Jimma University

Jimma Institute of Technology

School of Graduate Studies

Faculty of Civil and Environmental Engineering

Geotechnical Engineering

Investigation on some of the Engineering Properties of Soil in Teppi Town

A Thesis Submitted to the School of Graduate Studies of Jimma Institute of Technology, in the Partial Fulfillment for Degree of Masters of Science in Civil Engineering (Geotechnical Engineering).

By:

Firew Gizaw

April 28, 2022

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Advisor: Damtew Tsige (PhD)

Co-Advisor: Mr. Alemineh Sorsa

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitles "**Investigation on Some of the Engineering Properties of Soil in Teppi Town.**" is my original work and has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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ABBREVIATIONS

ASTM	American Society for Testing Materials standard
AASHTO	American Association of Highway and Transportation Officials
C_c	Coefficient of compression index
C_v	Coefficient of consolidation
CBR	California bearing ratio
C_u	Undrained shear strength
CRS	Controlled rate of strain
CTS	controlled stress rate
e	Void ratio
Fs	Free swell
Gs	Specific gravity
LL	liquid limit
MDD	Maximum dry density
N	Number of blows
OMC	Optimum moisture content
OCR	Over consolidation ratio
PI	Plastic Index
PL	Plastic limit
P	Effective vertical stress
q_u	Unconfined compressive strength
SNNPR	Southern Nations, Nationalities, and Peoples' Region
TP	Test pit
USCS	Unified Soil Classification System
UCS	Unconfined compressive strength
W	Water content
γ_d	Dry unit weight
γ_w	Unit weight of water
γ_b	Bulk unit weight
$\sigma'o$	Pre consolidation pressure

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ABSTRACT

Nowadays, the construction of civil engineering structures is increasing from time to time in Teppi Town as it is a developing town. For this infrastructure, a geotechnical investigation is mandatory to have a safe structure. Currently, there is no enough detailed geotechnical investigation that was done for Teppi town. Therefore, this research was aimed to give a clue on Investigation on some of the engineering properties of soil found in Teppi town. This study has addressed analyzing the visual identification, index property determination, compaction characteristics, consolidation, and shear strength analysis by taking the disturbed and undisturbed samples from ten test pits. The sampling procedure and tests were based on American society for testing material (ASTM) manual standards. A selected test pit was dug out with hand tools of a disturbed and undisturbed soil sample then taken to the laboratory to test the index and engineering properties of the study area, the laboratory test types, which was conducted at the average depth of 1.5m and 3.0m were moisture content, Atterberg limit, sieve analysis, standard compaction, etc. The result of the study shows that the natural moisture content varies from 32.18% to 59.45%. The specific gravity varies from 2.53 to 2.78. The majority of soils were categorized as fine-grained soils from which more than 50% of the particle sizes are smaller than 0.075 mm except from two test pits in which they are coarse-grained soil. The liquid limits range from 55% to 104% and plastic limits vary from 25% to 57%. The free swell ranges from 40% to 100%. Based on the free swell index result most of the study area soil was experiences a very high degree of expansiveness, and two tests pit degree of expansiveness belong high. The investigated sample has an undrained shear strength value ranging from 72.11 kPa-131 kPa as shown by the unconfined compression strength test. The compression index value ranges from 0.28 to 0.40. Within the depth of the exploration, the compaction test shows that the maximum dry density of the teppi soil is between 12.96 KN/m^3 *to 15.45 KN/m*^{3} *and the optimum moisture content ranges from 19.5% to 35.80%. A comparison was made in is this study with previously done research in other parts of Ethiopia. The comparison indicates that the engineering properties of these soils of the study area soil lies within the range of different researchers in the other part of the country.*

Keywords- Investigation, Engineering properties, Soil classification, Teppi

CHAPTER ONE

1. INTRODUCTION

1.1. Background

A soil investigation is a significant part of the design and construction of a proposed structural system (building, dams, roads, etc.). Soils are identified, observed, and extracted during a soil investigation of a proposed site. Usually, soils investigations are conducted only on a fraction of a proposed site because it could be prohibitively expensive to perform an extensive investigation of a whole site. We then have to make estimates and judgments based on information from a limited set of observations from field and laboratory test data that will have profound effects on the performance and costs of structures constructed at a site [1]. All structures that are founded on earth rely on our ability to design safe and economic foundations. Because of the natural vagaries of soils, failures do occur. Some failures have been catastrophic and have caused severe damage to lives and property; others have been insidious. Failures occur because of inadequate site and soil investigations [2].

In the study area some problems observed due to not considering proper design for Soil present at the site location such as there are roadside retaining wall failures and gravel road sliding problems and building are shown cracks on their block wall and beams and also door and window distortion.

Teppi is a town in Southwest Ethiopia located in the Sheka Zone of South Nation Nationality People Regional State and 611 Km from Addis Ababa. The town has one governmental university (Mizan Teppi University, Teppi campus), technical and vocational college, and some commercial buildings. In the town, many buildings are constructed and are under construction without adequate and detailed geotechnical investigation.

In this research, investigation on some of the Engineering properties of the soil in Teppi Town will be covered to minimize the problem caused by design that is not considered soil property.

1.2. Statement of the Problem

All structures that are founded on earth rely on our ability to design safe and economic foundations. Because of the natural vagaries of soils, failures do occur. Some failures have been catastrophic and have caused severe damage to lives and property; others have been insidious. Failures occur because of the inadequate site and soil investigations [1].

The construction of buildings and roads is at the beginning of development in the study area, meanwhile, investigation of the subsurface soil properties was not conducted yet.

Insufficient geotechnical investigation, faulty interpretation of results, or failure to portray results in a clearly understandable manner may contribute to inappropriate designs. In response to this problem, this study proposes to investigate index properties of soil found in Teppi town for addressing structural failure and settlement for the underestimated design and also save unnecessary costs resulting from overestimated design [3].

Little is known about the engineering behavior of Teppi soils. Even though there is a road project in the town, a detailed engineering properties investigation has not been conducted so far.

1.3. Research Question

The research questions that the researcher attempted to answer are:

1. What types of soil are found in the Teppi town?
2. What is the range of index properties of soil found in Teppi Town?
3. What are the ranges of shear strength and consolidation parameters of soil**s?**

1.4. Objective

1.4.1. General objective

The main objective of this research is to investigate some of the Engineering properties of the soil found in Teppi town.

1.4.2. Specific objectives

The specific objective of this study includes: -

- To identify types of soil in Teppi town
- To determine the range of index properties of soil in Teppi town soils.
- To determine the shear strength and consolidation parameters of the soil.
- To investigate the expansive behavior of the soils found in the Teppi town.
- To classify the soils found in the area, which can help for further studies.
- To fill the gap in terms of determining the engineering properties of soils found in Ethiopia.

1.5. Scope of the Study

The scope of the study is limited to investigating some of the engineering properties of soil like index property, shear strength parameter, compaction, consolidation, and explaining the behavior of soil. In this study, ten sampling pits were identified and selected upon the geologic nature of the soil. The sample was taken from Teppi town where the major construction activities are planned and the pit depth is limited up to three meters.

1.6. Significance of the Study

Investigating some of the engineering properties of Teppi town soil will provide helpful information to various stakeholders. It can help the owner, contractor, and consultant design proper foundation types for specified construction projects. It can be used to select which area of soil need stabilization when using the soil understructure of construction projects. Additionally, other researchers can use the finding as a reference for further similar and different research types.

1.7. Structure of the Study

The thesis work have five Chapters, which cover a specific topic of the research work. The Chapter one includes the background, statement of the problem, research question, objective, scope, significate and structure of the study are discussed. Chapter two deals with the literature review about the geotechnical properties and engineering properties of the soil, and review of previous study. Chapter three discuss about the study area, methodology that followed to achieve the study goals. Chapter four deals with types of laboratory test and their results, looking the test result discussion was made and finally comparison of test result of previous similar research was made. Chapter five deals with the conclusion and recommendation drawn from the research. Finally, each laboratory test result with tabular and figurative form were presented in Appendices.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. General

The natural aggregate of mineral grains, which contains organic matters or not was known as soil. Rocks exposed for weathering transferred through time to soils. This weathering of rocks was processed by physical disintegration and/or by chemical decomposition. This process decreases the cohesive forces, which hold each other in nature the mineral grains and results in the disintegration of bigger masses into tiny particles. Physical weathering is the process of reduction of particles size on which no change occurs in the original composition of the rocks, that caused by exfoliation, unloading, erosion, freezing, and thawing. Meanwhile, chemical weathering in addition to reducing particle size it changes the chemical composition of the rook by the means of hydration, carbonation, and oxidation [4].

The geotechnical design primarily focuses on analyzing and classifying the soils and rocks conditions from investigated test reports, which was presented in the form of borehole logs, geophysical records, and/or in-situ test profile. Interpolation and/or extrapolating of results from test reports and visualization at discrete points such as boreholes involves significant engineering and geological judgment. The interpretation process is time-consuming and tedious to do manually, therefore using Knowledge-Based Systems is important, such systems use specific knowledge in a specified area, usually in the form of facts, heuristics, or rules of thumb, holding in their knowledge base. They are emerging as a powerful means of dealing with the ill-structured problems encountered in many engineering and medical applications [5].

2.2. General Soil Type and Formation

Regardless of Soils being formed by the process of weathering, weathered rock is categorized by its size like ranging from colloidal to boulders. When we came to soil types based on particle size classified as cobbles, gravel, sand, silt, and clay. The particles size ranging from 4.75 to 76.2 mm, 4.75 to 0.075 mm, 0.075 to 0.002 mm, and finer than 0.002 mm categorized under gravel, sand, silt, and clay soils respectively [6]

2.3. Soil Mineralogical Composition

Inorganic particles are present as soil minerals derived from weathered parent material and decayed plants and animals. List of rocks transferred to soils by weathering, such as quartz and feldspar changed to gravel and sand through time. Very fine quartz and some flake-shaped particles may change to silt soils. When we come to flaked-shaped microscopic and submicroscopic particles of mica and other minerals these rock types form clay soil through time [6]. Chemical weathering of rock particles and hydrates of aluminum, iron, or magnesium silicate is the makeup of clay minerals, which make sheet-like structures. The tetrahedral unit of silica and the octahedral unit of the hydroxide of aluminum, iron, or magnesium produces clay mineral sheet [6].

Mostly based on the presence of mineral sheet structure in clay soils, basically grouped as kaolinite, halloysite, illite, and montmorillonite [6].

I. Kaolinite group

Kaolinite formed from large stacks of alternating single tetrahedral sheets of silicate and octahedral sheets of aluminum. Which was characterized by their stability with strong structure and a little absorbance of water. They have low swelling and shrinkage responses to water content variation and the most dominant clay deposits [6].

II. Halloysite group

Halloysite minerals are formed by successive layers with the same structural composition as those of composing kaolinite, however, the successive parts are randomly packed and may be separated by a single molecular layer of water. The removal of water molecules by the hydration process cause change in the properties of the minerals [6].

III. Illite group

Illite minerals formed from a single octahedral sheet of aluminum sandwiched between tetrahedral sheets of silicon. They tend to absorb more water than kaolinites and have higher swelling and shrinkage characteristics [6].

IV. Montmorillonite group

Both montmorillonite and Illite minerals possess the same sheet structure, however, in the tetrahedral sheets, the presence of silicon some parts is replaced by iron, magnesium, and aluminum. They show extremely high-water absorption, swelling, and shrinkage characteristics [6].

2.4. Properties of Soil

A soil mass has solid particles which form a porous structure. The porous area was covered by air and water [7]. Based on physical characteristics and properties soils were categorized for the help of geotechnical and geology engineers. Because of the wide range of characteristics of the various soils, it was relatively a broad scope. For a proper evaluation of the suitability, identifying the cause of failure and selecting proper construction methods of the soil, besides the classification of the soils type information about its properties is very essential. Those properties which use to get the engineering behavior of any soil and help in determining its classification accurately are termed as ‘Index Properties’. Laboratory and field tests required to determine the index properties are classification tests. Index properties can be determined relatively quickly, easily, and with less cost, which has a bearing on important aspects of engineering behavior such as strength or load-bearing capacity, swelling, and settlement. The study of soil properties takes samples that were undisturbed and or disturbed or remolded soil samples, which can represent the in-situ condition. Physical properties of soil that were tested by laboratories or visualization include soil color, structure, texture, particle size, specific gravity, moisture content, consistency limit, and others [6].

2.4.1. Natural Water Content

The moisture content (w) is defined as the ratio of the mass of water to the mass of solids, which is expressed as in percentage [7]. It was expressed by

$$w = \frac{Mw}{Ms} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The water content present in fine-grain soil is much generally greater than of coarse-grain soils. The water content may range more than 100%, which shows more than 50% of the total mass is that of water [7].

The water content of soil can be determined by different test methods such as

1, Oven Drying method
2, Torsion Balance method
3, Pycnometer method
4, Sand Bath method
5, Alcohol method
6,Calcium Carbide method
7, Radiation method

2.4.2. Grain Size Analysis

2.4.2.1. Sieve Analysis

Sieve analysis is conducted by using a set of standard sieves. The sieve sizes used for grain size analysis are given in terms of the number of openings per inch. Thus, ASTM 60 sieves has 60 opening per inch width with each opening of 0.250 mm. usually the soil used for analysis was oven-dried [8]

$$Percentage\ retaing = \frac{mass\ of\ soil\ retained}{total\ soil\ mass} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{Cumulative \%age retained} = \text{sum of \%age retained on all coarser sieves} \ldots\ldots\ldots.\ldots(3)$$

$$\text{Percentage finer than} = 100\% - \text{cumulative percentage retained} \ldots\ldots\ldots\ldots\ldots.(4)$$

2.4.2.2. Hydrometer Method of Analysis

The hydrometer method was originally developed in 1926 by Prof. Bouyoucos and later modified by Casagrande (1931). This method depends upon variations in the density of a soil suspension contained in a 1000 ml graduated cylinder. At determined time intervals, the density of the suspension was measured with a hydrometer; later the coarser diameter of particles in suspension at a given time and the percentage of particles finer than that coarser diameter are calculated. The calculation is based on Stokes' formula.

For the hydrometer analysis from others methods, ASTM 152 H was selected. The hydrometer is determined the unit weight of suspensions at different depths and particular intervals of time. A unit volume of soil suspension at a depth L and at any time t contains particles finer than a particular diameter D. the value of this diameter is calculated by using Stokes' law whereas the percentage finer than this diameter is evaluated by the use of the hydrometer. The principle of the method is that the reading of the hydrometer gives the unit weight of the suspension at the center of the volume of the hydrometer [9].

2.4.3. Atterberg Limits

Atterberg limit test used to show the range of plastic state. It was defined as the water content corresponding to the transition from one state to another. The shifting state from the liquid state to a plastic state is termed as a liquid limit. At this stage, the soil will have small shear strength. The shifting from a plastic state to a semi-solid was called a plastic limit. Further decreasing water content result transform from semi-solid to solid-state, at this time the soil color start to change from dark to light this state termed as shrinkage limit [10]. The difference between the liquid and plastic limit is termed as a plastic index, PI.

$$PI = LL - PL \quad (5)$$

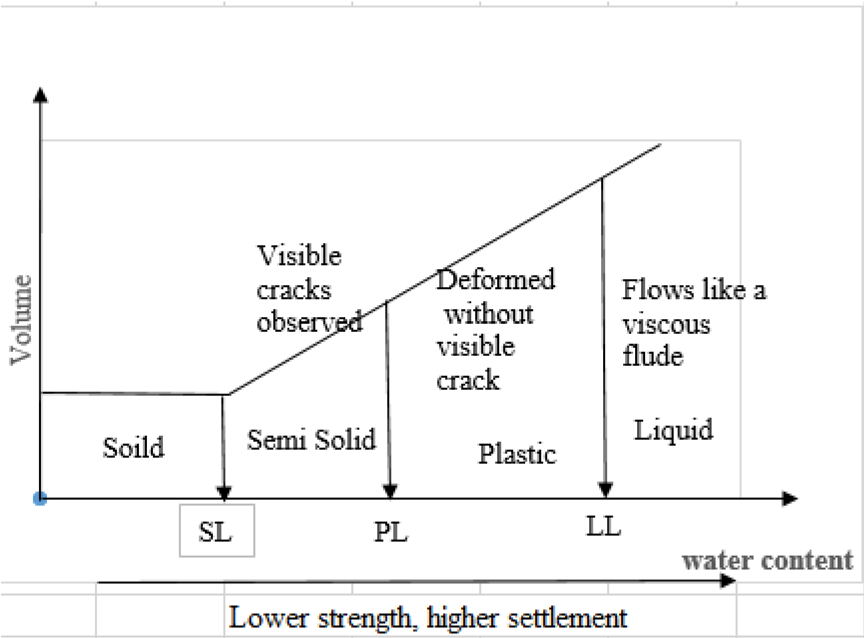

Figure 2. 1 Changes in soil-state as a function of soil volume and water content

2.4.3.1. Liquidity index

The liquidity index was used to show the consistency of undisturbed soils. It was expressed as

$$LI = \frac{wn - PL}{PI} \quad (6)$$

The value ranges from less than zero to greater than one, and use for determining the consistency of soils.

Table 2. 1 Description of the strength of fine-grained soils based on liquidity index [7]

Values of L_I	Description of soil strength
$L_I < 0$	Semisolid state: high strength, brittle (sudden) fracture is expected
$0 < L_I < 1$	Plastic state: intermediate strength, soil deforms like a plastic material
$L_I > 1$	Liquid state: low strength, soil deforms like a viscous fluid

2.4.3.2. Consistency Index

Reflect the state of the clay soil condition in the field is the undisturbed state. Soil consistency or simply consistency is analogous to viscosity in liquids and indicates internal resistance to forces that tend to deform the soil. The internal resistance may come from inter-particle forces (cohesion or adhesion), cementation, inter-particle friction, and soil suction. Terms such as stiff, hard, firm, plastic, soft, and very soft were often used to describe consistency. Consistency changes with water content. A measure of consistency was provided by the consistency index defined as [11]

$$CI = \frac{LL-w}{PL-LL} = \frac{LL-W}{PI} \ldots\ldots (7)$$

Table 2. 2 Description of fine-grained soils based on Consistency Index [7].

Consistency	Consistency index (CI) (%)	Unconfined compression strength q_u (kN/m^2)
Very soft	0- 25	< 25
Soft	25 - 50	25-50
Firm or Medium	50 - 75	50-100
Stiff	75 - 100	100-200
Very stiff	>100	200-400

2.4.4.3. Activity

Skempton (1953) observed that the significant change in the volume of clay soil during shrinking or swelling is a function of the plasticity index and the quality of colloidal clay particles present in the soil. And classify them as inactive, normal, or active [12].

$$Activity = plasticity \frac{index}{percent} finer\ than\ 0.002mm \ldots\ldots (8)$$

2.4.4. Specific Gravity of Solids

The specific gravity of solid particles (Gs) is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water at 4^o C. It was expressed as

$$Gs = \frac{\rho s}{\rho w} \ldots\ldots (9)$$

The mass density of water ρw at 4C is 1gm/ml, 1000 kg/m^3, or 1Mg/m^3.

Most natural soils the specific gravity ranges from 2.65 to 2.80, whereas organic soils were variable and may fall below 2.0 [7].

The specific gravity of solid is determined by different laboratory method

1, Density bottle method
2, Pycnometer method
3, Measuring flask method
4, Gas jar method
5, Shrinkage limit

2.4.5. Free Swell

Free swell was defined as the ratio between the differences in a final volume of poured soil to the initial dry volume of poured soil and the initial dry volume of poured soil.

$$FS = \frac{(Vf - Vi) * 100}{Vi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

According to Holtz and Gibbs (1956), 10cm^3 (V_i) of dry soil passing through a No. 40 sieve is poured into a 100cm^3 graduated cylinder filled with water. The volume of settled soil is measured after 24 hours which gives the value of V_f bentonite –clay is supposed to have a free swell value ranging from 1200 to 2000 percent. The free swell value increase with the plasticity index [13].

2.4.6. Shear Strength

The shear strength of soil was defined as the maximum resistance to shear stress just before the failure. Soils are rarely subject to direct shear, however, the shear stress develops when the soil is subjected to direct compression. In addition, shear stress can be developed when soils are subjected to direct tension, but this shear stress is not relevant, as the soil in this case fails in tension and does not fail in shear.

Shear strength is the basic engineering property that controls the stability of a soil mass under loads. It governs the bearing capacity of soils, the stability of slopes in soils, and earth pressure against retaining structures [7].

There are different types of tests to evaluate the shear strength of a soil

1, Direct shear test
4, Unconfined compression test
2, Triaxial compression test
3, Vane Shear test

2.4.6.1. Direct Shear Test

The test is used for testing cohesionless soils on drained conditions as the thickness of the sample is comparatively small, therefore drainage is quick. The stress condition is determined only at failure. The measurement of pore pressure is not possible.

2.4.6.2. Triaxial Compression Test

Used to determine the shear strength of both cohesive and cohesionless soil. The apparatus is elaborate, costly, and bulky. The strain condition in the specimen is not uniform due to the frictional restraint produced by the loading cap and the pedestal disc. This results from a dead zone at each end of the specimen.

2.4.6.3. Unconfined Compression Test

Unconfined compression test is a special form of triaxial test in which there is no confining pressure adapted here. The test is only used for clayey soils which can be stable without confinement. The test is may be given the wrong result for soils for which the angle of shear resistance is not zero. For such soil, the shear strength is not equal to half the compressive strength.

2.4.6.4. Vane Shear Test

Vane shear test determines the undrained shear strength of soft clays. The test does not give accurate results when the failure envelope is not horizontal [14].

2.4.7. Compaction

Compaction is defined as the compression of the soil particles close to each other with the expulsion of air from void space by mechanical methods. Here the mass density and shear strength will be increased as the soil compacted more up to optimum moisture content. And help the soil to reduce its permeability and compressibility of the soil. There are two methods of test for performing compaction standard proctor test and modified proctor test.

For the aim of supporting highways or building or retaining walls as in earth dams, the soil material must possess certain properties while in place. These desirable features will be achieved by the proper placement of appropriate soil material. Most of those desirable qualities are related to dry density, which can be achieved by compaction [7].

2.4.8. Consolidation

Consolidation expressed as a saturated clay-water system was subjected to an external pressure, the pressure applied in the beginning resist by the water in the pores resulting thereby in excess pore pressure, after long time application of load the water flow out through the soil and soil mass start to compress [7]. The total compression of saturated clay soil under excess effective pressure may be considered as the sum of:

1, Immediate compression

2, Primary consolidation, and

3, Secondary consolidation.

The compressibility of a saturated, clay-water system is determined by laboratory apparatus called an oedometer. It is the standard one dimension consolidation test method. Here in the test compressibility properties were obtained for determining the magnitude and rate of settlement.

Coefficient of compressibility

Is described as a decrease in void ratio per unit increase in effective stress.

$$av = -\frac{\Delta e}{\Delta \sigma'} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (11)$$

It decreases with an increase in the effective stress, in addition, the soil becomes stiffer as the effective stress is increased and the curve becomes flatter.

Coefficient of Volume Change

The coefficient of volume change is known as the volumetric strain per unit increase in effective stress. Also known as the coefficient of volume compressibility.

$$mv = \frac{\Delta V - Vo}{\Delta \sigma'} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (12)$$

Compression Index

The compression index Cc) is equal to the slope of the linear portion of the void ratio versus log σ'.

$$Cc = \frac{\Delta e}{\log(p2 - p1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (13)$$

The compression index is extremely helpful for the calculation of the settlement in the field.

Normally consolidated and Overconsolidated Clays

A normally consolidated soil is defended by soil which not been subjected or experienced to a pressure greater than the present applied load. Whereas Over consolidated soil had been experienced in the past time to pressure over the present load applied [7].

2.5. Soil Classification System

All widely used engineering soil classifications involve a combination of particle size and measures of plasticity and textural soil classifications. In addition to providing an orderly system for classification, the use of particle size and plasticity permits the Engineer to estimate the engineering properties of soils such as compaction, settlement, drainage, frost susceptibility, placement, excavation, and embankment characteristics. Among different types, the followings are the two most popular engineering soil classifications: USCS and AASHTO classification systems [8].

2.5.1. Unified Soil Classification System (USCS)

The USC system is a textural-plasticity classification scheme. Soils were divided into two major groups, coarse-grained and fine-grained soils, using the No. 200 sieve as the size criterion. When more than half of the soil sample is larger than the No. 200 sieve, it was classified as coarse-grained and is further subdivided by sieving and gradation. When more than half of the soil sample is smaller than the No. 200 sieve, it was classified as fine-grained and is subdivided primarily based on liquid limit values and degree of plasticity. The presence of organic material is an additional classification factor for fine-grained soils. Paired letter symbols were used for each soil group in the USC system. The first symbol refers to the predominant particle size (with the exception of organics). The second symbol for coarse-grained soils refer to gradation for clean (little or no fines) soils and the presence of silt and clay-size particles for soils with appreciable amounts of fines. The second symbol for fine-grained soils subdivides based on low (L) or high (H) plasticity [7].

Laboratory determination of liquid limit and plasticity indexes for a soil sample permits assignment of fine-grained soils (including the fine fraction of coarse-grained soils) to the proper group by use of the plasticity chart, or A-line diagram, as illustrated by Figure 2.2. Field test procedures may be used to estimate the group to which a fine-grained soil should be assigned prior to more definitive laboratory testing. These tests are measures of crushing strength, dilatancy, and toughness, all measures of relative proportions of silt and clay sizes and plasticity.

