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	34.8	39.1	43.4	40.4	2.3	1.9	2.6	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	35.4	39.6	43.9	40.9	7	5.5	7.7	
Water content, W %= ((M_w)/(M_s))*100%	98.31	98.74	98.86	98.78	32.86	34.55	33.77	
Number of Blows, N	34	26	19	22				
Average (%)	98.68				33.70			64.98

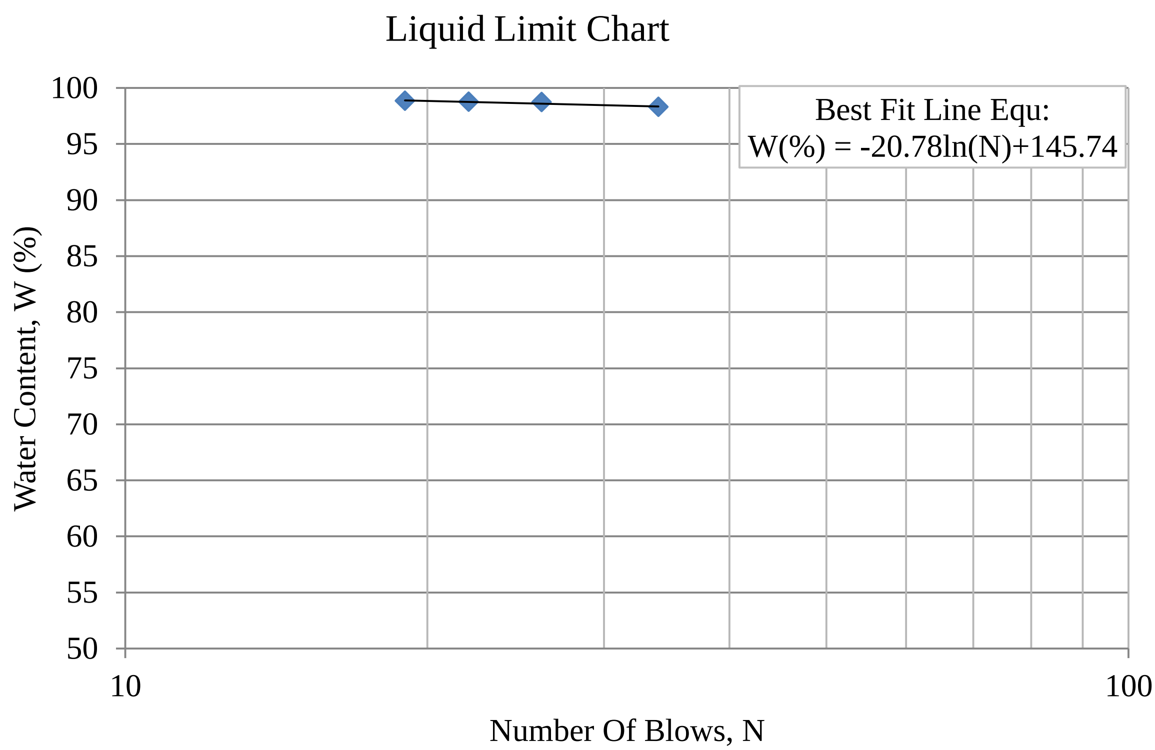

Figure A3-18 Liquid Limit determination for TP-9@3 m

Table A3-19 Atterberg Limit Determination

-Sample No: 10 - Depth: 1.5 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	31.2	34.6	28.2	34.6	29.3	36.3	34.6	
M_{cms}= Mass of can, lid, and moist soil (g)	110.5	119	115	116.4	39.5	43.5	45.5	
M_{cds} = Mass of can, lid, and dry soil (g)	72.7	78.3	73.1	77.2	37	41.8	42.9	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	37.8	40.7	41.9	39.2	2.5	1.7	2.6	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	41.5	43.7	44.9	42.6	7.7	5.5	8.3	
Water content, W %= ((M_w)/(M_s))*100%	91.08	93.14	93.32	92.02	32.47	30.91	31.33	
Number of Blows, N	33	23	18	27				
Average (%)	92.46				31.69			60.77

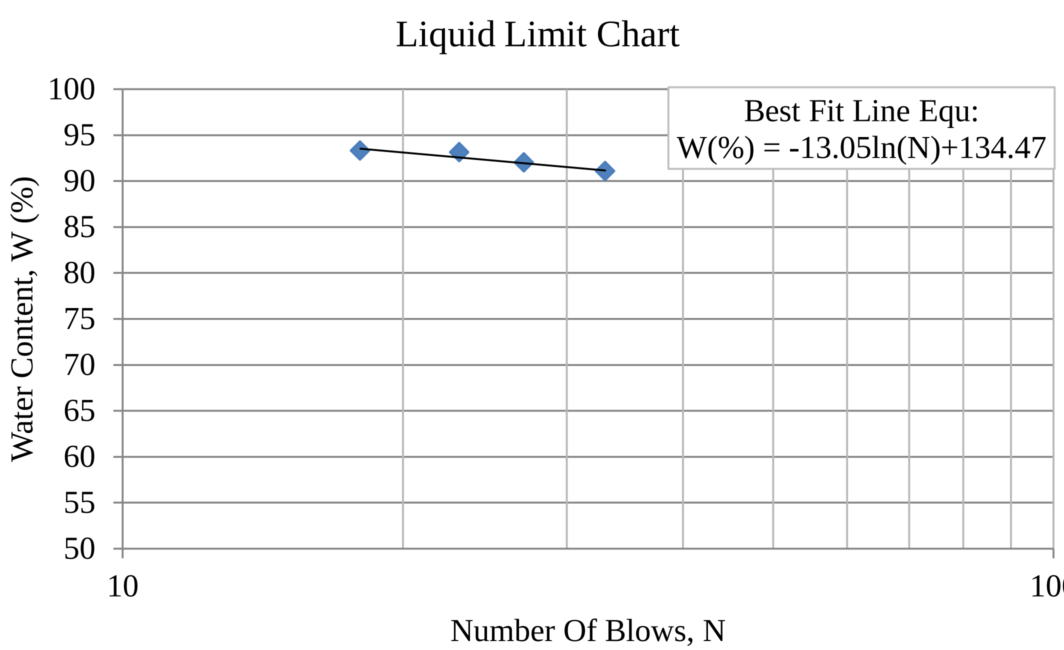

Figure A3-19 Liquid Limit determination for TP-10@1.5 m

Table A3-20 Atterberg Limit Determination

-Sample No: 10 - Depth: 3 m	LL				PL			PI
Container no.	1	2	3	4	1	2	3	
M_c= Mass of empty, clean can + lid (g)	36.3	34.6	29.3	36.3	31.2	24.8	31.2	
M_{cms}= Mass of can, lid, and moist soil (g)	110.7	105.5	118	106.4	43	42.5	42.6	
M_{cds} = Mass of can, lid, and dry soil (g)	75.7	71.9	75.8	73.8	40.2	38	39.8	
M_w=(M_{cms}-M_{cds})=Mass of pore water(g)	35	33.6	42.2	32.6	2.8	4.5	2.8	
M_s=(M_{cds}- M_c)= Mass of soil solids (g)	39.4	37.3	46.5	37.5	9	13.2	8.6	
Water content, W %= ((M_w)/(M_s))*100%	88.83	90.08	90.75	86.93	31.11	34.09	32.56	
Number of Blows, N	30	23	17	34				
Average (%)	89.64				32.60			57.04

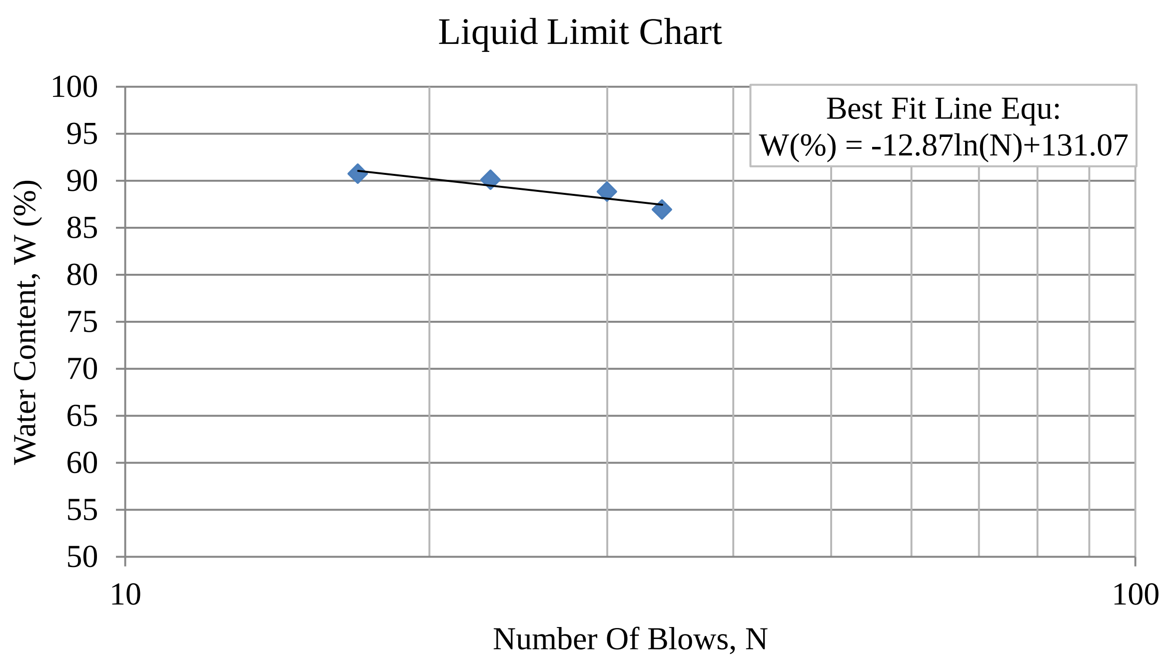

Figure A10-20 Liquid Limit determination for TP-10@3 m

Appendix A4. Grain Size Distribution Analysis

Table A4.1 Sieve Analysis for TP-1@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	510.7	510.2	2.2	1.2	0.44	0.2	99.56	99.8
3/8"	9.5	476.5	475.5	480.8	477.3	4.3	1.8	0.86	0.3	98.7	99.5
No 4	4.75	464	464	470	467	6	3	1.2	0.5	97.5	99
No 10	2	435	435	438.25	438.6	3.25	3.6	0.65	0.6	96.85	98.4
No 40	0.425	316.5	317	321.25	322.4	4.75	5.4	0.95	0.9	95.9	97.5
No 200	0.075	290	291	297	300	7	9	1.4	1.5	94.5	96
Pan		275.5	274.5	748	850.5	472.5	576	94.5	96	0	0
Total Mass(g)=						500	600				
% Gravel								2.5	1		
% Sand								3	3		
% Fines								94.5	96		

Table A4.2 Hydrometer Analysis for TP-1@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.67										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,R_A	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L (cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:21AM	1	26	1.0315	0.0028	1.0287	8.69	0.01263	0.0372	91.77	86.72
03:22AM	2	26	1.0310	0.0028	1.0282	8.84	0.01263	0.0266	90.17	85.21
03:24AM	4	26	1.0300	0.0028	1.0272	9.14	0.01263	0.0191	86.97	82.19
03:28AM	8	26	1.0290	0.0028	1.0262	9.36	0.01263	0.0137	83.78	79.17
03:35AM	15	26	1.0275	0.0028	1.0247	9.79	0.01263	0.0102	78.98	74.64
03:50AM	30	26	1.0260	0.0028	1.0232	10.16	0.01263	0.0074	74.18	70.10
04:20AM	60	26	1.0255	0.0028	1.0227	10.29	0.01263	0.0052	72.59	68.59
05:20AM	120	26	1.0235	0.0028	1.0207	10.79	0.01263	0.0038	66.19	62.55
07:20AM	240	27	1.0230	0.0028	1.0202	10.94	0.01246	0.0027	64.59	61.04
03:20AM	1440	26	1.0220	0.0028	1.0192	11.24	0.01263	0.0011	61.39	58.02

Table A4.3 Hydrometer Analysis for TP-1@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.70										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading ,R_A	Composite correction	Corr. Hydr. Reading , R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
04:17AM	1	24.3	1.0335	0.0028	1.0307	8.19	0.01279	0.0366	97.52	93.62
04:18AM	2	24.3	1.0335	0.0028	1.0307	8.19	0.01279	0.0259	97.52	93.62
04:20AM	4	24.3	1.0325	0.0028	1.0297	8.46	0.01279	0.0186	94.34	90.57
04:24AM	8	24.5	1.0320	0.0028	1.0292	8.56	0.01274	0.0132	92.75	89.04
04:31AM	15	24.5	1.0320	0.0028	1.0292	8.56	0.01274	0.0096	92.75	89.04
04:41AM	30	24.8	1.0310	0.0028	1.0282	8.84	0.01271	0.0069	89.58	85.99
05:16AM	60	25	1.0305	0.0028	1.0277	8.99	0.01267	0.0049	87.99	84.47
06:02AM	120	25.5	1.0290	0.0028	1.0262	9.36	0.01267	0.0035	83.22	79.89
08:16AM	240	26.5	1.0285	0.0028	1.0257	9.49	0.01246	0.0025	81.64	78.37
04:16AM	1440	25	1.0275	0.0028	1.0247	9.79	0.01267	0.0010	78.46	75.32

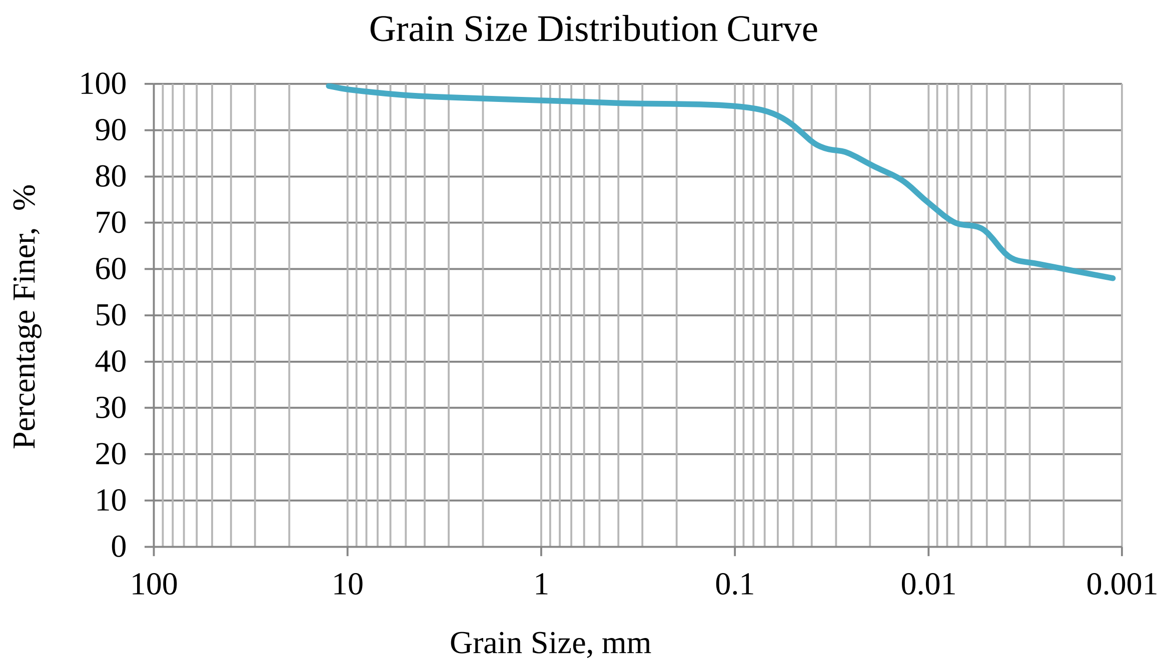

Figure A4.1 Grain size Distribution Curve for TP-1@1.5 m

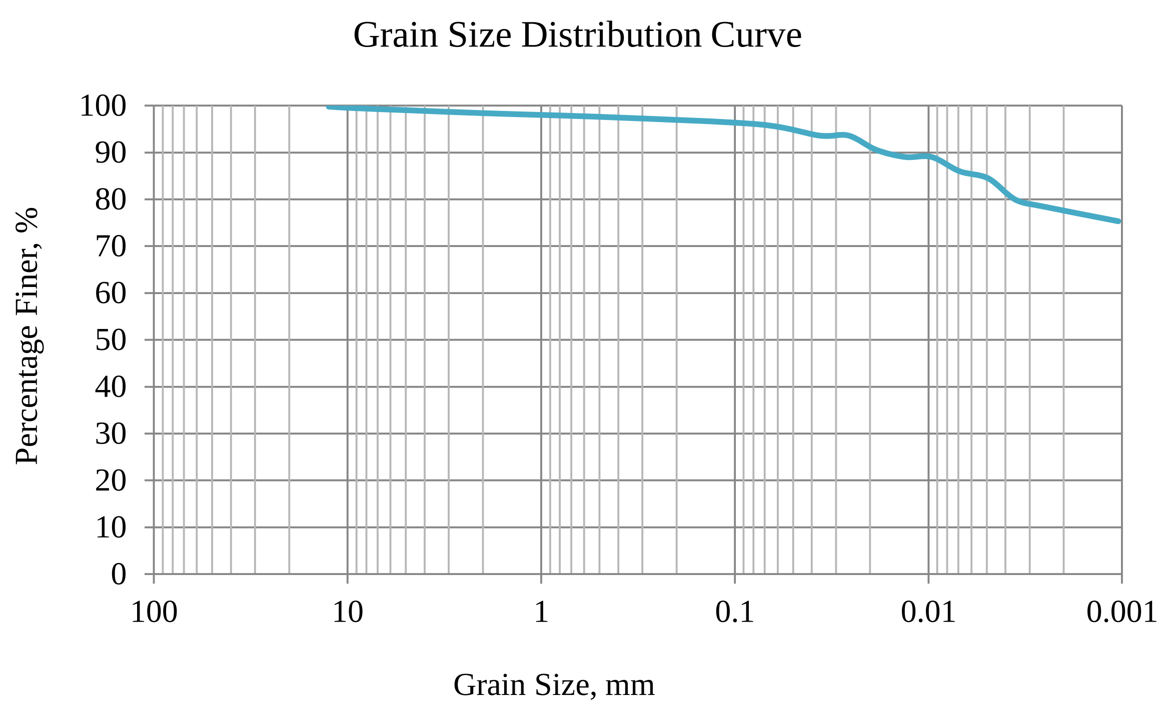

Figure A4.2 Grain size Distribution Curve for TP-1@3 m

Table A4.4 Sieve Analysis for TP-2@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	508.5	509	0	0	0	0	100	100
3/8"	9.5	476.5	475.5	476.5	475.5	0	0	0	0	100	100
No 4	4.75	464	464	464	478.7	0	14.7	0	2.1	100	97.9
No 10	2	435	435	435	443.3	0	8.26	0	1.18	100	96.72
No 40	0.425	316.5	317	334.51	319.5	18.01	2.52	2.77	0.36	97.23	96.36
N200	0.075	290	291	306.45	296.4	16.45	5.39	2.53	0.77	94.7	95.59
Pan		275.5	274.5	891.05	943.6	615.6	669.13	94.7	95.59	0	0
Total Mass(g)=						650	700				
% Gravel								0	2.1		
% Sand								5.3	2.31		
% Fines								94.7	95.59		

Table A4.5 Hydrometer Analysis for TP-2@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.74										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,R_A	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L (cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:36AM	1	26.5	1.0315	0.0028	1.0287	8.69	0.01249	0.0368	90.39	85.60
03:37AM	2	26.5	1.0300	0.0028	1.0272	9.14	0.01249	0.0267	85.66	81.12
03:39AM	4	26.5	1.0295	0.0028	1.0267	9.26	0.01249	0.0190	84.09	79.63
03:43AM	8	26.5	1.0280	0.0028	1.0252	9.64	0.01249	0.0137	79.37	75.16
03:50AM	15	26.9	1.0275	0.0028	1.0247	9.79	0.01242	0.0100	77.79	73.67
04:05AM	30	27.2	1.0265	0.0028	1.0237	10.06	0.01219	0.0071	74.64	70.69
04:35AM	60	27.4	1.0260	0.0028	1.0232	10.16	0.01217	0.0050	73.07	69.19
05:35AM	120	27.5	1.0245	0.0028	1.0217	10.56	0.01215	0.0036	68.34	64.72
07:35AM	240	28	1.0235	0.0028	1.0207	10.79	0.01211	0.0026	65.19	61.74
03:35AM	1440	25	1.0230	0.0028	1.0202	10.94	0.01253	0.0011	63.62	60.25

Table A4.6 Hydrometer Analysis for TP-2@3 m

Hydrometer Number=151H, weight of Dry Soil,Ws =50g, Gs=2.62										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,R_A	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L (cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:06AM	1	25	1.0330	0.0028	1.0302	8.34	0.01299	0.0375	97.68	93.38
03:07AM	2	25	1.0325	0.0028	1.0297	8.46	0.01299	0.0267	96.07	91.83
03:09AM	4	25	1.0315	0.0028	1.0287	8.69	0.01299	0.0191	92.83	88.74
03:13AM	8	25	1.0290	0.0028	1.0262	9.36	0.01299	0.0141	84.75	81.01
03:20AM	15	25	1.0285	0.0028	1.0257	9.49	0.01299	0.0103	83.13	79.46
03:35AM	30	25	1.0280	0.0028	1.0252	9.64	0.01299	0.0074	81.51	77.92
04:05AM	60	25.5	1.0265	0.0028	1.0237	10.06	0.01290	0.0053	76.66	73.28
05:05AM	120	25.5	1.0255	0.0028	1.0227	10.29	0.01290	0.0038	73.42	70.19
07:05AM	240	27	1.0235	0.0028	1.0207	10.79	0.01286	0.0027	66.96	64.00
03:05AM	1440	27	1.0210	0.0028	1.0182	11.46	0.01286	0.0011	58.87	56.27

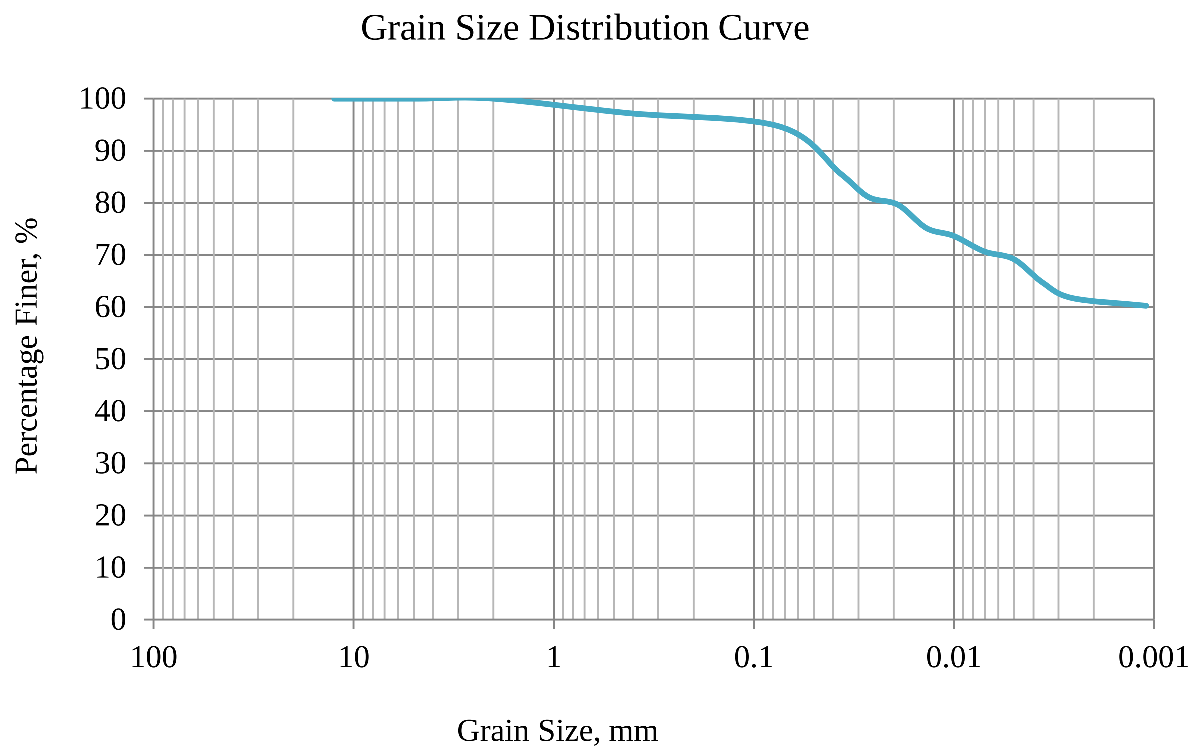

Figure A4.3 Grain size Distribution Curve for TP-2@1.5 m

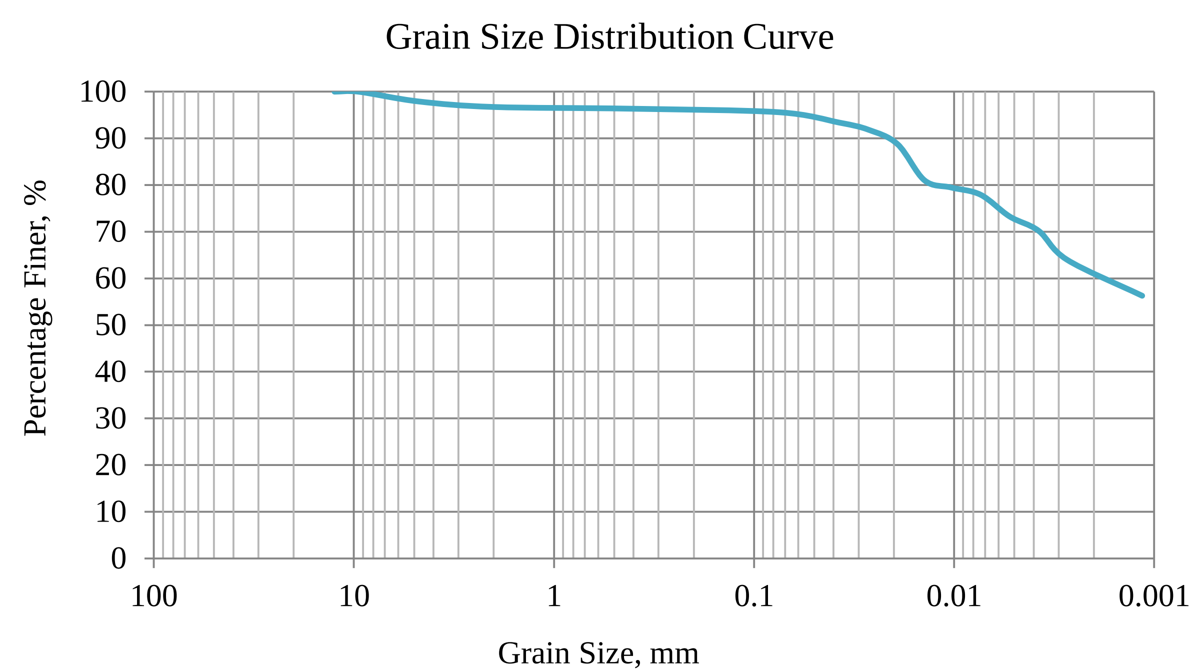

Figure A4.4 Grain size Distribution Curve for TP-2@3 m

Table A4.7 Sieve Analysis for TP-3@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	520.79	522.1	12.29	13.095	2.73	2.91	97.27	97.09
3/8"	9.5	476.5	475.5	494.1	485.5	17.6	9.99	3.91	2.22	93.36	94.87
No 4	4.75	464	464	483.35	470.8	19.35	6.75	4.3	1.5	89.06	93.37
No 10	2	435	435	440.99	438.4	5.985	3.375	1.33	0.75	87.73	92.62
No 40	0.425	316.5	317	320.78	317.1	4.275	0.135	0.95	0.03	86.78	92.59
N200	0.075	290	291	293.02	293.3	3.015	2.25	0.67	0.5	86.11	92.09
Pan		275.5	274.5	663	688.9	387.5	414.40	86.1	92.09	0	0
Total Mass(g)=						450	450				
% Gravel								10.94	6.63		
% Sand								2.95	1.28		
% Fines								86.11	92.09		