The USC system includes typical soil names with the classification system. Soils that are intermediate between two groups may be identified symbolically by a combined notation such as SM-ML and SC-CL. Figure 2.2 is also used to classify fine-grained soils from Atterberg limits using USC system notation

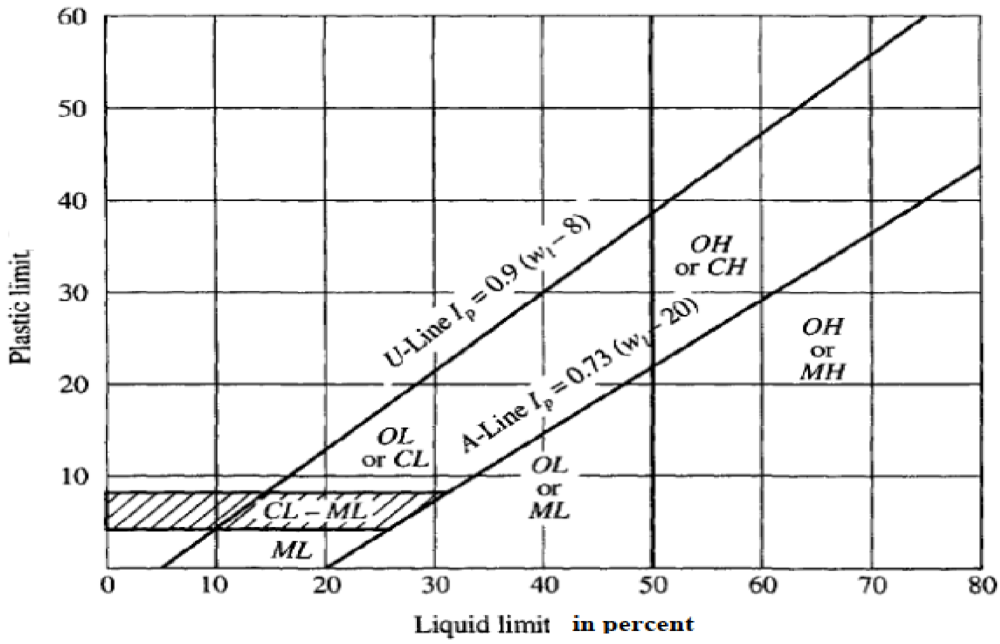

Figure 2. 2 Plasticity chart for classification of fine-grained soils [6]

2.5.2. AASHTO Classification System

In addition to the USC system, an engineering soil classification was developed in 1928 by the U.S. Bureau of Public Roads, which is now called the American Association of State Highway and Transportation Officials (AASHTO). It is a textural-plasticity classification that uses sieved fractions and Atterberg limits for the assignment of soils to seven main groups and several subgroups. The classification is more specific than the USC system in the limits placed on size ranges and amounts and ranges of liquid limits and plasticity indexes for fines. As with the USC system, these limits are placed on groups within both the granular (coarse-grained) and silty/clay (fine-grained) soils as required by soil gradations. Rather than using the No. 4 sieve (4.75 mm) of the USC system as the upper limit of the sand-size range, the AASHTO classification uses the No. 10 sieve (2.0 mm) as the upper size limit of sand. However, the No. 200 sieve (0.075 mm) used in the USC system is retained to separate the finer fractions from sand [6].

The AASHTO system classifies soils into eight groups, A-1 through A-8. Soil group A-8 is not shown but is peat or muck based on a visual classification. Illustrated groups from A-1 through A-7 categories with two general classifications are Granular material and Silt Clay material A-1 up to A-3 and A-4 up to A-7 respectively [6].

2.6. Previously conducted research

1. Soil Investigation results conducted in Jimma Town.

[15] In his research shows the natural moisture content varies from 37% to 68%. The specific gravity varies from 2.58 to 2.82. The soils were categorized as fine-grained soils from which more than 90% of the particle sizes are smaller than 0.075mm. The liquid limit ranges from 53% to 108%, and plastic limits vary from 27% to 41%. According to the Unified Soil Classification System, the soils were categorized as CH-clay with high plasticity (fat clay) with a potential of expansion. And as per AASHTO classification system, these soils classified as plastic clay which is unfavorable for subgrade construction.

2. Soil Investigation results that conducted in Dembecha Town.

[16] In his research, conclude that two types of soils mainly covered the Dembecha town area. "The first groups of soils are red soils which are classified as inorganic clay and silts according to Unified Soil Classification System. These soils have a specific gravity, liquid limit, plasticity index, free swell, and clay fraction ranges from 2.80 to 2.84, 61% to 80%, 28 to 41%, 30% to 50% and 71.52% respectively. Compression index, recompression index, pre-consolidation pressure values were 0.176, and 0.015, and 200 kPa respectively whereas coefficient of permeability ranging from 0.168*10-9 to 1.375*10-9 cm/sec''

"The second groups of soils are brown soils which are all classified as inorganic clay except one test pit which is classified as inorganic silt according to Unified Soil Classification System. These soils have a specific gravity, liquid limit, plasticity index, free swell, and clay fraction ranges from 2.73 to 2.85, 59% to 89%, 26 to 59%, 40% to 93% and 45.15% to 65.69% respectively. Compression index, recompression index, pre-consolidation pressure values were 0.191 to 0.197, and 0.026 to 0.059, and 100 to 150 kPa respectively whereas coefficient of permeability ranging from 0.083*10-9 to 1.237*10-9 cm/sec''

3. Soil Investigation results conducted in Kemise Town.

According to [17] his study shows that

"According to engineering properties test results, it is concluded that the type of soils found in Kemise town is clay, silt, and silty sand.

Based on the type of soils identified the clay soils have liquid limit ranging from 40 to 84.9%, plastic index ranging from 16.7 to 55.4%. Silt soils have liquid limit ranging from 36.8 to 67.5%, plastic index ranging from 12.1 to 34.7% while silty sand soil has liquid limit ranging from 30.7 to 37.4%, plastic index ranging from 6.5 to 10%.

The consistency of soils, which are stiff to hard identify based on the liquidity index value. The results obtained from consolidation test, the values of the coefficient of consolidation and Coefficient of permeability are reduced with effective stress increment".

4. Soil Investigation results that conducted in Haromaya Town.

According to [18] his study shows that

"Based on the Unified Soil Classification System, the soil is categorized as CH (high plastic clay soil), CL (low to medium plastic clay soil), and SM (silty sand). The AASHTO Classification System shows that most of the soils of study areas categorized on A-7-6 and A-6; therefore, those soils have poor quality for use as subgrade".

5. Soil Investigation results conducted in Debre Birhan Town.

According to [19], his study shows that.

"In-situ soil properties show that the natural moisture content for the area under study ranges from 20.11% to 58.99 % and the in-situ unit weight was in the range of 14.02 kPa to 18.53 kPa. Specific gravity is between 2.62 and 2.81. It is above 2.62, indicating that inorganic soils are dominant as most of the organic soils contain a value of less than 2.40. The grain size analysis of the area indicated the soil contains gravel 0-24.63%, Sand 2.37%-38.74%, Silt 27.28%-55.9% and clay in between 8.77% to 67.5%. This indicates that the dominant soil types in the area are Silt and Clay. The liquid limit of the soils was in the range of 31%-80%. Plastic limit of the soils lies in between 18% to 43%. Plasticity index for the area under study lies between 13%-46%. Soil classification for the area under study is made by both USCS and AASHTO. Soils classification by USCS shows that the soil contains around 41% CH, 18% CL, 18% MH, 14% ML, 4.5% SM and 4.5% SC and AASTHO classification system shows the soils are classified in either of A-6 or A-7".

6. Soil Investigation results conducted in Bahir Dar Town.

According to [20] his study shows that

"The test results showed that the Specific Gravity ranges from 2.55 to 2.81. The Index Property Test showed that the Plasticity Index ranges from 44.5 to 76.42%. The clay content of the soil is from 55.4 to 87%. Free Swell tests conducted on the collected samples showed a range from 78 to 215%.

According to the USCS, the soil is categorized as Fat or Organic Clay with a potential of expansion and AASHTO Classification System also shows that the soil is Plastic Clay with high volume change capacity.”

7. Soil Investigation results conducted in Shashemene Town.

According to [21], his study shows that moisture content range in the area from 26-36%, liquid limit ranges from 39-50%, plastic limit ranges from 27-36%, plasticity index ranges from 8-16%, linear shrinkage limit ranges from 4-6%, free swell ranges from 21-35% and specific gravity ranges from 2.43-2.60.

The previous study shows the different value of the investigated result. The variety of Geotechnical soil properties is a place to place is natural, and this lead to an investigation of soil is necessary before staring construct construction project.

Soil Index Property Investigation enables to approximately guess expensive Soil tests by knowing Index properties of soil using ANN.

Soil Index Property Investigation enables to treat those soils categorized under Expansive Soil.

CHAPTER THREE

3. METHODOLOGY

3.1. Study Area Description

3.1.1. Description and Location of the Study Area

This study was conducted at the Southern Nations and Nationalities Peoples Regional State, Sheka Zone, Yeki Woreda at the Teppi town, which is located about 611 Km from Addis Ababa. It is located at approximate geographic coordinates of 7°20'N, and 35°50E and altitude of 1200 meters above sea level and has a mean maximum and minimum temperature of 29.5 °C and 15.3° C, respectively [22]. The seismic hazard (PGA) condition according to the world health organization, 2010 categorized under very low ranging from 0.0 to 0.2m/s^2.

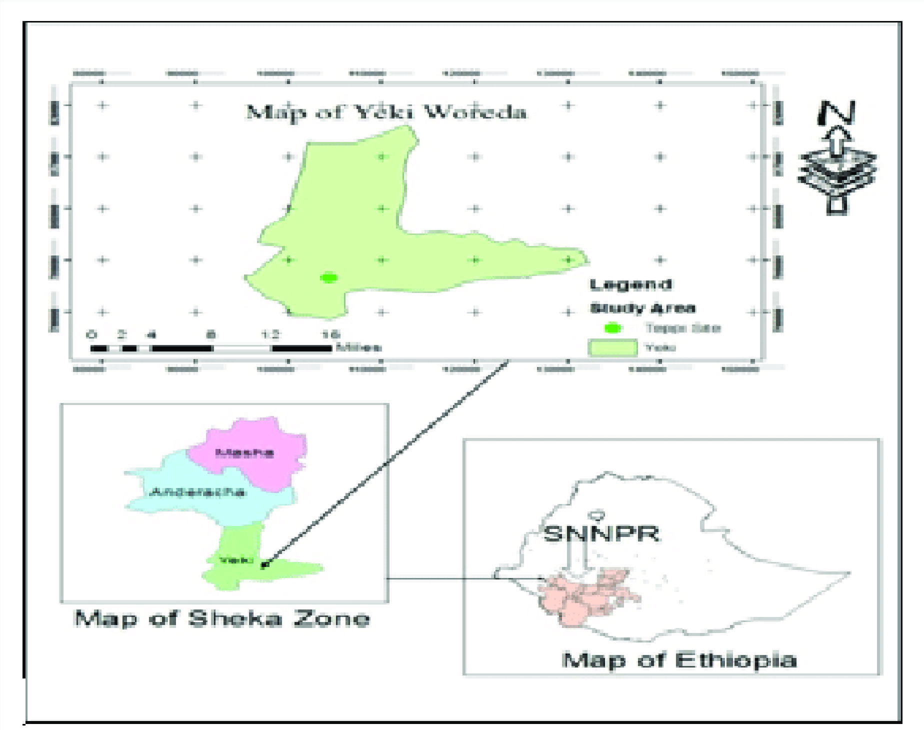

Figure 3. 1 Map of the study area (Source: Yeki Woreda Municipality)

3.2. Data Collection Method and Soil Mapping

Data for this study area were collected from ten test pits according to the reach area of future buildings and roads proposed by the structural plan of the town. The location of the test pits and types of soil were shown in the following figures below, the coordinate of each test pits locations shown in table 4.1.

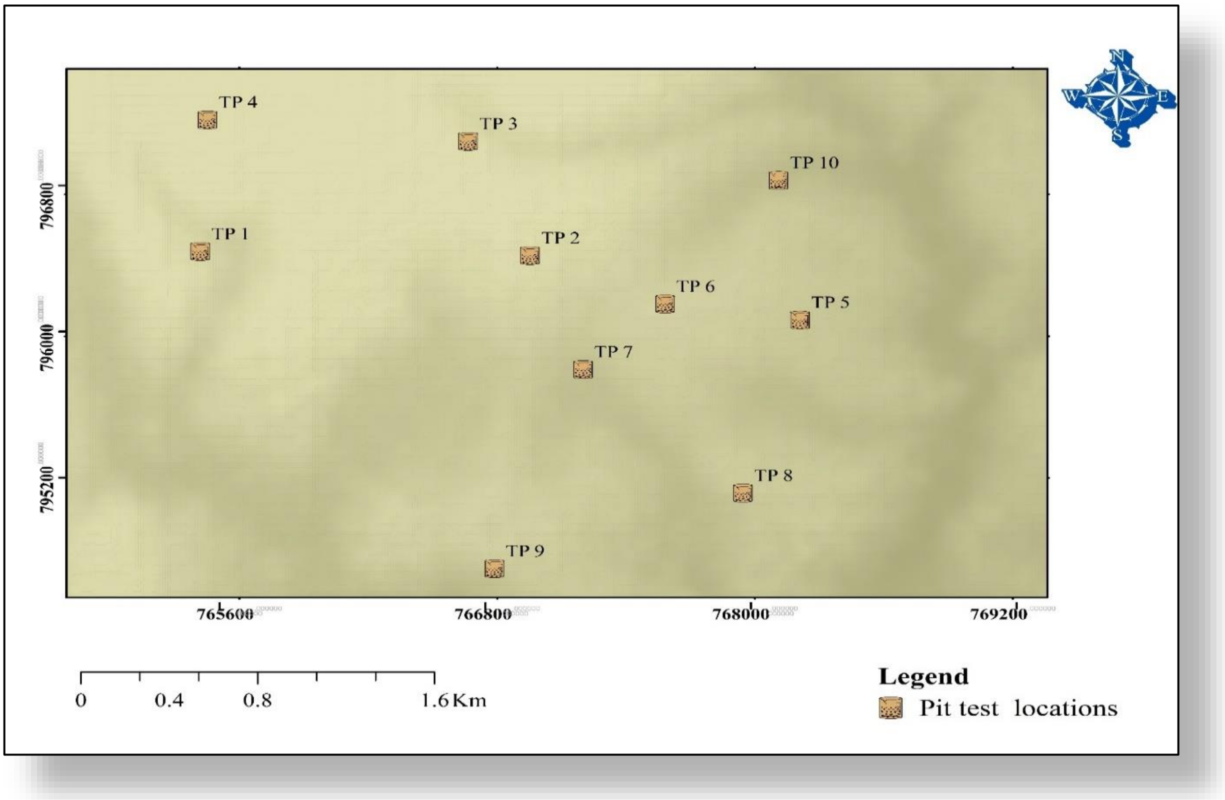

Figure 3. 2 Test pit location (Arc GIS)

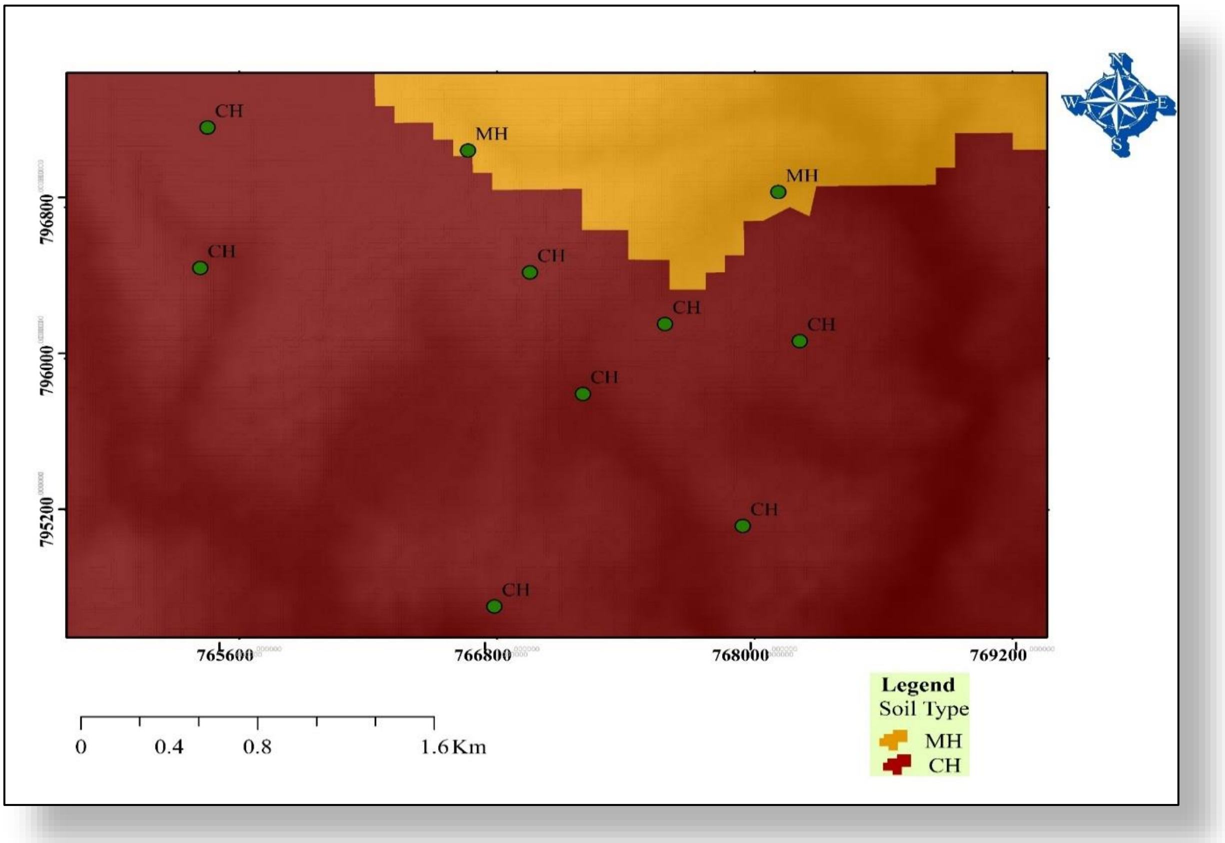

Figure 3. 3 Soil mapping Type of soil (Arc GIS)

3.3. Sample size and Sampling Procedure

Depending on the standard which describes the sample size (number of test pits) for a study area was the sample size for this research. From a different area of the town, ten test pits were selected.

The ASTM sampling procedures were followed on selected sites; to disturbed and undisturbed samples for laboratory analysis. After carefully conducting the laboratory test the data are organized and tabulated.

3.4. Study Design

A study design was a process that guides a researcher on how to collect analyses and interpret the observation. This study was designed for investigating some of the engineering properties of the soil found in the study area below 1.5m and 3.0m from ground level and then after describing the classification, strength, consolidation, and compaction characteristic, and also to specify the swelling nature of the soil by taking the samples and performing laboratory test.

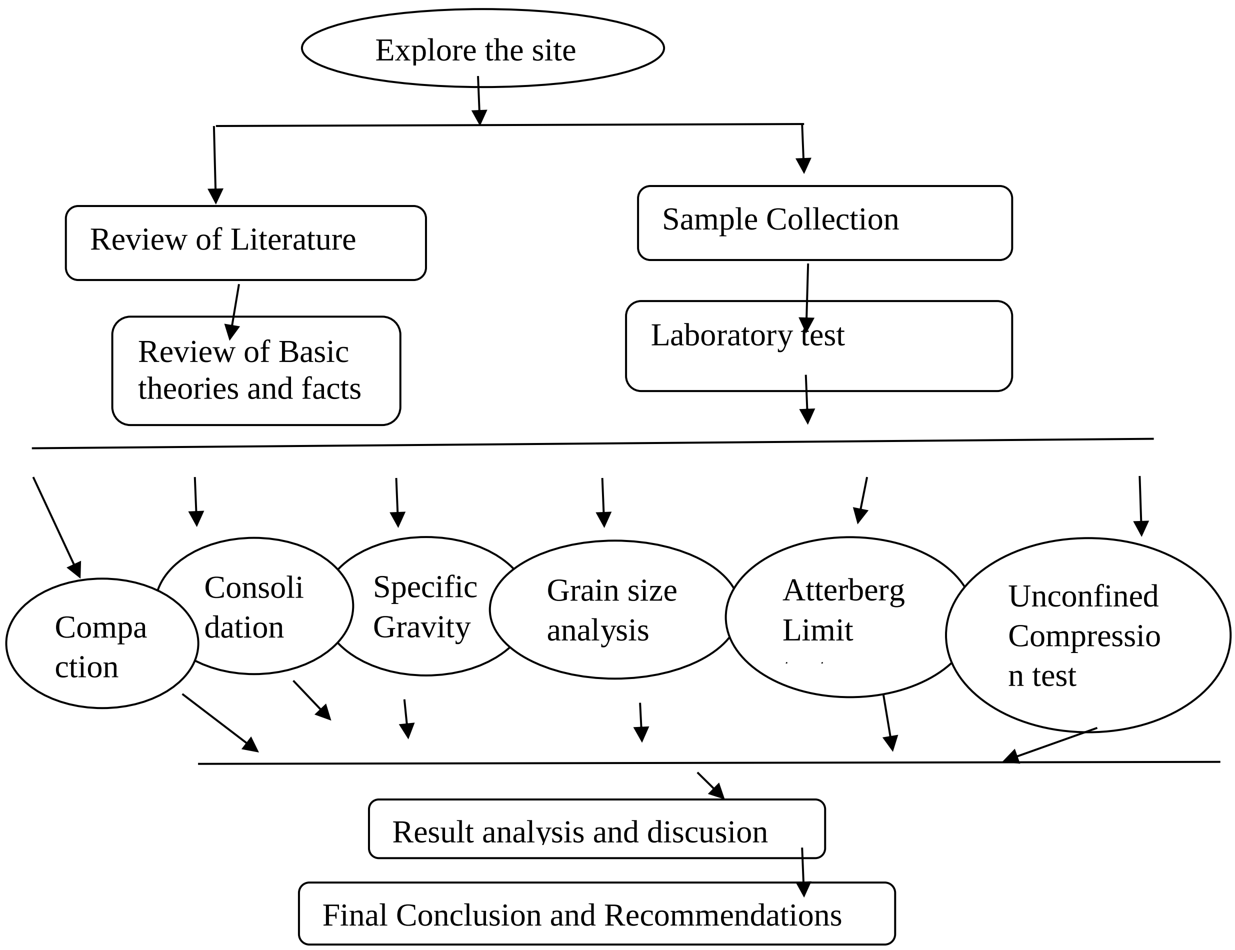

Figure 3. 4 Flow chart for the study.

3.5. Data Processing and Analysis

In processing all the design and analysis, identifying the literature review of researches, AASHTO design specification was assessed for evaluating the research output. The following laboratory tests are conducted by the procedure of the ASTM design manual. Then finally depending on design manual specification and other standards the result of the analysis was presented to meet the research objectives.

3.6. Natural Moisture Content

Natural moisture content is determined by the ratio of the weight of water in a sample to the weight of the solids. The excavated sample was weighted, at about 110^o C temperature oven-dried, after 24 hours the dried sample was weighted. The change in weight of the wet and dry samples is called water weight. The test procedure and analysis were performed in guidance specified in ASTM D 2216.

3.7. Grain Size Analysis

The distribution of grain size particles in the test pits sample was performed according to sieve analysis and hydrometer analysis for coarse-grain soil and fine-grained soil respectively [7].

3.7.1. Sieve Analysis

Based on standard sieve size about 1000 gr dry mass of samples was washed on sieve size No. 200, this was done by measuring the retained particle size by causing the sample to pass through a series of wire screens by the method of horizontal shaking for 10 minutes of the whole nest of sieves which set properly in accordance of decreasing order of sieve opening size. A typical set of grain size distribution curves with the grain size D as the abscissa on the logarithmic scale and the percent finer P as the ordinate on the arithmetic scale was adapted. The procedure has used a set of sieves, which was yielded equal grain size intervals on a logarithmic scale. The procedure and analysis were conducted in accordance with ASTM C 136.

3.7.2. Hydrometer

In this research, the hydrometer test was carried out based on Stokes Law. The particle size pass through sieve No.200 was taken for hydrometer analysis which was about 50 grams by weight. The laboratory procedure and analysis were conducted according to ASTM D 422.

3.8. Atterberg Limits

Atterberg limits consist of the liquid limits, plastic limit, and shrinkage limit, even so, in this research only liquid and plastic limits are used in AASHTO and USCS for the classification and categorization purpose.

3.8.1. Liquid Limit (LL)

The liquid limit was defined as the moisture content of the soil in between the liquid and plastic states. The test was determined by preparing the soil cake and putting it on the Casagrande apparatus and performing different bowls, when the bowl was dropped 25 times of 10mm at the rate of 2 drops/second was taken as the liquid limit [23], detailed test procedure, and analysis technic was performed in accordance of ASTM D 4318.

3.8.2. Plastic Limit (PL)

The plastic limit was defined as the moisture content of the soil in between the plastic states and semi-solid states. The plastic limit performed in this research paper was determined by ascertaining the moisture content at which the soil sample can be rolled into threads of diameter 3.2 mm without crumbling. The test procedure and analysis were performed in accordance with ASTM D 4318.

3.9. Specific Gravity of Soils

The specific gravity of soil, G_s, determined the ratio of the mass in air of a given volume of soil particles to the mass in air of an equal volume of gas-free distilled water at a stated temperature of 20^{o} C. the procedure was carried out by calibrated pycnometer, the mass of soil which passes through sieve No. 4 and distilled water. Here the temperature was measured; while taking the test [6]. For this research’ the test procedure and analysis were performed in accordance with ASTM C 854.

3.10. Shear Strength Test

The maximum shearing stress the soil structure can resist before failure is known as the shear strength of soil [7]. There are different shear strength evaluating methods for this research Unconfined compression test was selected because of the soil types classified in accordance of ASTM, basically, the test is conducted on the undisturbed samples, however for comparison purposes the test was conducted in both states, which is undisturbed and remolded samples.