Table A4.8 Hydrometer Analysis for TP-3@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.71										
Time	Elapsed Time (min)	Temp. (^oc)	Actual H. Reading,R_A	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L (cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
04:17AM	1	24	1.0295	0.0028	1.0267	9.26	0.01278	0.0389	84.63	72.87
04:18AM	2	24	1.0290	0.0028	1.0262	9.36	0.01278	0.0276	83.04	71.51
04:20AM	4	24.5	1.0290	0.0028	1.0262	9.36	0.01265	0.0405	83.04	71.51
04:24AM	8	24.8	1.0280	0.0028	1.0252	9.56	0.01261	0.0138	79.87	68.78
04:31AM	15	24.8	1.0275	0.0028	1.0247	9.66	0.01261	0.0101	78.29	67.41
04:41AM	30	24.8	1.0270	0.0028	1.0242	9.76	0.01261	0.0072	76.70	66.05
05:16AM	60	25	1.0260	0.0028	1.0232	10.16	0.01264	0.0052	73.53	63.32
06:02AM	120	25	1.0245	0.0028	1.0217	10.59	0.01264	0.0038	68.78	59.23
08:16AM	240	27.5	1.0230	0.0028	1.0202	10.94	0.01244	0.0027	64.03	55.13
04:16AM	1440	25	1.0200	0.0028	1.0172	11.74	0.01264	0.0011	54.52	46.94

Table A4.9 Hydrometer Analysis for TP-3@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.73										
Time	Elapsed Time (min)	Temp. (^oc)	Actual H. Reading,R_A	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L (cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:36AM	1	25.2	1.0300	0.0028	1.0272	9.14	0.01259	0.0381	85.85	79.05
03:37AM	2	25.2	1.0295	0.0028	1.0267	9.26	0.01259	0.0271	84.27	77.60
03:39AM	4	25.3	1.0285	0.0028	1.0257	9.49	0.01256	0.0193	81.11	74.70
03:43AM	8	25.5	1.0270	0.0028	1.0242	9.94	0.01253	0.0140	76.38	70.34
03:50AM	15	25.5	1.0265	0.0028	1.0237	10.06	0.01253	0.0103	74.80	68.88
04:05AM	30	26	1.0260	0.0028	1.0232	10.16	0.01242	0.0072	73.22	67.43
04:35AM	60	26	1.0245	0.0028	1.0217	10.56	0.01242	0.0052	68.49	63.07
05:35AM	120	26.5	1.0245	0.0028	1.0217	10.56	0.01235	0.0037	68.49	63.07
07:35AM	240	27.5	1.0245	0.0028	1.0217	10.56	0.01228	0.0026	68.49	63.07
03:35AM	1440	23.5	1.0240	0.0028	1.0212	10.66	0.01283	0.0011	66.91	61.62

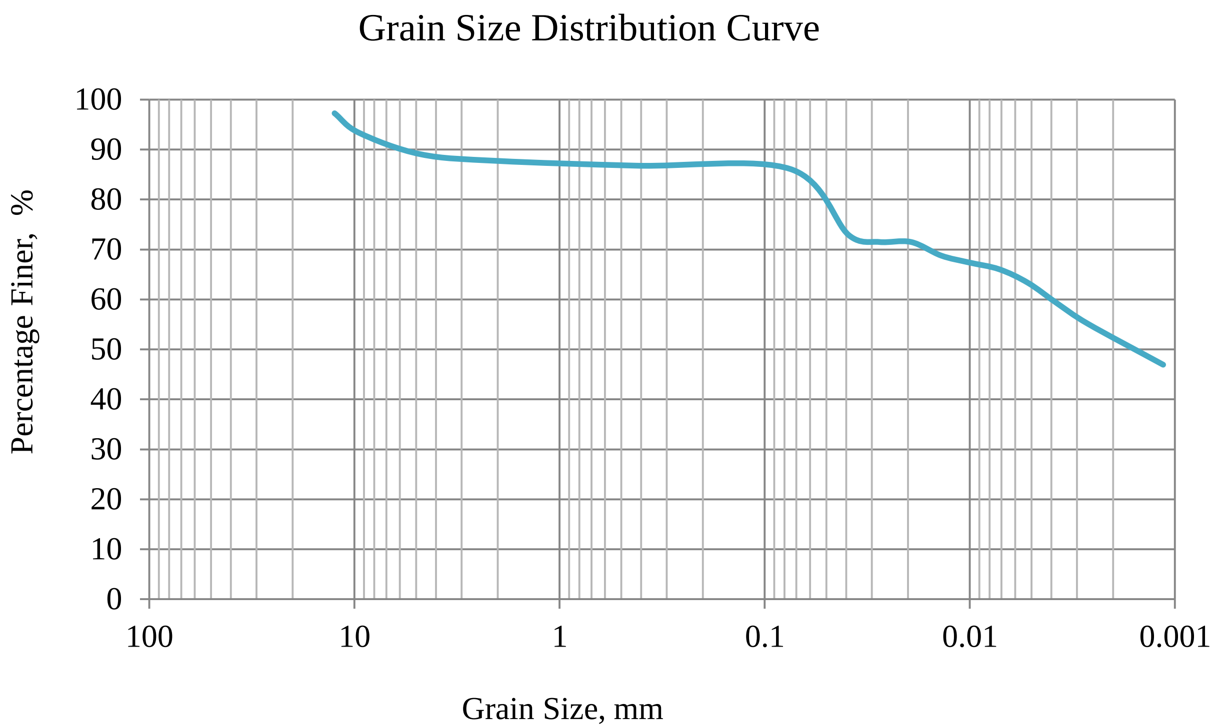

Figure A4.5 Grain size Distribution Curve for TP3-@1.5 m

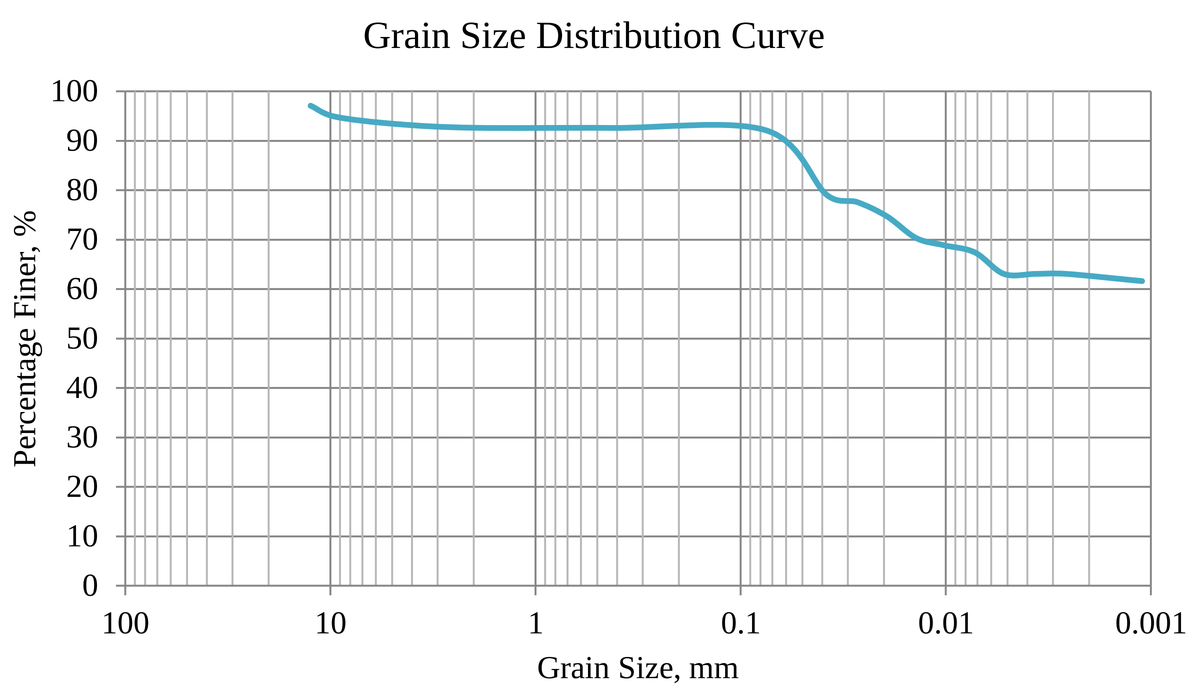

Figure A4.6 Grain size Distribution Curve for TP-3@3 m

Table A4.10 Sieve Analysis for TP4@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	508.5	509	0	0	0	0	100	100
3/8"	9.5	476.5	475.5	476.5	475.5	0	0	0	0	100	100
No 4	4.75	464	464	465.75	464	1.75	0	0.35	0	99.65	100
No 10	2	435	435	439.7	442.9	4.7	7.865	0.94	1.43	98.71	98.57
No 40	0.425	316.5	317	319.15	320.1	2.65	3.08	0.53	0.56	98.18	98.01
N 200	0.075	290	291	297.35	296.2	7.35	5.225	1.47	0.95	96.71	97.06
Pan		275.5	274.5	759.05	808.3	483.6	533.83	96.71	97.06	0	0
Total Mass(g)=						500	550				
% Gravel								0.35	0		
% Sand								2.94	2.94		
% Fines								96.71	97.06		

Table A4.11 Hydrometer Analysis for TP-4@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.67										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:36AM	1	23.5	1.0335	0.0028	1.0307	8.19	0.01299	0.0372	98.17	94.94
03:37AM	2	23.5	1.0330	0.0028	1.0302	8.34	0.01299	0.0265	96.57	93.39
03:39AM	4	23.5	1.0325	0.0028	1.0297	8.46	0.01299	0.0189	94.97	91.84
03:43AM	8	23.5	1.0320	0.0028	1.0292	8.56	0.01299	0.0134	93.37	90.30
03:50AM	15	24.2	1.0315	0.0028	1.0287	8.69	0.01288	0.0098	91.77	88.75
04:05AM	30	24.5	1.0310	0.0028	1.0282	8.84	0.01285	0.0070	90.17	87.21
04:35AM	60	25	1.0310	0.0028	1.0282	8.84	0.01279	0.0049	90.17	87.21
05:35AM	120	25.5	1.0300	0.0028	1.0272	9.64	0.01272	0.0036	86.97	84.11
07:35AM	240	26	1.0285	0.0028	1.0257	9.14	0.01264	0.0025	82.18	79.47
03:35AM	1440	24	1.0275	0.0028	1.0247	9.79	0.01293	0.0011	78.98	76.38

Table A4.12 Hydrometer Analysis for TP-4@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.70										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:59AM	1	27	1.0335	0.0028	1.0307	8.19	0.01239	0.0355	97.52	94.65
04:00AM	2	27	1.0335	0.0028	1.0307	8.19	0.01239	0.0251	97.52	94.65
04:02AM	4	27	1.0320	0.0028	1.0292	8.56	0.01239	0.0181	92.75	90.03
04:06AM	8	27	1.0315	0.0028	1.0287	8.69	0.01239	0.0129	91.16	88.48
04:13AM	15	27	1.0315	0.0028	1.0287	8.69	0.01239	0.0094	91.16	88.48
04:28AM	30	27	1.0310	0.0028	1.0282	8.84	0.01239	0.0067	89.58	86.94
04:58AM	60	28.5	1.0300	0.0028	1.0272	9.14	0.01234	0.0048	86.40	83.86
05:58AM	120	28.5	1.0280	0.0028	1.0252	9.64	0.01234	0.0035	80.05	77.69
07:58AM	240	29	1.0260	0.0028	1.0232	10.16	0.01212	0.0025	73.69	71.53
03:58AM	1440	27	1.0250	0.0028	1.0222	10.44	0.01239	0.0011	70.52	68.44

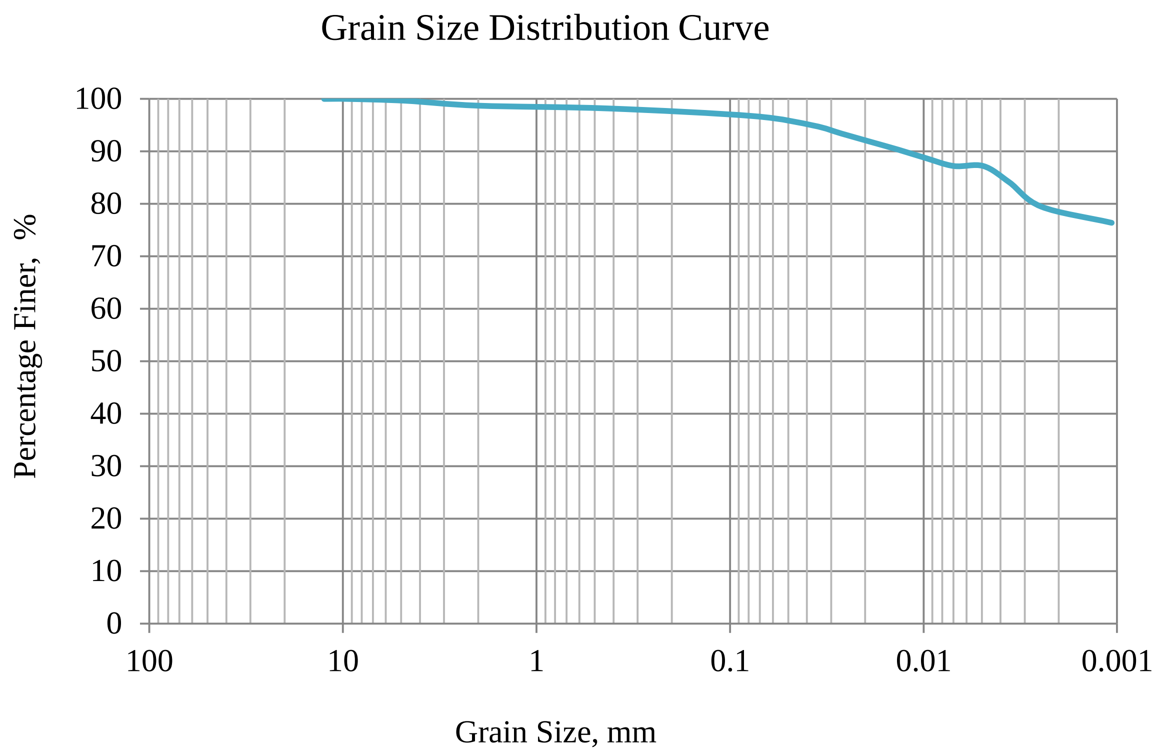

Figure A4.7 Grain size Distribution Curve for TP-4@1.5 m

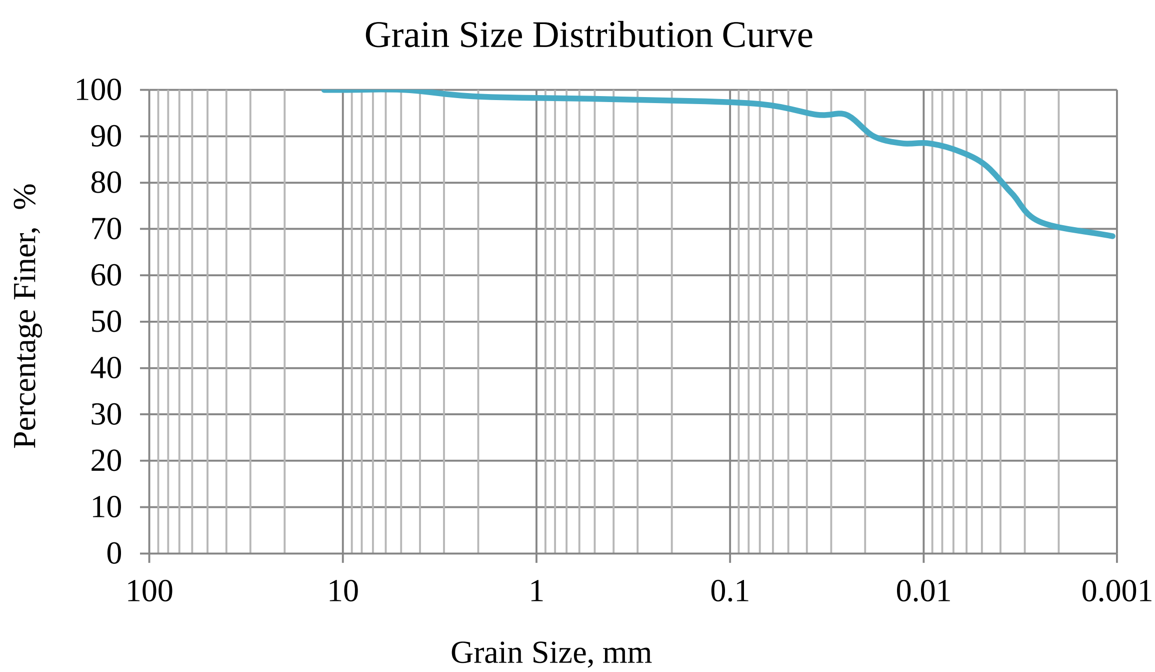

Figure A4.8 Grain size Distribution Curve for TP-4@3 m

Table A4.13 Sieve Analysis for TP-5@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	508.5	509.5	0	0.54	0	0.09	100	99.91
3/8"	9.5	476.5	475.5	480.25	478.8	3.75	3.3	0.75	0.55	99.25	99.36
No 4	4.75	464	464	468.55	465	4.55	0.96	0.91	0.16	98.34	99.2
No 10	2	435	435	442.35	440.9	7.35	5.88	1.47	0.98	96.87	98.22
No 40	0.425	316.5	317	326.75	322.2	10.25	5.16	2.05	0.86	94.82	97.36
N200	0.075	290	291	290.35	293.2	0.35	2.22	0.07	0.37	94.75	96.99
Pan		275.5	274.5	749.25	856.4	473.8	581.94	94.75	96.99	0	0
Total Mass(g)=						500	600				
% Gravel								1.66	0.8		
% Sand								3.59	2.21		
% Fines								94.75	96.99		

Table A4.14 Hydrometer Analysis for TP-5@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.65										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
04:05AM	1	24	1.0315	0.0028	1.0287	8.69	0.01301	0.0384	92.19	87.35
04:06AM	2	24	1.0310	0.0028	1.0282	8.84	0.01301	0.0274	90.58	85.83
04:08AM	4	24	1.0300	0.0028	1.0272	9.14	0.01301	0.0197	87.37	82.78
04:12AM	8	24	1.0285	0.0028	1.0257	9.49	0.01301	0.0142	82.55	78.22
04:16AM	15	24	1.0270	0.0028	1.0242	9.94	0.01301	0.0106	77.73	73.65
04:34AM	30	24	1.0255	0.0028	1.0227	10.16	0.01293	0.0075	72.92	69.09
05:04AM	60	26	1.0235	0.0028	1.0207	10.79	0.01272	0.0054	66.49	63.00
06:04AM	120	26	1.0230	0.0028	1.0202	10.94	0.01272	0.0038	64.88	61.48
08:04AM	240	27	1.0220	0.0028	1.0192	11.24	0.01258	0.0027	61.67	58.43
04:04AM	1440	28	1.0190	0.0028	1.0162	12.04	0.01244	0.0011	52.04	49.30

Table A4.15 Hydrometer Analysis for TP-5@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.68										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading, (R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:36AM	1	23	1.0310	0.0028	1.0282	8.84	0.01303	0.0387	89.97	87.26
03:37AM	2	23	1.0310	0.0028	1.0282	8.84	0.01303	0.0274	89.97	87.26
03:39AM	4	23	1.0305	0.0028	1.0277	8.99	0.01303	0.0195	88.38	85.72
03:43AM	8	23	1.0300	0.0028	1.0272	9.14	0.01303	0.0139	86.78	84.17
03:50AM	15	23.3	1.0290	0.0028	1.0262	9.36	0.01299	0.0103	83.59	81.07
04:05AM	30	23.7	1.0280	0.0028	1.0252	9.64	0.01293	0.0073	80.40	77.98
04:35AM	60	24	1.0275	0.0028	1.0247	9.79	0.01284	0.0052	78.80	76.43
05:35AM	120	24.9	1.0265	0.0028	1.0237	10.06	0.01271	0.0037	75.61	73.34
07:35AM	240	25.5	1.0250	0.0028	1.0222	10.44	0.01263	0.0026	70.83	68.70
03:35AM	1440	23.5	1.0245	0.0028	1.0217	10.56	0.01295	0.0011	69.23	67.15

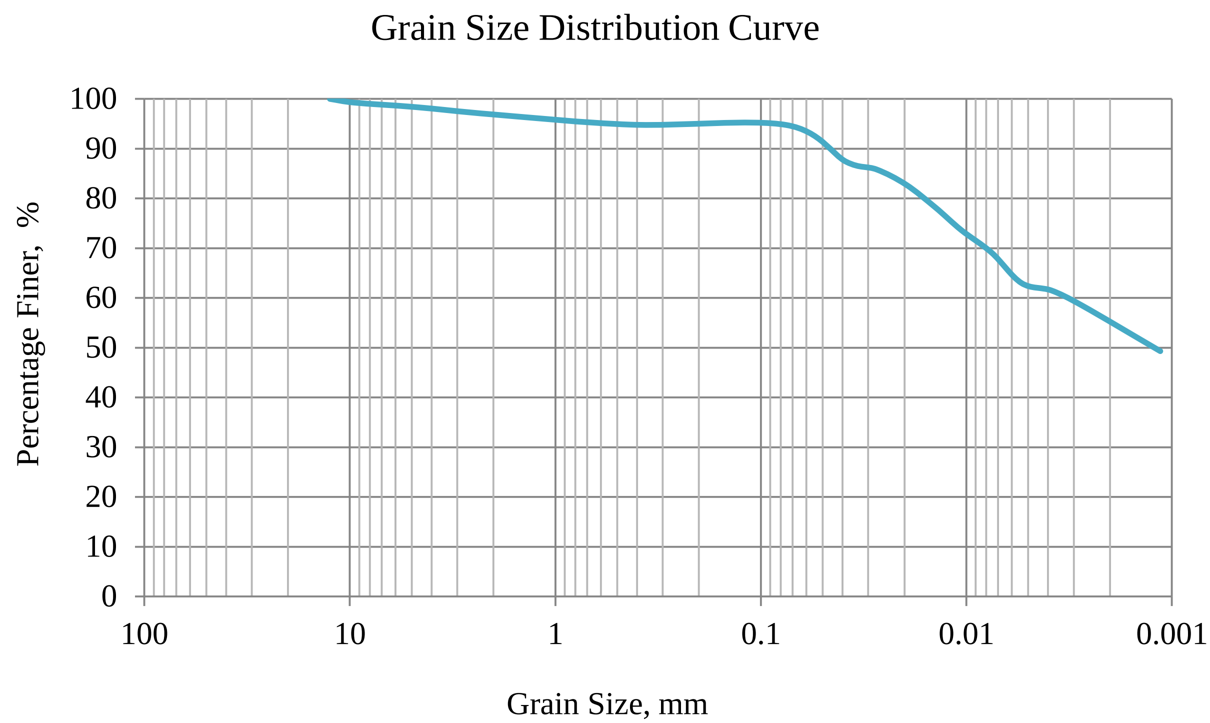

Figure A4.9 Grain size Distribution Curve for TP-5@1.5 m

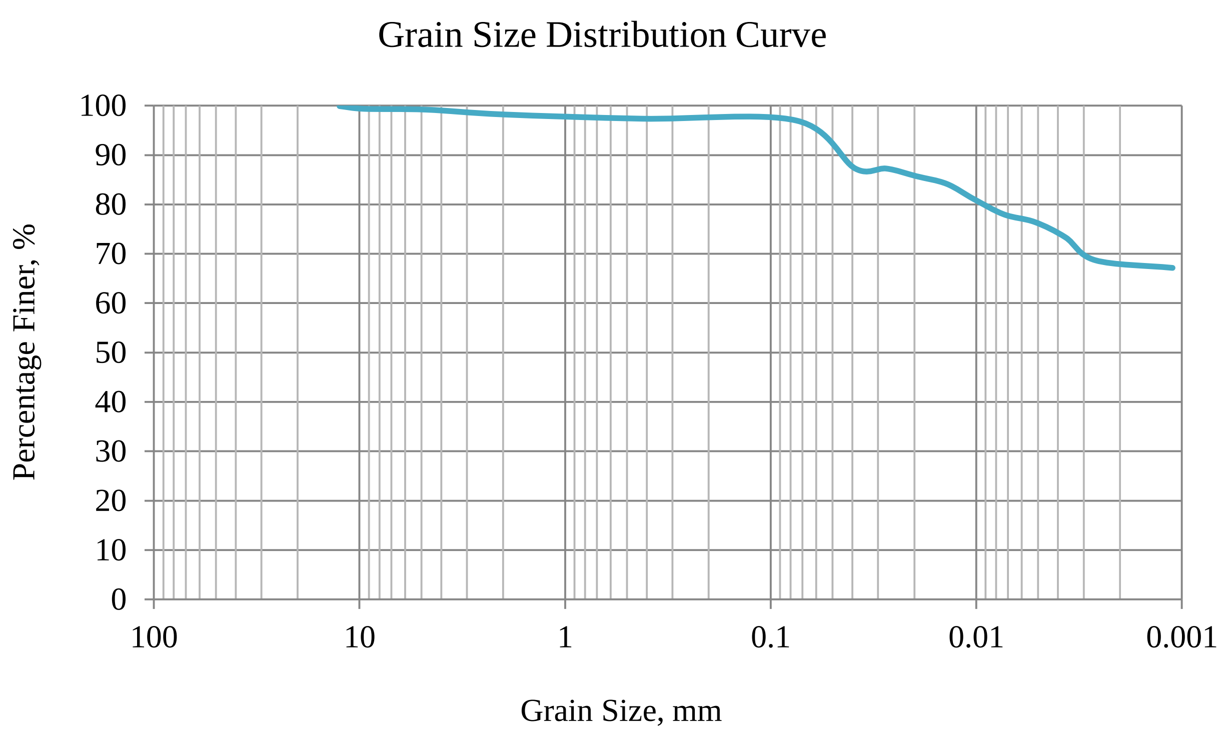

Figure A4.10 Grain size Distribution Curve TP5@3 m

Table A4.16 Sieve Analysis TP6@1.5 mand3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	527.2	519.5	18.7	10.5	3.4	2.1	96.6	97.9
3/8"	9.5	476.5	475.5	502.63	485.1	26.13	9.55	4.75	1.91	91.85	95.99
No4	4.75	464	464	480.12	482.6	16.12	18.55	2.93	3.71	88.92	92.28
No10	2	435	435	440.23	445.5	5.225	10.5	0.95	2.1	87.97	90.18
No40	0.425	316.5	317	320.52	326.5	4.015	9.5	0.73	1.9	87.24	88.28
N200	0.075	290	291	292.48	291.6	2.475	0.55	0.45	0.11	86.79	88.17
Pan		275.5	274.5	752.85	715.4	477.3	440.85	86.79	88.17	0	0
Total Mass(g)=						550	500				
% Gravel								11.08	7.72		
% Sand								2.13	4.11		
% Fines								86.79	88.17		

Table A4.17 Hydrometer Analysis for TP-6@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.57										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
04:01AM	1	23.3	1.0330	0.0028	1.0302	8.34	0.01344	0.0388	98.87	85.81
04:02AM	2	23.3	1.0325	0.0028	1.0297	8.46	0.01344	0.0276	97.23	84.39
04:04AM	4	23.5	1.0315	0.0028	1.0287	8.69	0.01339	0.0197	93.96	81.55
04:08AM	8	23.5	1.0310	0.0028	1.0282	8.84	0.01339	0.0141	92.32	80.13
04:15AM	15	24	1.0300	0.0028	1.0272	9.14	0.01333	0.0104	89.05	77.29
04:30AM	30	24	1.0295	0.0028	1.0267	9.26	0.01333	0.0074	87.41	75.87
05:00AM	60	24.5	1.0275	0.0028	1.0247	9.79	0.01325	0.0054	80.86	70.18
06:00AM	120	25.5	1.0260	0.0028	1.0232	10.16	0.01312	0.0038	75.95	65.92
08:00AM	240	26	1.0255	0.0028	1.0227	10.29	0.01303	0.0027	74.32	64.50
04:00AM	1440	24	1.0245	0.0028	1.0217	10.56	0.01333	0.0011	71.04	61.66

Table A4.18 Hydrometer Analysis for TP-6@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.59										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:36AM	1	25	1.0325	0.0028	1.0297	8.46	0.01303	0.0379	96.76	85.31
03:37AM	2	25	1.0320	0.0028	1.0292	8.59	0.01303	0.0270	95.13	83.88
03:39AM	4	25	1.0315	0.0028	1.0287	8.69	0.01303	0.0192	93.50	82.44
03:43AM	8	25	1.0310	0.0028	1.0282	8.84	0.01303	0.0137	91.87	81.00
03:50AM	15	25	1.0295	0.0028	1.0267	9.26	0.01303	0.0102	86.98	76.69
04:05AM	30	25	1.0280	0.0028	1.0252	9.64	0.01303	0.0074	82.10	72.39
04:35AM	60	25	1.0265	0.0028	1.0237	10.06	0.01303	0.0053	77.21	68.08
05:35AM	120	26.5	1.0245	0.0028	1.0217	10.56	0.01281	0.0038	70.70	62.33
07:35AM	240	27	1.0230	0.0028	1.0202	10.94	0.01273	0.0027	65.81	58.02
03:35AM	1440	25	1.0210	0.0028	1.0182	11.46	0.01303	0.0012	59.29	52.28

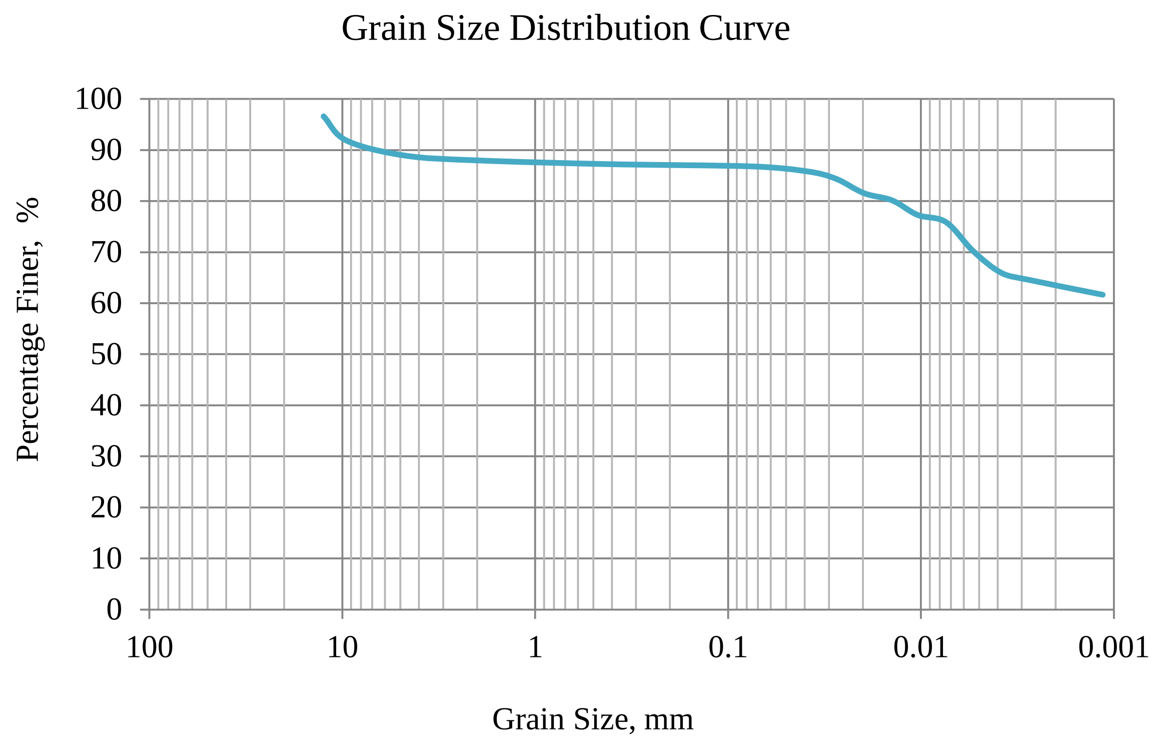

Figure A4.11 Grain size Distribution Curve for TP-6@1.5 m

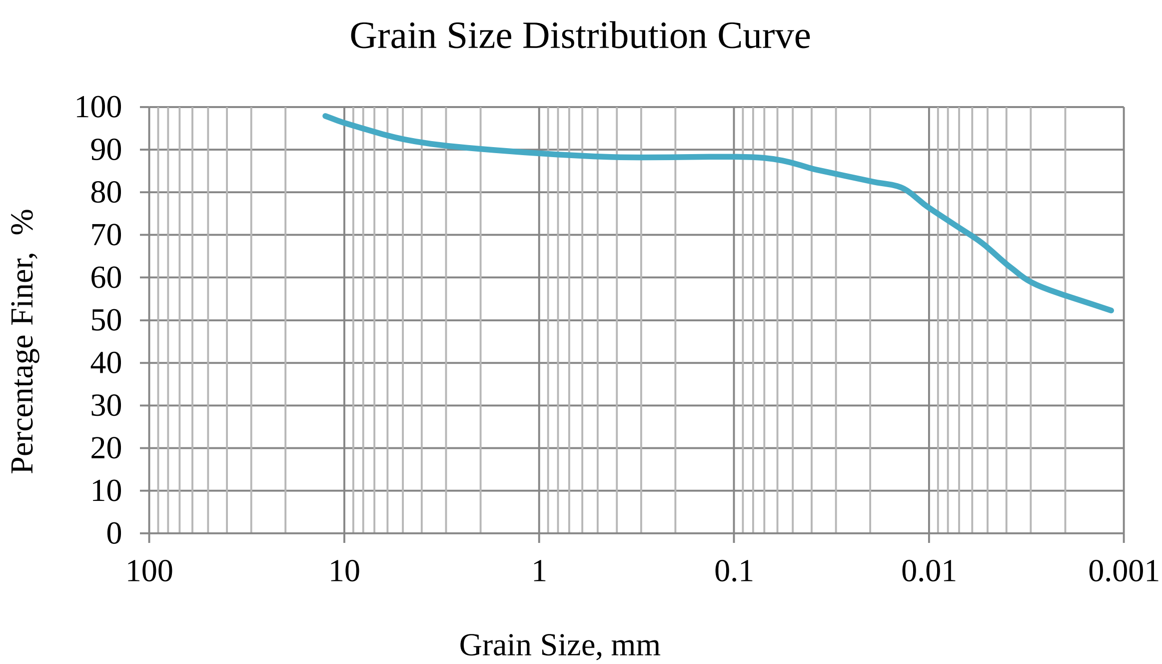

Figure A4.12 Grain size Distribution Curve for TP-6@3 m

Table A4.19 Sieve Analysis for TP-7@1.5 m and 3m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	526.2	523.9	17.7	14.905	2.95	2.71	97.05	97.29
3/8"	9.5	476.5	475.5	501.28	491.7	24.78	16.225	4.13	2.95	92.92	94.34
No4	4.75	464	464	465.98	475.6	1.98	11.605	0.33	2.11	92.59	92.23
No10	2	435	435	439.26	435.8	4.26	0.825	0.71	0.15	91.88	92.08
No40	0.425	316.5	317	317.88	321.8	1.38	4.785	0.23	0.87	91.65	91.21
N200	0.075	290	291	292.7	294.1	2.7	3.08	0.45	0.56	91.2	90.65
Pan		275.5	274.5	819.7	773.1	547	498.575	91.2	90.65	0	0
Total Mass(g)=						600	550				
% Gravel								7.41	7.77		
% Sand								1.39	1.58		
% Fines								91.2	90.65		

Table A4.20 Hydrometer Analysis for TP-7@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.63										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:21AM	1	23	1.0295	0.0028	1.0267	9.26	0.01325	0.0403	86.16	78.15
03:22AM	2	23	1.0285	0.0028	1.0257	9.49	0.01325	0.0289	82.93	75.22
03:24AM	4	23	1.0270	0.0028	1.0242	9.94	0.01325	0.0209	78.09	70.83
03:28AM	8	23	1.0260	0.0028	1.0232	10.16	0.01325	0.0149	74.87	67.90
03:35AM	15	23	1.0255	0.0028	1.0227	10.29	0.01325	0.0110	73.25	66.44
03:50AM	30	23.4	1.0235	0.0028	1.0207	10.79	0.01319	0.0079	66.80	60.59
04:20AM	60	24.5	1.0220	0.0028	1.0192	11.24	0.01303	0.0056	61.96	56.20
05:20AM	120	25.2	1.0215	0.0028	1.0187	11.36	0.01292	0.0040	60.34	54.73
07:20AM	240	26.3	1.0205	0.0028	1.0177	11.59	0.01277	0.0028	57.12	51.81
03:20AM	1440	23.5	1.0195	0.0028	1.0167	11.89	0.01317	0.0012	53.89	48.88

Table A4.21 Hydrometer Analysis for TP-7@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.55										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading, (R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
02:58AM	1	23.5	1.0300	0.0028	1.0272	9.14	0.01350	0.0408	89.50	81.13
02:59AM	2	23.5	1.0295	0.0028	1.0267	9.26	0.01350	0.0290	87.85	79.64
03:01AM	4	23.5	1.0295	0.0028	1.0267	9.26	0.01350	0.0205	87.85	79.64
03:05AM	8	23.5	1.0285	0.0028	1.0257	9.49	0.01350	0.0147	84.56	76.65
03:12AM	15	23.8	1.0270	0.0028	1.0242	9.94	0.01345	0.0109	79.63	72.18
03:27AM	30	24	1.0260	0.0028	1.0232	10.16	0.01342	0.0078	76.34	69.20
03:57AM	60	24.5	1.0255	0.0028	1.0227	10.29	0.01334	0.0055	74.69	67.71
04:57AM	120	25.5	1.0250	0.0028	1.0222	10.44	0.01319	0.0039	73.05	66.22
07:35AM	240	26	1.0245	0.0028	1.0217	10.56	0.01312	0.0028	71.40	64.72
02:58AM	1440	24	1.0235	0.0028	1.0207	10.79	0.01342	0.0012	68.11	61.74

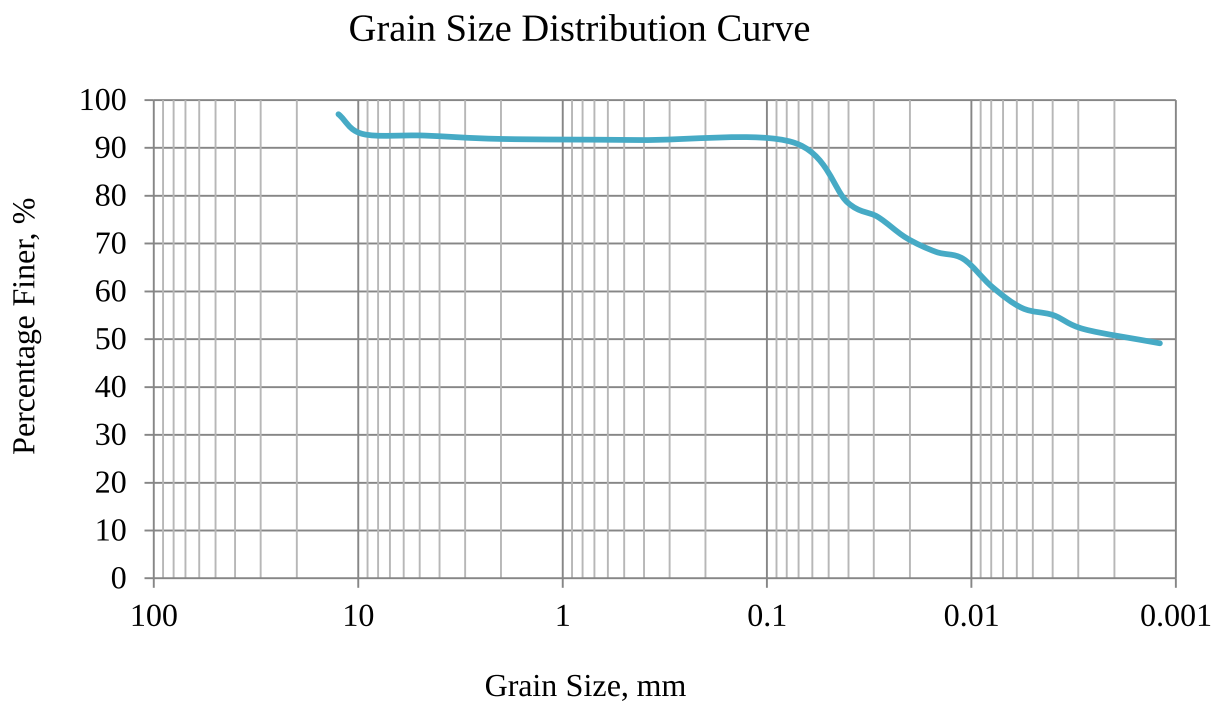

Figure A4.13 Grain size Distribution Curve for TP-7@1.5 m

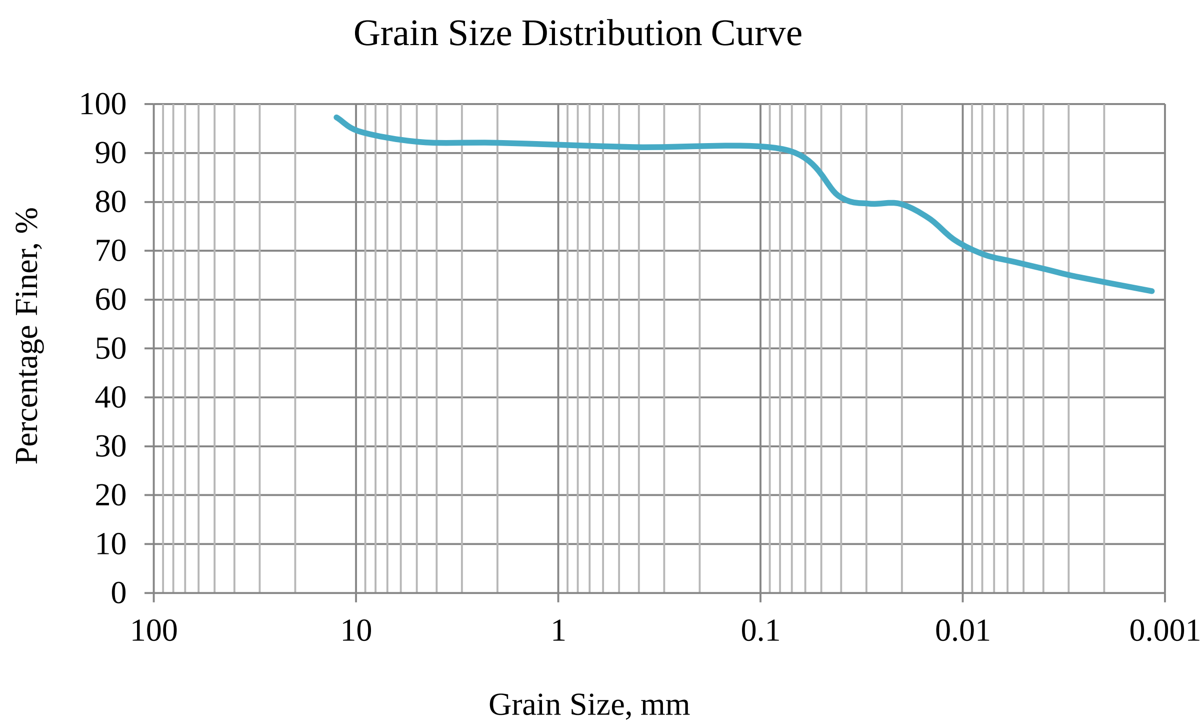

Figure A4.14 Grain size Distribution Curve for TP-7@3 m

Table A4.22 Sieve Analysis for TP-8@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	508.5	509	0	0	0	0	100	100
3/8"	9.5	476.5	475.5	476.5	475.5	0	0	0	0	100	100
No4	4.75	464	464	464	464	0	0	0	0	100	100
No10	2	435	435	438.14	437.6	3.135	2.64	0.57	0.48	99.43	99.52
No40	0.425	316.5	317	321.95	327.2	5.445	10.23	0.99	1.86	98.44	97.66
N200	0.075	290	291	302.76	297.4	12.76	6.38	2.32	1.16	96.12	96.5
Pan		275.5	274.5	804.16	805.3	528.7	530.75	96.12	96.5	0	0
Total Mass(g)=						550	550				
% Gravel								0	0		
% Sand								3.88	3.5		
% Fines								96.12	96.5		

Table A4.23 Hydrometer Analysis for TP-8@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.73										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:36AM	1	25.2	1.0310	0.0028	1.0282	8.84	0.01259	0.0374	89.00	85.55
03:37AM	2	25.2	1.0310	0.0028	1.0282	8.84	0.01259	0.0265	89.00	85.55
03:39AM	4	25.3	1.0305	0.0028	1.0277	8.99	0.01256	0.0188	87.42	84.03
03:43AM	8	25.5	1.0300	0.0028	1.0272	9.14	0.01253	0.0134	85.85	82.51
03:50AM	15	25.5	1.0290	0.0028	1.0262	9.36	0.01253	0.0099	82.69	79.48
04:05AM	30	26	1.0280	0.0028	1.0252	9.64	0.01242	0.0070	79.53	76.45
04:35AM	60	26	1.0275	0.0028	1.0247	9.79	0.01242	0.0050	77.95	74.93
05:35AM	120	26.5	1.0265	0.0028	1.0237	10.06	0.01235	0.0036	74.80	71.90
07:35AM	240	27.5	1.0250	0.0028	1.0222	10.44	0.01228	0.0026	70.06	67.35
03:35AM	1440	23.5	1.0245	0.0028	1.0217	10.56	0.01283	0.0011	68.49	65.83

Table A4.24 Hydrometer Analysis for TP-8@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.76										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
04:05AM	1	24	1.0310	0.0028	1.0282	8.84	0.01261	0.0375	88.45	85.35
04:06AM	2	24	1.0305	0.0028	1.0277	8.99	0.01261	0.0267	86.88	83.84
04:08AM	4	24	1.0305	0.0028	1.0277	8.99	0.01261	0.0189	86.88	83.84
04:12AM	8	24.5	1.0295	0.0028	1.0267	9.26	0.01253	0.0135	83.74	80.81
04:16AM	15	24.5	1.0290	0.0028	1.0262	9.36	0.01253	0.0099	82.17	79.30
04:34AM	30	24.5	1.0280	0.0028	1.0252	9.64	0.01253	0.0071	79.04	76.27
05:04AM	60	25	1.0265	0.0028	1.0237	10.06	0.01244	0.0051	74.33	71.73
06:04AM	120	25	1.0260	0.0028	1.0232	10.16	0.01244	0.0036	72.76	70.22
08:04AM	240	27	1.0240	0.0028	1.0212	10.66	0.01217	0.0026	66.49	64.16
04:04AM	1440	25	1.0210	0.0028	1.0182	11.46	0.01244	0.0011	57.08	55.08

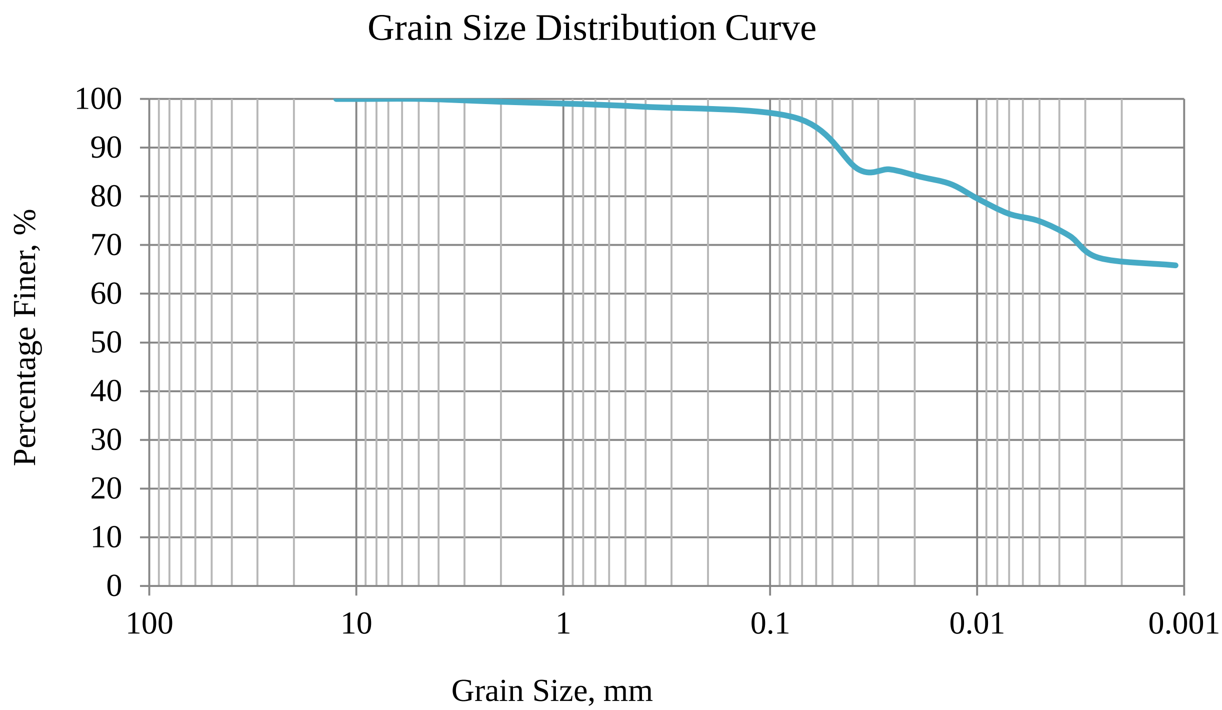

Figure A4.15 Grain size Distribution Curve for TP-8@1.5 m

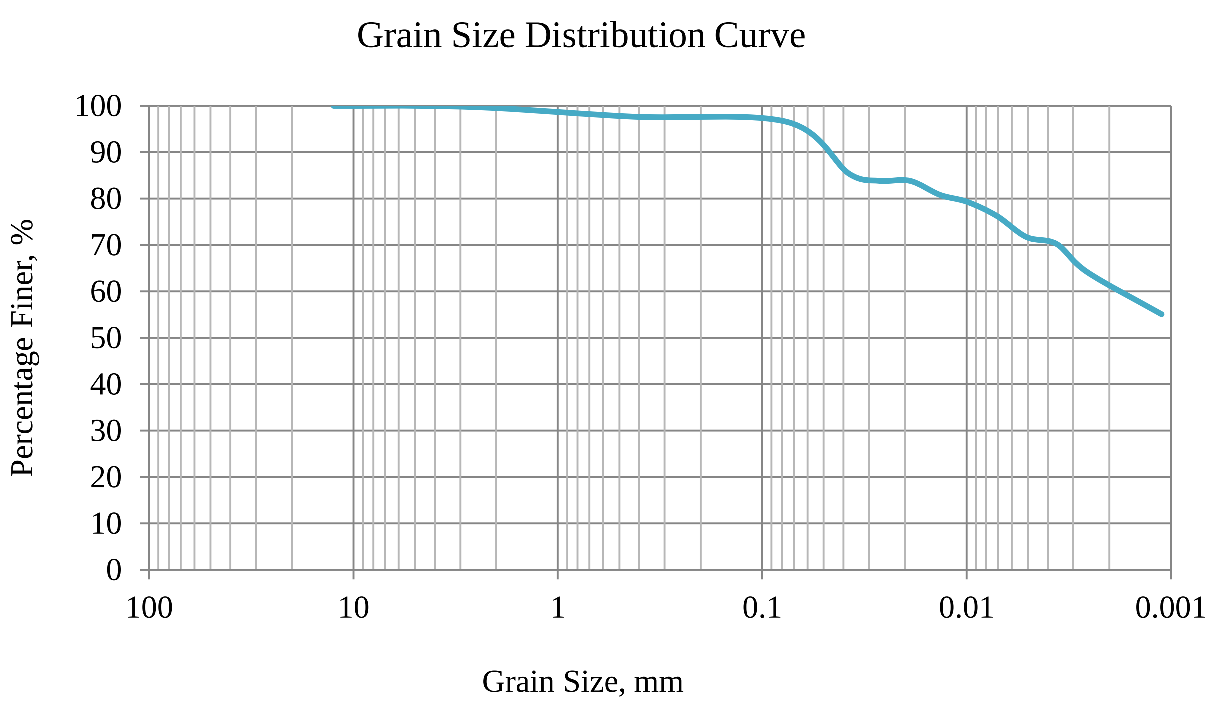

Figure A4.16 Grain size Distribution Curve for TP-8@3 m

Table A4.25 Sieve Analysis for TP9@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	508.5	509	0	0	0	0	100	100
3/8"	9.5	476.5	475.5	476.5	475.5	0	0	0	0	100	100
No4	4.75	464	464	464	465.9	0	1.925	0	0.35	100	99.65
No10	2	435	435	440.58	439.8	5.58	4.785	0.93	0.87	99.07	98.78
No40	0.425	316.5	317	326.76	324.3	10.26	7.315	1.71	1.33	97.36	97.45
N200	0.075	290	291	297.32	301.4	7.32	10.395	1.22	1.89	96.14	95.56
Pan		275.5	274.5	852.34	800.1	576.8	525.58	96.14	95.56	0	0
Total Mass(g)=						600	550				
% Gravel								0	0.35		
% Sand								3.86	4.09		
% Fines								96.14	95.56		