3.10.1. Unconfined Compression Test

A cylindrical sample was prepared for this test, during the test procedure an axial load is applied on the unconfined sample until failure occurs. ASTM recommends the test was adapted for cohesive soils. After the test was performed the cohesion of the soil is equal to half of the obtained unconfined compressive strength q_u. In this research, the test procedure and analysis were performed in accordance with ASTM D 2166.

3.11. Compaction Test

A compaction test was determined the optimum water content and maximum dry density of the soil samples, which was achieved using specified compaction effort in accordance with ASTM. Compaction effort used is dependent upon the proposed purpose of the site, the grain size of particles, and the loading to which it was subjected. In laboratory tests, there are two compaction methods standard proctor and modified proctor [7]. For this research method based on the grain size of soil sample was got from classification. The standard proctor method was adapted.

3.11.1. Standard Proctor

The test method was used a 2.5 kg rammer dropped from a height of 305 mm, which the soil sample was compacted into three layers. Here for this research the test procedure and analysis were performed in accordance with ASTM D 698.

3.12. Consolidation Test

Cohesive soils settle or consolidate over time when large loads was applied, this happens because water from void space squeezing out and rearrangement of soil particles occurs [6]. This test method in the laboratory was performed by a one-dimensional test procedure.

3.12.1. One-Dimensional Test

From different consolidation tests types, one-dimensional test was used mostly. During the test drainage was permitted various loading increment with loading and unloading procedures was used during testing, different consolidation parameter was driven from the test result. The test procedure and analysis were performed in accordance with ASTM D 2435. The loading methods were included the constant rate of strain test prescribed in ASTM D 4186, in which the sample was subjected to a constantly changing load while maintaining a constant rate of strain.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. General Description of Test Pits

The general test pit location and their visual characteristics were described below

Table 4. 1 The global coordinates and visual description of test pits

Test Pit	Sample designation	Location	Easting	Northing	Elevation (m)	Color
TP 1	TP-1 @1.5m	MTU	765418.50	796479.0	1240.80	Red
	TP-1 @3m					
TP 2	TP-2 @1.5m	Elementary	766953.39	796455.45	1293.50	Red
	TP-2 @3m					
TP 3	TP-3 @1.5m	Technic	767246.74	797363.34	1246.72	Yellowish Red
	TP-3@3m					
TP 4	TP-4 @1.5m	To Guri	7765077.47	797386.13	1283.07	Red
	TP-4 @3m					
TP 5	TP-5 @1.5m	Youth Center	768210.06	796092.00	1207.67	Red
	TP-5 @3m					
TP 6	TP-6 @1.5m	Spice Market	7764915.15	798674.03	1302.34	Brownish Gray
	TP-6 @3m					
TP 7	TP-7 @1.5m	Mizan Ber	767200.14	795812.84	1211.53	Red
	TP-7 @3m					
TP 8	TP-8 @1.5m	Stadium	767944.59	795115.19	1220.16	Brown
	TP-8 @3m					
TP 9	TP-9 @1.5m	EELPA Substation	766787.99	794689.33	1208.21	Yellowish Red
	TP-9 @3m					
TP 10	TP-10 @1.5m	Secondary and Preparatory School	768110.15	796879.71	1193.55	Yellowish Red
	TP-10@3m					

From visual observation of the soil found located in the above coordinate location (Table 4.1), the color of soil varies from test pit to test pits as observed variety soil colors like red, brown, brownish gray, and yellow-red soil color presented and during excavating the test pits there was no odor smell this was found to be there was no biodegradable waste material deposit on the test pit locations and also the water content of the test pit soil varies from moist to wet, the wet condition happed during the presence of rainfall during excavation of test pits.

For the extraction of soil samples using Hand tools, commonly depths are on the order of 2.0 m to 5.0 m, as on roadways, or airport runways, or investigation for small buildings [24].

The test pit depth selected here ranges from 1.5 m to 3.0 m because of the development of the Teppi town in building construction foundation depth types was found in ranges of 1.5 meters to 3.0 meters. Table 4.1 shows the local coordinate which was according to the structural plan of the Teppi town.

4.2. Test Pits Soil Properties

4.2.1. Natural Water Content

According to the ASTM D2216-92 test procedure, the natural water content of the test pits soil was conducted and the test result is described below in table 4-2 for the detailed analysis see appendix-A.

Table 4. 2 Moisture content result for all test pits

Test Pit	Sample designation	Location	Natural Moisture Content (%)
TP-1	TP-1 @1.5m	MTU	52.65
	TP-1 @3m		46.54
TP 2	TP-2 @1.5m	Elementary	49.28
	TP-2 @3m		41.72
TP 3	TP-3 @1.5m	Technic	45.67
	TP-3 @3m		48.54
TP 4	TP-4 @1.5m	To Guri	49.82
	TP-4 @3m		50.55
TP 5	TP-5 @1.5m	Youth Center	45.33
	TP-5 @3m		59.45
TP 6	TP-6 @1.5m	Spice Market	35.51
	TP-6 @3m		32.18
TP 7	TP-7 @1.5m	Mizan Ber	48.82
	TP-7 @3m		49.16
TP 8	TP-8 @1.5m	Stadium	40.91
	TP-8 @3m		42.23
TP 9	TP-9 @1.5m	EElpa Sub station	44.97
	TP-9 @3m		49.62
TP 10	TP-10 @1.5m	Secondary and Preparatory School	43.51
	TP-10@3m		47.21

Conducting laboratory tests to determine the natural water content of the soil is very important because the moisture content of the soil is one of the factors that affect the dry density of soils and increase or reduce density indices of the soils. [25] Concluded that the relationship between NMC and density index (DI) is significate ($P<0.01$), this technique could be useful in the quick assessment of pavement material (soils) before use in road construction. It can also be used to evaluate road failure.

From above table 4.2, it can be observed that the natural moisture content of the study area ranges from 32.18% to 59.45%, this was indicated the moisture content of the soil varies from test pit to test pit because of the water precipitation presence in the area during rainfall happed, also from depth variation there was moisture content variation observed, this was happened because of the capillarity and absorption behavior of the soils particles.

4.2.2. Specific Gravity

According to the ASTM D854 test procedure, the specific gravity of the test pits soils of the study area was calculated for the detailed analysis seen in appendix-B, stopped bottle used for determining specific gravity and oven dried soils taken for conducting the test, mass of soils taken for the test was 10 g which pass sieve no. 10 (2 mm), and here proper calibration, using de-aired distilled water, and keeping clean of laboratory equipment's was essential and must to if not the laboratory result will be affected and gives wrong result. The summarized test result was listed here below in table 4-3.

As shown below in table 4.3 the specific gravity of soils under investigation lies within a range of 2.53 to 2.78, generally specific gravity test result for soil types ranges similarly such as gravel and sand soil Gs value ranges from 2.65 to 2.68 and silt and silty sands Gs value ranges from 2.66 to 2.70, based on specific gravity result could not determine the type of soil that was clay, silt, sand, and gravel. Beside this categorization of organic soil and inorganic soil could be made by Gs values, therefore the soils can be categorized as inorganic soils since their Gs values are greater than 2.5 [7].

Table 4. 3 Specific gravity test results

Test Pit	Sample designation	Location	Specific gravity (G_s)
TP-1	TP-1 @1.5m	MTU	2.68
	TP-1 @3m		2.63
TP 2	TP-2 @1.5m	Elementary	2.71
	TP-2 @3m		2.69
TP 3	TP-3 @1.5m	Technic	2.68
	TP-3 @3m		2.65
TP 4	TP-4 @1.5m	To Guri	2.73
	TP-4 @3m		2.78
TP 5	TP-5 @1.5m	Youth Center	2.68
	TP-5 @3m		2.68
TP 6	TP-6 @1.5m	Spice Market	2.69
	TP-6 @3m		2.56
TP 7	TP-7 @1.5m	Mizan Ber	2.62
	TP-7 @3m		2.67
TP 8	TP-8 @1.5m	Stadium	2.69
	TP-8 @3m		2.61
TP 9	TP-9 @1.5m	EElpa Sub station	2.65
	TP-9 @3m		2.53
TP 10	TP-10 @1.5m	Secondary and Preparatory School	2.66
	TP-10@3m		2.64

4.2.3. Grain Size Analysis

According to ASTM D2217-85 and ASTMD7928-17 sieve analysis and hydrometer analysis was conducted respectively, for the detailed analysis seen in appendix-C, the summarized test result is listed here below in table 4.4 and figure 4.1. As shown in figure 4.1 percentage of passing to standard sieve opening was plotted, from table 4.4.

According to [9] classification of soil based on the grain size or particle size classified the soil as gravel soil particle size greater than 2.0mm, sand soil particle size ranges from 2.0mm to 0.075mm, silt soil particle size ranges from 0.075 to 0.002, clay soil particle size less than 0.002mm. Meanwhile according to the AASHTO classification system from sieve analysis particle size if soil particle pass no. 200 more than 35% is categorized under fine-grained soil, whereas USC classification system from sieve analysis particle size if soil particle pass no. 200 more than 50% is categorized under fine-grained soil, if not categorized under coarse-grained soils type [14].

From below table 4.4, it can be observed that the soil grain size percentage of finer pass No. 200 ranges from 63% to 95%, so that all the study area soil type categorized under fine-grained soil and poorly graded soil. Those soil types are unsuitable for most engineering construction [2].

Table 4. 4 Grain size analysis of Teppi town

Test Pit	Sample designation	Location	Percentage amount of particles size (%)				% Finer than 0.075mm
			Gravel	Sand	Silt	Clay	
TP 1	TP-1 @1.5m	MTU	0	9	34	57	91
	TP-1 @3m		0	10	34	56	90
TP 2	TP-2 @1.5m	Elementary	3	7	37	53	90
	TP-2 @3m		0	6	39	55	94
TP 3	TP-3 @1.5m	Technic	10	18	38	34	72
	TP-3@3m		11	20	38	30	68
TP 4	TP-4 @1.5m	To Guri	0	1	41	53	94
	TP-4 @3m		1	5	41	53	94
TP 5	TP-5 @1.5m	Youth Center	0	8	34	58	92
	TP-5 @3m		1	9	38	52	90
TP 6	TP-6 @1.5m	Spice Market	0	5	34	61	95
	TP-6 @3m		0	9	32	59	91
TP 7	TP-7 @1.5m	Mizan Ber	1	7	34	58	92
	TP-7 @3m		1	9	34	56	90
TP 8	TP-8 @1.5m	Stadium	1	11	32	56	88
	TP-8 @3m		1	7	29	63	92
TP 9	TP-9 @1.5m	EELPA Substation	0	5	40	55	95
	TP-9 @3m		0	5	42	53	95
TP 10	TP-10 @1.5m	SAP School	14	10	31	45	76
	TP-10@3m		13	14	32	31	63

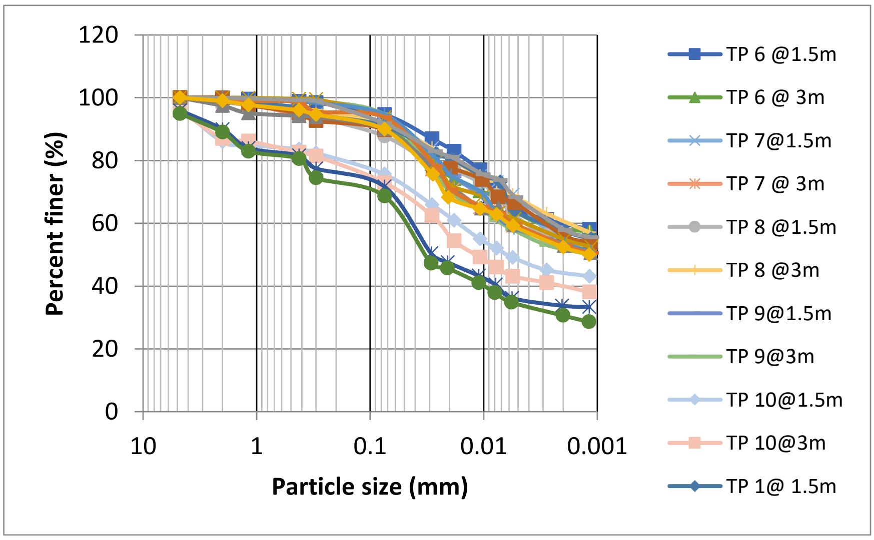

Figure 4. 1 Summary of companied grain size distribution curve of all test pits

4.2.4. Atterberg Limit

According to ASTM D4318-10, test results were conducted with Casagrande method, table 4-5 shows the test result here, while the detailed analysis presented with a number of blows versus water content chart plotted and detail calculation discussed on appendix -D

Table 4. 5 Atterberg limit test result of all test pits

Test Pit	Sample designation	Location	Liquid limit (LL %)	Plastic limit (PL %)	Plasticity index (PI)	Description (based on Casagrande) [6]
TP-1	TP-1 @1.5m	MTU	87	38	49	Highly plastic
	TP-1 @3m		82	37	45	Highly plastic
TP 2	TP-2 @1.5m	Elementary	86	34	52	Highly plastic
	TP-2 @3m		74	33	43	Highly plastic
TP 3	TP-3 @1.5m	Technic	62	34	28	Highly plastic
	TP-3@3m		55	32	23	Highly plastic
TP 4	TP-4 @1.5m	To Guri	101	39	62	Highly plastic
	TP-4 @3m		87	33	54	Highly plastic
TP 5	TP-5 @1.5m	Youth Center	84	33	51	Highly plastic
	TP-5 @3m		104	57	47	Highly plastic
TP 6	TP-6 @1.5m	Spice Market	79	29	50	Highly plastic
	TP-6 @3m		69	25	44	Highly plastic
TP 7	TP-7 @1.5m	Mizan Ber	104	40	64	Highly plastic
	TP-7 @3m		91	34	57	Highly plastic
TP 8	TP-8 @1.5m	Stadium	75	29	46	Highly plastic
	TP-8 @3m		80	30	50	Highly plastic
TP 9	TP-9 @1.5m	EELPA Substation	93	39	54	Highly plastic
	TP-9 @3m		89	36	53	Highly plastic
TP 10	TP-10 @1.5m	Secondary and Preparatory School	71	42	29	Highly plastic
	TP-10@3m		74	41	33	Highly plastic

From grain size analysis it was found almost all test pits are fine-grained soil with much present of clay, therefore testing atterberg limit was performed which help to identify basic properties of soil which are able to relate to another costly test type by correlation and empirical formula. From the test result observed above in table 4-5 and below table 4-6, of the study area shown, LL ranges from 55% to 104%, PL ranges from 25% to 57%, PI range from 23 to 64, LI ranges from 0.052 to 0.488 and CI ranges from 0.5 to 0.95. The Liquid limits test result of all test pits of the study area greater than 50% and PI value was shown greater than 17%, therefore according to Casagrande all test pits soil were categorized under highly plasticity, all test pits LI value ranges between 0 to 1 and CI value ranges from 1 to

0, which observed that the clay soil condition in the field in an undisturbed state its' consistence based on LI value, were range from very stiff state to very soft state [6].

Table 4. 6 Plasticity, liquidity, and consistency index result of all test pits

Test Pit	Sample designation	Location	Plasticity index (PI)	Liquidity index, LI	Consistency index, CI
TP-1	TP-1 @1.5m	MTU	49	0.156	0.84
	TP-1 @3m		45	0.212	0.79
TP 2	TP-2 @1.5m	Elementary	52	0.198	0.8
	TP-2 @3m		43	0.249	0.75
TP 3	TP-3 @1.5m	Technic	28	0.488	0.51
	TP-3@3m		23	0.502	0.5
TP 4	TP-4 @1.5m	To Guri	62	0.175	0.83
	TP-4 @3m		54	0.325	0.68
TP 5	TP-5 @1.5m	Youth Center	51	0.242	0.76
	TP-5 @3m		47	0.052	0.95
TP 6	TP-6 @1.5m	Spice Market	50	0.13	0.87
	TP-6 @3m		44	0.163	0.84
TP 7	TP-7 @1.5m	Mizan Ber	64	0.138	0.86
	TP-7 @3m		57	0.266	0.73
TP 8	TP-8 @1.5m	Stadium	46	0.172	0.83
	TP-8 @3m		50	0.185	0.82
TP 9	TP-9 @1.5m	EELPA Substation	54	0.111	0.89
	TP-9 @3m		53	0.257	0.74
TP 10	TP-10 @1.5m	Secondary and Preparatory School	29	0.087	0.91
	TP-10@3m		33	0.128	0.87

These soil types CH and MH will present risk of failure when to be used in construction. Such soils types will require stabilization or modification for possible use in engineering application [2].

Using fine grained soils in earth dam, highway, airfield, and small projects, there was recommended technic of compaction based on plastic index values, if PI >30 recommendable compacted layers not exceeding thickness of 150 mm, equipment type used during compaction was Sheepsfoot rollers with dimension of foot contact area, and pressure 30 to 80 cm^2 and 1700 to 3400 kN/m^2 respectively. Whereas, PI <30 recommendable compacted layers not exceeding thickness of 150 mm, equipment type used during compaction was Sheepsfoot rollers with dimension of foot contact area, and pressure 45 to 90 cm^2 and 1400 to 2800 kN/m^2 respectively [2].

4.2.4.1. Activity of Clay Soil

According to Skempton considers that the significant change in the volume of clay soil during shrinking or swelling is a function of the plasticity index and the number of colloidal particles present in the soil [6].

Table 4. 7 Activity of soil of all test pits

Test Pit	Sample designation	Location	Clay (%)	Plasticity index (PI)	Description (A.A.B. William,1957)
TP-1	TP-1 @1.5m	MTU	57	49	Very High
	TP-1 @3m		56	45	Very High
TP 2	TP-2 @1.5m	Elementary	53	52	Very High
	TP-2 @3m		55	43	Very High
TP 3	TP-3 @1.5m	Technic	34	28	High
	TP-3@3m		30	23	High
TP 4	TP-4 @1.5m	To Guri	53	62	Very High
	TP-4 @3m		53	54	Very High
TP 5	TP-5 @1.5m	Youth Center	58	51	Very High
	TP-5 @3m		52	47	Very High
TP 6	TP-6 @1.5m	Spice Market	61	50	Very High
	TP-6 @3m		59	44	Very High
TP 7	TP-7 @1.5m	Mizan Ber	58	64	Very High
	TP-7 @3m		56	57	Very High
TP 8	TP-8 @1.5m	Stadium	56	46	Very High
	TP-8 @3m		63	50	Very High
TP 9	TP-9 @1.5m	EELPA Substation	55	54	Very High
	TP-9 @3m		53	53	Very High
TP 10	TP-10 @1.5m	Secondary and Preparatory School	45	29	High
	TP-10@3m		31	33	Very High

From the test result observed above in table 4-7, the activity of soil based on A.A.B William,1957-58, plotting activity chart shown below in figure 4.2, test pit TP-3, and only TP-10 at 1.5m the high, and the rest test pits was found very high [3]. The activity of the study area falls near to activity 1.

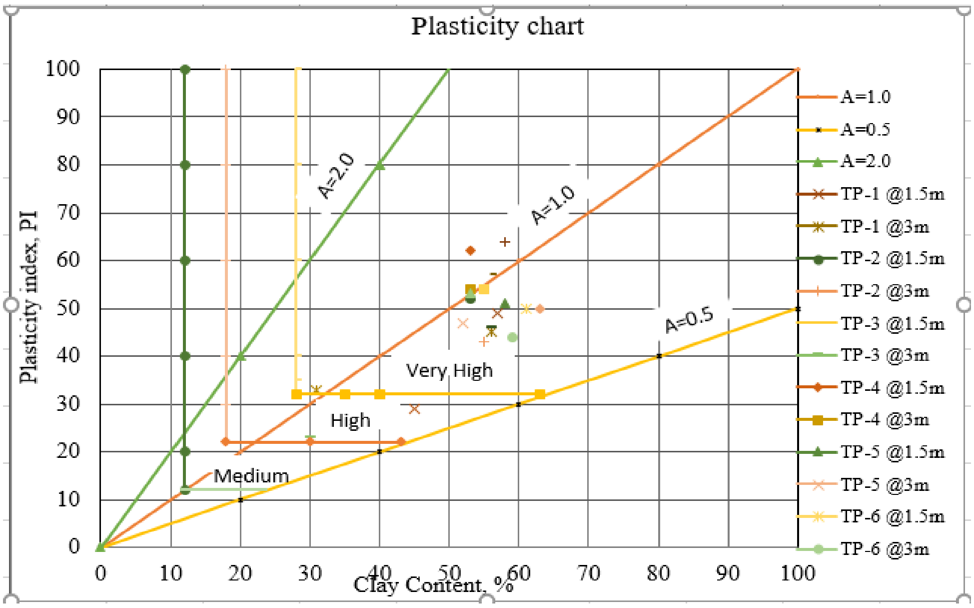

Figure 4. 2 Activity Chart (after A.A.B. William)

4.2.5. Free Swell

Table 4. 8 Free swell value of soil of all test pits

Test Pit	Sample location	Location	Plasticity index, %	Free swell index, %	Degree of expansiveness
TP-1	TP-1 @1.5m	MTU	49	80	Very high
	TP-1 @3m		45	75	Very high
TP 2	TP-2 @1.5m	Elementary	52	65	Very high
	TP-2 @3m		43	60	Very High
TP 3	TP-3 @1.5m	Technic	28	50	High
	TP-3@3m		23	40	High
TP 4	TP-4 @1.5m	To Guri	62	100	Very high
	TP-4 @3m		54	85	Very high
TP 5	TP-5 @1.5m	Youth Center	51	85	Very high
	TP-5 @3m		47	75	Very high
TP 6	TP-6 @1.5m	Spice Market	50	95	Very high
	TP-6 @3m		44	90	Very high
TP 7	TP-7 @1.5m	Mizan Ber	64	100	Very high
	TP-7 @3m		57	95	Very high
TP 8	TP-8 @1.5m	Stadium	46	80	Very high
	TP-8 @3m		50	100	Very high
TP 9	TP-9 @1.5m	EELPA Substation	54	85	Very high
	TP-9 @3m		53	75	Very high
TP 10	TP-10 @1.5m	Secondary and Preparatory School	29	50	High
	TP-10@3m		33	55	Very High

According to Holtz and Gibbs free swell was calculated from initial dry soil volume and final poured volume of soil [13].

From table 4.8 is shown the free swell from test result range 40% to 100%, the test pit TP-3, and TP-10 only at 1.5 m FS value is in between 35-50% so its degree of expansiveness is high, however, rest test pits their degree of expansiveness is very high which is greater than 50%.

4.2.6. Classification of Soils

There were many methods of classifying soil types based on grain size and atterberg limit for this study AASHTO and USCS classification system were adapted.

4.2.6.1. Unified Soil Classification System

Table 4. 9 Classification of Teppi town soils based on USCS

Test Pit	Sample designation	Location	(LL)	(PI)	(USCS)
TP-1	TP-1 @1.5m	MTU	87	49	CH
	TP-1 @3m		82	45	CH
TP 2	TP-2 @1.5m	Elementary	86	52	CH
	TP-2 @3m		74	43	CH
TP 3	TP-3 @1.5m	Technic	62	28	MH
	TP-3@3m		55	23	MH
TP 4	TP-4 @1.5m	To Guri	101	62	CH
	TP-4 @3m		87	54	CH
TP 5	TP-5 @1.5m	Youth Center	84	51	CH
	TP-5 @3m		104	47	CH
TP 6	TP-6 @1.5m	Spice Market	79	50	CH
	TP-6 @3m		69	44	CH
TP 7	TP-7 @1.5m	Mizan Ber	104	64	CH
	TP-7 @3m		91	57	CH
TP 8	TP-8 @1.5m	Stadium	75	46	CH
	TP-8 @3m		80	50	CH
TP 9	TP-9 @1.5m	EELPA Substation	93	54	CH
	TP-9 @3m		89	53	CH
TP 10	TP-10 @1.5m	SAP school	71	29	MH
	TP-10@3m		74	33	MH

The USC classification system based on texture and plasticity of soil. Also the system divide the soils into two major categories, coarse grained and fine grained, as separated by the No. 200 (0.075mm) sieve. In the USC system the No. 4 sieve is used to separate gravel from sand from the viewpoint of soil-separation size limit, sieve No. 4 is not acceptable upper limit for sand. Here the gravely and sandy soils are clearly separated. According to the USC system, fine-grained soils more than 50 percent of material pass sieve No. 200, moreover liquid limit greater than 50 belongs to a group of soil MH, CH, and OH Silts and clays soil [9].

After tabular data preparations, the below figure 4.3 plotted, from the figure shown here test pits TP-3 and TP-10 lied below A-line and percentage of pass greater than 63% of the soil mass pass through sieve No.200, therefore the type of soil found to be inorganic silt of high compressibility MH, and the rest test pits lied above A-line which was the soils characterized to inorganic clay of high plasticity CH soil type. Such soil types MH and CH will present risk of failure when to be used in construction. Such soils types will require stabilization or modification for possible use in engineering application [2].