Table A4.26 Hydrometer Analysis for TP-9@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.72										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:21AM	1	24	1.0330	0.0028	1.0302	8.34	0.01276	0.0368	95.52	91.83
03:22AM	2	24	1.0325	0.0028	1.0297	8.46	0.01276	0.0262	93.93	90.31
03:24AM	4	24	1.0315	0.0028	1.0287	8.69	0.01276	0.0188	90.77	87.27
03:28AM	8	24.5	1.0290	0.0028	1.0262	9.36	0.01269	0.0137	82.87	79.67
03:35AM	15	24.5	1.0285	0.0028	1.0257	9.49	0.01269	0.0101	81.28	78.15
03:50AM	30	24.5	1.0280	0.0028	1.0252	9.64	0.01269	0.0072	79.70	76.63
04:20AM	60	25	1.0265	0.0028	1.0237	10.06	0.01261	0.0052	74.96	72.06
05:20AM	120	25	1.0255	0.0028	1.0227	10.29	0.01261	0.0037	71.80	69.02
07:20AM	240	27	1.0235	0.0028	1.0207	10.79	0.01233	0.0026	65.47	62.94
03:20AM	1440	25	1.0210	0.0028	1.0182	11.46	0.01261	0.0011	57.56	55.34

Table A4.27 Hydrometer Analysis for TP-9@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.73										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
04:05AM	1	25.2	1.0335	0.0028	1.0307	8.19	0.01259	0.0360	96.89	92.59
04:06AM	2	25.2	1.0335	0.0028	1.0307	8.19	0.01259	0.0255	96.89	92.59
04:08AM	4	25.3	1.0320	0.0028	1.0292	8.56	0.01256	0.0184	92.16	88.07
04:12AM	8	25.5	1.0315	0.0028	1.0287	8.69	0.01253	0.0131	90.58	86.56
04:16AM	15	25.5	1.0315	0.0028	1.0287	8.69	0.01253	0.0095	90.58	86.56
04:34AM	30	26	1.0310	0.0028	1.0282	8.84	0.01242	0.0067	89.00	85.05
05:04AM	60	26	1.0300	0.0028	1.0272	9.14	0.01242	0.0048	85.85	82.03
06:04AM	120	26.5	1.0280	0.0028	1.0252	9.64	0.01235	0.0035	79.53	76.00
08:04AM	240	27.5	1.0260	0.0028	1.0232	10.16	0.01228	0.0025	73.22	69.97
04:04AM	1440	23.5	1.0250	0.0028	1.0222	10.44	0.01283	0.0011	70.06	66.95

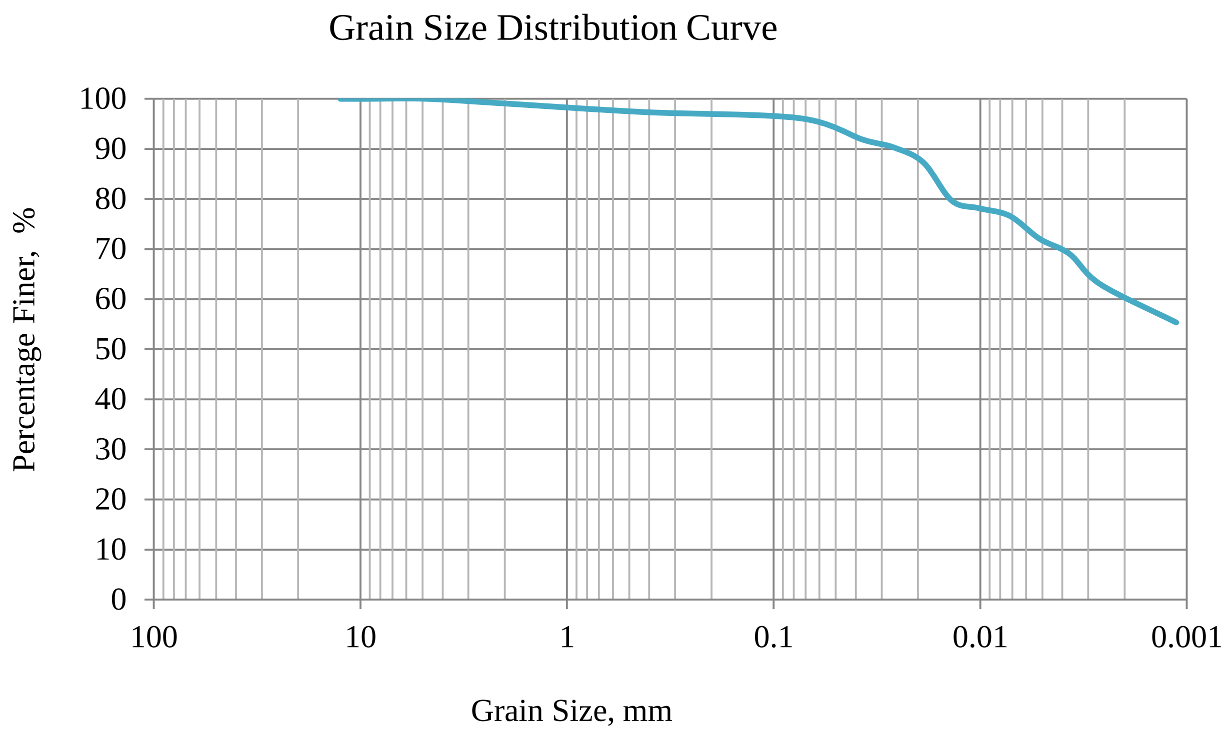

Figure A4.17 Grain size Distribution Curve for TP-9@1.5 m

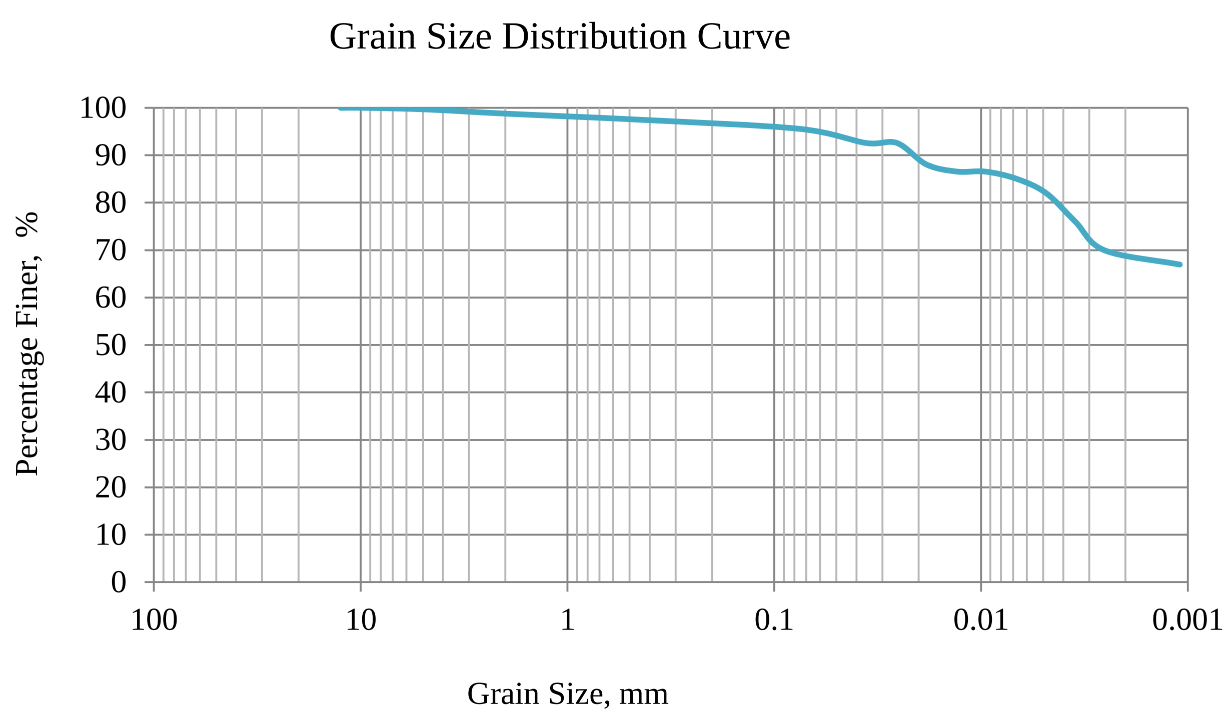

Figure A4.18 Grain size Distribution Curve for TP-9@3 m

Table A4.28 Sieve Analysis for TP-10@1.5 m and 3 m

Sieve No.	Dia (mm)	Mass of Empty Sieve (g)		Mass of Sieve + Soil Retained (g)		Soil Retained (g)		Percent Retained (%)		Percent Passing (%)	
		1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m	1.5 m	3 m
1/2"	12.5	508.5	509	508.5	509	0	0	0	0	100	100
3/8"	9.5	476.5	475.5	476.5	475.5	0	0	0	0	100	100
No4	4.75	464	464	464	466.4	0	2.38	0	0.34	100	99.66
No10	2	435	435	435	438.2	0	3.15	0	0.45	100	99.21
No40	0.425	316.5	317	323.72	324.2	7.215	7.21	1.11	1.03	98.89	98.18
N200	0.075	290	291	300.27	303.3	10.27	12.25	1.58	1.75	97.31	96.43
Pan		275.5	274.5	908.02	949.5	632.5	675.01	97.31	96.43	0	0
Total Mass(g)=						650	700				
% Gravel								0	0.34		
% Sand								2.69	3.23		
% Fines								97.31	96.43		

Table A4.29 Hydrometer Analysis for TP-10@1.5 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.67										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:14AM	1	24.2	1.0325	0.0028	1.0297	8.46	0.01292	0.0376	94.97	92.41
03:15AM	2	24.2	1.0325	0.0028	1.0297	8.46	0.01292	0.0266	94.97	92.41
03:17AM	4	24.2	1.0320	0.0028	1.0292	8.56	0.01292	0.0189	93.37	90.86
03:21AM	8	24.2	1.0315	0.0028	1.0287	8.69	0.01292	0.0135	91.77	89.30
03:28AM	15	24.5	1.0300	0.0028	1.0272	9.14	0.01286	0.0100	86.97	84.64
03:43AM	30	24.5	1.0285	0.0028	1.0257	9.49	0.01286	0.0072	82.18	79.97
04:13AM	60	24.8	1.0275	0.0028	1.0247	9.79	0.01283	0.0052	78.98	76.86
05:13AM	120	25.5	1.0265	0.0028	1.0237	10.06	0.01273	0.0037	75.78	73.74
07:33AM	240	26	1.0260	0.0028	1.0232	10.16	0.01264	0.0026	74.18	72.19
03:13AM	1440	24.5	1.0245	0.0028	1.0217	10.56	0.01286	0.0011	69.39	67.52

Table A4.30 Hydrometer Analysis for TP-10@3 m

Hydrometer Number=151H, weight of Dry Soil, Ws =50g, Gs=2.68										
Time	Elapsed Time (min)	Temp. (^{o}c)	Actual H. Reading,(R_A)	Composite correction	Corr. Hydr. Reading, R_C	Effective dept, L(cm)	Coefficient, K from Table	Grain Size, D (mm)	Percentage Finer, P (%)	Combined Perc. Finer, P_A (%)
03:41AM	1	23.5	1.0275	0.0028	1.0247	9.79	0.01295	0.0405	78.80	75.99
03:42AM	2	23.5	1.0270	0.0028	1.0242	9.94	0.01295	0.0289	77.21	74.45
03:44AM	4	23.5	1.0260	0.0028	1.0232	10.29	0.01295	0.0208	74.02	71.38
03:48AM	8	23.5	1.0255	0.0028	1.0227	9.36	0.01295	0.0140	72.42	69.84
03:55AM	15	23.7	1.0240	0.0028	1.0212	10.66	0.01293	0.0109	67.64	65.22
04:10AM	30	23.9	1.0225	0.0028	1.0197	11.09	0.01291	0.0078	62.85	60.61
04:40AM	60	24.4	1.0215	0.0028	1.0187	11.36	0.01277	0.0056	59.66	57.53
05:40AM	120	24.9	1.0200	0.0028	1.0172	11.74	0.01271	0.0040	54.88	52.92
07:40AM	240	25.5	1.0190	0.0028	1.0162	11.89	0.01263	0.0028	51.69	49.84
03:40AM	1440	24	1.0175	0.0028	1.0147	12.39	0.01285	0.0012	46.90	45.23

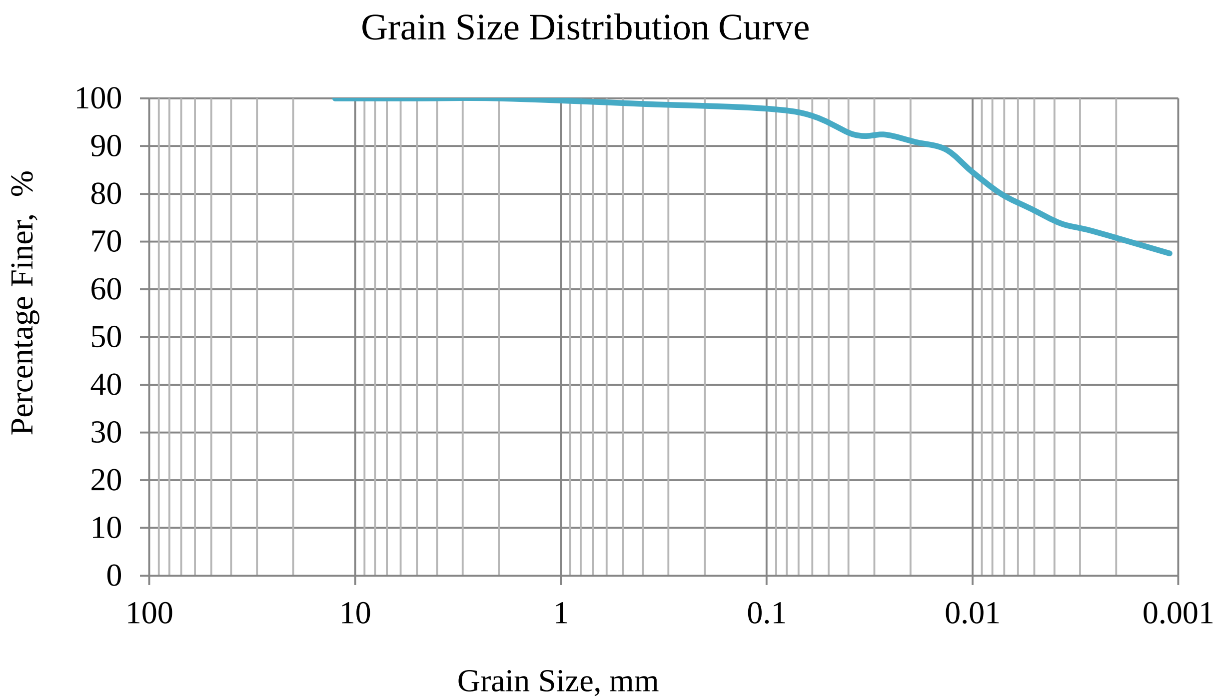

Figure A4.19 Grain size Distribution Curve for TP-10@1.5 m

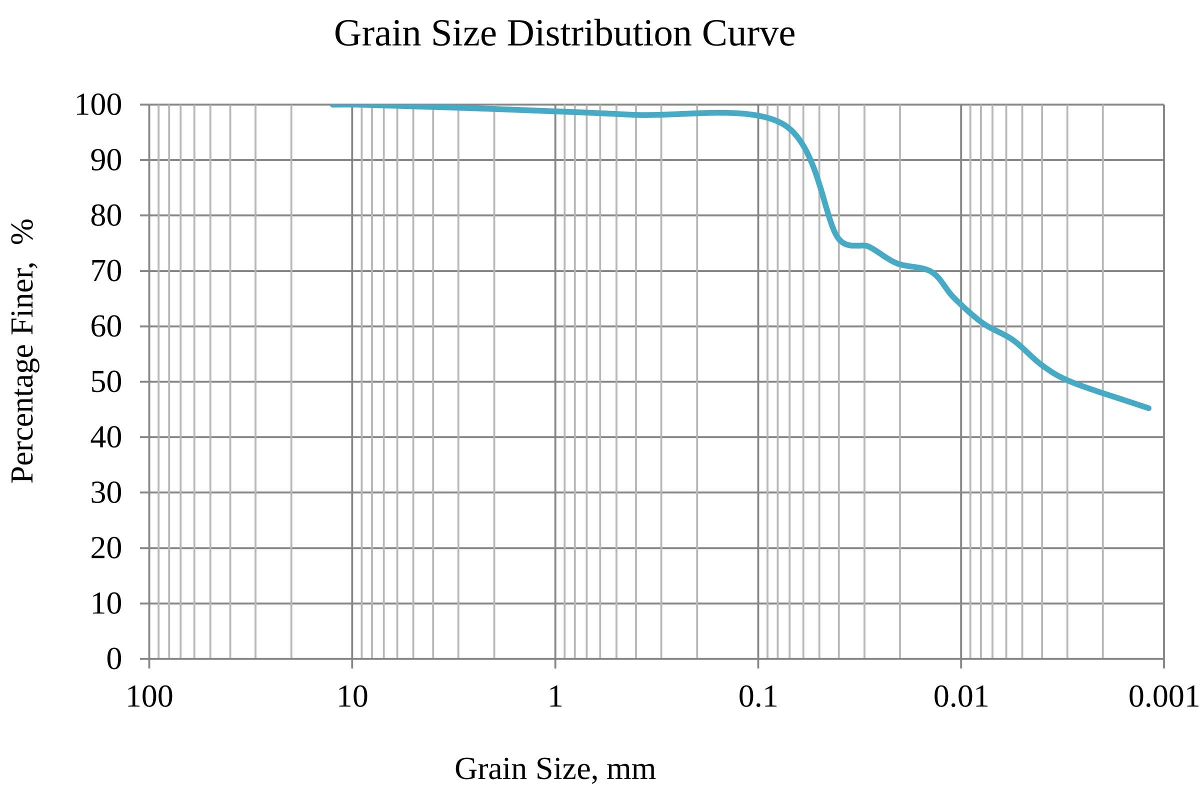

Figure A4.20 Grain size Distribution Curve for TP-10@3 m

Appendix-B: Unconfined Compressive Strength (UCS) Test Results

Table B.1 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-1					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					@1.5 m			@3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm)	Strain, (ΔL/Lo)	% Strain, ε [(ΔL/Lo) *100]	Corrected Area,(m^2) Ac = Ao/ (1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (KN/ m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/ m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.0000	0.00	0	0.000	0.00
20	0.2	0.0026	0.2632	0.00114	0.14	0.0063	5.53	0.18	0.008	7.11
40	0.4	0.0053	0.5263	0.00114	0.23	0.0103	9.06	0.29	0.013	11.43
60	0.6	0.0079	0.7895	0.00114	0.36	0.0162	14.15	0.47	0.021	18.47
80	0.8	0.0105	1.0526	0.00115	0.56	0.0252	21.95	0.78	0.035	30.58
100	1.0	0.0132	1.3158	0.00115	0.64	0.0288	25.02	0.96	0.043	37.53
120	1.2	0.0158	1.5789	0.00115	0.79	0.0355	30.80	1.06	0.048	41.33
140	1.4	0.0184	1.8421	0.00116	0.88	0.0395	34.22	1.19	0.053	46.28
160	1.6	0.0211	2.1053	0.00116	1.01	0.0454	39.17	1.32	0.059	51.19
180	1.8	0.0237	2.3684	0.00116	1.12	0.0503	43.32	1.44	0.065	55.70
200	2.0	0.0263	2.6316	0.00116	1.21	0.0544	46.67	1.62	0.073	62.49
220	2.2	0.0289	2.8947	0.00117	1.35	0.0607	51.93	1.80	0.081	69.25
240	2.4	0.0316	3.1579	0.00117	1.50	0.0674	57.55	2.01	0.090	77.12
260	2.6	0.0342	3.4211	0.00117	1.65	0.0741	63.13	2.15	0.097	82.26
280	2.8	0.0368	3.6842	0.00118	1.83	0.0822	69.83	2.36	0.106	90.05
300	3.0	0.0395	3.9474	0.00118	2.01	0.0903	76.49	2.63	0.118	100.08
320	3.2	0.0421	4.2105	0.00118	2.11	0.0948	80.07	2.72	0.122	103.22
340	3.4	0.0447	4.4737	0.00119	2.19	0.0984	82.88	2.76	0.124	104.45
360	3.6	0.0474	4.7368	0.00119	2.24	0.1006	84.54	2.71	0.122	102.28
380	3.8	0.0500	5.0000	0.00119	2.27	0.1020	85.43	2.63	0.118	98.98
400	4.0	0.0526	5.2632	0.00120	2.25	0.1011	84.45	2.50	0.112	93.83
420	4.2	0.0553	5.5263	0.00120	2.22	0.0997	83.09	2.39	0.107	89.45
440	4.4	0.0579	5.7895	0.00120	2.15	0.0966	80.24	2.28	0.102	85.10
460	4.6	0.0605	6.0526	0.00121	2.07	0.0930	77.04			

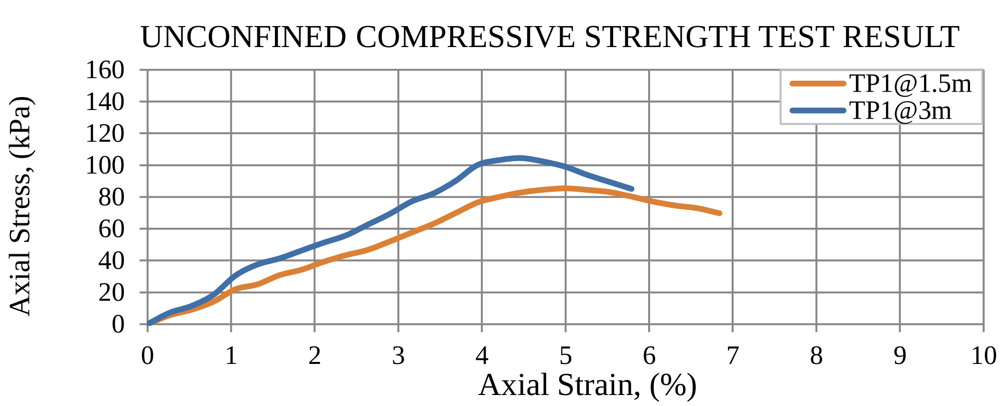

Figure B.1 Unconfined Compressive Strength (UCS) Test Results

Table B.2 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-2					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					1.5 m			3 m		
Deform Dial Read (Division)	Sample Deformaton, ΔL (mm)	Strain, (ΔL/Lo)	%Strain, ε [(ΔL/Lo)*100]	Corrected Area, (m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.00000	0.000	0	0.000	0.000
20	0.2	0.0026	0.2632	0.00114	0.11	0.00494	4.346	0.31	0.013	12.249
40	0.4	0.0053	0.5263	0.00114	0.26	0.01168	10.246	0.42	0.018	16.551
60	0.6	0.0079	0.7895	0.00114	0.39	0.01752	15.329	0.53	0.023	20.831
80	0.8	0.0105	1.0526	0.00115	0.49	0.02202	19.208	0.66	0.029	25.872
100	1.0	0.0132	1.3158	0.00115	0.68	0.03055	26.585	0.85	0.038	33.231
120	1.2	0.0158	1.5789	0.00115	0.86	0.03864	33.532	0.99	0.044	38.601
140	1.4	0.0184	1.8421	0.00116	0.99	0.04448	38.498	1.22	0.054	47.442
160	1.6	0.0211	2.1053	0.00116	1.17	0.05257	45.376	1.42	0.063	55.072
180	1.8	0.0237	2.3684	0.00116	1.35	0.06066	52.216	1.58	0.070	61.112
200	2.0	0.0263	2.6316	0.00116	1.46	0.06560	56.318	1.74	0.078	67.119
220	2.2	0.0289	2.8947	0.00117	1.63	0.07324	62.706	1.98	0.088	76.171
240	2.4	0.0316	3.1579	0.00117	1.74	0.07818	66.756	2.05	0.092	78.650
260	2.6	0.0342	3.4211	0.00117	1.79	0.08042	68.488	1.95	0.087	74.610
280	2.8	0.0368	3.6842	0.00118	1.76	0.07908	67.157	1.73	0.077	66.012
300	3.0	0.0395	3.9474	0.00118	1.67	0.07503	63.548	1.58	0.070	60.124
320	3.2	0.0421	4.2105	0.00118	1.57	0.07054	59.579			
340	3.4	0.0447	4.4737	0.00119	1.46	0.0656	55.25			