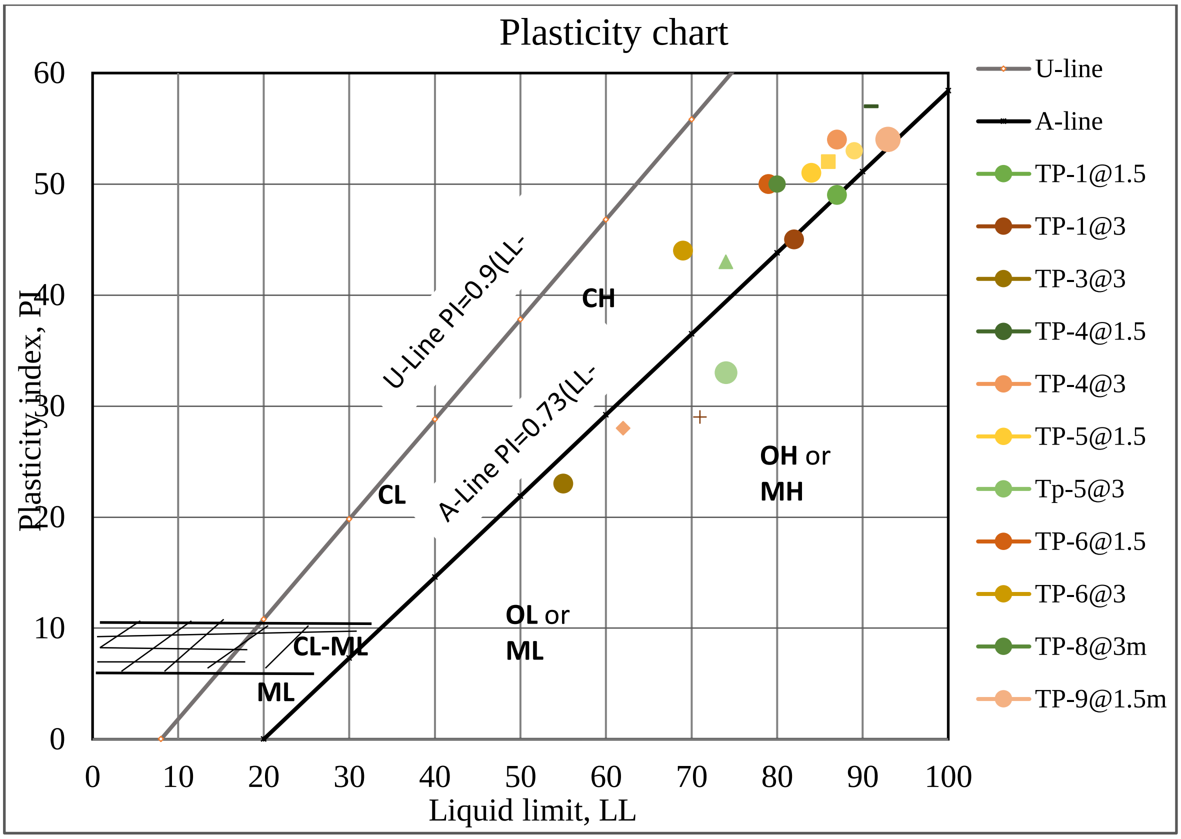

Figure 4. 3 Plasticity chart according to USCS classification

4.2.6.2. AASHTO Classification of Soil

The AASHTO classification system based on texture and plasticity of soil. Also the system divide the soils into two major categories, coarse grained and fine grained, as separated by the No. 200 (0.075mm) sieve. In the AASHTO system the No. 10 sieve is used to separate gravel from sand, but here the gravely and sandy soils are not clearly separated. Regarding separation between gravel and sand AASHTO system is more appropriate than USC system [2].

Table 4. 10 Classification of Teppi town soils based on AASHTO

Test Pit	Sample designation	Location	% finer pass 0.075mm	Liquid limit (LL)%	Plasticity index (PI)%	Group classification (AASHTO)
TP-1	TP-1 @1.5m	MTU	91	87	49	A-7-5
	TP-1 @3m		90	82	45	A-7-5
TP 2	TP-2 @1.5m	Elementary	90	86	52	A-7-5
	TP-2 @3m		94	74	43	A-7-5
TP 3	TP-3 @1.5m	Technic	72	62	28	A-7-5
	TP-3@3m		68	55	23	A-7-5
TP 4	TP-4 @1.5m	To Guri	94	101	62	A-7-5
	TP-4 @3m		94	87	54	A-7-5
TP 5	TP-5 @1.5m	Youth Center	92	84	51	A-7-5
	TP-5 @3m		90	104	47	A-7-5
TP 6	TP-6 @1.5m	Spice Market	95	79	50	A-7-6
	TP-6 @3m		91	69	44	A-7-6
TP 7	TP-7 @1.5m	Mizan Ber	92	104	64	A-7-5
	TP-7 @3m		90	91	57	A-7-5
TP 8	TP-8 @1.5m	Stadium	88	75	37	A-7-6
	TP-8 @3m		92	80	51	A-7-6
TP 9	TP-9 @1.5m	EELPA Substation	95	93	54	A-7-5
	TP-9 @3m		95	89	53	A-7-5
TP 10	TP-10 @1.5m	Secondary and Preparatory School	76	71	35	A-7-5
	TP-10@3m		63	74	36	A-7-5

According to ASTM D-3242 and AASHTO M-145 silty clay material more than 35% of the total sample passing sieve No. 200 categorized under A-4, A-5, A-6, and A-7, for separating the soil grouped under A-4, A-5, A-6 & A-7 there was criterial that was soils requirement under percentage passing no. 200 sieve is a minimum of 36%, LL value a minimum of 41, and PI value is a minimum of 11, therefore the soil grouped under A-7 with group family of A-7-5 and A-7-6 depending on plasticity index [26].

After tabular data preparation the below figure 4.4 plotted, from above table 4.10 it was observed that, the data ranges of LL value 55% to 104%, PI value ranges from 23% to 64%, percentage of passing sieve size no. 200 is greater than 63% and from those values calculated test pits TP-6, and TP-8 lied above PI=LL-30 line, therefore, those test pits categorized under A-7-6, whereas the rest test pits lied below PI=LL-30 line so that categorized under A-7-5 group of soil. Those soil type of the study area rating as subgrade range from fair to poor, to use such soil for subgrade material one should take CBR test and shall check AASHTO recommendation.

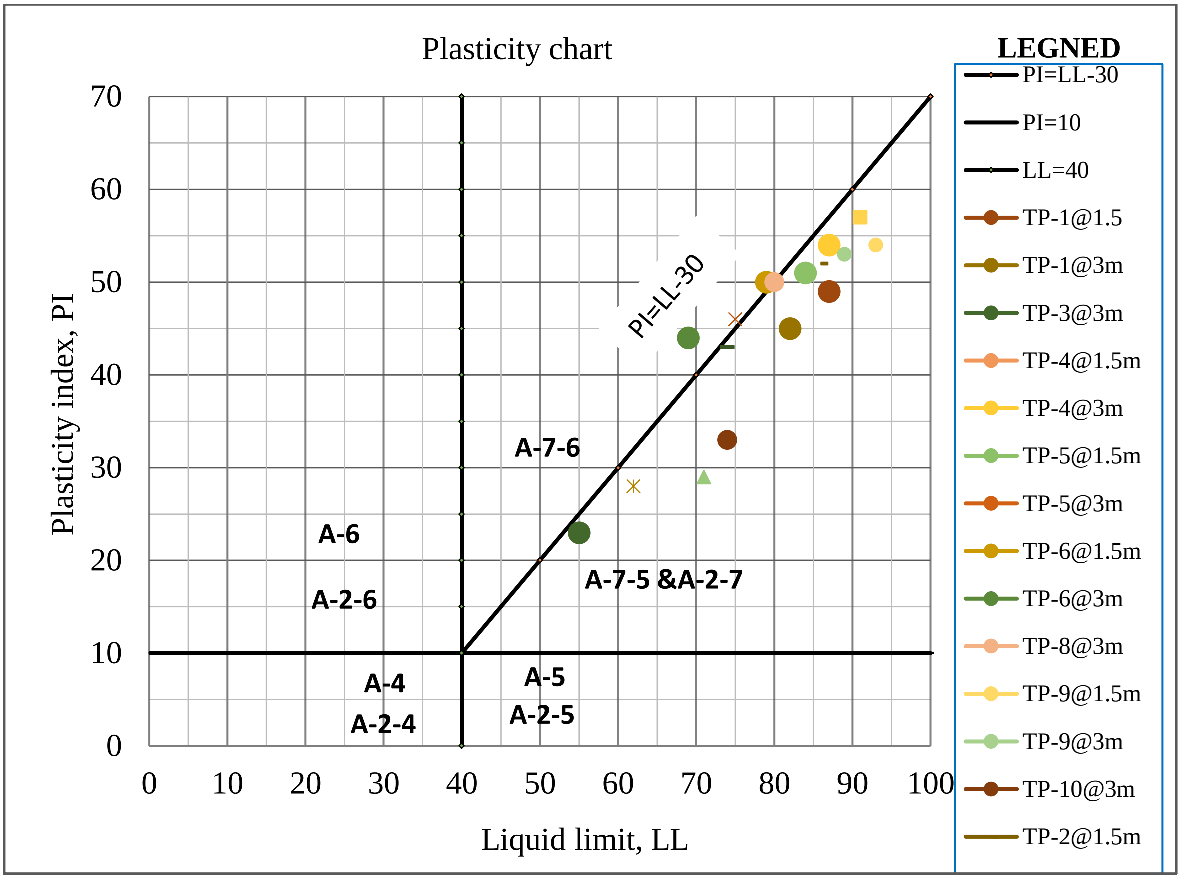

Figure 4. 4 Plasticity chart according to AASHTO classification

4.2.7. Unconfined Compression Strength Test

From previous soil property laboratory results and analysis, the soil was categorized under fine-grained soil, therefore to calculate the shear strength of soils from different triaxial compression test types according to recommendation on ASTM unconfined compression test was selected and with the procedure listed under ASTM D 2166, the tests were taken. The calculated result for investigated soil is presented below with its axial strain versus axial strain diagram followed by determining the undrained shear strength of the specimen from the plotted graph.

From below table 4.11 it can be observed that the soil found in TP-2 at 3.0 m and TP-8 at 3.0 m the unconfined compression strength was 144.21 kPa and 185.10 kPa, unconfined shear strength ranges from 72.11 kPa to 92.55 kPa respectively, from this the test pits were categorized under stiff soil based on their unconfined compressive strength values which determined the consistency, meanwhile test pits TP-6 at 3.0m, TP-8 at 1.5 m and TP-9 at 1.5 m was shown 262.13 kPa, 254.21 kPa and 202 kPa respectively those test pits were categorized under very stiff soil based on unconfined compressive strength values which determined the consistency. In the study area soil, natural moisture content was near to plastic limit, so that consistency index result from table 4.6 is near to 1, this shows the stiffness of the study area soils at in-situ condition this was related with unconfined compressive strength result of undisturbed sample. If the natural water content was near to liquid limit the soil become soft, this directly relate with low unconfined compressive strength result.

Undisturbed sample

Table 4. 11 Summary of unconfined shear strength of selected test pits

Test Pit	Sample designation	Location	Consistency	NMC	Unconfined compressive strength, q_u(kPa)	Unconfined shear strength, c_u(kPa)
TP 2	TP-2 @3.0m	Elementary	Stiff	41.72	144.21	72.11
TP 6	TP-6 @3.0m	Spice Market	Very stiff	32.18	262.13	131.1
TP 8	TP-8 @1.5m	Youth Center	Very stiff	40.91	254.21	122.61
	TP-8 @3m		Stiff	42.23	185.10	92.55
TP 9	TP-9 @1.5m	EELPA Substation	Very stiff	44.97	202	101

Remolded sample

After selection of test pits, remolded sample made at the same water content as that of undisturbed sample prepared and then comparisons for an undisturbed and remolded sample of shear strength were presented in table 4.11 and table 4.12.

From table 4. 12 it can be observed that the soil found in TP-6 at 3.0m, TP-8 at 3.0m, and TP-9 at 1.5 m the unconfined compression strength was 132 kPa, 103 kPa, and 104 kPa respectively. From the obtained data the remolded sample shear strength was less than that of the undisturbed sample, which is because remolding destroys the structure of soil and the particle orientation [6].

Table 4. 12 Summary of unconfined shear strength of remolded samples

Test Pit	Sample designation	Location	NMC	Unconfined compressive strength, q_u'(kPa)	Unconfined shear strength, c_u(kPa)
TP 6	TP-6 @3.0m	Spice Market	32.18	132	66
TP 8	TP-8 @3m	Youth Center	42.23	103	52
TP 9	TP-9 @1.5m	EELPA Substation	44.97	104	52

Sensitivity

Based on the test result sensitivity of clay was calculated, from tabular data of table 4.13, it was found that sensitivity of TP-6, TP-8, and TP-9 was 1.98, 1.78, and 1.94 from this the test pits were categorized under low sensitivity [6].

Table 4. 13 Summary of sensitive nature of the soil of selected test pits

Test Pit	Sample designation	Location	Unconfined compressive strength, q_u (kPa)	Unconfined compressive strength, q'_u (kPa)	Sensitivity ($s=q_u/q_u$')	Nature of clay
TP 6	TP-6 @3.0m	Spice Market	262.13	132	1.98	Low sensitive
TP 8	TP-8 @3m	Youth Center	185.1	103	1.78	Low sensitive
TP 9	TP-9 @1.5m	EELPA Substation	202	104	1.94	Low sensitive

4.2.8. Compaction Test

From grain size analysis it was observed that the soil particle retained on sieve No.4 (4.75 mm) was less than 20%, then standard proctor test was selected instead of modified proctor test [7]. According to ASTM D 698 standard proctor test procedure was followed for the compaction of soil for selected test pits and then the dry density versus water content figure was plotted to obtain maximum dry density and optimum moisture content. Compaction laboratory test results were summarized in table 4.14 below with those dry density and water content values figure 4.5 was plotted below.

Table 4. 14 Summary of the compaction test result of the soil of selected test pits

Test Pit	Sample designation	Location	Maximum dry unit weight (KN/m^3)	Optimum moisture content (%)
TP-1	TP-1@3.0m	MTU	12.99	21
TP-2	TP-2@1.5m	Elementary	14.41	30.98
TP-3	TP-3@1.5m	Technic	15.45	29.83
TP-8	TP-8@3.0m	Youth Center	13.38	32.06
TP-9	TP-9@1.5m	EELPA Substation	12.96	35.80
TP-10	TP-10@3.0m	Secondary and Preparatory School	15.07	19.50

From laboratory test results it was observed that, the maximum dry density ranges from 12.96 KN/m^3 to 15.45 KN/m^3 and optimum moisture content ranges from 19.50% to 35.80%.

From the test result observed maximum dry density affected by the grain size of a soil sample.

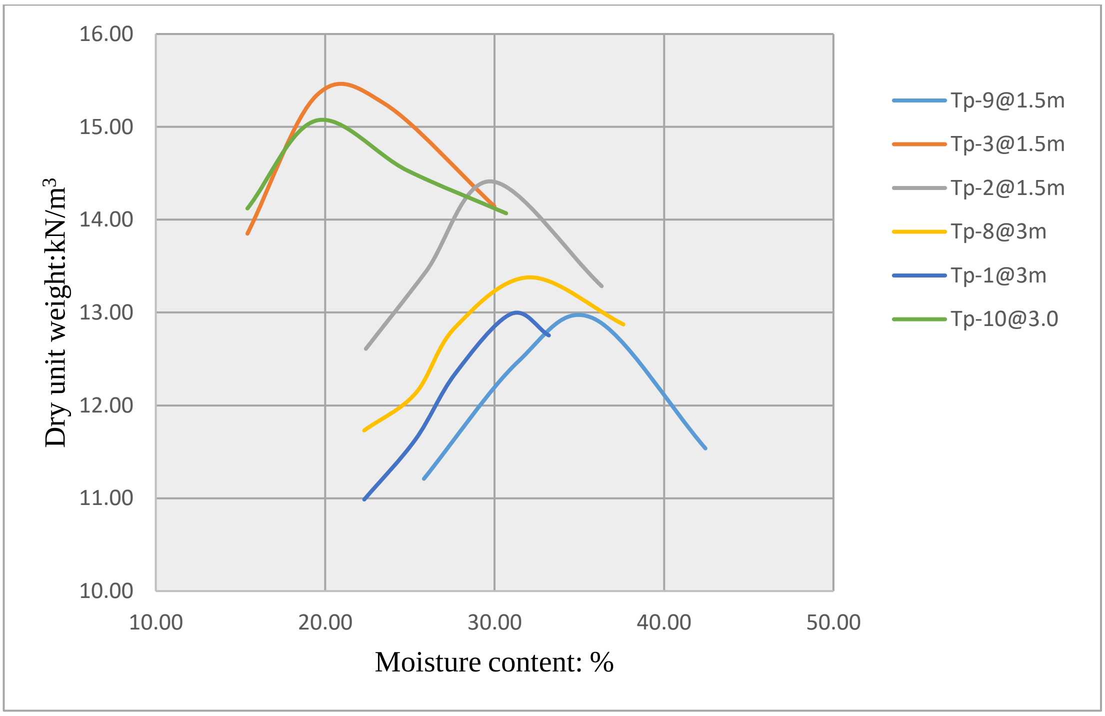

Figure 4. 5 Summary of compaction curve of selected test pits

From engineering property of Teppi town soil is described below

Table 4. 15 Laboratory test referring Engineering use chart (after Wagner, 1957)

Typical name of soil groups	Group symbols	permeability when compacted	shearing strength when compacted and saturated	Compressibility when compacted and saturated	workability as a construction material
Inorganic silts micaceous or diatomaceous fine sandy or silty soil, elastic silt	MH	Semi pervious to impervious	Fair to good	High	poor
Inorganic clays of high plasticity, flat clays	CH	Impervious	Poor	High	poor

Zero air void line and compaction curve

The saturation of soil is equal to a hundred percent (s=100) there is no air in the sample while compacting. Compaction is the densification of soil by removing air, from the figure 4.6 and figure 4.7 observed that the compaction method could not able to remove the air totally form the void of soils, therefore soil never become fully saturated. In addition under no circumstances should any part of the compaction curve lie to the right of the zero-air-void curve [2].

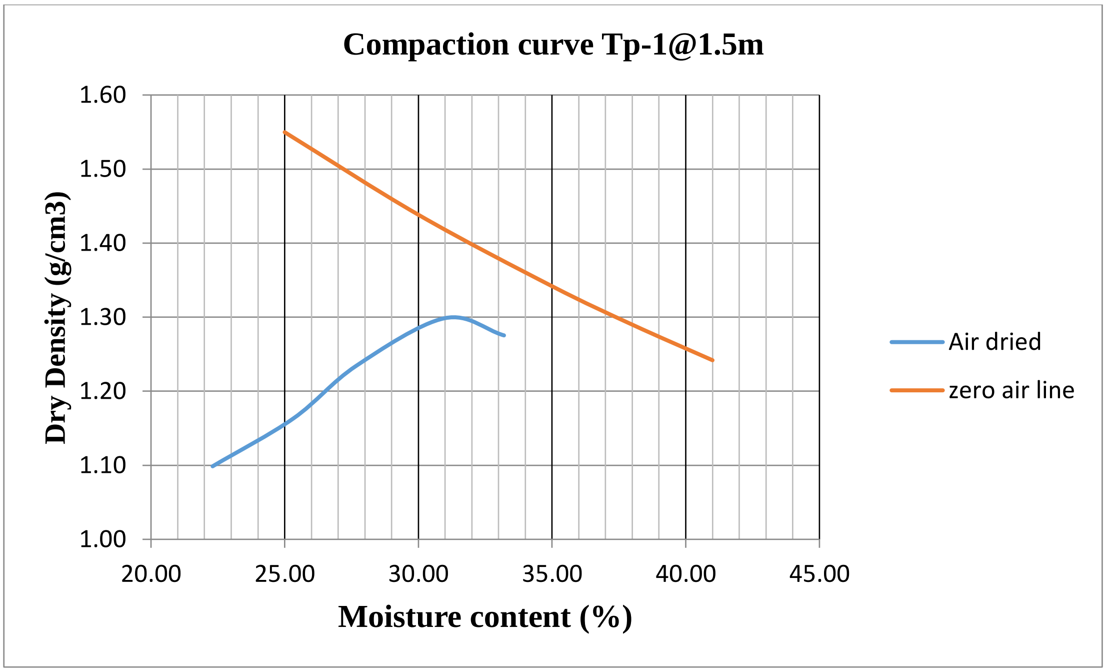

Figure 4. 6 Zero air void line and compaction curve of test pit TP-1 at 1.5m

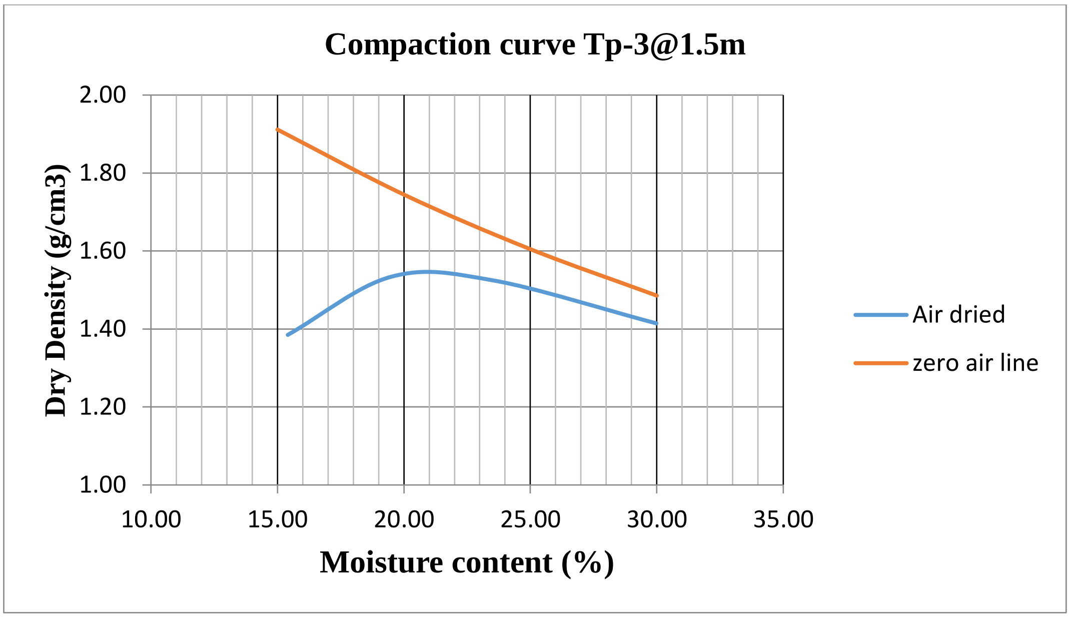

Figure 4. 7 Zero air void line and compaction curve of test pit TP-3 at 1.5m

4.2.9. Consolidation Test

The test was performed in accordance with ASTM D 2435, there are two types of testing methods: Controlled rate of strain (CRS) and controlled stress test (CTS). For this laboratory test, CTS was adapted and the test was conducted according to ASTM D 4186. The data from a consolidation test is presented on an e-log p curve, which plots void ratio (e) as a function of the log of pressure (p), from this data compression index, recompression index, pre-consolidation pressure, and initial void ratio calculated.

As shown below in table 4. 16, the test result of selected samples are the overconsolidated state which overconsolidation ratio was greater than 3. This shows the soil sample have experienced higher effective pressure in their past geological history and/or the soil might be pre-consolidated and cemented by chemical and shrinkage action [24].

The compression index and recompression index of the selected soil samples, which was computed from the void ratio and logarithm of effective pressure range from 0.28 to 0.40 and 0.04 to 0.075 respectively. Cc value which calculated from Nagari and Srinivasa Murtys' formula is relatively closer to the laboratory Cc result than Hough's Cc value.

Table 4. 16 Summary of consolidation test of TP-1@ 3.0m

Consolidation pressure (kPa)	Change in height of specimen,	Height of specimen (mm)	Equivalent height of voids,	Void ratio, e
0	0	20.000	9.463	0.898
10	0.030	19.970	9.433	0.895
50	0.172	19.828	9.291	0.882
100	0.384	19.616	9.079	0.862
200	0.849	19.151	8.614	0.817
400	1.562	18.438	7.901	0.750
600	2.483	17.517	6.980	0.662
800	3.556	16.444	5.907	0.561
1600	3.484	16.516	5.979	0.567
400	3.218	16.782	6.245	0.593
100	2.876	17.124	6.587	0.625
10	2.536	17.464	6.927	0.657

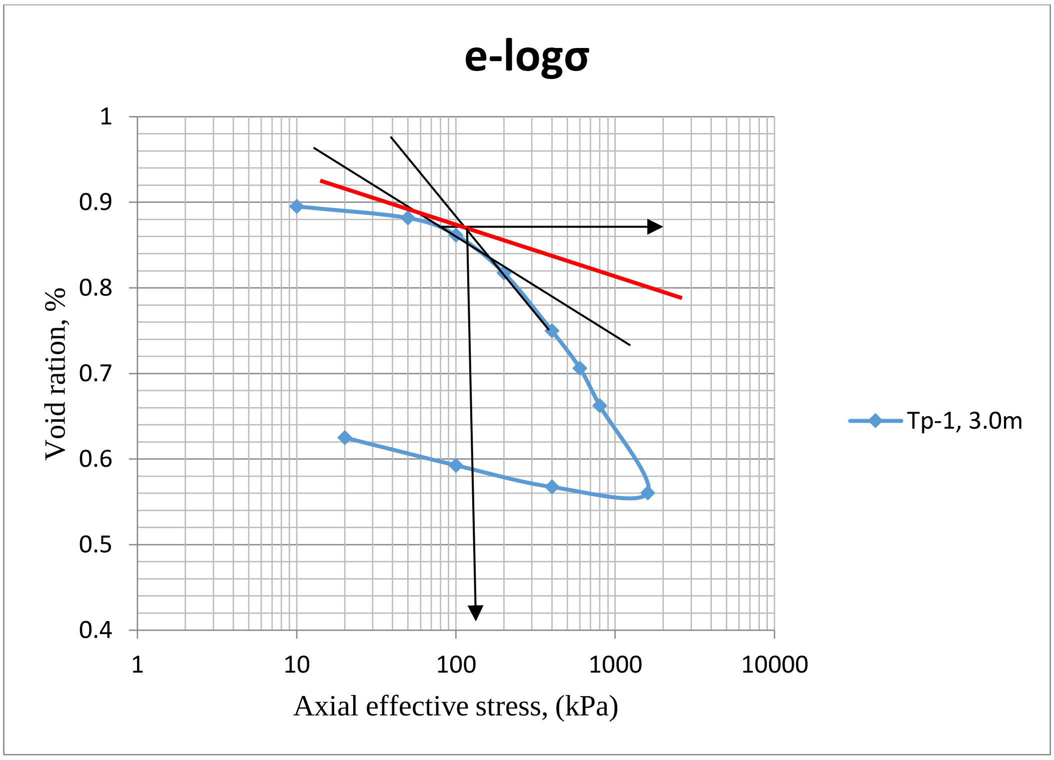

Figure 4. 8 Pre-consolidation pressure calculation TP-1 @3.0m

Table 4. 17 Summary of consolidation pressure result

Sample designation	Initial moisture content (%)	Bulk unit weight (kN/m^3)	Over burden pressure (kPa)	Pre-consolidation pressure, σ' kPa)	Cc lab result	Cc (Nagari and Srinivasa Murty)	Cc (Hough formula)	OCR
TP-1@3.0m	32.96	15.35	46.05	145	0.38	0.35	0.19	3.15
TP-2@3.0m	30.04	16.00	48.0	155	0.37	0.34	0.18	3.23
TP-6@3.0m	31.92	15.60	46.80	195	0.28	0.37	0.20	4.17
TP-8@3.0m	37.48	16.69	50.07	188	0.40	0.38	0.21	3.74

Summary of the results

Table 4. 18 Summary of test result of selected test pits

No	Sample Locations	WC (%)	q_u (kPa)	Su (kPa)	MDD (KN/m^3)	OMC (%)	σ' (kPa)	Cc
1	TP-1@3.0m				12.99	21	145	0.38
2	TP-2@1.5m				14.41	30.98		
3	TP-2 @3.0m	41.72	144.21	72.11			155	0.37
4	TP-3@1.5m				15.45	29.83		
5	TP-6 @3.0m	32.18	262.13	131.1			195	0.28
6	TP-8 @1.5m	40.91	254.21	122.61				
7	TP-8 @3.0m	42.23	185.10	92.55	13.38	32.06	188	0.40
8	TP-9 @1.5m	44.97	202	101	12.96	35.80		
9	TP-10@3.0m				15.07	19.50		

Table 4. 19 Summary result all test pits

No	Location	WC (%)	Gs	LL (%)	PL (%)	PI (%)	FSI (%)	Gravel	Sand	Silt	Clay	% finer No.200	USC	AASHTO
1	TP-1 @1.5m	52.65	2.68	87	38	49	80	0	9	34	57	91	CH	A-7-5
2	TP-1 @3m	46.54	2.63	82	37	45	75	0	10	34	56	90	CH	A-7-5
3	TP-2 @1.5m	49.28	2.71	86	34	52	65	3	7	37	53	90	CH	A-7-5
4	TP-2 @3m	41.72	2.69	74	33	43	60	0	6	39	55	94	CH	A-7-5
5	TP-3 @1.5m	45.67	2.68	62	34	28	50	10	18	38	34	72	MH	A-7-5
6	TP-3 @3m	48.54	2.65	55	32	23	40	11	20	38	30	68	MH	A-7-5
7	TP-4 @1.5m	49.82	2.73	101	39	62	100	0	1	41	53	94	CH	A-7-5
8	TP-4 @3m	50.55	2.78	87	33	54	85	1	5	41	53	94	CH	A-7-5
9	TP-5 @1.5m	45.33	2.68	84	33	51	85	0	8	34	58	92	CH	A-7-5
10	TP-5 @3m	59.45	2.68	104	57	47	75	1	9	38	52	90	CH	A-7-5
11	TP-6 @1.5m	35.51	2.69	79	29	50	95	0	5	34	61	95	CH	A-7-6
12	TP-6 @3m	32.18	2.56	69	25	44	90	0	9	32	59	91	CH	A-7-6
13	TP-7 @1.5m	48.82	2.62	104	40	64	100	1	7	34	58	92	CH	A-7-5
14	TP-7 @3m	49.16	2.67	91	34	57	95	1	9	34	56	90	CH	A-7-5
15	TP-8 @1.5m	40.91	2.69	75	29	46	80	1	11	32	56	88	CH	A-7-5
16	TP-8 @3m	42.23	2.61	80	30	50	100	1	7	29	63	92	CH	A-7-5
17	TP-9 @1.5m	44.97	2.65	93	39	54	85	0	5	40	55	95	MH	A-7-6
18	TP-9 @3m	49.62	2.53	89	36	53	75	0	5	42	53	95	MH	A-7-6
19	TP-10 @1.5m	43.51	2.66	71	42	29	50	14	10	31	45	76	CH	A-7-5
20	TP-10@3m	47.21	2.64	74	41	33	55	13	14	32	31	63	CH	A-7-5

4.3. Comparison of Test Result with Previous Works

4.3.1. Index Properties Comparison

Similar research titles were done in Ethiopia, therefore a comparison was made between previous study results with current research results.

Under this research work, different laboratory tests are conducted, such as moisture content, grain size, specific gravity, Atterberg limit, compaction, consolidation, and shear strength test.

4.3.2. Comparison of the laboratory test result with other researchers'

There are many researchers conducted soil investigations in worldwide. Here below in table 4.20 shown various researcher test results got from the investigation of soil properties from different locations of Ethiopia. Comparing different laboratory test result of current study with different previous studies in Ethiopia of clayey soil type has similar range and lies between standard values indicated by scholars.

Table 4. 20 Comparison of test result with another researcher

Sr. No.	Researcher Name	Current Study	Saol T. [27]	Solomon M. [19]	Jemal J. [15]
	Location	Tepi	Arba Minch Zuria	Debre Birhan	Jimma
	Soil type	Clay and Silty Clay	Clay and Silty Clay	Silt and Clay	Clay and Silty Clay
1	Specific gravity	2.53-2.78	2.68-2.73	2.62-2.80	2.58-2.72
2	Free swell (%)	40-100	-	35-100	80-160
3	Clay Content (%)	30-63	28.48- 41.16	13.83-67.50	40-59
4	Liquid limit (%)	55-104	55-64.23	32-80	72-108
5	Plastic index (%)	23-64	20.99-33.21	15-46	36-68
6	UCS q_u (kPa)	144.21-262.13	97.05-145.17	75-233	85-285.6
7	Moisture content (%) for selected pits	32.18-44.97	21.39-33.58	23.62-58.99	33-66
8	Consistency CI for selected pits	0.75-0.89	0.89-1.11	0.051-1.38	0.53 to 0.94
9	Cc	0.28-0.40	0.43-0.53	0.20-0.38	0.238-0.399
10	Classification	CH, & MH	CM, & MH group only taken	MH, & CH group only taken	CH, & MH

4.3.3. Discussion for Test Result Comparison

From table 4.18 comparison of specific gravity test result of all researcher lies Gs value of ordinary ranges in 2.5 to 2.8 [3].

From table 4.18 comparison of free swell according to [15], free swell the greater than 100% for black and light gray soil type, in the current study area black and light gray clay soils were not observed and only TP-3 at 3.0 m have FS value less than 50%. Free swell affected by the clay fraction content, percentage of clay minerals, cation exchange capacity, calcium carbonate content and plastic index [28].

From table 4.20, comparison of unconfined compression strength test result according to [15], [19], and [27] one test pits have 85, 75, and 97 kPa; and also comparison with natural moisture content values were 66%, 58.99%, and 31.14% respectively, which is much lesser than the rest soils sample, unconfined compression test affected by the consistency of soil which natural water content become near to liquid limit and much higher than liquid limit which was consistency become soft, with different water content and bond of soil particles will have different q_u value, the current study area selected soil samples their consistency of the soil were become stiff to very stiff and the natural water content much lesser than liquid limit.

From table 4.20 comparison of consolidation index of soils all researcher slightly varies each other. Different researcher develop equation to get Cc approximately when in the absence of consolidated test data. Nagaraj and Srinivasa Murty Cc result much closer than Hough's formula in the case of the current study area soil type, therefore, one can use Nagaraj and Srnivasa Murty formula to determine Cc value. Determining Cc result, the Skempton's formula used for normally consolidated soil and Terzagi and peck formula used for remolded soil sample. Because of the current study area soil were overconsolidated soil and undisturbed soil sample nether Skempton's nor Terzagi and Peck formula used for comparison purpose.

Compression index determination formula:

Nagaraj and Srinivasa Murty formula [29]

$$Cc = 0.39 * (eo) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

Hough's formula [30]

$$Cc = 0.3 * (eo - 0.27) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

Based on the test results the following conclusions may be drawn:

- From test result the natural moisture content and specific gravity showed that it vary from 32.18% to 59.45% and 2.53 to 2.78 respectively, based on the Gs test result, the study area soil type is categorized under inorganic soil.
- The maximum dry density and optimum moisture content test result indicated that it vary from 1.296 g/cm^3 to 1.545 g/cm^3 and 19.50% to 35.80% respectively.
- From the atterberg limit test liquid limit, and plastic limit, result shows that it ranges in between, 55% to 104%, and 25% to 57% respectively. The study area the PI value greater than 17 the soil that lies under high plasticity soil nature. Meanwhile the percentage finer pass sieve No.200 is greater than 63, therefore the soil type categorized under fined-grained soil.
- The study area of free swell shown from test result, the free swell test result range 40% to 100%, test pit TP-3 and TP-10 at 1.5 m FS value is in between 35-50% so its degree of expansiveness was high, however, rest test pits their degree of expansiveness is very high.
- The undrained shear strength for undisturbed and remolded samples of selected test pits varies from 72.11 kPa to 131 kPa and 52 kPa to 66 kPa respectively and the sensitivity of soil ranges from 1.78 to 1.98, which was categorized under low sensitivity.
- From the consolidation test, the compression index Cc, pre-consolidation pressure, and OCR ranges from 0.28 to 0.40, 140 kPa to 195 kPa, and greater than 3 respectively. Therefore, from test result shown conclude that the soil is under overconsolidated condition.

5.2. Recommendation

- For making the investigation sound and adequate in the study area there to be further investigation of soil parameters by conducting laboratory test which is different from selected test pits location with different depth from ground level.
- Other engineering properties of the soils shall be investigated in order to use for road work and to check their relationship.
- To conduct soil mapping of the study area more test pits shall be selected and laboratory test shall be conducted.
- Soil found below the depth greater than 3.0m from ground level shall be investigated for high rising building.

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APPENDICES

Appendix-A

Moisture Content

Existing moisture content

Natural Moisture Content for TP-1@1.5m

Trial No	1	2	3
Container No	12	1	48
Mass of container, g	17.60	15.50	15.00
Mass of container + Wet soil, g	191.35	172.00	189.48
Mass of container + Dry soil, g	131.00	101.14	129.32
Mass of water, g	60.35	70.86	60.16
Mass of dry soil, g	113.40	136.00	114.32
Water content, %	53.22	52.10	52.62
Ave. moisture content,% =	52.65		

Natural Moisture Content for TP-1@3.0m

Trial No	1	2	3
Container No	12	1	48
Mass of container, g	17.50	17.35	17.60
Mass of container + Wet soil, g	192.41	184.12	176.02
Mass of container + Dry soil, g	138.14	120.06	124.98
Mass of water, g	54.27	64.06	51.04
Mass of dry soil, g	120.64	136.00	107.38
Water content, %	44.99	47.10	47.53
Ave. moisture content,% =	46.54		

Natural Moisture Content for TP-2@1.5m

Trial No	1	2	3
Container No	12	1	48
Mass of container, g	17.65	18.21	17.85
Mass of container + Wet soil, g	185.20	195.10	185.18
Mass of container + Dry soil, g	131.20	127.23	129.13
Mass of water, g	54.00	67.87	56.05
Mass of dry soil, g	113.55	136.00	111.28
Water content, %	47.56	49.90	50.37
Ave. moisture content,% =	49.28		

Natural Moisture Content for TP-2@3.0m

Trial No	1	2	3
Container No	12	1	48
Mass of container, g	15.00	16.00	15.50
Mass of container + Wet soil, g	203.70	191.74	195.52
Mass of container + Dry soil, g	150.47	132.91	141.72
Mass of water, g	53.23	58.83	53.80
Mass of dry soil, g	135.47	136.00	126.22
Water content, %	39.29	43.26	42.62
Ave. moisture content,% =	41.72		

Natural Moisture Content for TP-3@1.5m

Trial No	1	2	3
Container No	E1	E2	E3
Mass of container, g	16.25	16.54	17.65
Mass of container + Wet soil, g	155.34	169.14	157.08
Mass of container + Dry soil, g	113.26	105.13	112.78
Mass of water, g	42.08	64.01	44.30
Mass of dry soil, g	97.01	136.00	95.13
Water content, %	43.38	47.07	46.57
Ave. moisture content,% =	45.67		

Natural Moisture Content for TP-3@3.0m

Trial No	1	2	3
Container No	AA	AB	AC
Mass of container, g	15.20	15.30	15.70
Mass of container + Wet soil, g	174.19	174.53	176.14
Mass of container + Dry soil, g	122.55	111.59	121.78
Mass of water, g	51.64	62.94	54.36
Mass of dry soil, g	107.35	136.00	106.08
Water content, %	48.10	46.28	51.24
Ave. moisture content,% =	48.54		

Natural Moisture Content for TP-4@1.5m

Trial No	1	2	3
Container No	A1	A2	A3
Mass of container, g	16.10	16.40	16.30
Mass of container + Wet soil, g	178.30	178.30	172.16
Mass of container + Dry soil, g	123.65	109.58	121.53
Mass of water, g	54.65	68.72	50.63
Mass of dry soil, g	107.55	136.00	105.23
Water content, %	50.81	50.53	48.11
Ave. moisture content,% =	49.82		

Natural Moisture Content for TP-4@3.0m

Trial No	1	2	3
Container No	11	13	16
Mass of container, g	16.00	15.00	15.00
Mass of container + Wet soil, g	194.13	197.28	184.93
Mass of container + Dry soil, g	135.98	125.89	127.76
Mass of water, g	58.15	71.39	57.17
Mass of dry soil, g	119.98	136.00	112.76
Water content, %	48.47	52.49	50.70
Ave. moisture content,% =	50.55		

Natural Moisture Content for TP-5@1.5m

Trial No	1	2	3
Container No	B1	B2	B3
Mass of container, g	16.20	15.70	15.90
Mass of container + Wet soil, g	148.51	164.95	146.19
Mass of container + Dry soil, g	109.18	104.28	103.29
Mass of water, g	39.33	60.67	42.90
Mass of dry soil, g	92.98	136.00	87.39
Water content, %	42.30	44.61	49.09
Ave. moisture content,% =	45.33		

Natural Moisture Content for TP-5@3.0m

Trial No	1	2	3
Container No	B1	B2	B3
Mass of container, g	16.30	15.45	15.74
Mass of container + Wet soil, g	173.42	196.99	196.75
Mass of container + Dry soil, g	113.41	116.02	131.01
Mass of water, g	60.01	80.97	65.74
Mass of dry soil, g	97.11	136.00	115.27
Water content, %	61.80	59.54	57.03
Ave. moisture content,% =	59.45		

Appendix-B

Specific gravity

TP-1@1.5m

Determination No.	No	1	2	3
Mass of empty pycnometer (g)	Wp	32.152	30.982	26.716
Mass of pycnometer + soil (g)	Wps	42.197	41.046	36.762
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	85.15	81.15	76.185
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	78.76	74.83	69.985
Mass of dry soil , ws (g)	Ws	10.045	10.064	10.046
Specific gravity	Gs	2.75	2.69	2.61
Average specific gravity of soil	Gs av	2.68		

TP-1@3.0m

Determination No.	No	2	5	6
Mass of empty pycnometer (g)	Wp	39.97	39.17	36.28
Mass of pycnometer + soil (g)	Wps	53.08	53.5	49.63
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	97.84	96.8	91.02
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	89.69	87.95	82.72
Mass of dry soil , ws (g)	Ws	13.11	14.33	13.35
Specific gravity	Gs	2.64	2.61	2.64
Average specific gravity of soil	Gs av	2.63		

TP-2@1.5m

Determination No.	No	7	8	9
Mass of empty pycnometer (g)	Wp	27.8	28.2	28.4
Mass of pycnometer + soil (g)	Wps	42.23	45	44.2
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	88.6	88.9	89.4
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	79.5	78.3	79.4
Mass of dry soil , ws (g)	Ws	14.43	16.8	15.8
Specific gravity	Gs	2.71	2.71	2.72
Average specific gravity of soil	Gs av	2.71		

TP-2@3.0m

Determination No.	No	A	B	C
Mass of empty pycnometer (g)	Wp	29	28.5	29.4
Mass of pycnometer + soil (g)	Wps	39.4	39.2	40.1
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	71.6	73.38	74.2
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	65.1	66.7	67.45
Mass of dry soil , ws (g)	Ws	10.4	10.7	10.7
Specific gravity	Gs	2.67	2.66	2.71
Average specific gravity of soil	Gs av	2.69		

TP-3@1.5m

Determination No.	No	A	B	C
Mass of empty pycnometer (g)	Wp	19	18.5	19.4
Mass of pycnometer + soil (g)	Wps	29.4	29.2	30.1
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	51.6	53.4	53.2
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	45.1	46.7	46.4
Mass of dry soil , ws (g)	Ws	10.4	10.7	10.7
Specific gravity	Gs	2.667	2.68	2.71
Average specific gravity of soil	Gs av	2.68		

TP-3@3.0m

Determination No.	No	C	D	E
Mass of empty pycnometer (g)	Wp	30.1	26.2	26
Mass of pycnometer + soil (g)	Wps	40.3	36.35	37.66
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	81.7	78.9	79.45
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	75.25	72.61	72.3
Mass of dry soil , ws (g)	Ws	10.2	10.15	11.66
Specific gravity	Gs	2.72	2.63	2.59
Average specific gravity of soil	Gs av	2.65		

TP-4@1.5m

Determination No.	No	F	G	H
Mass of empty pycnometer (g)	Wp	26	29.3	28.3
Mass of pycnometer + soil (g)	Wps	37.24	40.1	38.5
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	75.253	77.98	77.2
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	68.203	71.13	70.65
Mass of dry soil , ws (g)	Ws	11.24	10.8	10.2
Specific gravity	Gs	2.68	2.73	2.79
Average specific gravity of soil	Gs av	2.73		

TP-4@3.0m

Determination No.	No	I	J	K
Mass of empty pycnometer (g)	Wp	25.4	25.7	26.3
Mass of pycnometer + soil (g)	Wps	37.6	38.2	38.7
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	75.4	76.25	77.8
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	67.59	68.27	69.85
Mass of dry soil , ws (g)	Ws	12.2	12.5	12.4
Specific gravity	Gs	2.78	2.77	2.79
Average specific gravity of soil	Gs av	2.78		

TP-5@1.5m

Determination No.	No	L	M	N
Mass of empty pycnometer (g)	Wp	29	28.5	29.4
Mass of pycnometer + soil (g)	Wps	39.4	39.2	40.1
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	81.6	82.4	83.15
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	75.1	75.7	76.43
Mass of dry soil , ws (g)	Ws	10.4	10.7	10.7
Specific gravity	Gs	2.67	2.68	2.69
Average specific gravity of soil	Gs av	2.68		

Specific Gravity

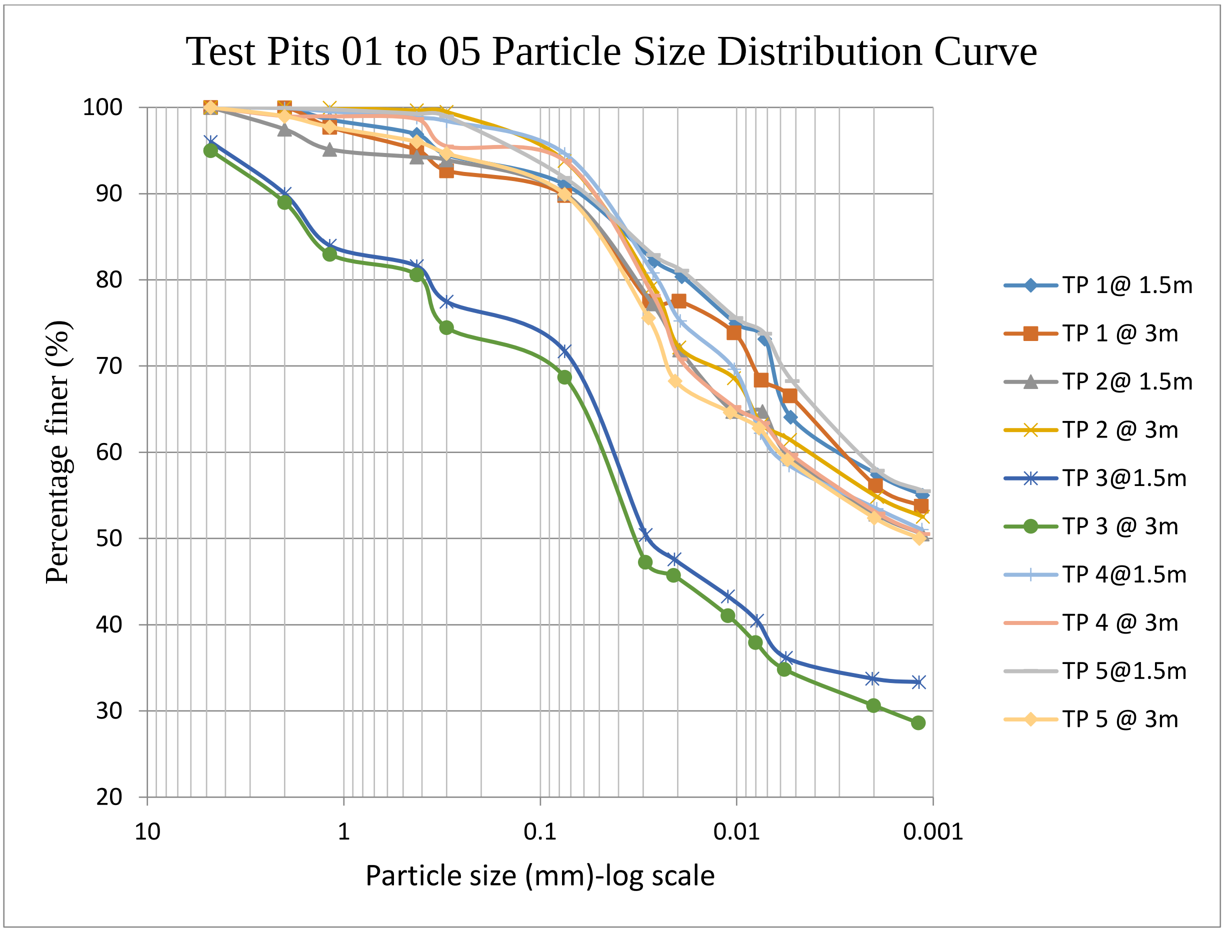
TP-5@3.0m

Determination No.	No	O	P	Q
Mass of empty pycnometer (g)	Wp	30.22	30.2	30.4
Mass of pycnometer + soil (g)	Wps	42.28	42.9	42.97
Mass of pycnometer + soil + water, Wpws (g)	Wpsw	83.71	84.14	84.3
Mass of pycnometer + water at Tx , Wpw(atTx) (g)	Wsw	76.03	76.29	76.38
Mass of dry soil , ws (g)	Ws	12.06	12.7	12.57
Specific gravity	Gs	2.75	2.62	2.7
Average specific gravity of soil	Gs av	2.69		

Appendix-C

Grain Size Analysis

Grain size distribution curve for TP-1 to TP-5



Wet Sieve analysis

TP 1@ 1.5 m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	0	0	0	100
2	0.378	0.0378	0.0378	99.9622
1.18	14.05	1.405	1.4428	98.595
0.425	31.096	3.1096	4.5524	96.8904
0.3	54.764	5.4764	10.0288	94.5236
0.075	89.304	8.9304	18.9592	91.0696

TP 1 @ 3m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	0	0	0	100
2	0.42	0.042	0.042	99.958
1.18	22.798	2.2798	2.3218	97.7202
0.425	49.264	4.9264	7.2482	95.0736
0.3	73.296	7.3296	14.5778	92.6704
0.075	101.92	10.192	24.7698	89.808

TP 2@ 1.5m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	0	0	0	100
2	25.32	2.532	2.532	97.468
1.18	48.65	4.865	7.397	95.135
0.425	57.56	5.756	13.153	94.244
0.3	60.828	6.0828	19.2358	93.9172
0.075	99.632	9.9632	29.199	90.0368

TP 2 @ 3m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	0	0	0	100
2	0.058	0.0058	0.0058	99.9942
1.18	0.288	0.0288	0.0346	99.9712
0.425	3.448	0.3448	0.3794	99.6552
0.3	5.032	0.5032	0.8826	99.4968
0.075	61.948	6.1948	7.0774	93.8052

TP 3@1.5m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	40	4	4	96
2	60.06	6.006	10.006	89.994
1.18	60.11	6.011	16.017	83.983
0.425	23.834	2.3834	18.4004	81.5996
0.3	41.18	4.118	22.5184	77.4816
0.075	57.6	5.76	28.2784	71.7216

TP 3 @ 3m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	50	5	5	95
2	60.058	6.0058	11.0058	88.9942
1.18	60.106	6.0106	17.0164	82.9836
0.425	23.834	2.3834	19.3998	80.6002
0.3	61.18	6.118	25.5178	74.4822
0.075	57.76	5.776	31.2938	68.7062

TP 4@1.5m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	0	0	0	100
2	0.858	0.0858	0.0858	99.9142
1.18	4.578	0.4578	0.5436	99.5422
0.425	11.778	1.1778	1.7214	98.8222
0.3	15.736	1.5736	3.295	98.4264
0.075	53.58	5.358	8.653	94.642