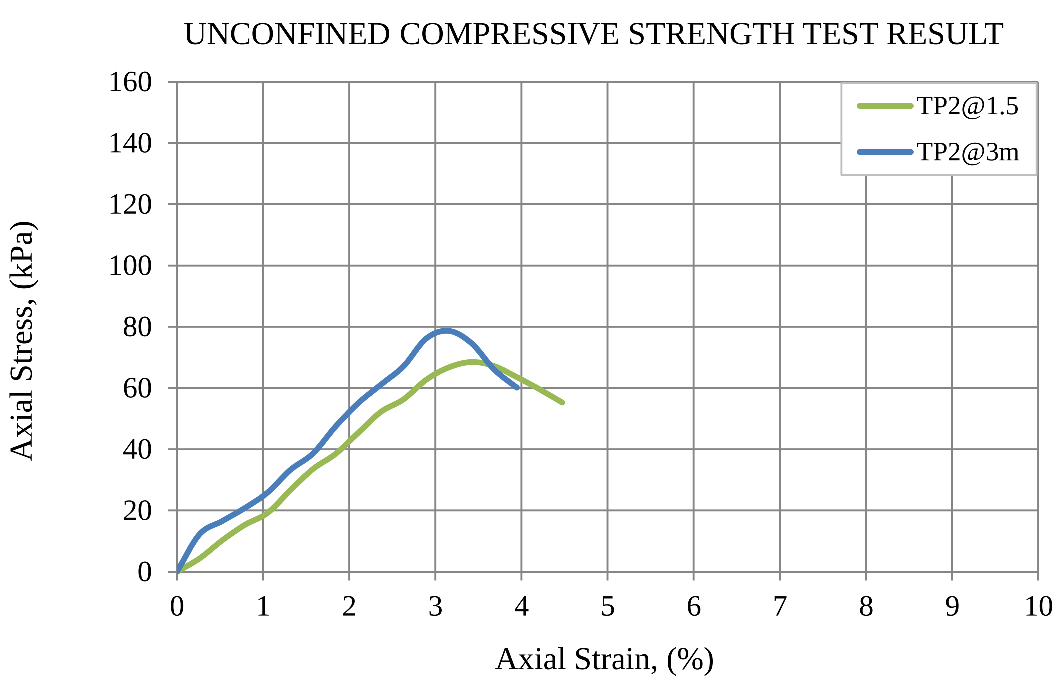

Figure B.2 Unconfined Compressive Strength (UCS) Test Results

Table B.3 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-3					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					@1.5 m			@3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm)	Strain, (ΔL/Lo)	% Strain, ε [(ΔL/Lo) *100]	Corrected Area,(m^2) Ac = Ao/ (1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (KN/ m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/ m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.00000	0.000	0	0.000	0.00
20	0.2	0.0026	0.2632	0.00114	0.09	0.00404	3.556	0.13	0.006	5.14
40	0.4	0.0053	0.5263	0.00114	0.15	0.00674	5.911	0.35	0.016	13.79
60	0.6	0.0079	0.7895	0.00114	0.28	0.01258	11.005	0.49	0.022	19.26
80	0.8	0.0105	1.0526	0.00115	0.33	0.01483	12.936	0.88	0.040	34.50
100	1.0	0.0132	1.3158	0.00115	0.40	0.01797	15.638	1.05	0.047	41.05
120	1.2	0.0158	1.5789	0.00115	0.51	0.02291	19.886	1.16	0.052	45.23
140	1.4	0.0184	1.8421	0.00116	0.65	0.02920	25.277	1.30	0.058	50.55
160	1.6	0.0211	2.1053	0.00116	0.88	0.03954	34.129	1.56	0.070	60.50
180	1.8	0.0237	2.3684	0.00116	1.01	0.04538	39.065	1.70	0.076	65.75
200	2.0	0.0263	2.6316	0.00116	1.09	0.04897	42.046	1.85	0.083	71.36
220	2.2	0.0289	2.8947	0.00117	1.25	0.05616	48.087	1.93	0.087	74.25
240	2.4	0.0316	3.1579	0.00117	1.40	0.06290	53.712	2.03	0.091	77.88
260	2.6	0.0342	3.4211	0.00117	1.55	0.06964	59.305	2.30	0.103	88.00
280	2.8	0.0368	3.6842	0.00118	1.65	0.07413	62.959	2.50	0.112	95.39
300	3.0	0.0395	3.9474	0.00118	1.78	0.07998	67.734	2.71	0.122	103.12
320	3.2	0.0421	4.2105	0.00118	1.84	0.08267	69.826	2.76	0.124	104.74
340	3.4	0.0447	4.4737	0.00119	1.86	0.08357	70.391	2.81	0.126	106.34
360	3.6	0.0474	4.7368	0.00119	1.83	0.08222	69.065	2.75	0.124	103.79
380	3.8	0.0500	5.0000	0.00119	1.76	0.07908	66.239	2.73	0.123	102.75
400	4.0	0.0526	5.2632	0.00120	1.65	0.07413	61.927	2.65	0.119	99.46
420	4.2	0.0553	5.5263	0.00120				2.50	0.112	93.57

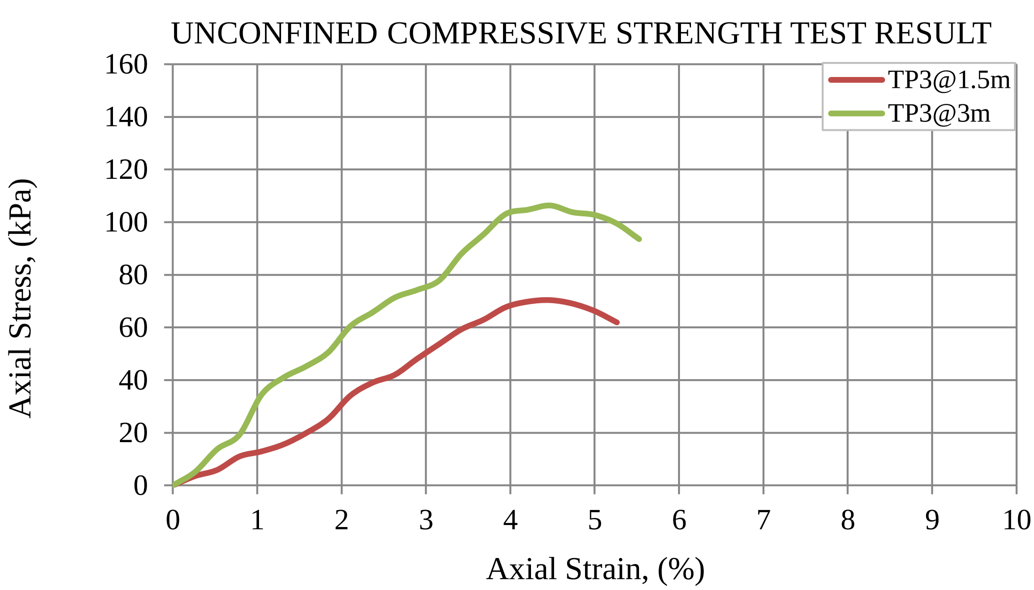

Figure B.3 Unconfined Compressive Strength (UCS) Test Results

Table B.4 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-4					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					1.5 m			3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm)	Strain, (ΔL/Lo)	% Strain, ε [(ΔL/Lo)*100]	Corrected Area,(m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (KN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.00000	0.000	0	0.00000	0.000
20	0.2	0.0026	0.2632	0.00114	0.13	0.00584	5.137	0.13	0.00584	5.137
40	0.4	0.0053	0.5263	0.00114	0.22	0.00988	8.670	0.21	0.00944	8.276
60	0.6	0.0079	0.7895	0.00114	0.31	0.01393	12.184	0.34	0.01528	13.363
80	0.8	0.0105	1.0526	0.00115	0.42	0.01887	16.464	0.59	0.02651	23.128
100	1.0	0.0132	1.3158	0.00115	0.53	0.02381	20.721	0.76	0.03415	29.713
120	1.2	0.0158	1.5789	0.00115	0.72	0.03235	28.074	0.92	0.04134	35.872
140	1.4	0.0184	1.8421	0.00116	0.96	0.04313	37.332	1.12	0.05032	43.553
160	1.6	0.0211	2.1053	0.00116	1.15	0.05167	44.600	1.32	0.05931	51.193
180	1.8	0.0237	2.3684	0.00116	1.29	0.05796	49.895	1.46	0.06560	56.471
200	2.0	0.0263	2.6316	0.00116	1.39	0.06245	53.618	1.58	0.07099	60.947
220	2.2	0.0289	2.8947	0.00117	1.61	0.07234	61.937	1.78	0.07998	68.477
240	2.4	0.0316	3.1579	0.00117	1.71	0.07683	65.605	1.94	0.08716	74.430
260	2.6	0.0342	3.4211	0.00117	1.76	0.07908	67.340	2.12	0.09525	81.114
280	2.8	0.0368	3.6842	0.00118	1.88	0.08447	71.736	2.31	0.10379	88.143
300	3.0	0.0395	3.9474	0.00118	1.99	0.08941	75.725	2.46	0.11053	93.610
320	3.2	0.0421	4.2105	0.00118	2.11	0.09480	80.072	2.54	0.11412	96.390
340	3.4	0.0447	4.4737	0.00119	1.94	0.08716	73.418	2.62	0.11772	99.152
360	3.6	0.0474	4.7368	0.00119	1.81	0.0813	68.31	2.54	0.11412	95.860
380	3.8	0.0500	5.0000	0.00119				2.4	0.10783	90.326
400	4.0	0.0526	5.2632	0.00120				2.26	0.10154	84.822
420	4.2	0.0553	5.5263	0.00120				2.16	0.09705	80.843

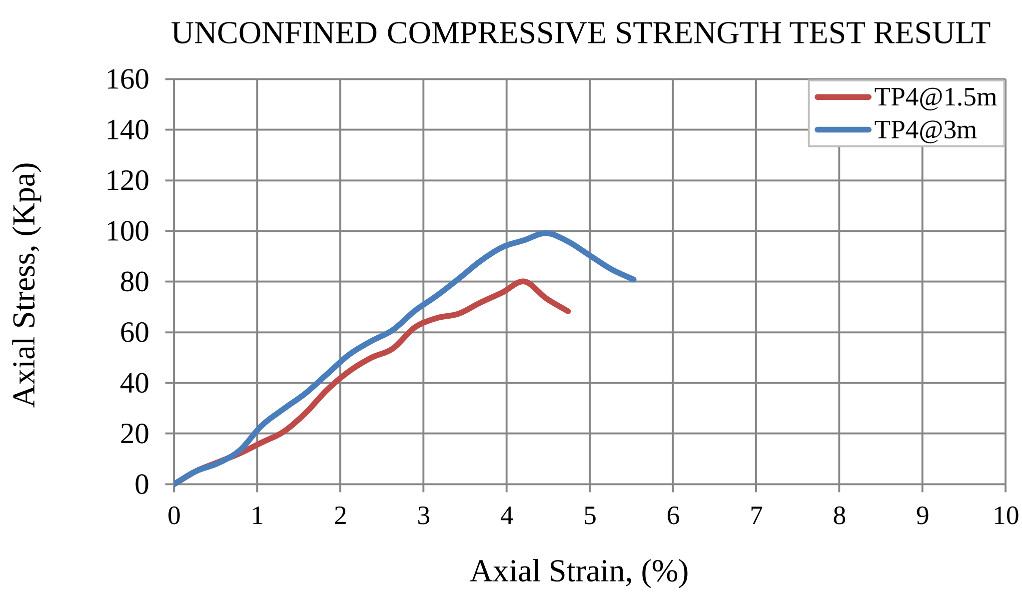

Figure B.4 Unconfined Compressive Strength (UCS) Test Results

Table B.5 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-5					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					1.5 m			3 m		
Deform Dial Read (Division)	Sample Deformation,Δ L (mm)	Strain, (ΔL/Lo)	%Strain ,ε [(ΔL/Lo)*100]	Corrected Area, (m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.0000	0.00	0	0.00000	0.000
20	0.2	0.0026	0.2632	0.00114	0.12	0.0054	4.74	0.22	0.01085	9.538
40	0.4	0.0053	0.5263	0.00114	0.22	0.0099	8.67	0.41	0.02021	17.729
60	0.6	0.0079	0.7895	0.00114	0.33	0.0148	12.97	0.62	0.03057	26.739
80	0.8	0.0105	1.0526	0.00115	0.42	0.0189	16.46	0.82	0.04043	35.270
100	1.0	0.0132	1.3158	0.00115	0.58	0.0261	22.68	1.02	0.05029	43.756
120	1.2	0.0158	1.5789	0.00115	0.69	0.0310	26.90	1.27	0.06261	54.335
140	1.4	0.0184	1.8421	0.00116	0.83	0.0373	32.28	1.41	0.06951	60.164
160	1.6	0.0211	2.1053	0.00116	1.01	0.0454	39.17	1.61	0.07937	68.513
180	1.8	0.0237	2.3684	0.00116	1.08	0.0485	41.77	1.81	0.08923	76.817
200	2.0	0.0263	2.6316	0.00116	1.22	0.0548	47.06	1.92	0.09466	81.266
220	2.2	0.0289	2.8947	0.00117	1.36	0.0611	52.32	2.08	0.10254	87.800
240	2.4	0.0316	3.1579	0.00117	1.5	0.0674	57.55	2.31	0.11388	97.245
260	2.6	0.0342	3.4211	0.00117	1.57	0.0705	60.07	2.48	0.12226	104.118
280	2.8	0.0368	3.6842	0.00118	1.82	0.0818	69.45	2.6	0.12818	108.858
300	3.0	0.0395	3.9474	0.00118	2.01	0.0903	76.49	2.71	0.13360	113.154
320	3.2	0.0421	4.2105	0.00118	2.23	0.1002	84.63	2.81	0.13853	117.008
340	3.4	0.0447	4.4737	0.00119	2.27	0.1020	85.91	3.01	0.14839	124.991
360	3.6	0.0474	4.7368	0.00119	2.45	0.1101	92.46	3.12	0.15382	129.202
380	3.8	0.0500	5.0000	0.00119	2.58	0.1159	97.10	3.18	0.15677	131.323
400	4.0	0.0526	5.2632	0.00120	2.64	0.1186	99.08	3.22	0.15875	132.606
420	4.2	0.0553	5.5263	0.00120	2.85	0.1281	106.6	3.16	0.15579	129.774
440	4.4	0.0579	5.7895	0.00120	2.98	0.1339	111.2	3.07	0.15135	125.727
460	4.6	0.0605	6.0526	0.00121	3.09	0.1388	115.0	2.96	0.14593	120.883

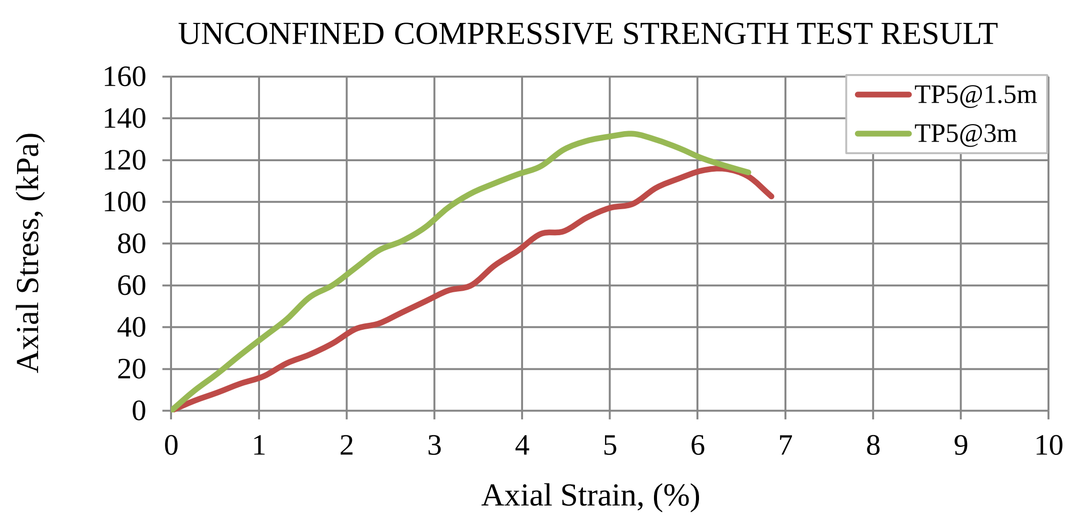

Figure B.5 Unconfined Compressive Strength (UCS) Test Results

Table B.6 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP6					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					@1.5 m			@3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm)	Strain, (ΔL/Lo)	% Strain, ε [(ΔL/Lo)*100]	Corrected Area,(m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (KN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.0000	0.00	0	0.00000	0.000
20	0.2	0.0026	0.2632	0.00114	0.11	0.0049	4.35	0.24	0.01183	10.405
40	0.4	0.0053	0.5263	0.00114	0.25	0.0112	9.85	0.45	0.02219	19.459
60	0.6	0.0079	0.7895	0.00114	0.35	0.0157	13.76	0.66	0.03254	28.464
80	0.8	0.0105	1.0526	0.00115	0.46	0.0207	18.03	0.88	0.04338	37.851
100	1.0	0.0132	1.3158	0.00115	0.61	0.0274	23.85	1.08	0.05324	46.330
120	1.2	0.0158	1.5789	0.00115	0.73	0.0328	28.46	1.33	0.06557	56.902
140	1.4	0.0184	1.8421	0.00116	0.87	0.0391	33.83	1.46	0.07198	62.297
160	1.6	0.0211	2.1053	0.00116	1.05	0.0472	40.72	1.66	0.08184	70.641
180	1.8	0.0237	2.3684	0.00116	1.12	0.0503	43.32	1.87	0.09219	79.364
200	2.0	0.0263	2.6316	0.00116	1.26	0.0566	48.60	1.99	0.09811	84.229
220	2.2	0.0289	2.8947	0.00117	1.39	0.0625	53.47	2.15	0.10600	90.755
240	2.4	0.0316	3.1579	0.00117	1.55	0.0696	59.47	2.39	0.11783	100.61
260	2.6	0.0342	3.4211	0.00117	1.62	0.0728	61.98	2.55	0.12572	107.05
280	2.8	0.0368	3.6842	0.00118	1.90	0.0854	72.50	2.65	0.13065	110.95
300	3.0	0.0395	3.9474	0.00118	2.06	0.0926	78.39	2.77	0.13656	115.65
320	3.2	0.0421	4.2105	0.00118	2.16	0.0970	81.97	2.90	0.14297	120.75
340	3.4	0.0447	4.4737	0.00119	2.30	0.1033	87.04	3.05	0.15037	126.65
360	3.6	0.0474	4.7368	0.00119	2.51	0.1128	94.73	3.19	0.15727	132.10
380	3.8	0.0500	5.0000	0.00119	2.65	0.1191	99.74	3.25	0.16023	134.21
400	4.0	0.0526	5.2632	0.00120	2.70	0.1213	101.34	3.28	0.16170	135.07
420	4.2	0.0553	5.5263	0.00120	2.85	0.1281	106.67	3.26	0.16072	133.88
440	4.4	0.0579	5.7895	0.00120	3.05	0.1370	113.84	3.20	0.15776	131.05
460	4.6	0.0605	6.0526	0.00121	3.15	0.1415	117.24	3.10	0.15283	126.60
480	4.8	0.0632	6.3158	0.00121	3.18	0.1429	118.02			
500	5.0	0.0658	6.5789	0.00121	3.10	0.1393	114.73			
520	5.2	0.0684	6.8421	0.00122	2.85	0.1281	105.18			

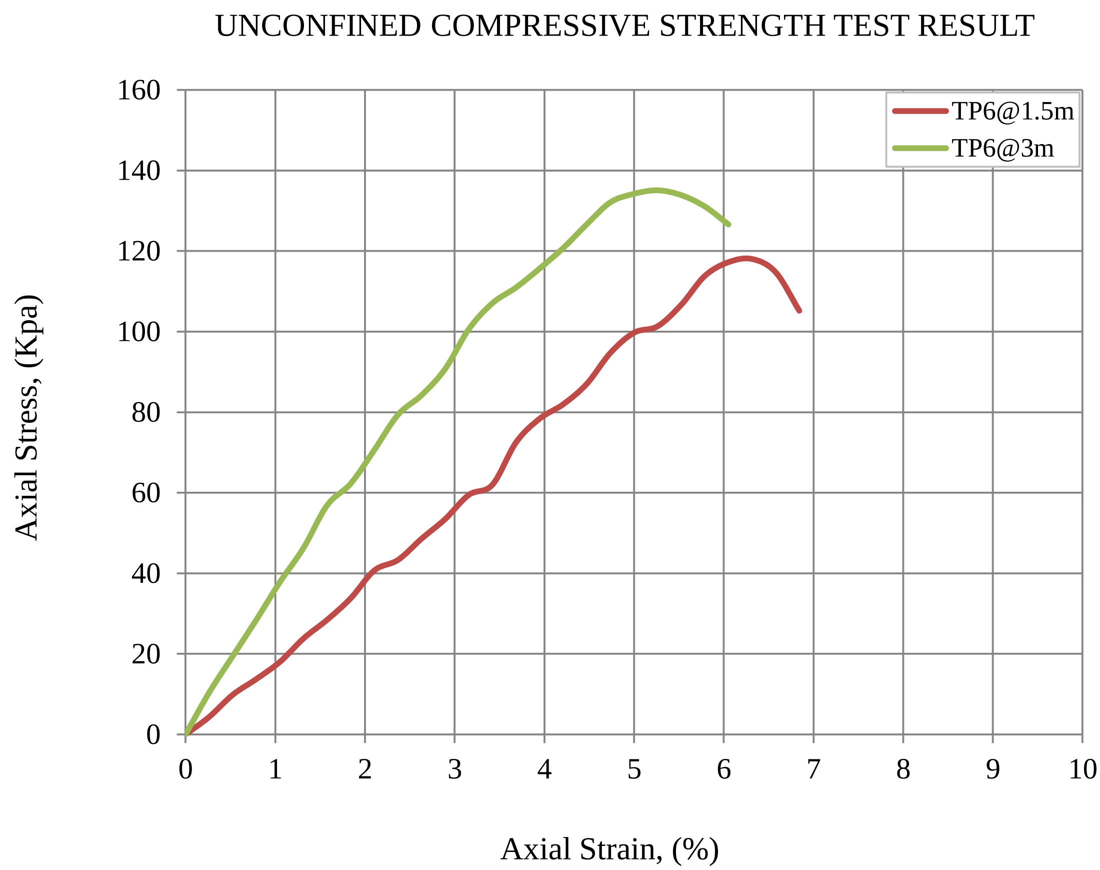

Figure B.6 Unconfined Compressive Strength (UCS) Test Results

Table B.7 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-7					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					1.5 m			3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm	Strain, (ΔL/ Lo)	%Strain, ε [(ΔL/Lo) *100]	Corrected Area, (m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.00000	0.000	0	0.000	0.00
20	0.2	0.0026	0.2632	0.00114	0.16	0.00719	6.322	0.14	0.006	5.53
40	0.4	0.0053	0.5263	0.00114	0.18	0.00809	7.093	0.33	0.015	13.00
60	0.6	0.0079	0.7895	0.00114	0.31	0.01393	12.184	0.58	0.026	22.80
80	0.8	0.0105	1.0526	0.00115	0.42	0.01887	16.464	0.78	0.035	30.58
100	1.0	0.0132	1.3158	0.00115	0.51	0.02291	19.939	1.02	0.046	39.88
120	1.2	0.0158	1.5789	0.00115	0.63	0.02831	24.564	1.21	0.054	47.18
140	1.4	0.0184	1.8421	0.00116	0.71	0.03190	27.610	1.37	0.062	53.28
160	1.6	0.0211	2.1053	0.00116	0.97	0.04358	37.619	1.62	0.073	62.83
180	1.8	0.0237	2.3684	0.00116	1.13	0.05077	43.707	1.78	0.080	68.85
200	2.0	0.0263	2.6316	0.00116	1.23	0.05526	47.446	1.93	0.087	74.45
220	2.2	0.0289	2.8947	0.00117	1.33	0.05976	51.165	1.99	0.089	76.56
240	2.4	0.0316	3.1579	0.00117	1.54	0.06919	59.083	2.11	0.095	80.95
260	2.6	0.0342	3.4211	0.00117	1.67	0.07503	63.897	2.35	0.106	89.91
280	2.8	0.0368	3.6842	0.00118	1.77	0.07953	67.538	2.61	0.117	99.59
300	3.0	0.0395	3.9474	0.00118	1.89	0.08492	71.920	2.82	0.127	107.31
320	3.2	0.0421	4.2105	0.00118	1.96	0.08806	74.379	2.89	0.130	109.67
340	3.4	0.0447	4.4737	0.00119	1.99	0.08941	75.310	2.94	0.132	111.26
360	3.6	0.0474	4.7368	0.00119	1.92	0.08627	72.461	2.86	0.128	107.94
380	3.8	0.0500	5.0000	0.00119	1.84	0.08267	69.250	2.78	0.125	104.63
400	4.0	0.0526	5.2632	0.00120	1.73	0.07773	64.930	2.69	0.121	100.96
420	4.2	0.0553	5.5263	0.00120	1.65	0.07413	61.76	2.58	0.116	96.56