TP 4 @ 3m

Computation of Percentage finer

Total mass of soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain	Percentage of finer (%)
4.75	0	0	0	100
2	10.058	1.0058	1.0058	98.9942
1.18	10.288	1.0288	2.0346	98.9712
0.425	13.448	1.3448	3.3794	98.6552
0.3	45.032	4.5032	7.8826	95.4968
0.075	61.948	6.1948	14.0774	93.8052

TP 5@1.5m

Computation of Percentage finer

Total mass of Soil 1000 gram

Sieve (mm)	Mass of Retain (g)	Percentage of retain (%)	Com. Percentage of retain (%)	Percentage of finer (%)
4.75	0	0	0	100
2	0.452	0.0452	0.0452	99.9548
1.18	2.228	0.2228	0.268	99.7772
0.425	7.216	0.7216	0.9896	99.2784
0.3	10.198	1.0198	2.0094	98.9802
0.075	81.612	8.1612	10.1706	91.8388

Hydrometer Analysis

TP-1 @ 1.5m

% finer Sieve No.200	91.0696%
G_s	2.68
Cm	1
Co/Cd	6
Ms/Ws	50gr

Elapsed Time	Temp ºC	Actual Reading (Ra)	Corrected reading for meniscus ®	Effective depth L	K	D=K*(√(L/t))	CT	Corr. for unit weight (a)	Corr. Hydro Reading Rc	% Finer	Adjusted % finer
0	22	55	54	7.4	0.0132						
1	22	52	51	7.9	0.0132	0.037101	0.4	0.994	46.4	92.243	84.005
2	22	51	50	8.1	0.0132	0.026564	0.4	0.994	45.4	90.255	82.195
4	22	50	49	8.3	0.0132	0.019014	0.4	0.994	44.4	88.267	80.384
8	22	47	46	8.8	0.0132	0.013844	0.4	0.994	41.4	82.303	74.953
15	22	47	46	8.8	0.0132	0.01011	0.4	0.994	41.4	82.303	74.953
30	22	46	45	8.9	0.0132	0.00719	0.4	0.994	40.4	80.315	73.143
60	22	41	40	9.7	0.0132	0.005307	0.4	0.994	35.4	70.375	64.09
120	22	41	40	9.7	0.0132	0.003753	0.4	0.994	35.4	70.375	64.09
240	23	38	37	10.2	0.01305	0.00269	0.7	0.994	32.7	65.008	59.203
480	23	37	36	10.4	0.01305	0.001921	0.7	0.994	31.7	63.02	57.392
1440	22	36	35	10.6	0.0132	0.001133	0.4	0.994	30.4	60.435	55.038

TP-1 @ 3.0m

% finer Sieve No.200	90%
G_s	2.6
Cm	1
Co	6
Ms/Ws	50g

Hydrometer Analysis

Elapsed Time	Temp ºC	Actual Reading (Ra)	Corr. reading for meniscus ®	Effective depth L	K	D= K*(√(L/t))	CT	Corr. for unit weight (a)	Corr. Hydro Reading Rc	% Finer	Adjusted % finer
0	22	50	49	8.3	0.0134						
1	22	48	47	8.6	0.0134	0.03931	0.4	1.004	42.4	85.14	76.462
2	22	48	47	8.6	0.0134	0.0278	0.4	1.004	42.4	85.14	76.462
4	22	48	47	8.6	0.0134	0.01965	0.4	1.004	42.4	85.14	76.462
8	22	46	45	8.9	0.0134	0.01414	0.4	1.004	40.4	81.12	72.855
15	22	46	45	8.9	0.0134	0.01032	0.4	1.004	40.4	81.12	72.855
30	22	43	42	9.4	0.0134	0.0075	0.4	1.004	37.4	75.1	67.445
60	22	42	41	9.6	0.0134	0.00536	0.4	1.004	36.4	73.09	65.642
120	22	41	40	9.7	0.0134	0.00381	0.4	1.004	35.4	71.08	63.838
240	23	37	36	10.4	0.01325	0.00276	0.7	1.004	31.7	63.65	57.166
480	23	36	35	10.6	0.01325	0.00197	0.7	1.004	30.7	61.65	55.363
1440	22	35	34	10.7	0.0134	0.00116	0.4	1.004	29.4	59.04	53.018

TP-3 at 1.5m

% finer Seive No.200	71.66%
G_s	2.68
Cm	1
Co/Cd	6
Ms/Ws	50g

Hydrometer Analysis

Elapsed Time	Temp °C	Actual Reading (Ra)	Corr. reading for meniscus ®	Effective depth L	K	D= K*(√(L/t))	CT	Corr. for unit weight (a)	Corr. Hydro Reading Rc	% Finer	Adjusted % finer
0	22	50	49	8.3	0.0132						
1	22	44	43	9.2	0.0132	0.040038	0.4	0.994	38.4	76.339	54.705
2	22	41	40	9.7	0.0132	0.02907	0.4	0.994	35.4	70.375	50.431
4	22	39	38	9.9	0.0132	0.020766	0.4	0.994	33.4	66.399	47.582
8	22	38	37	10.2	0.0132	0.014905	0.4	0.994	32.4	64.411	46.157
15	22	36	35	10.6	0.0132	0.011096	0.4	0.994	30.4	60.435	43.308
30	22	34	33	10.9	0.0132	0.007957	0.4	0.994	28.4	56.459	40.459
60	22	31	30	11.4	0.0132	0.005754	0.4	0.994	25.4	50.495	36.185
120	22	31	30	11.4	0.0132	0.004069	0.4	0.994	25.4	50.495	36.185
240	23	31	30	11.4	0.013262	0.00289	0.7	0.994	25.7	51.092	36.613
480	23	29	28	11.7	0.013262	0.002071	0.7	0.994	23.7	47.116	33.763
1440	22	29	27	11.9	0.0132	0.0012	0.4	0.994	23.4	46.519	33.336
2880	22	29	27	11.9	0.0132	0.000848	0.4	0.994	23.4	46.519	33.336

TP-3 at 3.0m

% finer Sieve No.200	75.65%
G_s	2.65
Cm	1
Co	6
Ms/Ws	50g

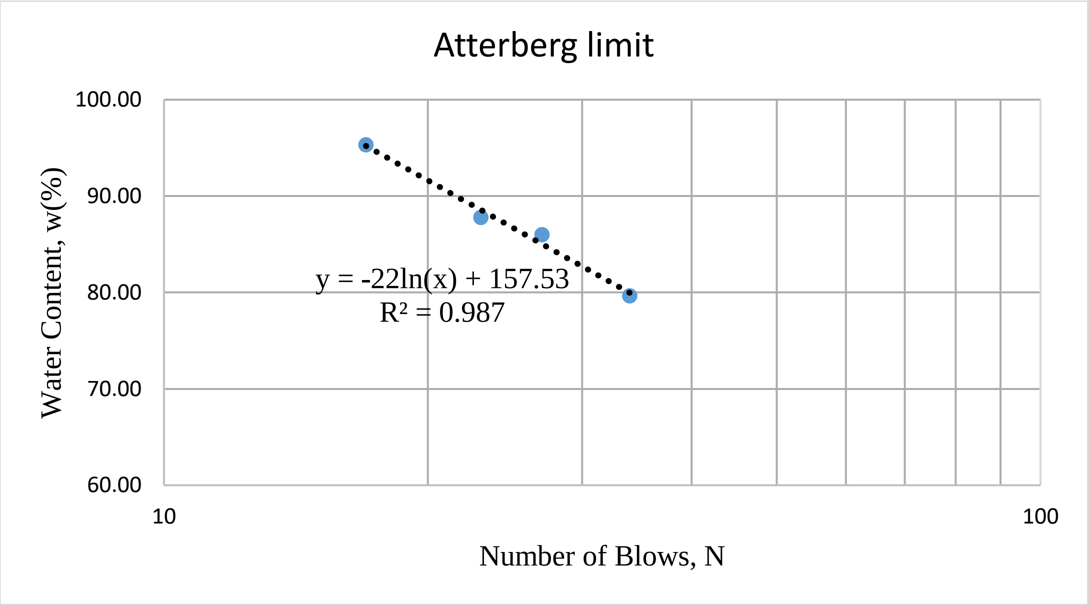
Hydrometer Analysis

Ela psed Time	Temp ºC	Actual Reading (Ra)	Corr. reading for meni scus ®	Effec tive depth L	K	D= K*(√(L/t))	CT	Corr. for unit weight (a)	Corr. Hydro Read ing Rc	% Finer	Adju sted % finer
0	22	45	44	9.1	0.01332						
1	22	43	42	9.4	0.01332	0.040838	0.4	1.028	37.4	76.894	58.17
2	22	36	35	10.4	0.01332	0.030374	0.4	1.028	30.4	62.502	47.283
4	22	35	34	10.7	0.01332	0.021785	0.4	1.028	29.4	60.446	45.727
8	22	34	33	10.9	0.01332	0.015548	0.4	1.028	28.4	58.39	44.172
15	22	32	31	11.2	0.01332	0.01151	0.4	1.028	26.4	54.278	41.061
30	22	30	29	11.5	0.01332	0.008247	0.4	1.028	24.4	50.166	37.951
60	22	28	27	11.9	0.01332	0.005932	0.4	1.028	22.4	46.054	34.84
120	22	28	27	11.9	0.01332	0.004195	0.4	1.028	22.4	46.054	34.84
240	23	26	25	12.2	0.01317	0.002969	0.7	1.028	20.7	42.559	32.196
480	23	25	24	12.4	0.01317	0.002117	0.7	1.028	19.7	40.503	30.641
1440	22	24	23	12.5	0.01332	0.001241	0.4	1.028	18.4	37.83	28.618

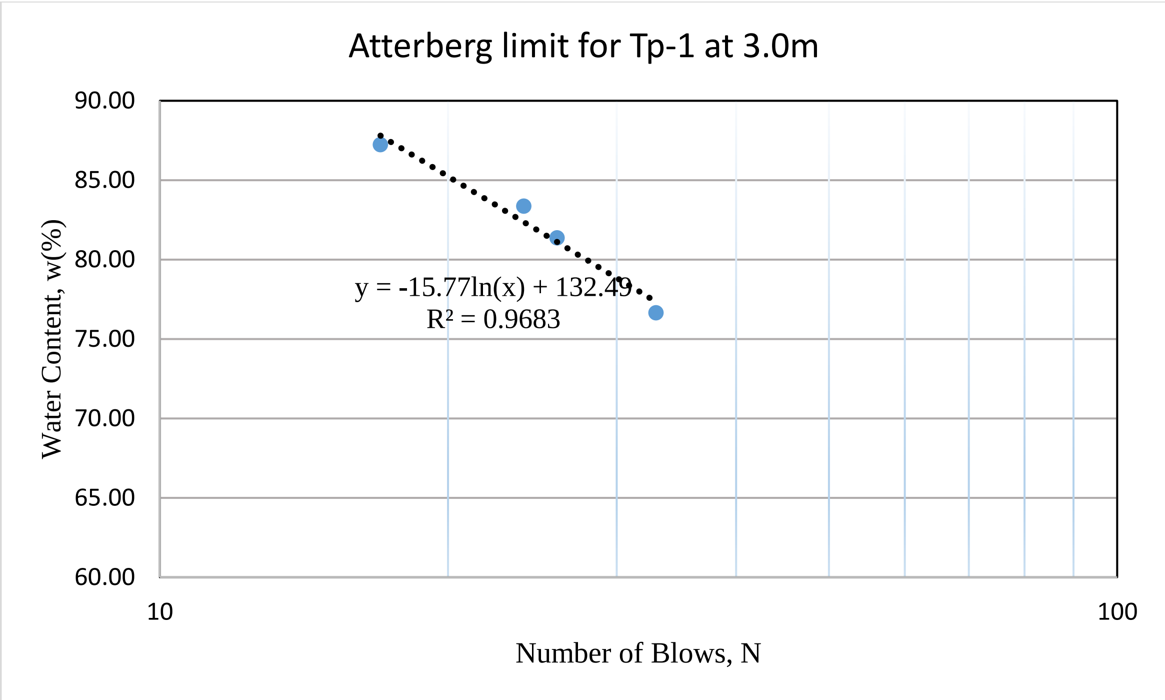
Appendix-D

Atterberg Limit

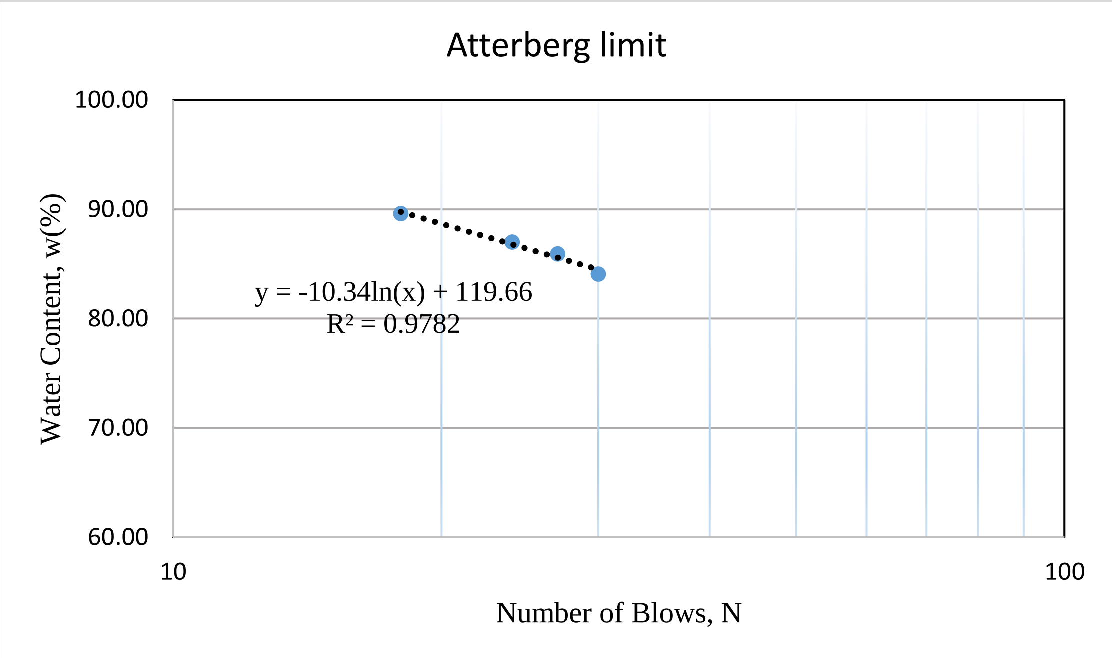
TP 1@ 1.5m	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	A26	A36	C31	C32	C34	71
Mass of container, g	21.61	20.94	20.52	18.99	20.64	22.10
Mass of container + Wet soil, g	38.55	37.14	38.21	33.56	27.41	28.73
Mass of container + Dry soil, g	31.04	29.65	29.94	26.45	25.53	26.90
Mass of water, g	7.51	7.49	8.27	7.11	1.88	1.83
Mass of dry soil, g	9.43	8.71	9.42	7.46	4.89	4.80
Water content, %	79.64	85.99	87.79	95.31	38.45	38.13
No of blows	34	27	23	17	38	
LL	87					



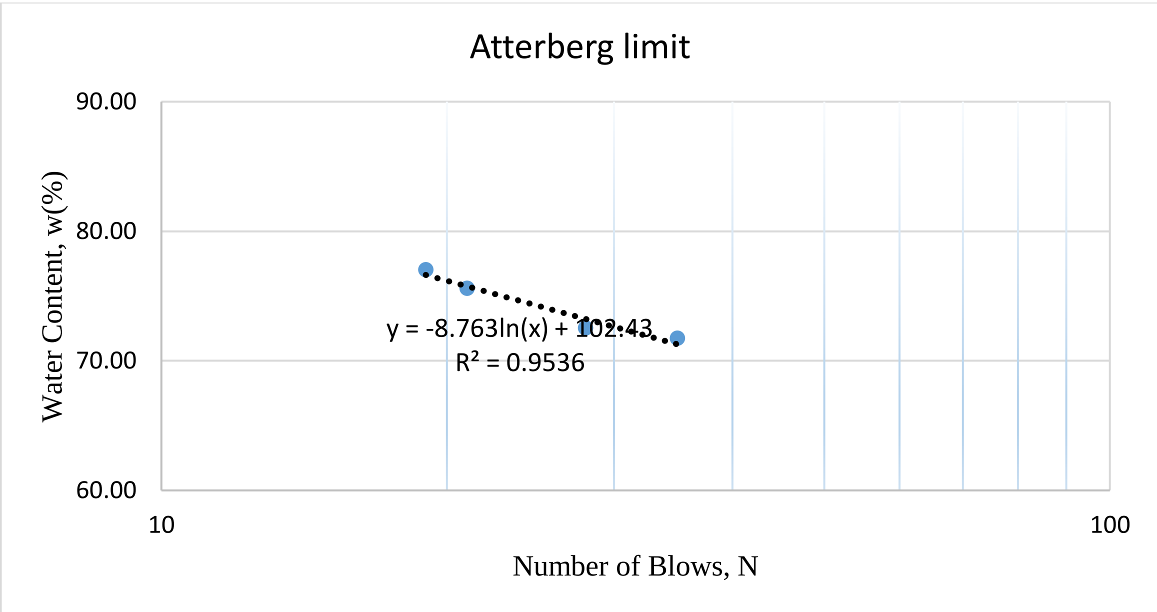
TP 1@ 3m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			A11	A12	A13	A14	B1	B2
Mass of container, g			18.94	18.32	20.86	20.66	19.95	21.01
Mass of container + Wet soil, g			34.38	33.41	35.18	35.62	28.62	29.37
Mass of container + Dry soil, g			27.68	26.64	28.67	28.65	26.30	27.09
Mass of water, g			6.70	6.77	6.51	6.97	2.32	2.28
Mass of dry soil, g			8.74	8.32	7.81	7.99	6.35	6.08
Water content, %			76.66	81.37	83.35	87.23	36.54	37.50
No of blows			33	26	24	17	37	
LL			82					



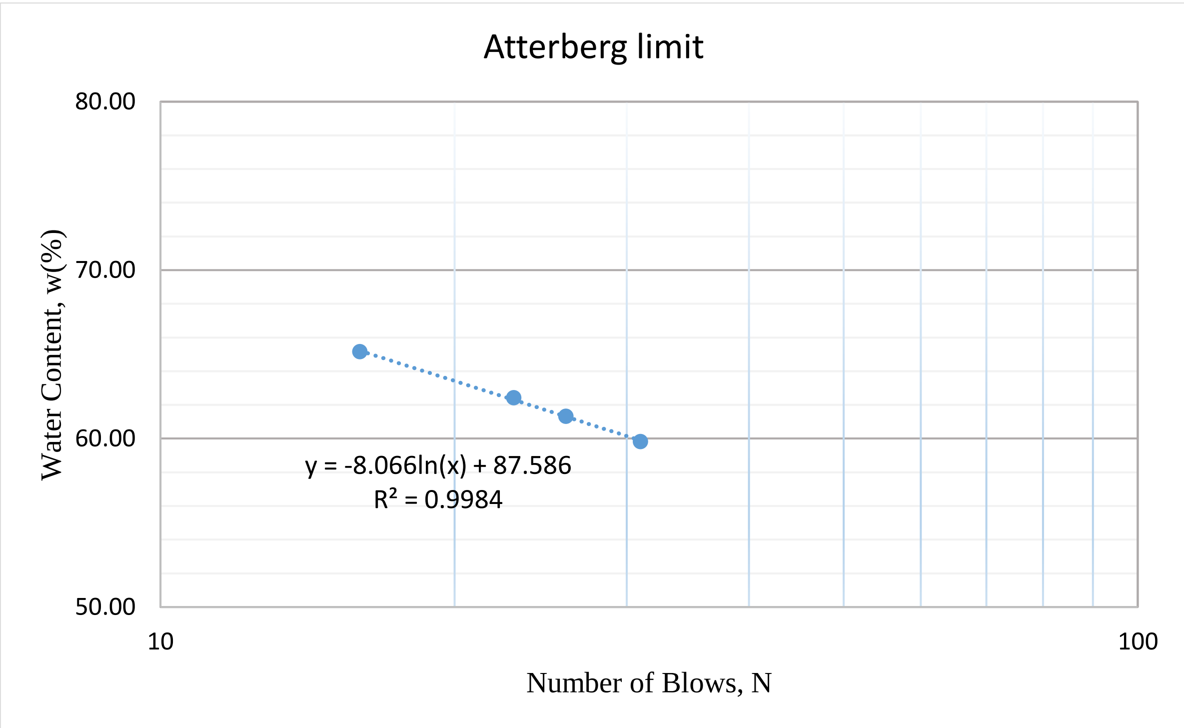
TP 2@ 1.5m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			T	B	D	E	CA	DB
Mass of container, g			23.66	24.98	26.15	21.09	19.88	19.97
Mass of container + Wet soil, g			34.19	35.28	36.08	32.58	29.30	29.37
Mass of container + Dry soil, g			29.38	30.52	31.46	27.15	26.92	26.95
Mass of water, g			4.81	4.76	4.62	5.43	2.38	2.42
Mass of dry soil, g			5.72	5.54	5.31	6.06	7.04	6.98
Water content, %			84.09	85.92	87.01	89.60	33.81	34.67
No of blows			30	27	24	18	34	
LL			86					



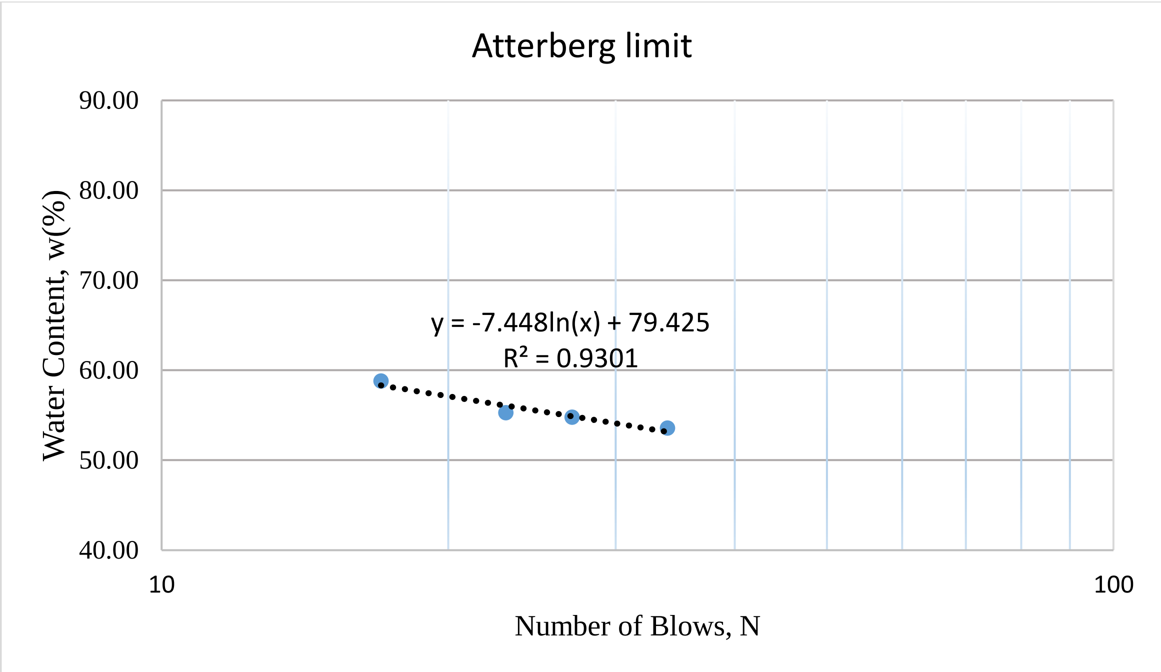
TP 2@ 3m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			C1	D	F4	E5	AA	AC
Mass of container, g			17.20	16.75	17.20	16.35	18.32	17.73
Mass of container + Wet soil, g			33.67	34.28	34.11	34.60	28.05	29.12
Mass of container + Dry soil, g			26.79	26.91	26.83	26.66	25.68	26.53
Mass of water, g			6.88	7.37	7.28	7.94	2.37	2.59
Mass of dry soil, g			9.59	10.16	9.63	10.31	7.36	8.80
Water content, %			71.74	72.54	75.60	77.01	32.20	29.43
No of blows			35	28	21	19	31	
LL			74					