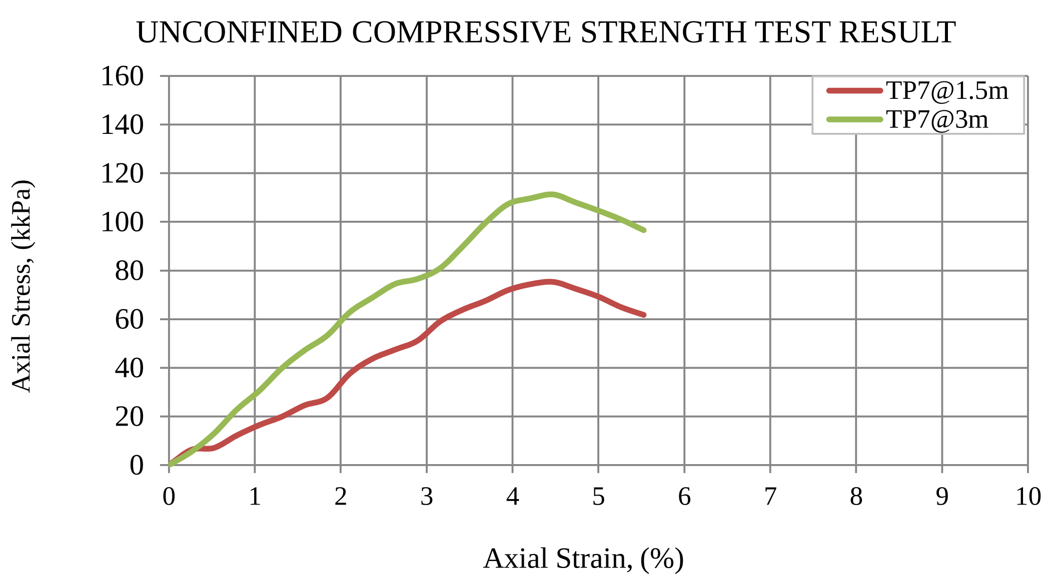

Figure B.7 Unconfined Compressive Strength (UCS) Test Results

Table B.8 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP8					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					@1.5 m			@3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm	Strain, (ΔL/Lo)	%Strain, ε [(ΔL/Lo) *100]	Corrected Area, (m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.00000	0.000	0	0.00000	0.000
20	0.2	0.0026	0.2632	0.00114	0.07	0.00315	2.766	0.13	0.00584	5.137
40	0.4	0.0053	0.5263	0.00114	0.16	0.00719	6.305	0.25	0.01123	9.852
60	0.6	0.0079	0.7895	0.00114	0.26	0.01168	10.219	0.35	0.01573	13.756
80	0.8	0.0105	1.0526	0.00115	0.35	0.01573	13.720	0.52	0.02336	20.384
100	1.0	0.0132	1.3158	0.00115	0.48	0.02157	18.766	0.73	0.03280	28.540
120	1.2	0.0158	1.5789	0.00115	0.64	0.02876	24.954	0.86	0.03864	33.532
140	1.4	0.0184	1.8421	0.00116	0.88	0.03954	34.221	1.02	0.04583	39.665
160	1.6	0.0211	2.1053	0.00116	1.00	0.04493	38.783	1.20	0.05392	46.539
180	1.8	0.0237	2.3684	0.00116	1.23	0.05526	47.575	1.35	0.06066	52.216
200	2.0	0.0263	2.6316	0.00116	1.33	0.05976	51.304	1.46	0.06560	56.318
220	2.2	0.0289	2.8947	0.00117	1.53	0.06874	58.859	1.65	0.07413	63.475
240	2.4	0.0316	3.1579	0.00117	1.61	0.07234	61.769	1.86	0.08357	71.360
260	2.6	0.0342	3.4211	0.00117	1.64	0.07369	62.749	2.03	0.09121	77.671
280	2.8	0.0368	3.6842	0.00118	1.59	0.07144	60.670	2.25	0.10109	85.854
300	3.0	0.0395	3.9474	0.00118	1.53	0.06874	58.221	2.39	0.10738	90.947
320	3.2	0.0421	4.2105	0.00118	1.45	0.06515	55.026	2.45	0.11008	92.974
340	3.4	0.0447	4.4737	0.00119	1.40	0.06290	52.982	2.51	0.11277	94.990
360	3.6	0.0474	4.7368	0.00119				2.43	0.10918	91.709
380	3.8	0.0500	5.0000	0.00119				2.30	0.10334	86.563
400	4.0	0.0526	5.2632	0.00120				2.15	0.09660	80.693
420	4.2	0.0553	5.5263	0.00120				2.05	0.09211	76.726

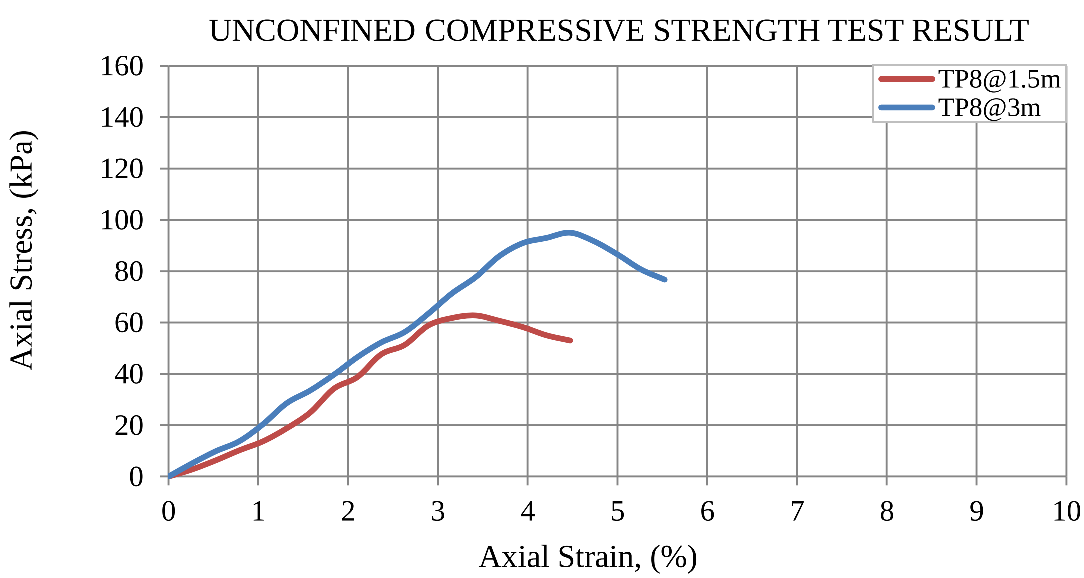

Figure B.8 Unconfined Compressive Strength (UCS) Test Results

Table B.9 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP-9					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao= 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					1.5 m			3 m		
Deform Dial Read (Division)	Sample Deformation, ΔL (mm	Strain, (ΔL/Lo)	%Strain, ε [(ΔL/Lo)*100]	Corrected Area, (m^2) Ac = Ao/(1-ε)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)	Load Dial Read, LDR	Axial Load (kN)	Stress (kN/m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.0000	0.00	0	0.000	0.00
20	0.2	0.0026	0.2632	0.00114	0.12	0.0054	4.74	0.14	0.006	5.53
40	0.4	0.0053	0.5263	0.00114	0.18	0.0081	7.09	0.25	0.011	9.85
60	0.6	0.0079	0.7895	0.00114	0.31	0.0139	12.18	0.43	0.019	16.90
80	0.8	0.0105	1.0526	0.00115	0.48	0.0216	18.82	0.74	0.033	29.01
100	1.0	0.0132	1.3158	0.00115	0.56	0.0252	21.89	0.91	0.041	35.58
120	1.2	0.0158	1.5789	0.00115	0.71	0.0319	27.68	1.02	0.046	39.77
140	1.4	0.0184	1.8421	0.00116	0.82	0.0368	31.89	1.15	0.052	44.72
160	1.6	0.0211	2.1053	0.00116	0.93	0.0418	36.07	1.28	0.058	49.64
180	1.8	0.0237	2.3684	0.00116	1.06	0.0476	41.00	1.39	0.062	53.76
200	2.0	0.0263	2.6316	0.00116	1.15	0.0517	44.36	1.58	0.071	60.95
220	2.2	0.0289	2.8947	0.00117	1.26	0.0566	48.47	1.75	0.079	67.32
240	2.4	0.0316	3.1579	0.00117	1.42	0.0638	54.48	1.98	0.089	75.96
260	2.6	0.0342	3.4211	0.00117	1.58	0.0710	60.45	2.11	0.095	80.73
280	2.8	0.0368	3.6842	0.00118	1.75	0.0786	66.78	2.32	0.104	88.52
300	3.0	0.0395	3.9474	0.00118	1.89	0.0849	71.92	2.57	0.115	97.80
320	3.2	0.0421	4.2105	0.00118	2.02	0.0908	76.66	2.68	0.120	101.70
340	3.4	0.0447	4.4737	0.00119	2.11	0.0948	79.85	2.72	0.122	102.94
360	3.6	0.0474	4.7368	0.00119	2.16	0.0970	81.52	2.67	0.120	100.77
380	3.8	0.0500	5.0000	0.00119	2.19	0.0984	82.42	2.57	0.115	96.72
400	4.0	0.0526	5.2632	0.00120	2.22	0.0997	83.32	2.44	0.110	91.58
420	4.2	0.0553	5.5263	0.00120	2.17	0.0975	81.22	2.35	0.106	87.95
440	4.4	0.0579	5.7895	0.00120	2.09	0.0939	78.01	2.24	0.101	83.60

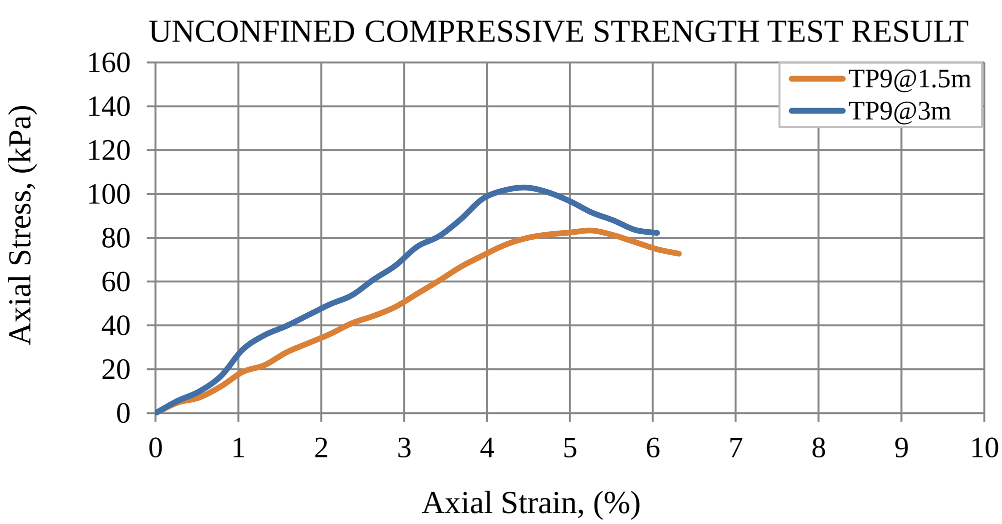

Figure B.9 Unconfined Compressive Strength (UCS) Test Results

Table B.10 Unconfined Compressive Strength (UCS) Test Results

Diameter of Sample: 38 mm					Sample No: TP10					
Height of Sample, Lo: 76 mm					Deformation Dial: 1 unit = 0.01 mm					
Area of Sample, Ao: 0.001134115 m^2					Load Dial: 1 unit = 44.93 N					
					@1.5 m			@3 m		
Deform Dial Read (Division)	Sample Deformat ion, ΔL (mm	Strain, (ΔL/Lo)	%Strain, ε [(ΔL/Lo) *100]	Corrected Area, (m^2) Ac = Ao/(1-ε)	Load Dial Rea d, LDR	Axial Load (kN)	Stress (kN/ m^2)	Load Dial Rea d, LDR	Axial Load (kN)	Stress (kN/ m^2)
0	0.0	0.0000	0.0000	0.00113	0	0.00000		0	0.00000	0.000
20	0.2	0.0026	0.2632	0.00114	0.08	0.00359	0.000	0.19	0.00854	7.507
40	0.4	0.0053	0.5263	0.00114	0.22	0.00988	8.670	0.31	0.01393	12.217
60	0.6	0.0079	0.7895	0.00114	0.36	0.01617	14.149	0.40	0.01797	15.722
80	0.8	0.0105	1.0526	0.00115	0.45	0.02022	17.640	0.56	0.02516	21.952
100	1.0	0.0132	1.3158	0.00115	0.64	0.02876	25.021	0.75	0.03370	29.322
120	1.2	0.0158	1.5789	0.00115	0.82	0.03684	31.973	0.92	0.04134	35.872
140	1.4	0.0184	1.8421	0.00116	0.96	0.04313	37.332	1.10	0.04942	42.776
160	1.6	0.0211	2.1053	0.00116	1.12	0.05032	43.437	1.29	0.05796	50.030
180	1.8	0.0237	2.3684	0.00116	1.29	0.05796	49.895	1.45	0.06515	56.084
200	2.0	0.0263	2.6316	0.00116	1.40	0.06290	54.004	1.65	0.07413	63.648
220	2.2	0.0289	2.8947	0.00117	1.59	0.07144	61.167	1.86	0.08357	71.554
240	2.4	0.0316	3.1579	0.00117	1.68	0.07548	64.454	1.92	0.08627	73.662
260	2.6	0.0342	3.4211	0.00117	1.72	0.07728	65.810	1.82	0.08177	69.636
280	2.8	0.0368	3.6842	0.00118	1.69	0.07593	64.486	1.60	0.07189	61.052
300	3.0	0.0395	3.9474	0.00118	1.60	0.07189	60.885			
320	3.2	0.0421	4.2105	0.00118	1.50	0.06740	56.923			

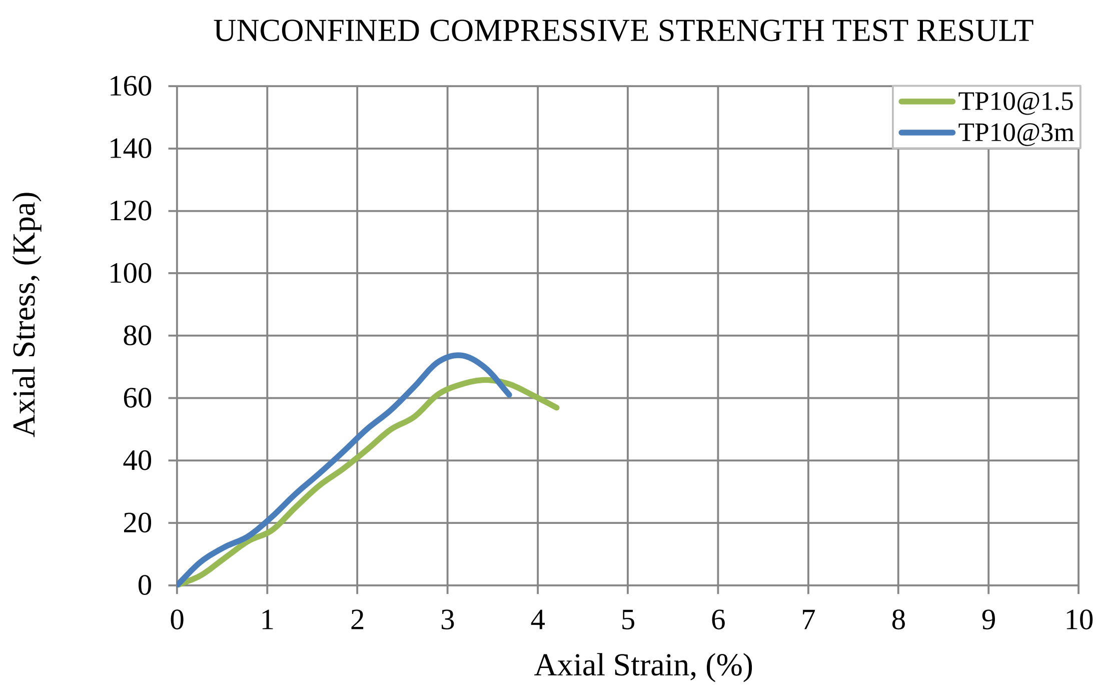

Figure B.10 Unconfined Compressive Strength (UCS) Test Results

Appendix-C: Consolidation Test Results

Table C.1 Data before and after commencement of the consolidation test

Data before and after commencement of the consolidation test		TP1 @3m	TP2 @3m	TP3 @3m	TP4 @3m	TP5 @3m	TP6 @3m	TP7 @3m	TP8 @3m	TP9 @3m	TP10 @3m
Data before commencement of the consolidation test	Inside diameter of the ring,(mm)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
	Height of specimen (mm), H_i	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	Area of specimen (mm^2), A	1963	1963	1963	1963	1963	1963	1963	1963	1963	1963
	Mass of specimen + ring (g)	139.2	145.6	142.6	143.7	131.7	131.7	142.6	143.7	139.2	145.6
	Natural moisture content of specimen, w_i (%)	36.7	36.6	36.2	41.2	37.8	22.9	29.0	39.6	39.4	37.3
	Specific gravity of solids, Gs	2.7	2.6	2.7	2.7	2.7	2.6	2.6	2.8	2.7	2.7
Data at the end of the consolidation test	Mass of can (g)	35.5	35.5	37.7	36.4	37.7	37.7	37.7	36.4	35.5	35.5
	Mass of can + wet soil (g)	92.7	90.6	88.8	93.6	93.6	91.0	89.3	95.6	93.5	91.3
	Mass of wet specimen (g)	57.1	55.0	51.1	57.2	55.9	53.4	51.7	59.2	58.0	55.8
	Mass of can + dry soil (g)	81.7	82.2	79.8	82.3	85.7	89.0	80.5	83.6	82.3	80.2
	Mass of dry specimen, Ms (g)	46.2	46.7	42.1	45.9	48.0	51.3	42.8	47.2	46.7	44.7
	Final moisture content of specimen, w_f (%)	23.7	17.9	21.4	24.6	16.4	4.0	20.7	25.3	24.1	24.9
Some Calculation Based on Test Data	Mass of solids in specimen, Ms (g) (Mass of dry specimen after test)	46.2	46.7	42.1	45.9	48.0	51.3	42.8	47.2	46.7	44.7
	Height of solids, Hs (mm) = Ms/A*Gs* ρw(same before and after test and ρw = 0.001 (g/mm^3)	8.8	9.1	7.9	8.7	9.1	10.1	8.5	8.7	8.9	8.5
	Void ratio before test, (e_o = Hi- Hs/ Hs)	1.3	1.2	1.5	1.3	1.2	1.0	1.3	1.3	1.3	1.4

Appendix C1. Void Ratio Determination

Table C1.1 Void Ratio Determination for TP-1@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading, (mm)	Change In Height of Specimen, ΔHj, (mm)	Summation of C.H. Specimen ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.790	0.000	0.000	20.000	11.197	0.000	1.27
	1	50	1.115	0.325	0.325	19.675	10.872	0.037	1.24
	2	100	1.600	0.485	0.810	19.190	10.387	0.055	1.18
	4	200	2.230	0.630	1.440	18.560	9.757	0.072	1.11
	8	400	3.055	0.825	2.265	17.735	8.932	0.094	1.01
	16	800	3.980	0.925	3.190	16.810	8.007	0.105	0.91
	32	1600	5.320	1.340	4.530	15.470	6.667	0.152	0.76
UN LOADING	8	400	4.855	-0.465	4.065	15.935	7.132	-0.053	0.81
	2	100	4.300	-0.555	3.510	16.490	7.687	-0.063	0.87
	0.14	7	2.865	-1.435	2.075	17.925	9.122	-0.163	1.04

Table C1.2 Void Ratio Determination for TP-2@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen, ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.880	0.000	0.000	20.000	10.926	0.000	1.20
	1	50	1.125	0.245	0.245	19.755	10.681	0.027	1.18
	2	100	1.565	0.440	0.685	19.315	10.241	0.048	1.13
	4	200	2.180	0.615	1.300	18.700	9.626	0.068	1.06
	8	400	3.025	0.845	2.145	17.855	8.781	0.093	0.97
	16	800	3.930	0.905	3.050	16.950	7.876	0.100	0.87
	32	1600	4.975	1.045	4.095	15.905	6.831	0.115	0.75
UN LOADING	8	400	4.685	-0.290	3.805	16.195	7.121	-0.032	0.78
	2	100	4.155	-0.530	3.275	16.725	7.651	-0.058	0.84
	0.14	7	2.945	-1.210	2.065	17.935	8.861	-0.133	0.98

Table C1.3 Void Ratio Determination for TP-3@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen, ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.975	0.000	0.000	20.000	12.148	0.000	1.55
	1	50	1.255	0.280	0.280	19.720	19.720	0.036	1.51
	2	100	1.625	0.370	0.650	19.350	19.350	0.047	1.46
	4	200	2.105	0.480	1.130	18.870	18.870	0.061	1.40
	8	400	2.655	0.550	1.680	18.320	18.320	0.070	1.33
	16	800	3.250	0.595	2.275	17.725	17.725	0.076	1.26
	32	1600	3.875	0.625	2.900	17.100	17.100	0.080	1.18
UN LOADING	8	400	3.760	-0.115	2.785	17.215	17.215	-0.015	1.19
	2	100	3.590	-0.170	2.615	17.385	17.385	-0.022	1.21
	0.14	7	2.955	-0.635	1.980	18.020	18.020	-0.081	1.29

Table C1.4 Void Ratio Determination for TP-4@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen, ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.860	0.000	0.000	20.000	11.342	0.000	1.31
	1	50	1.170	0.310	0.310	19.690	11.032	0.036	1.27
	2	100	1.625	0.455	0.765	19.235	10.577	0.053	1.22
	4	200	2.090	0.465	1.230	18.770	10.112	0.054	1.17
	8	400	2.695	0.605	1.835	18.165	9.507	0.070	1.10
	16	800	3.685	0.990	2.825	17.175	8.517	0.114	0.98
	32	1600	4.725	1.040	3.865	16.135	7.477	0.120	0.86
UN LOADING	8	400	4.380	-0.345	3.520	16.480	7.822	-0.040	0.90
	2	100	3.915	-0.465	3.055	16.945	8.287	-0.054	0.96
	0.14	7	2.810	-1.105	1.950	18.050	9.392	-0.128	1.08

Table C1.5 Void Ratio Determination for TP-5@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen, ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	1.295	0.000	0.000	20.000	10.873	0.000	1.19
	1	50	1.615	0.320	0.320	19.680	10.553	0.035	1.16
	2	100	2.030	0.415	0.735	19.265	10.138	0.045	1.11
	4	200	2.725	0.695	1.430	18.570	9.443	0.076	1.03
	8	400	3.640	0.915	2.345	17.655	8.528	0.100	0.93
	16	800	4.635	0.995	3.340	16.660	7.533	0.109	0.83
	32	1600	5.870	1.235	4.575	15.425	6.298	0.135	0.69
UN LOADING	8	400	5.585	-0.285	4.290	15.710	6.583	-0.031	0.72
	2	100	5.110	-0.475	3.815	16.185	7.058	-0.052	0.77
	0.14	7	4.000	-1.110	2.705	17.295	8.168	-0.122	0.89

Table C1.6 Void Ratio Determination for TP-6@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen, ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	1.355	0.000	0.000	20.000	9.910	0.000	0.98
	1	50	1.670	0.315	0.315	19.685	9.595	0.031	0.95
	2	100	2.095	0.425	0.740	19.260	9.170	0.042	0.91
	4	200	2.780	0.685	1.425	18.575	8.485	0.068	0.84
	8	400	3.705	0.925	2.350	17.650	7.560	0.092	0.75
	16	800	4.690	0.985	3.335	16.665	6.575	0.098	0.65
	32	1600	5.935	1.245	4.580	15.420	5.330	0.123	0.53
UN LOADING	8	400	5.650	-0.285	4.295	15.705	5.615	-0.028	0.56
	2	100	5.155	-0.495	3.800	16.200	6.110	-0.049	0.61
	0.14	7	4.055	-1.100	2.700	17.300	7.210	-0.109	0.71

Table C1.7 Void Ratio Determination for TP-7@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen, ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.935	0.000	0.000	20.000	11.454	0.000	1.34
	1	50	1.215	0.280	0.280	19.720	11.174	0.033	1.31
	2	100	1.585	0.370	0.650	19.350	10.804	0.043	1.26
	4	200	2.065	0.480	1.130	18.870	10.324	0.056	1.21
	8	400	2.610	0.545	1.675	18.325	9.779	0.064	1.14
	16	800	3.215	0.605	2.280	17.720	9.174	0.071	1.07
	32	1600	3.835	0.620	2.900	17.100	8.554	0.073	1.00
UN LOADING	8	400	3.715	-0.120	2.780	17.220	8.674	-0.014	1.01
	2	100	3.555	-0.160	2.620	17.380	8.834	-0.019	1.03
	0.14	7	2.920	-0.635	1.985	18.015	9.469	-0.074	1.11

Table C1.8 Void Ratio Determination for TP-8@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen,ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.790	0.000	0.000	20.000	11.287	0.000	1.30
	1	50	1.115	0.325	0.325	19.675	10.962	0.037	1.26
	2	100	1.550	0.435	0.760	19.240	10.527	0.050	1.21
	4	200	2.035	0.485	1.245	18.755	10.042	0.056	1.15
	8	400	2.630	0.595	1.840	18.160	9.447	0.068	1.08
	16	800	3.550	0.920	2.760	17.240	8.527	0.106	0.98
	32	1600	4.650	1.100	3.860	16.140	7.427	0.126	0.85
UN LOADING	8	400	4.325	-0.325	3.535	16.465	7.752	-0.037	0.89
	2	100	3.860	-0.465	3.070	16.930	8.217	-0.053	0.94
	0.14	7	2.745	-1.115	1.955	18.045	9.332	-0.128	1.07

Table C1.9 Void Ratio Determination for TP-9@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m^2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen,ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.820	0.000	0.000	20.000	11.123	0.000	1.25
	1	50	1.145	0.325	0.325	19.675	10.798	0.037	1.22
	2	100	1.630	0.485	0.810	19.190	10.313	0.055	1.16
	4	200	2.260	0.630	1.440	18.560	9.683	0.071	1.09
	8	400	3.085	0.825	2.265	17.735	8.858	0.093	1.00
	16	800	4.010	0.925	3.190	16.810	7.933	0.104	0.89
	32	1600	5.350	1.340	4.530	15.470	6.593	0.151	0.74
UN LOADING	8	400	4.885	-0.465	4.065	15.935	7.058	-0.052	0.80
	2	100	4.330	-0.555	3.510	16.490	7.613	-0.063	0.86
	0.14	7	2.895	-1.435	2.075	17.925	9.048	-0.162	1.02

Table C1.10 Void Ratio Determination for TP-10@3 m

Load Type	Applied Load Increment, (kg)	Applied Load Increment, P (kPa) [Lever Arm Ratio=1:10, Area of ring=0.00196m2, g=9.81]	Final Dial Reading,(mm)	Change In Height of Specimen,ΔHj, (mm)	Summation of C.H. Specimen,ΣΔH (mm)	Final Height of Specimen, (mm)	Height of Void, Hv (mm)	Change In Void Ratio, (Δei)	Void Ratio, e
LOADING	0.14	7	0.935	0.000	0.000	20.000	11.511	0.000	1.36
	1	50	1.170	0.235	0.235	19.765	11.276	0.028	1.33
	2	100	1.600	0.430	0.665	19.335	10.846	0.051	1.28
	4	200	2.235	0.635	1.300	18.700	10.211	0.075	1.20
	8	400	3.080	0.845	2.145	17.855	9.366	0.100	1.10
	16	800	3.995	0.915	3.060	16.940	8.451	0.108	1.00
	32	1600	5.020	1.025	4.085	15.915	7.426	0.121	0.87
UN LOADING	8	400	4.705	-0.315	3.770	16.230	7.741	-0.037	0.91
	2	100	4.200	-0.505	3.265	16.735	8.246	-0.059	0.97
	0.14	7	3.005	-1.195	2.070	17.930	9.441	-0.141	1.11

Appendix C2. Pre-consolidation Pressure Determination

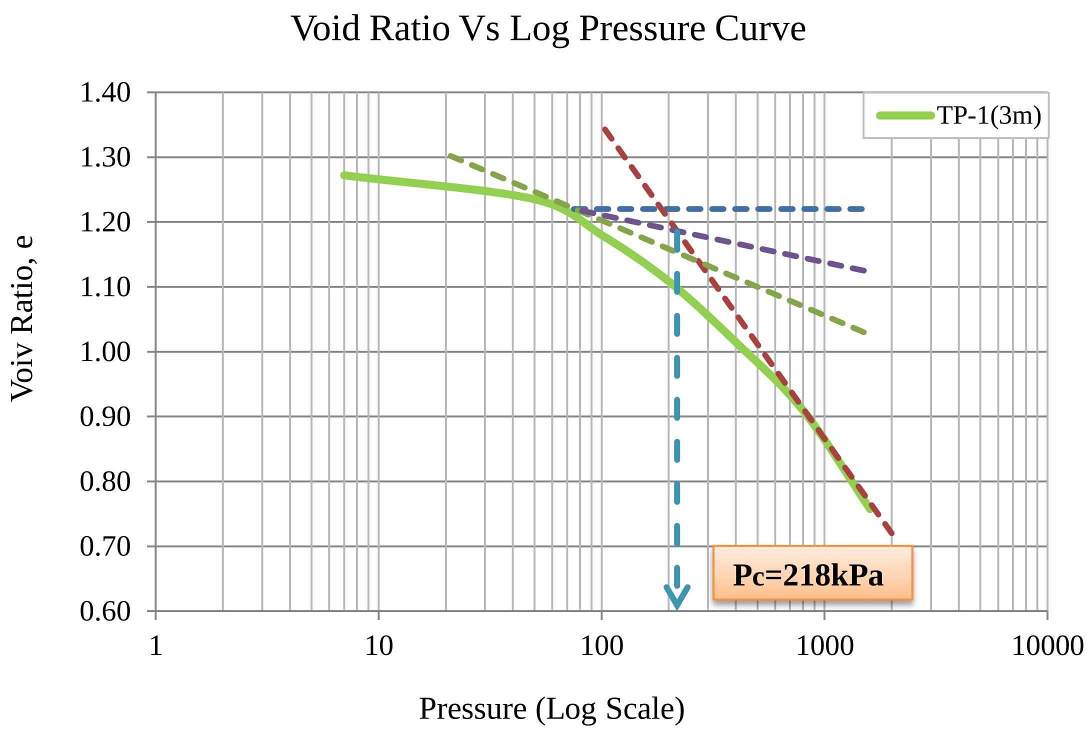

Figure C2.1 Void ratio V_s pressure curve used to determine, P_c

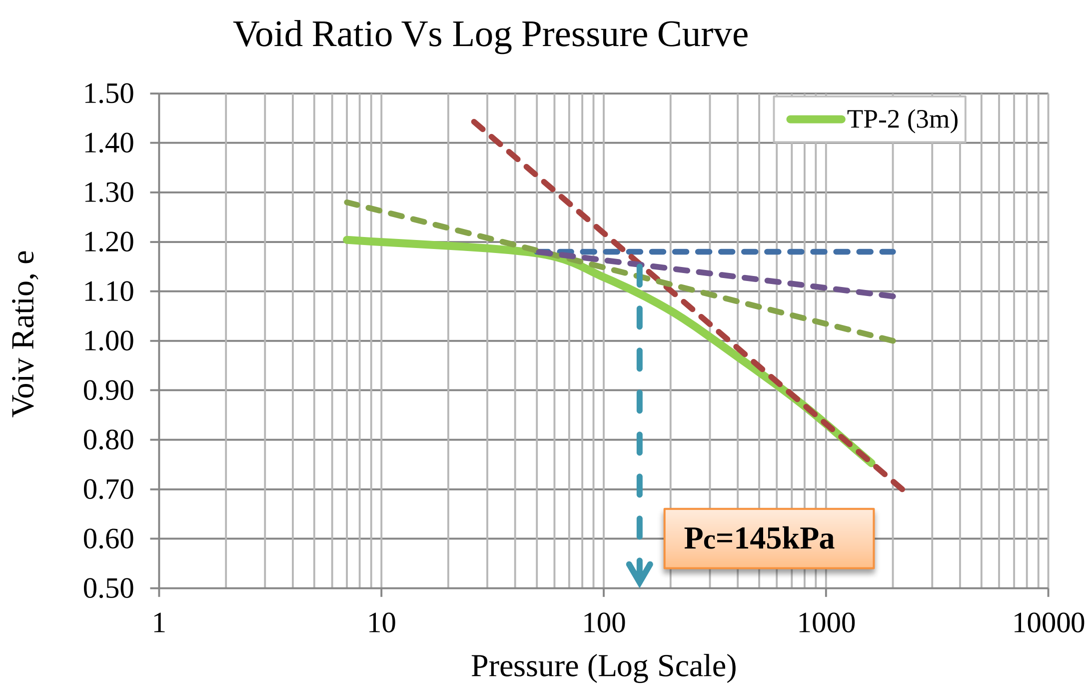

Figure C2.2 Void ratio V_s pressure curve used to determine, P_c

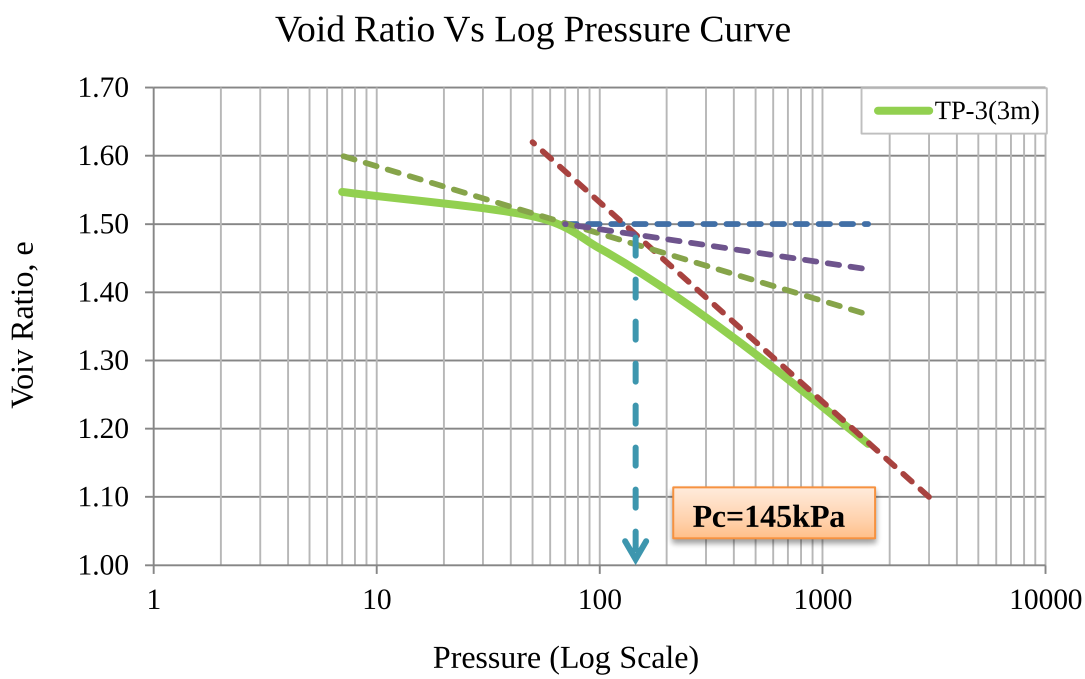

Figure C2.3 Void ratio V_s pressure curve used to determine, P_c

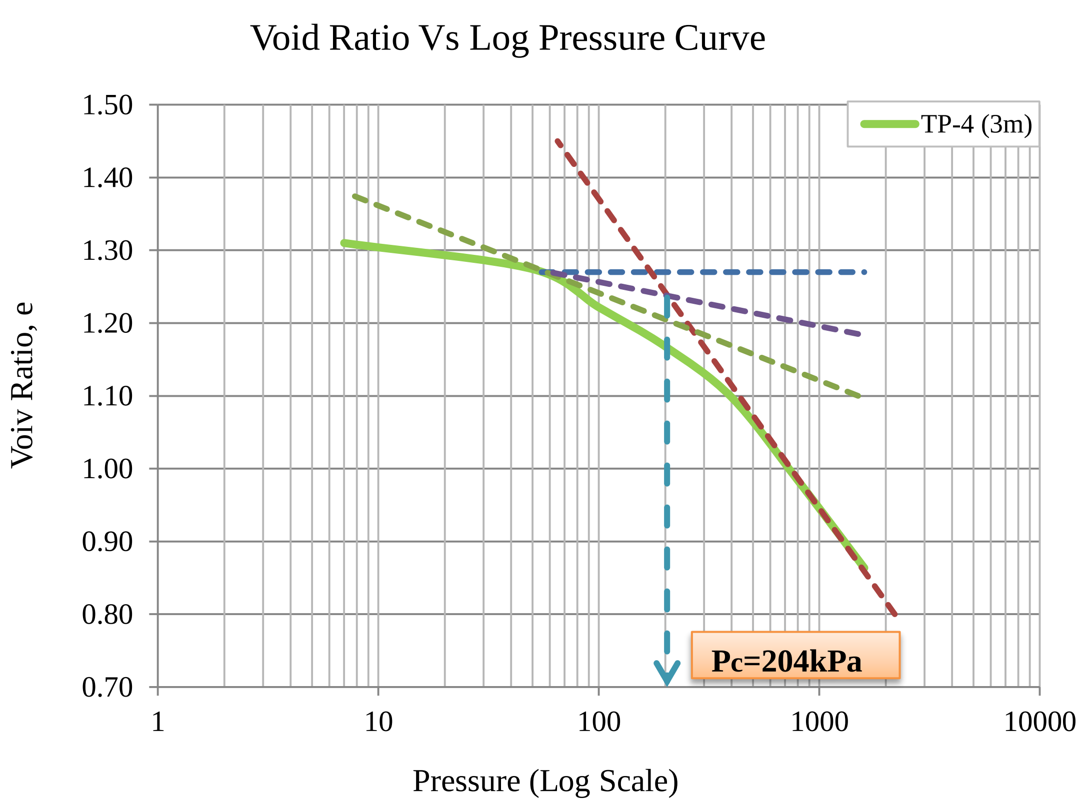

Figure C2.4 Void ratio V_s pressure curve used to determine, P_c

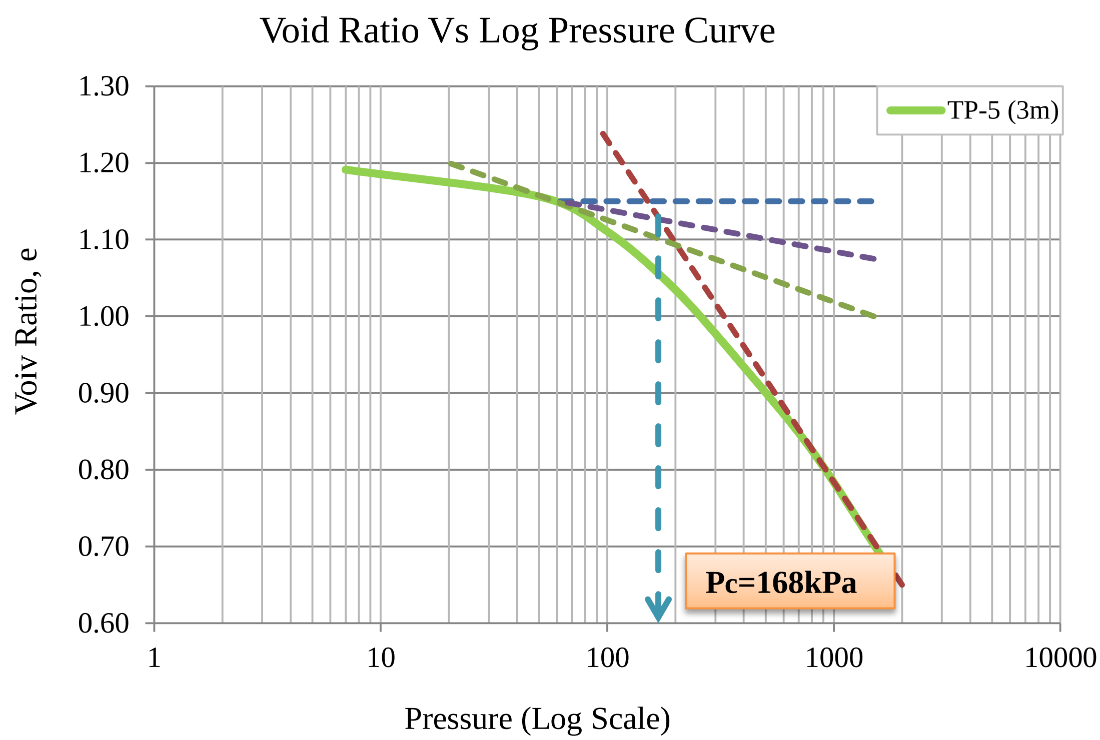

Figure C2.5 Void ratio V_s pressure curve used to determine, P_c

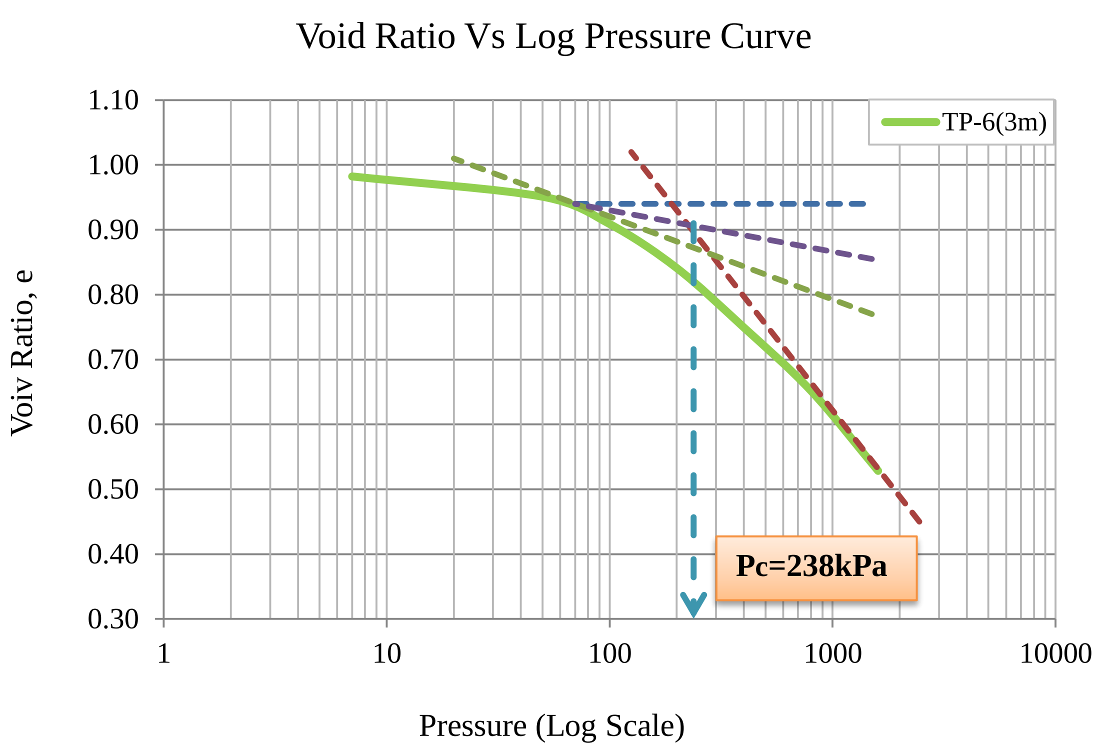

Figure C2.6 Void ratio V_s pressure curve used to determine, P_c

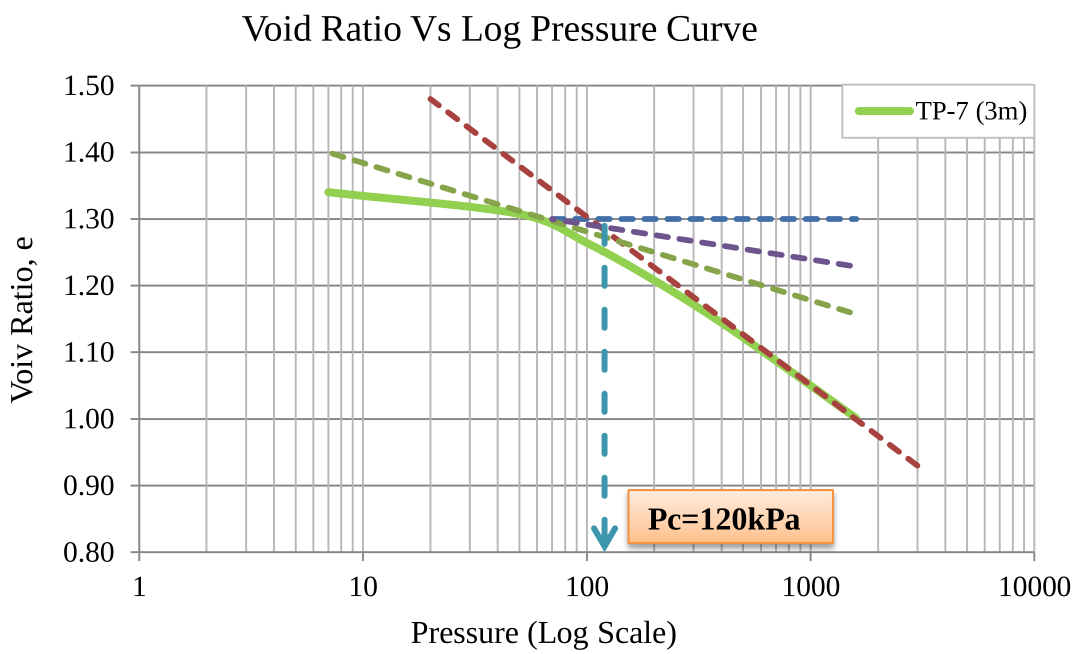

Figure C2.7 Void ratio V_s pressure curve used to determine, P_c

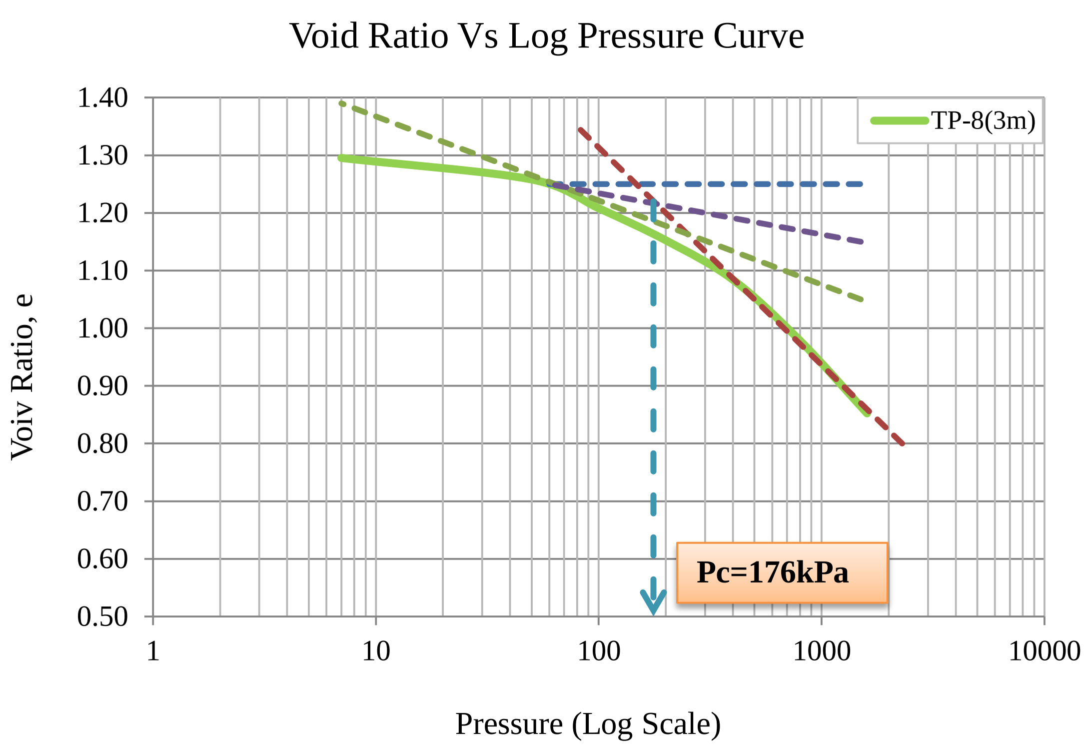

Figure C2.8 Void ratio V_s pressure curve used to determine, P_c

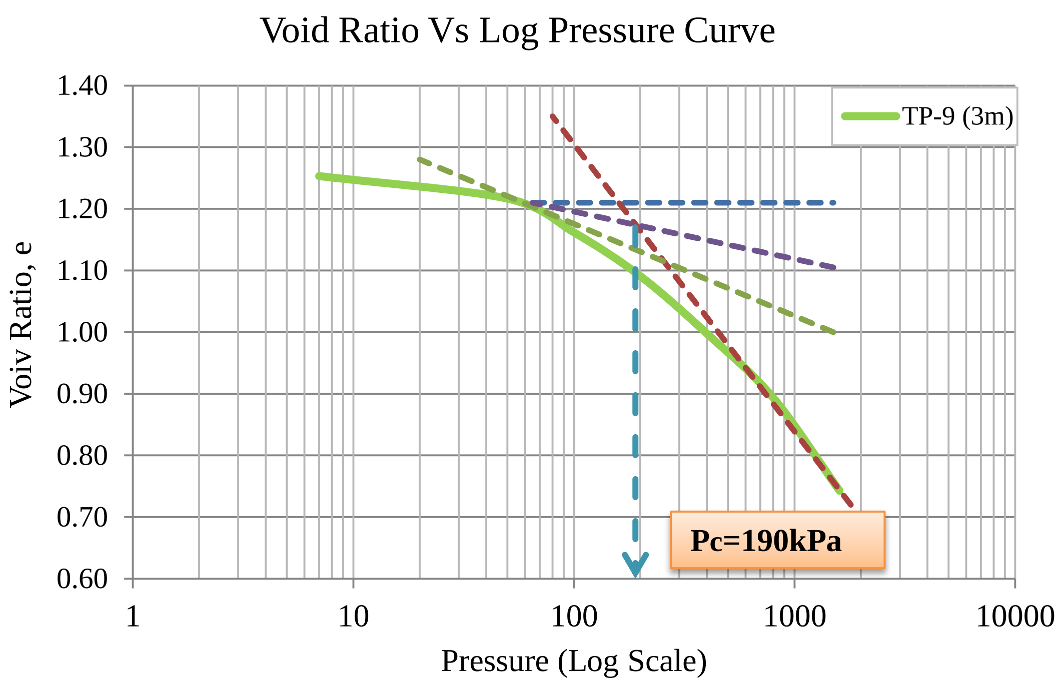

Figure C2.9 Void ratio V_s pressure curve used to determine, P_c

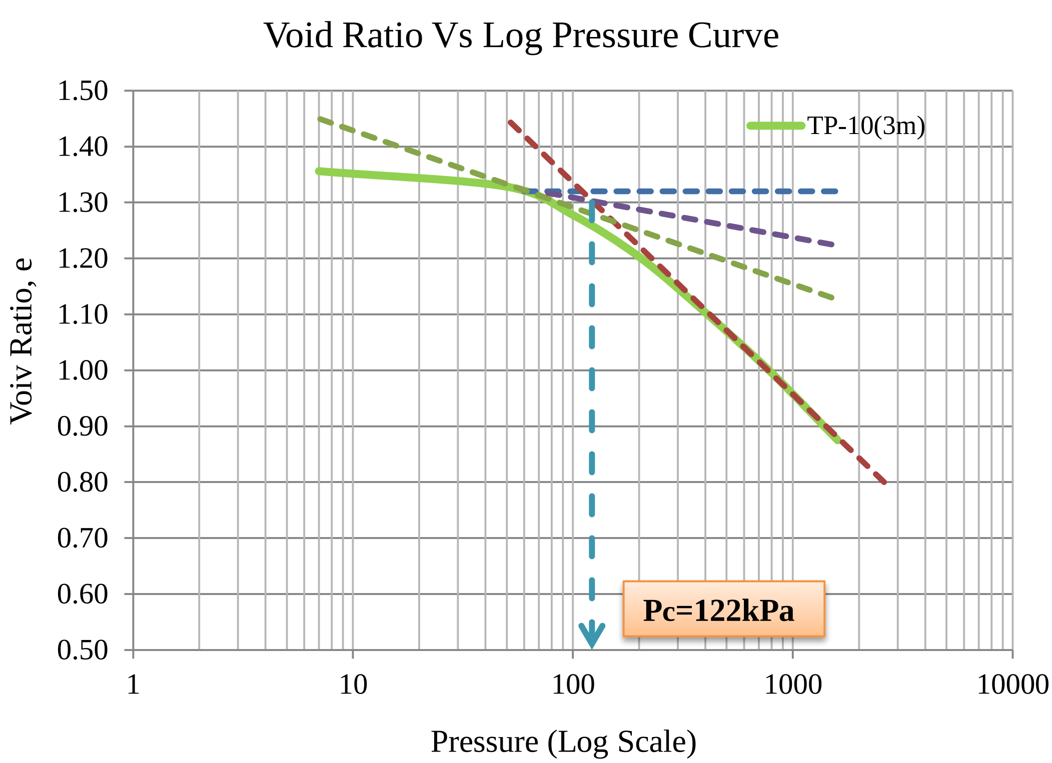

Figure C2.10 Void ratio V_s pressure curve used to determine, P_c

Appendix C3. Compression (C_c) and Recompression Index (C_r) Determination

Using the deformation results (void ratio or strain) corresponding to the end each increment loading or unloading versus logarithm of pressure and pressure respectively is drawn. These graphs are shown in figure C3.1. Based on this plot, the compression index, C_c will be the slope of loading curve and recompression index, C_r will be the slope of unloading curve. Therefore, by taking any two points on the straight portions for both loading and unloading:

$$\text{Compression Index } = \frac{e_1 - e_2}{log\ P_2 - \ log\ P_1}$$

$$\text{Compression Index } = \frac{1.01 - 0.76}{\log 1600 - \log 400} = \mathbf{0.427}$$

$$\text{Recompression Index } = \frac{e_1 - e_2}{log\ P_2 - \ log\ P_1}$$

$$\text{Recompression Index } = \frac{0.87 - 0.76}{\log 1600 - \log 100} = \mathbf{0.096}$$