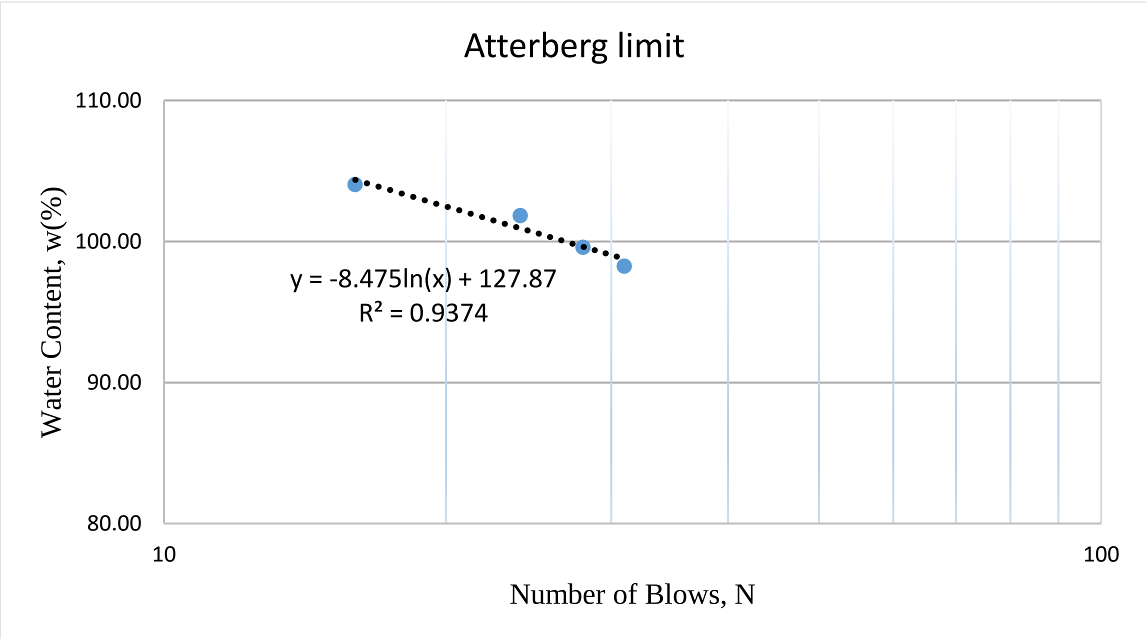
TP 3@ 1.5m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			B1	B2	B3	B4	C1	C2
Mass of container, g			16.94	17.69	17.81	12.45	19.12	17.84
Mass of container + Wet soil, g			32.41	32.45	32.85	32.60	25.96	25.32
Mass of container + Dry soil, g			26.62	26.84	27.07	24.65	24.23	23.40
Mass of water, g			5.79	5.61	5.78	7.95	1.73	1.92
Mass of dry soil, g			9.68	9.15	9.26	12.20	5.11	5.56
Water content, %			59.81	61.31	62.42	65.16	33.86	34.53
No of blows			31	26	23	16	34	
LL			62					



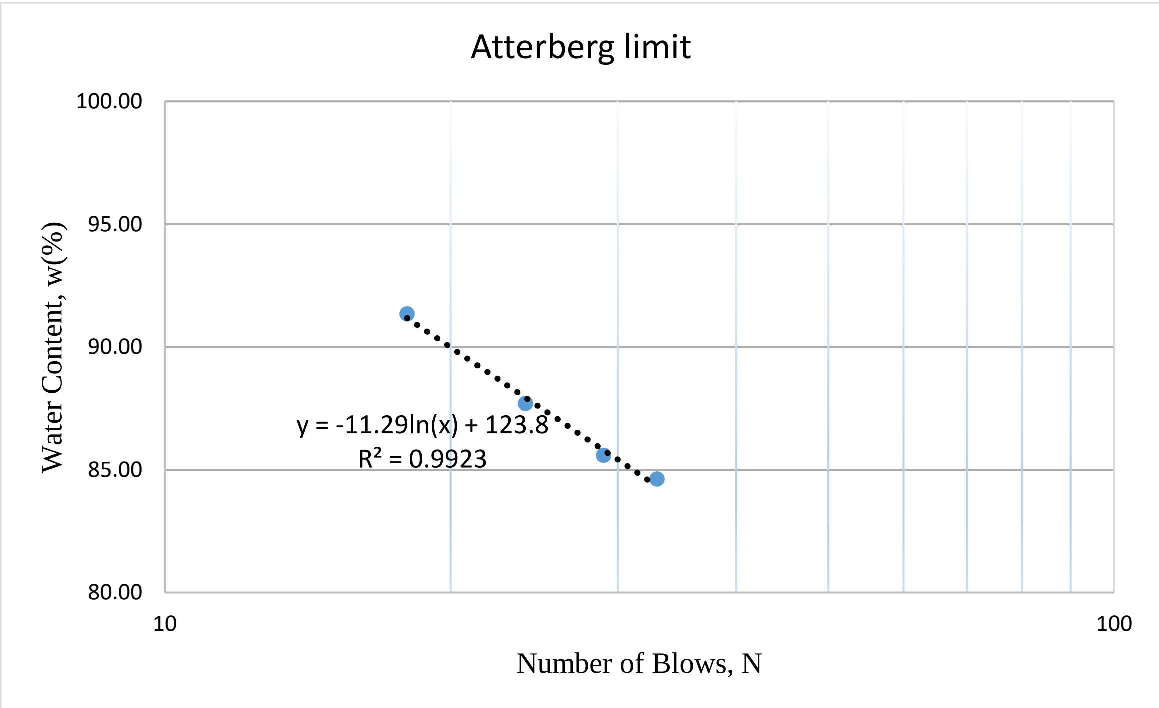
TP 3@ 3m				Liquid Limit				Plastic Limit	
Trial No				1	2	3	4	1	2
Container No				CD	CC	CB	BC	A11	A22
Mass of container, g				14.88	16.31	15.81	16.22	16.77	16.84
Mass of container + Wet soil, g				33.17	33.09	32.92	33.26	25.42	25.22
Mass of container + Dry soil, g				26.79	27.15	26.83	26.95	23.31	23.22
Mass of water, g				6.38	5.94	6.09	6.31	2.11	2.0
Mass of dry soil, g				11.91	10.84	11.02	10.73	6.54	6.38
Water content, %				53.57	54.80	55.26	58.81	32.26	31.35
No of blows				34	27	23	17	32	
LL				55					



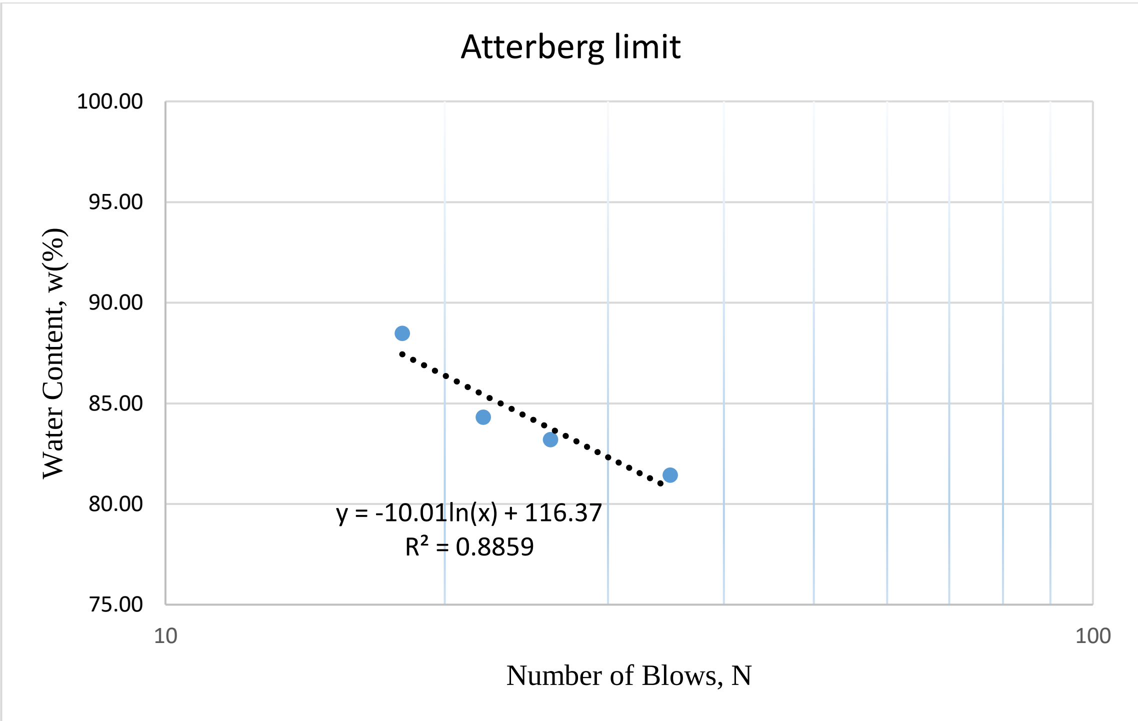
TP 4@ 1.5m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			XX	XY	XZ	XW	X1	X2
Mass of container, g			15.46	15.16	15.38	17.21	14.07	14.78
Mass of container + Wet soil, g			34.59	34.66	34.05	34.45	24.48	24.45
Mass of container + Dry soil, g			25.11	24.93	24.63	25.66	21.55	21.77
Mass of water, g			9.48	9.73	9.42	8.79	2.93	2.68
Mass of dry soil, g			9.65	9.77	9.25	8.45	7.48	6.99
Water content, %			98.24	99.59	101.84	104.02	39.17	38.34
No of blows			31	28	24	16	39	
LL			101					



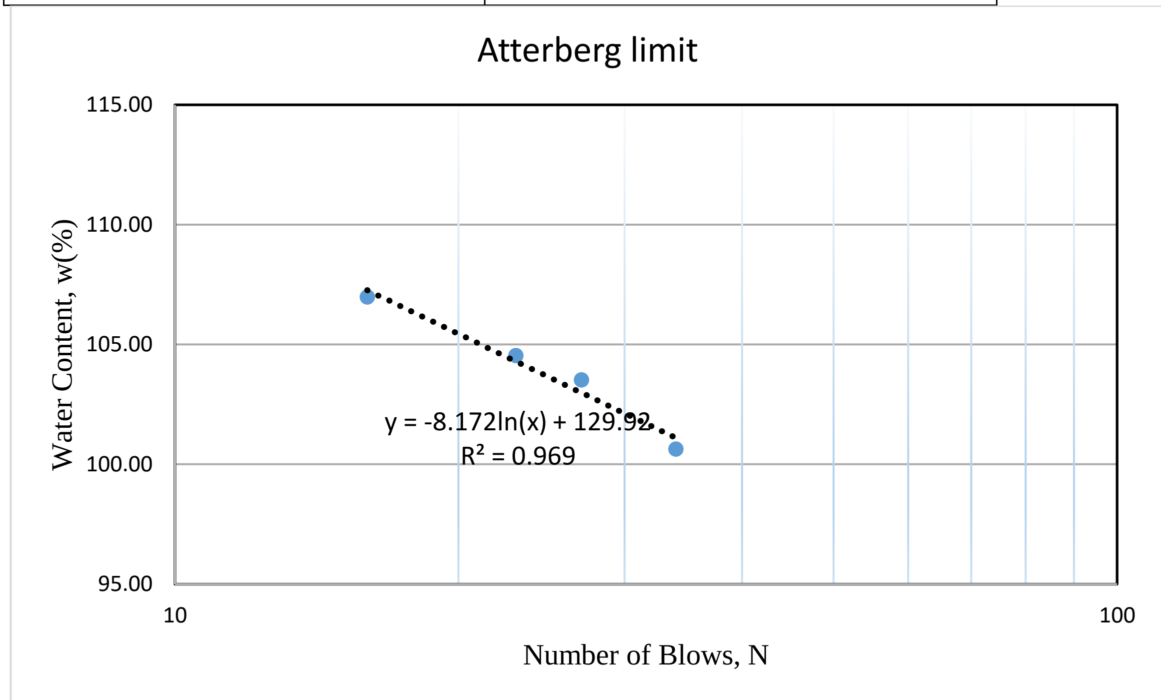
TP 4@ 3m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			YY	YX	YZ	YW	F1	F2
Mass of container, g			15.49	15.32	15.18	15.75	14.26	14.75
Mass of container + Wet soil, g			33.25	33.47	34.25	35.65	23.69	24.12
Mass of container + Dry soil, g			25.11	25.10	25.34	26.15	21.43	21.67
Mass of water, g			8.14	8.37	8.91	9.50	2.26	2.45
Mass of dry soil, g			9.62	9.78	10.16	10.40	7.17	6.92
Water content, %			84.62	85.58	87.70	91.35	31.52	35.4
No of blows			33	29	24	18	33	
LL			87					



TP 5@ 1.5m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			D1	D2	D3	D4	D11	D12
Mass of container, g			15.42	15.15	15.94	16.68	17.25	17.93
Mass of container + Wet soil, g			34.18	33.47	32.97	34.83	27.42	26.15
Mass of container + Dry soil, g			25.76	25.15	25.18	26.31	24.91	24.11
Mass of water, g			8.42	8.32	7.79	8.52	2.51	2.04
Mass of dry soil, g			10.34	10.00	9.24	9.63	7.66	6.18
Water content, %			81.43	83.20	84.31	88.47	32.77	33.01
No of blows			35	26	22	18	33	
LL			84					



TP 5@ 3m			Liquid Limit				Plastic Limit	
Trial No			1	2	3	4	1	2
Container No			E1	E2	E3	E4	A	B
Mass of container, g			15.55	15.26	15.38	17.21	18.22	17.73
Mass of container + Wet soil, g			34.73	34.94	34.30	34.70	29.02	30.77
Mass of container + Dry soil, g			25.11	24.93	24.63	25.66	25.18	25.93
Mass of water, g			9.62	10.01	9.67	9.04	3.84	4.84
Mass of dry soil, g			9.56	9.67	9.25	8.45	6.96	8.20
Water content, %			100.63	103.52	104.54	106.98	55.17	59.02
No of blows			34	27	23	16	57	
LL			104					



Appendix-E

Free Swell

Test Pit TP-01@1.5m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	19	17	18	80.0%

Test Pit TP-01@3.0m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	17	18	17.5	75.0%

Test Pit TP-02@1.5m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	17	16	16.5	65.0%

Test Pit TP-02@3.0m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	16	16	15	60.0%

Test Pit TP-03@1.5m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	15	15	15	50.0%

Test Pit TP-03@3.0m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	14	14	14	40.0%

Test Pit TP-04@1.5m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	20	20	20	100.0%

Test Pit TP-04@3.0m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	19	18	18.5	85.0%

Test Pit TP-05@1.5m

Initial volume (cc)	Final Volume		Average Final volume	Free swell index
	Sample no. 01	Sample no. 02		
10	17	18	17.5	75.0%

Appendix-F

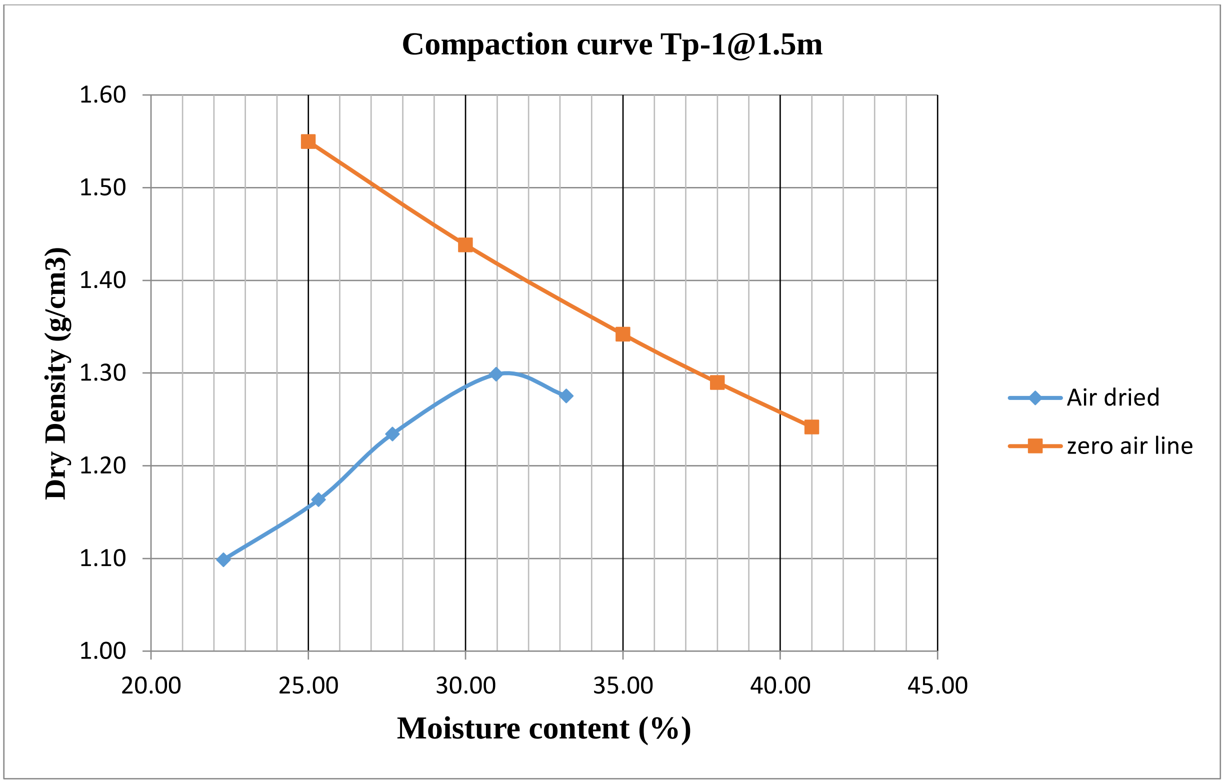
Compaction

Standard proctor test

Test pit TP-1@1.5m

	Bulk unit weight determination		
Weight of mold (g)	4345	Volume of mold (cm3)	944
Sample No	Mass of moist soil+ mold (g)	Mass of moist soil (g)	Bulk density, g/cm3
1	5613	1268	1.344
2	5721	1376	1.458
3	5833	1488	1.576
4	5951	1606	1.701
5	5949	1604	1.698847

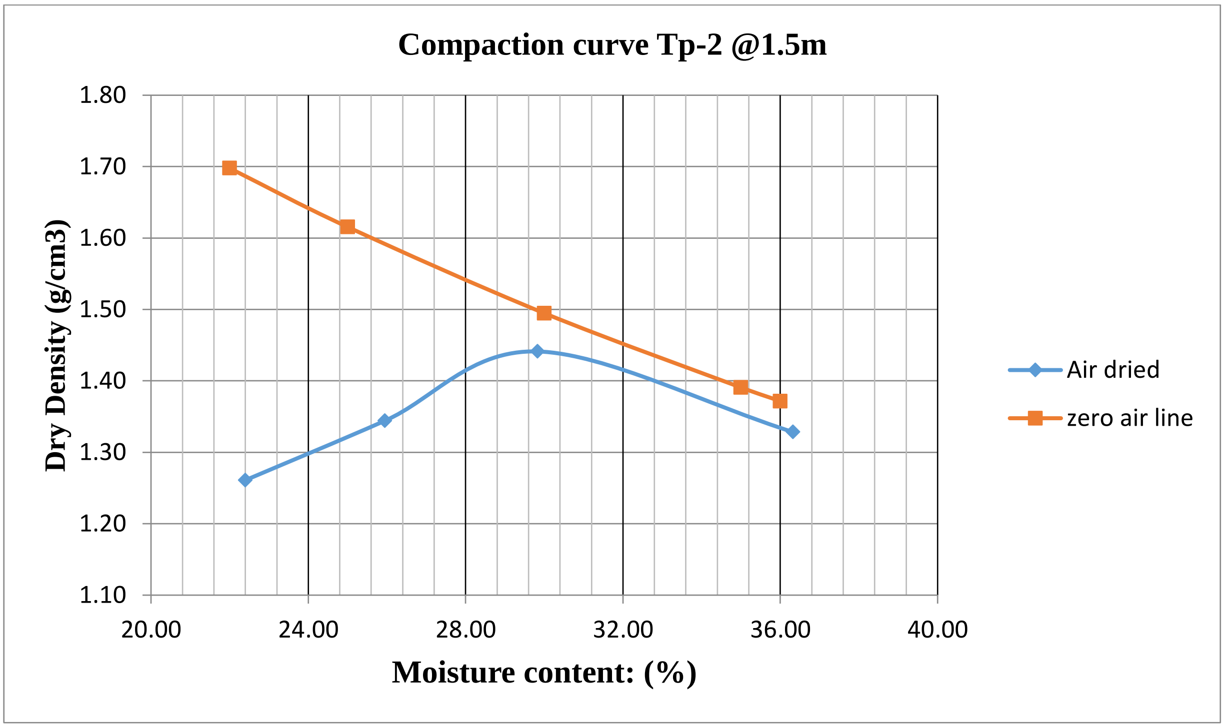
Can No.	Mass of can	Mass of can + soil	Mass of dried sample + can	Mass of water	Mass of dry soil	Water content	Dry unit weight of compacted soil
A1	29.9	162.6	138.4	24.2	108.5	22.30	1.10
BC	30.7	164.3	137.3	27	106.6	25.3	1.16
CE	33.3	161.1	133.4	27.7	100.1	27.7	1.23
AA	35.6	154.64	126.5	28.14	90.9	31	1.30
ED	33.8	139.3	113	26.3	79.2	33.2	1.28



Test pit TP-2@1.5m

	Bulk unit weight determination		
Weight of mold (g)	4345	Volume of mold (cm3)	944
Sample No	Mass of moist soil+mold (g)	Mass of moist soil (g)	Bulk density, g/cm3
1	5802	1457	1.543
2	5943	1598	1.693
3	6111.29	1766.29	1.871
4	6054.5	1709.5	1.811

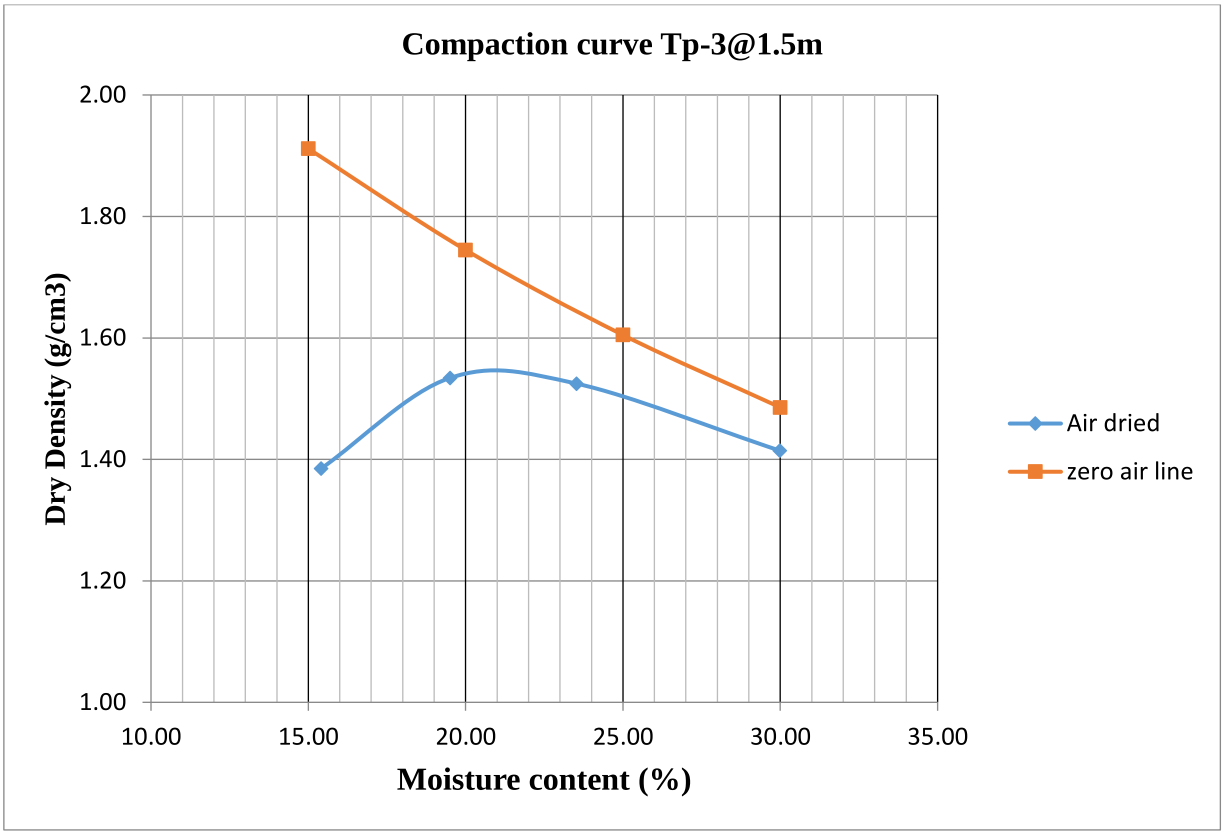
Can No.	Mass of can	Mass of can + soil	Mass of dried sample + can	Mass of water	Mass of dry soil	Water content	Dry unit weight of compacted soil
ZA	38.9	178.8	153.2	25.6	114.3	22.4	1.26
FR	38	174.4	146.3	28.1	108.3	25.9	1.34
KL	36.5	160.6	132.1	28.5	95.6	29.8	1.44
MM	41.4	158.9	127.6	31.3	86.2	36.3	1.33



Test pit TP-3@1.5m

	Bulk unit weight determination		
Weight of mold (g)	4345	Volume of mold (cm3)	944
Sample No	Mass of moist soil+ mold (g)	Mass of moist soil (g)	Bulk density, g/cm3
1	5853.87	1508.87	1.598
2	6075.63	1730.63	1.833
3	6122.92	1777.92	1.883
4	6080.58	1735.58	1.839