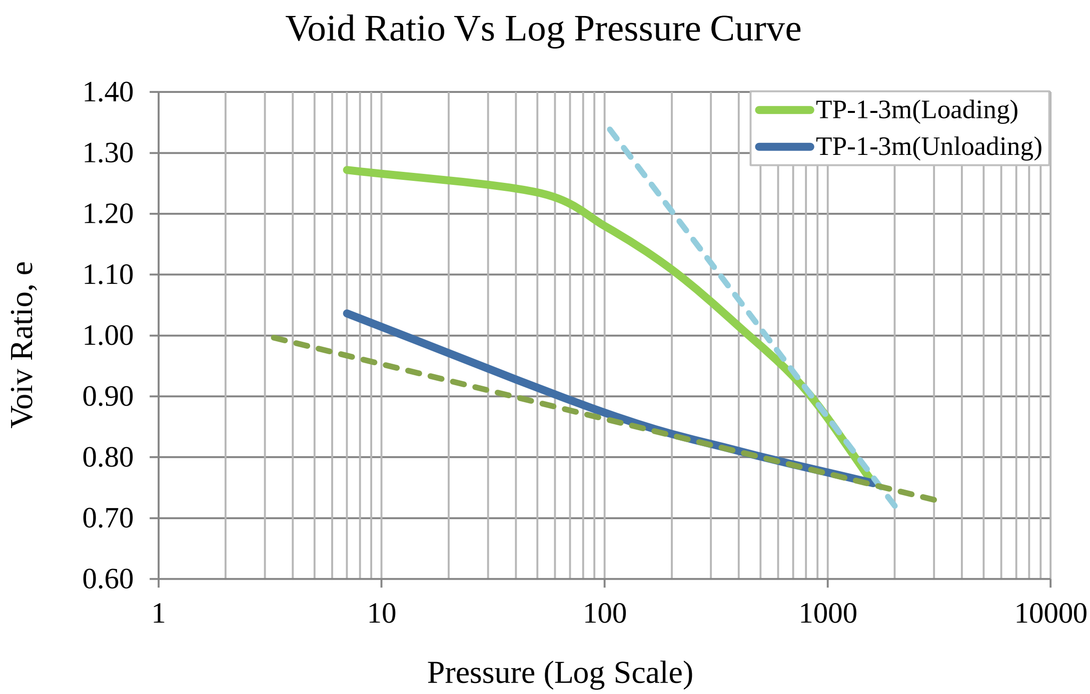

Figure C3.1 loading unloading curve to calculate compression and recompression index

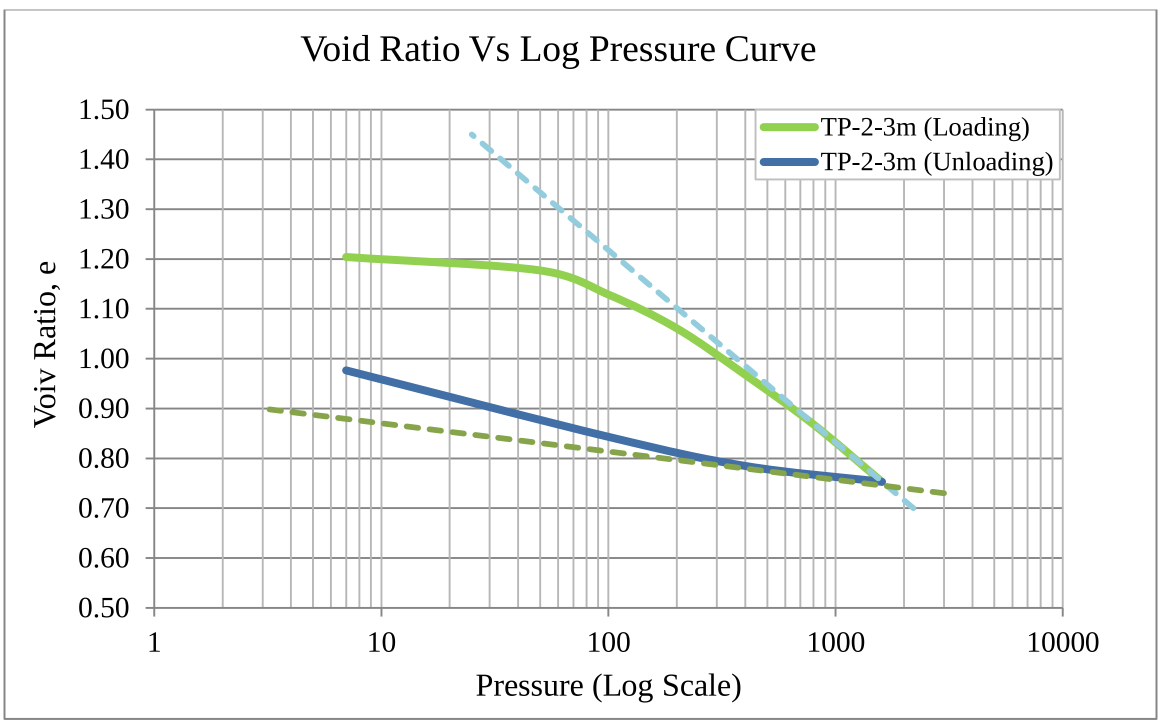

Figure C3.2 loading unloading curve to calculate compression and recompression index

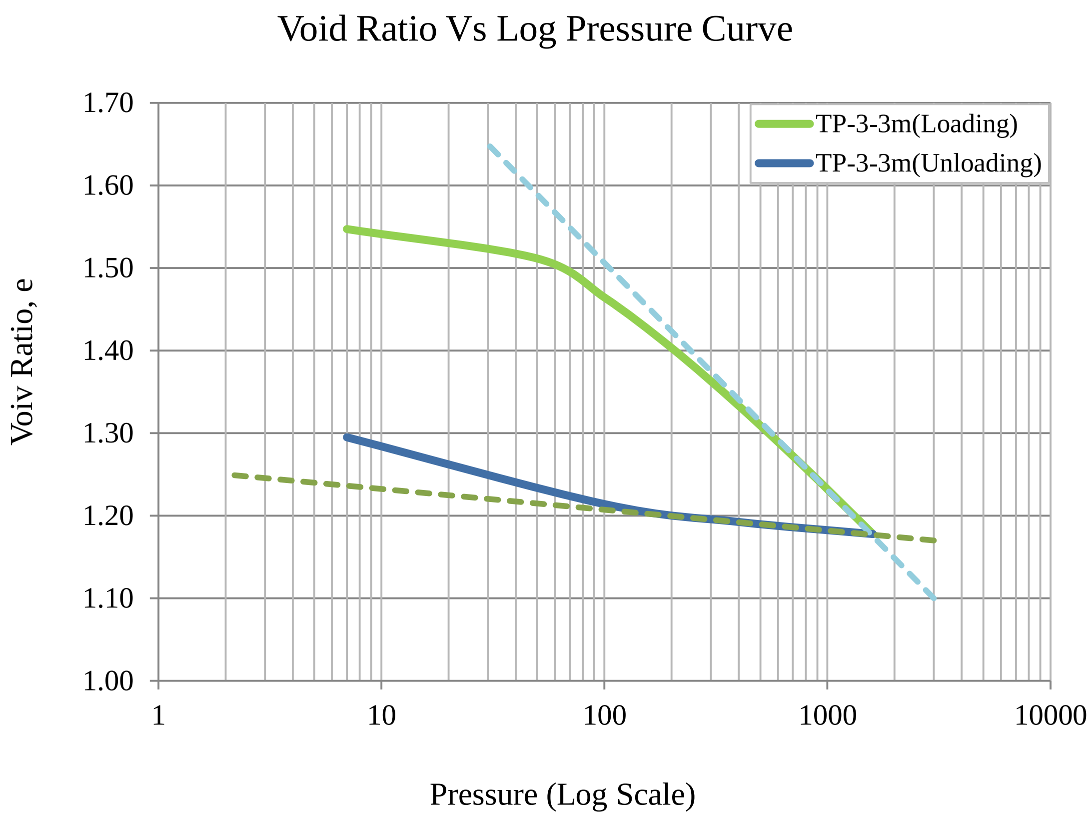

Figure C3.3 loading unloading curve to calculate compression and recompression index

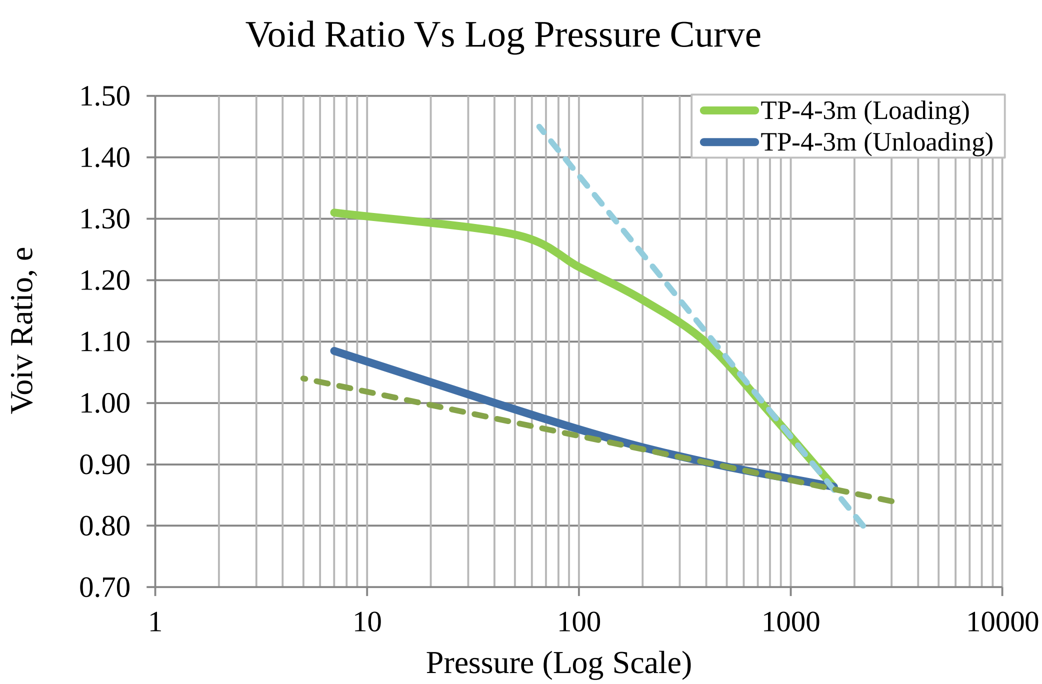

Figure C3.4 loading unloading curve to calculate compression and recompression index

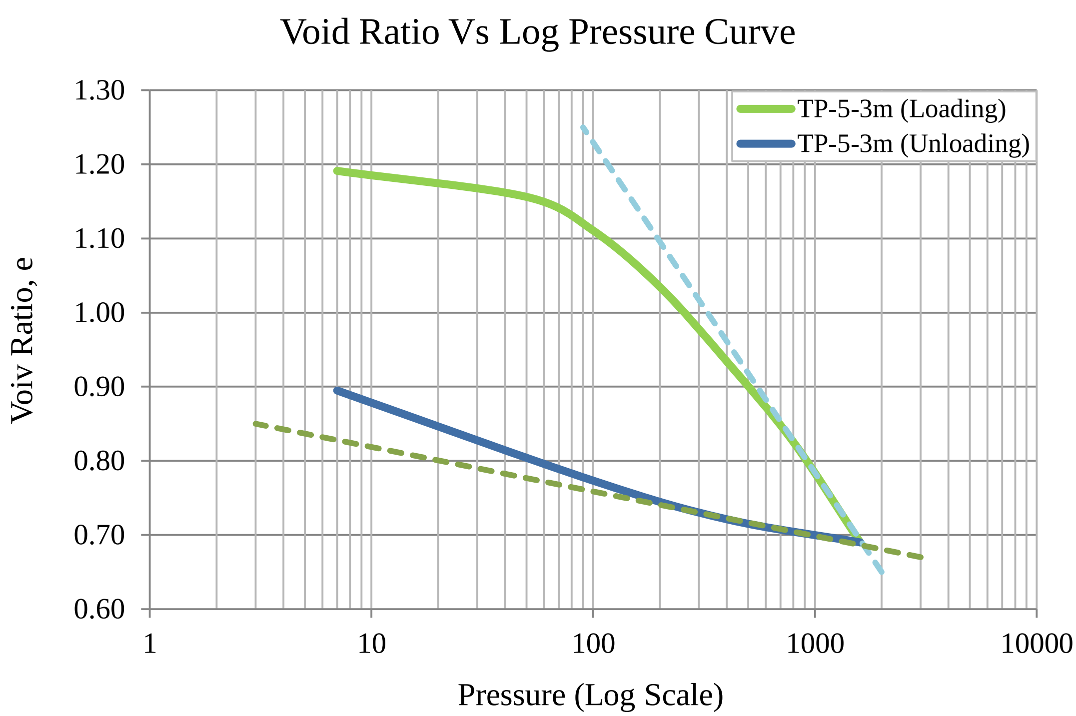

Figure C3.5 loading unloading curve to calculate compression and recompression index

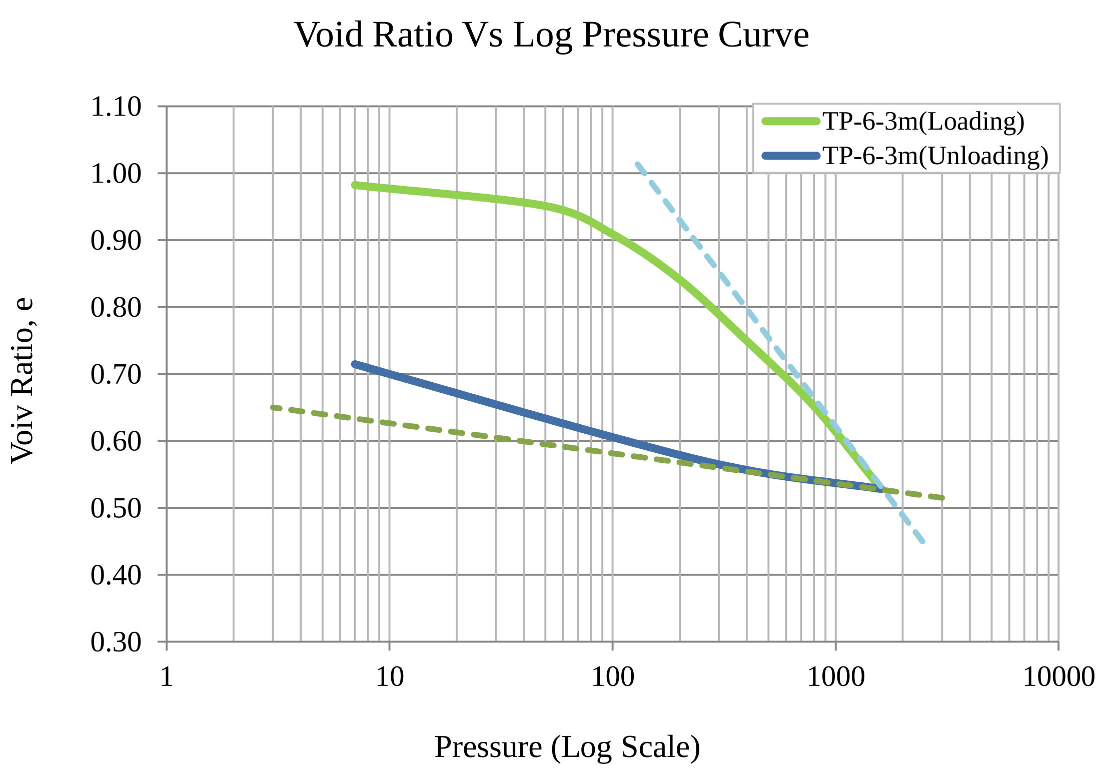

Figure C3.6 loading unloading curve to calculate compression and recompression index

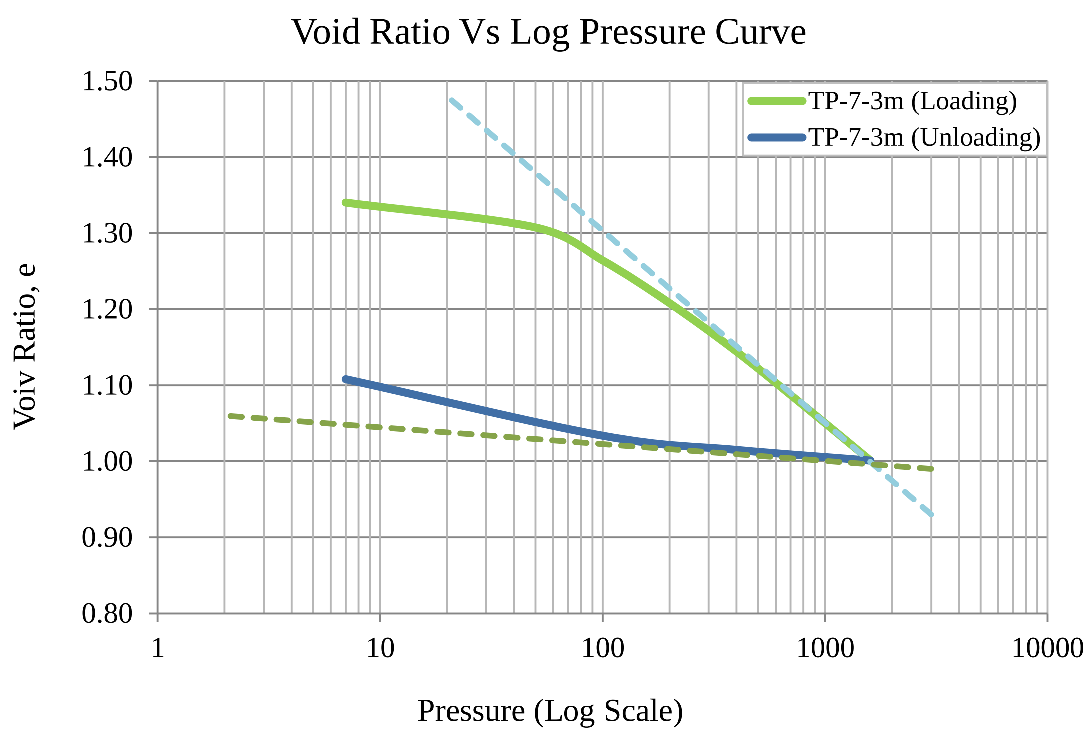

Figure C3.7 loading unloading curve to calculate compression and recompression index

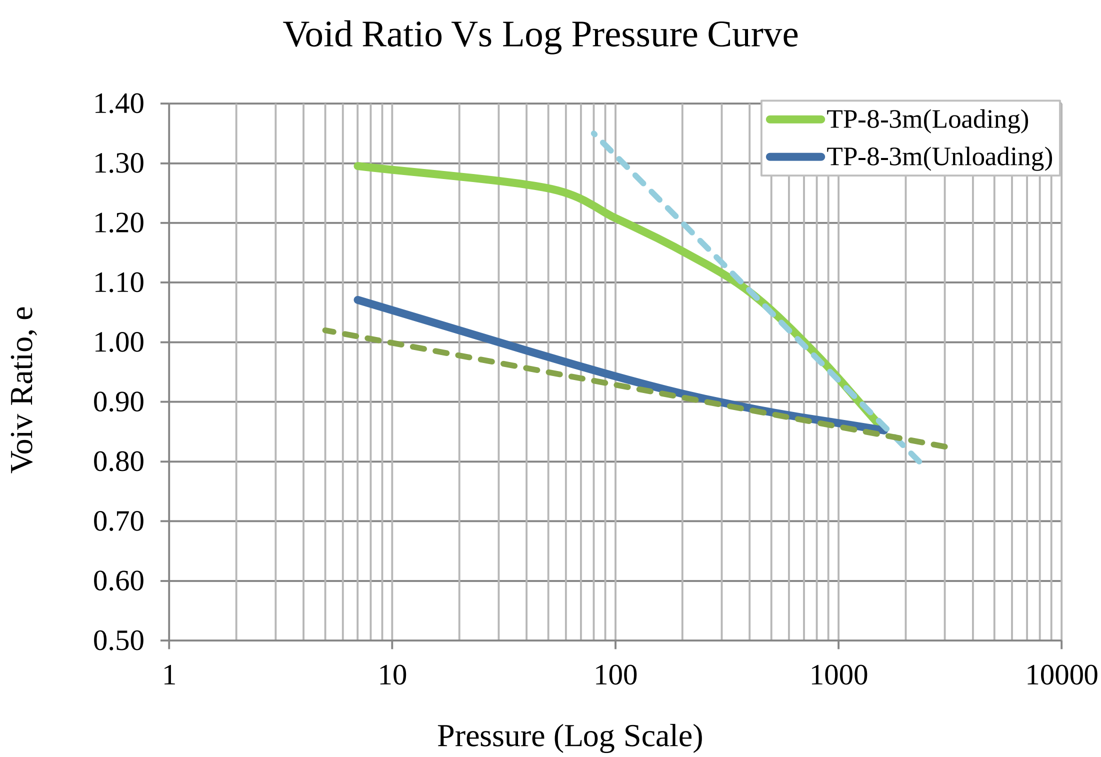

Figure C3.8 loading unloading curve to calculate compression and recompression index

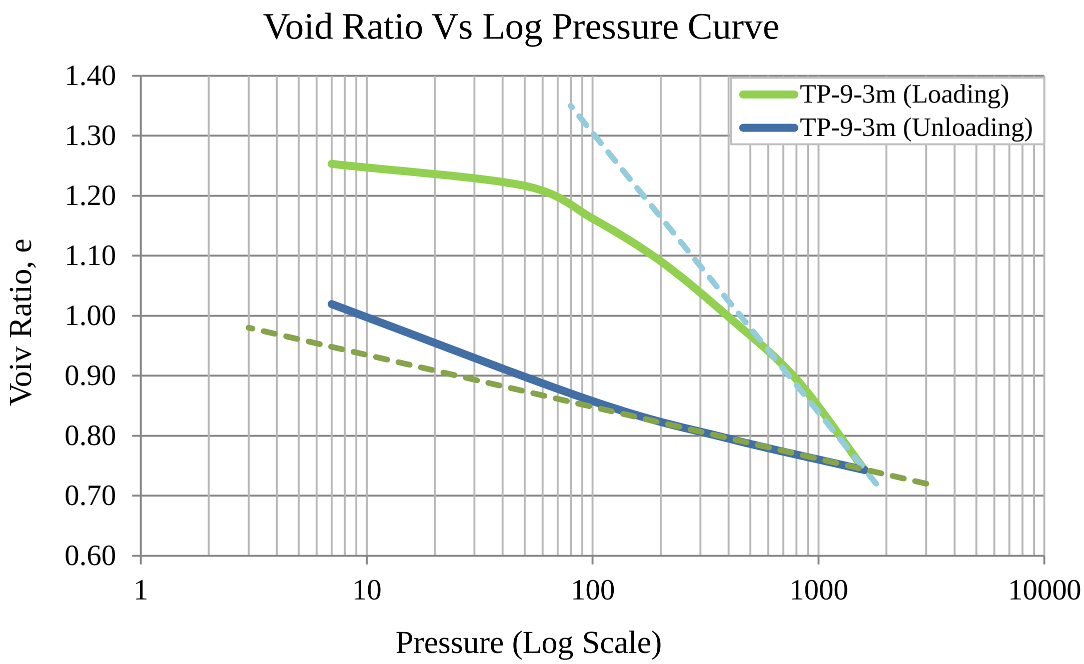

Figure C3.9 loading unloading curve to calculate compression and recompression index

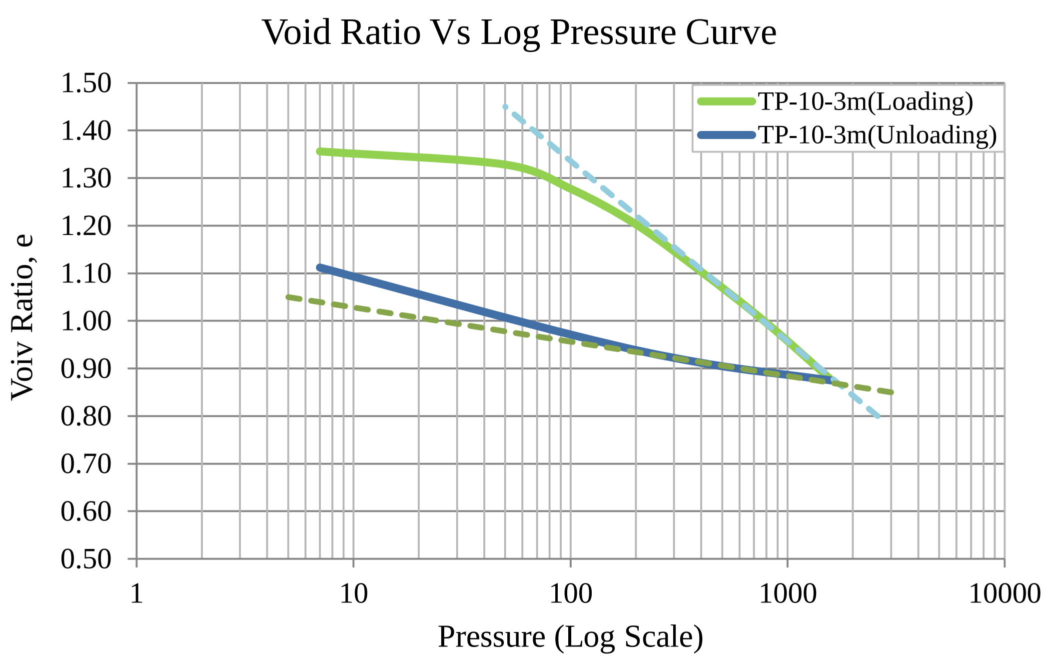

Figure C3.10 loading unloading curve to calculate compression and recompression index