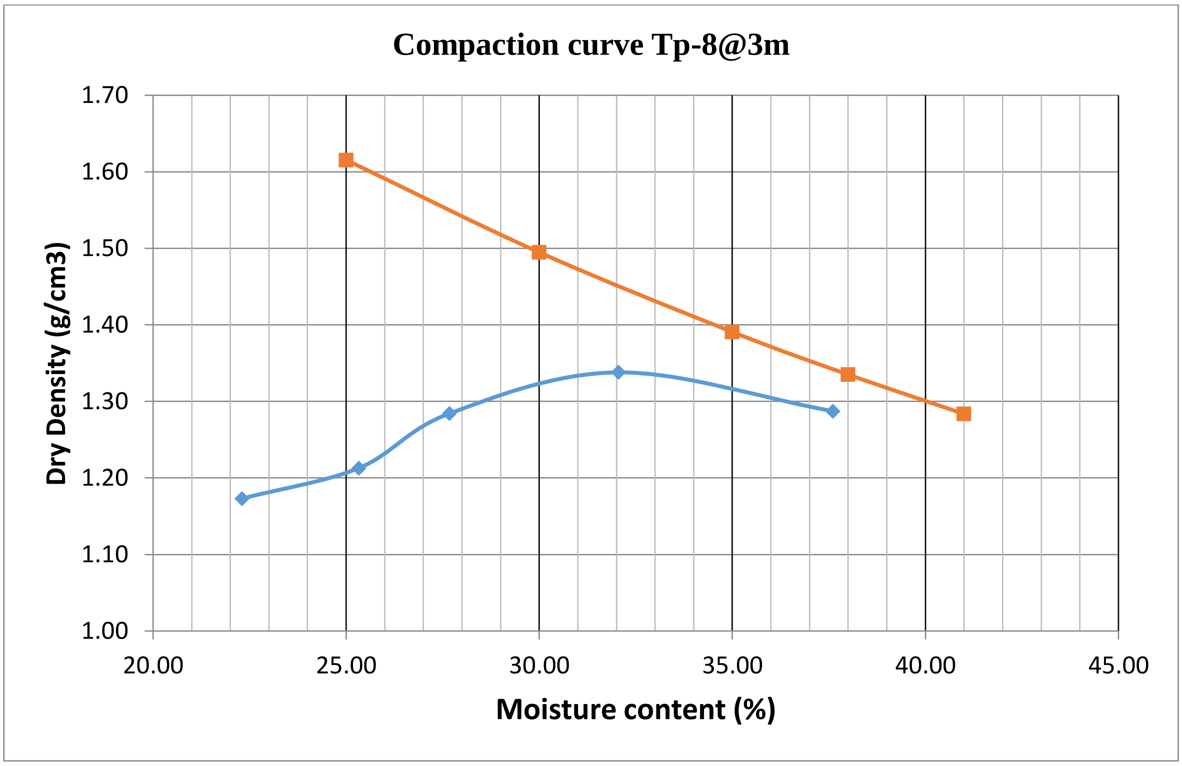
Can No.	Mass of can	Mass of can + soil	Mass of dried sample + can	Mass of water	Mass of dry soil	Water content	Dry unit weight of compacted soil
HH	31	141.9	127.1	14.8	96.1	15.41	1.38
GF	35	136	119.5	16.5	84.5	19.5	1.53
ON	40	140.7	121.5	19.2	81.5	23.53	1.52
BB	39	143.4	119.3	24.1	80.3	29.99	1.41



Test pit TP-8@3.0m

	Bulk unit weight determination		
Weight of mold (g)	4345	Volume of mold (cm3)	944
Sample No	Mass of moist soil+mold (g)	Mass of moist soil (g)	Bulk density, g/cm3
1	5699.36	1354.4	1.435
2	5779.98	1435	1.520
3	5892.74	1547.7	1.640
4	6012.915	1667.9	1.767
5	6017.088	1672.1	1.771

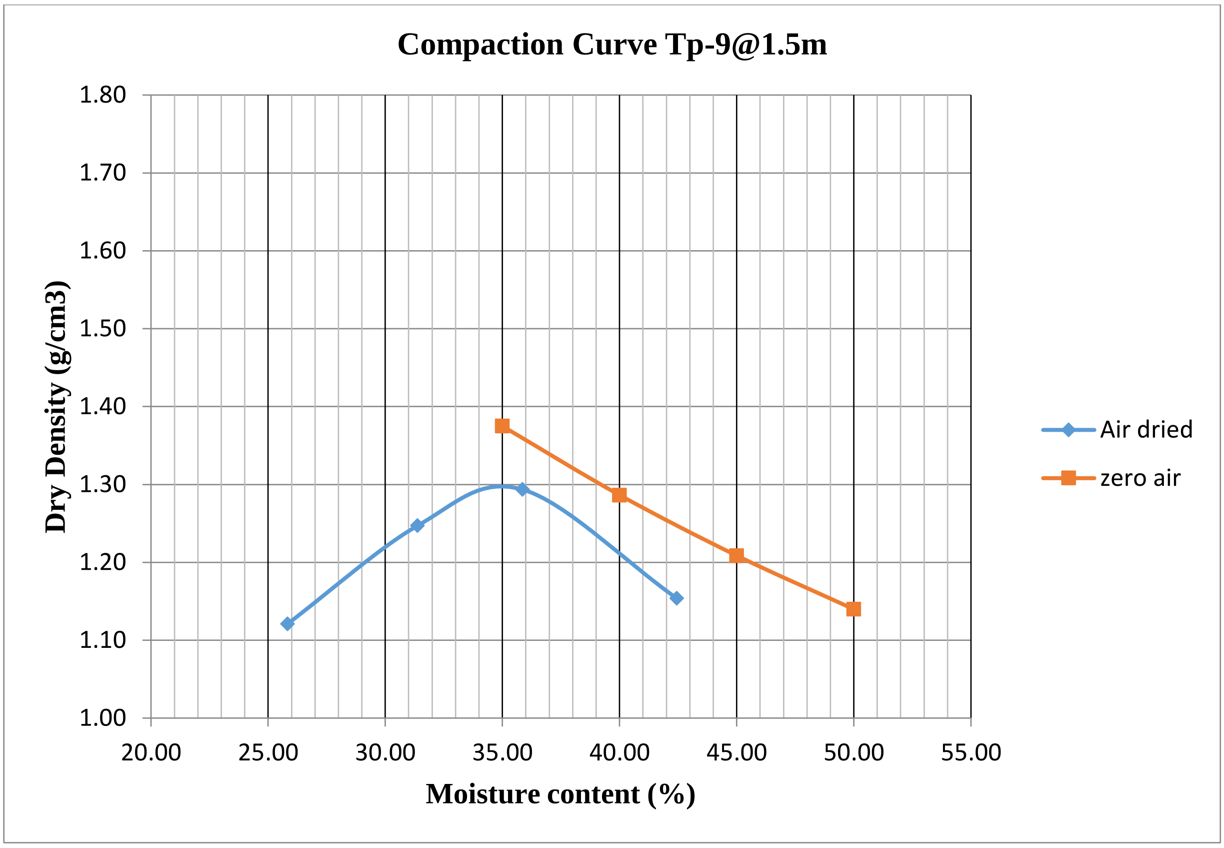
Can No.	Mass of can	Mass of can + soil	Mass of dried sample + can	Mass of water	Mass of dry soil	Water content	Dry unit weight of compacted soil
DE	29.9	162.6	138.4	24.2	108.5	22.3	1.17
GI	30.7	164.3	137.3	27	106.6	25.3	1.21
KL	33.3	161.1	133.4	27.7	100.1	27.7	1.28
WW	35.6	155.64	126.5	29.14	90.9	32.1	1.34
X2	33.8	14.28	113	29.8	79.2	37.6	1.29



Test pit TP-9@1.5m

	Bulk unit weight determination		
Weight of mold (g)	4345	Volume of mold (cm3)	944
Sample No	Mass of moist soil+mold (g)	Mass of moist soil (g)	Bulk density, g/cm3
1	5676.48	1331.48	1.410
2	5891.52	1546.52	1.638
3	6003.84	1658.84	1.757
4	5896.32	1551.32	1.643

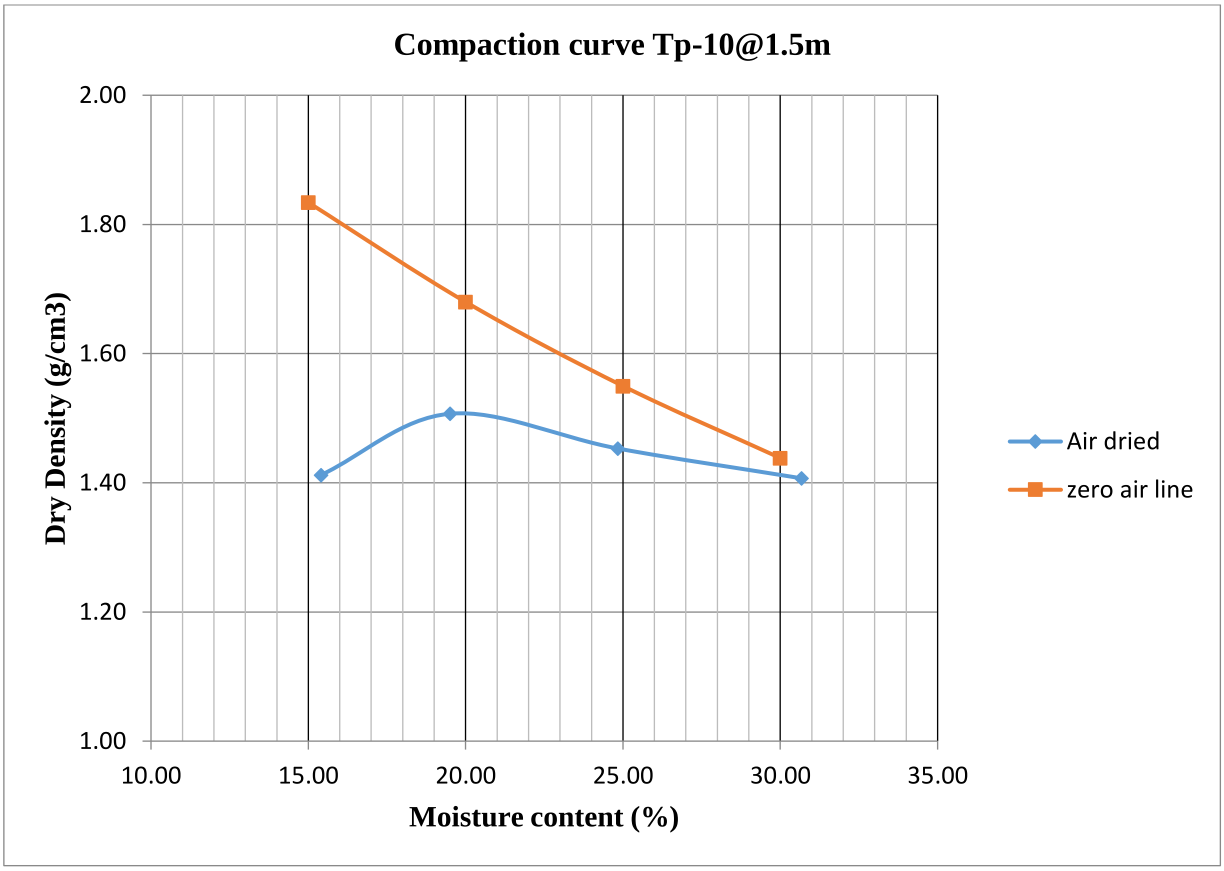
Can No.	Mass of can	Mass of can + soil	Mass of dried sample + can	Mass of water	Mass of dry soil	Water content	Dry unit weight of compacted soil
PO	31	151.9	127.1	24.8	96.1	25.83	1.41
A12	35	146	119.5	26.5	84.5	31.4	1.64
A11	40	150.7	121.5	29.2	81.5	35.9	1.76
BU	39	153.4	119.3	34.1	80.3	42.4	1.64



Test pit TP-9@1.5m

	Bulk unit weight determination		
Weight of mold (g)	4345	Volume of mold (cm3)	944
Sample No	Mass of moist soil+ mold (g)	Mass of moist soil (g)	Bulk density, g/cm3
1	5883.44	1538.44	1.630
2	6044.95	1699.95	1.801
3	6057.38	1712.38	1.814
4	6080.58	1735.58	1.839

Can No.	Mass of can	Mass of can + soil	Mass of dried sample + can	Mass of water	Mass of dry soil	Water content	Dry unit weight of compacted soil
VC	31	141.9	127.1	14.8	96.1	15.41	1.41
HG	35	136	119.5	16.5	84.5	19.5	1.51
LJ	40	141.7	121.5	20.2	81.5	24.84	1.45
NT	39	143.9	119.3	24.6	80.3	30.68	1.41

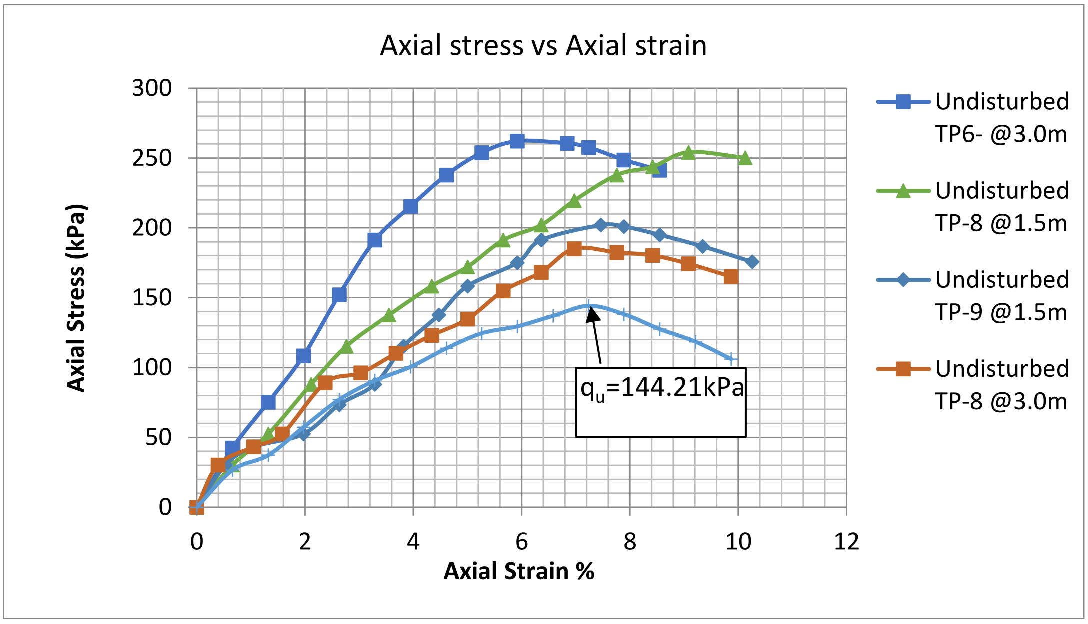


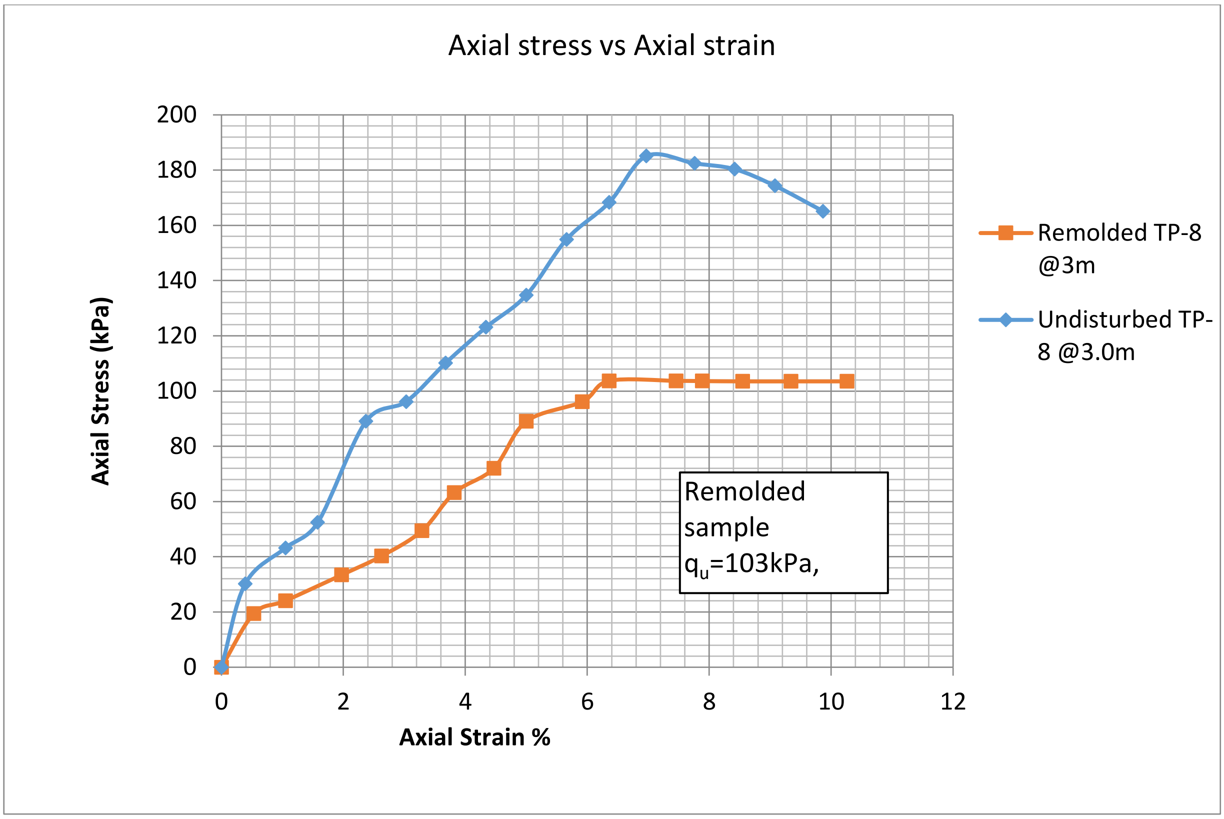
Appendix-G

Shear Strength

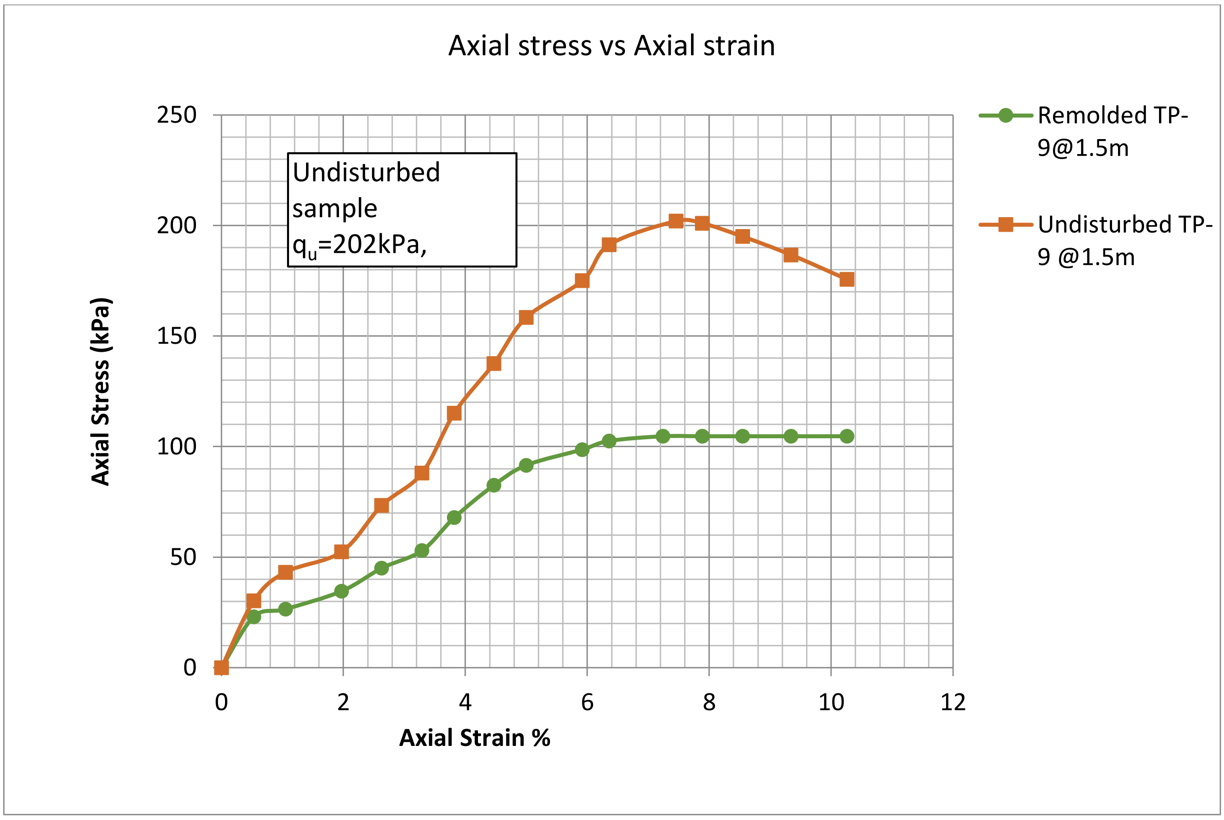
Unconfined Compression Test

Selected test pits





Test pit TP-9@1.5m



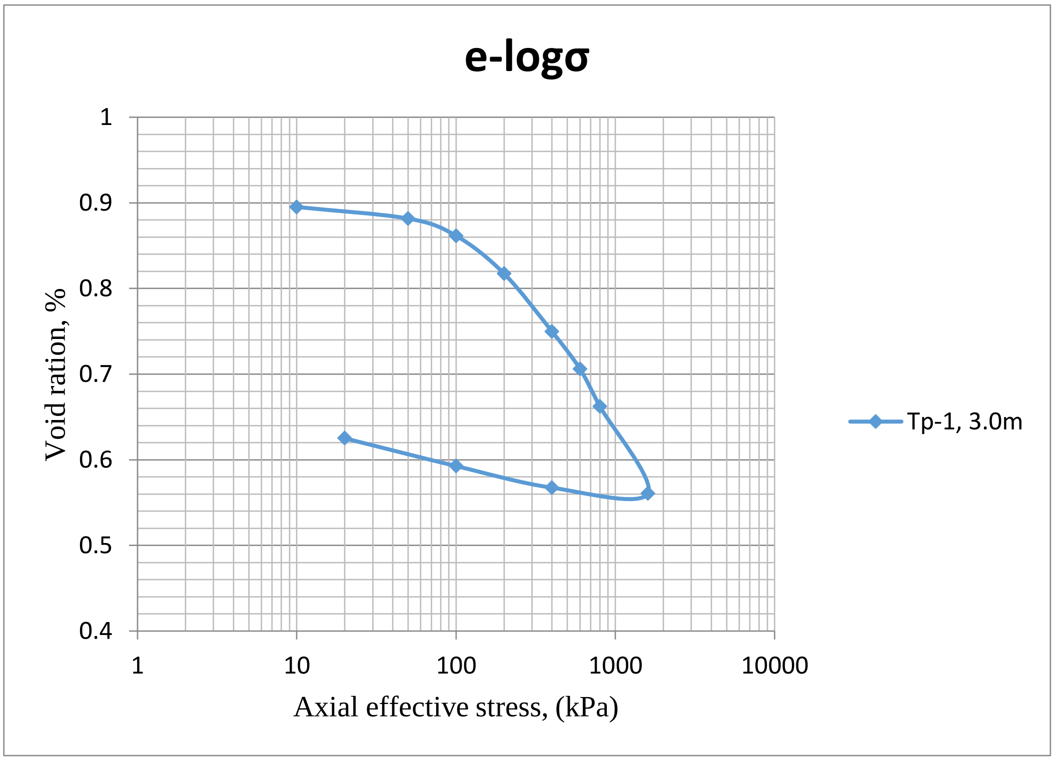
Appendix-H

Consolidation

Oedometer Test

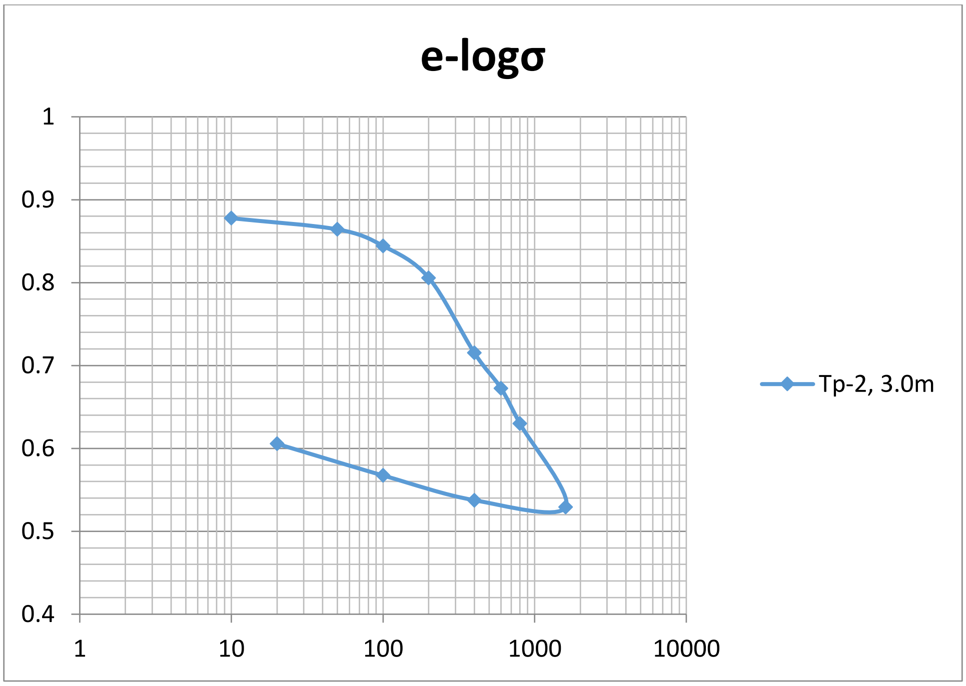
Test pit TP-1@3.0m

Consolidation pressure (kPa)	Change in height of specimen*, ΔH (mm)	Height of specimen ($H=H_i-\Delta H=20.0-\Delta H$) (mm)	Equivalent height of voids, (=2H - Hs) (mm)	Void ratio, e=(H - Hs)/Hs
0	0	20.000	9.463	0.898
10	0.030	19.970	9.433	0.895
50	0.172	19.828	9.291	0.882
100	0.384	19.616	9.079	0.862
200	0.849	19.151	8.614	0.817
400	1.562	18.438	7.901	0.750
600	2.023	17.978	7.440	0.706
800	2.483	17.517	6.980	0.662
1600	3.556	16.444	5.907	0.561
400	3.484	16.516	5.979	0.567
100	3.218	16.782	6.245	0.593
10	2.876	17.124	6.587	0.625
5	2.536	17.464	6.927	0.657



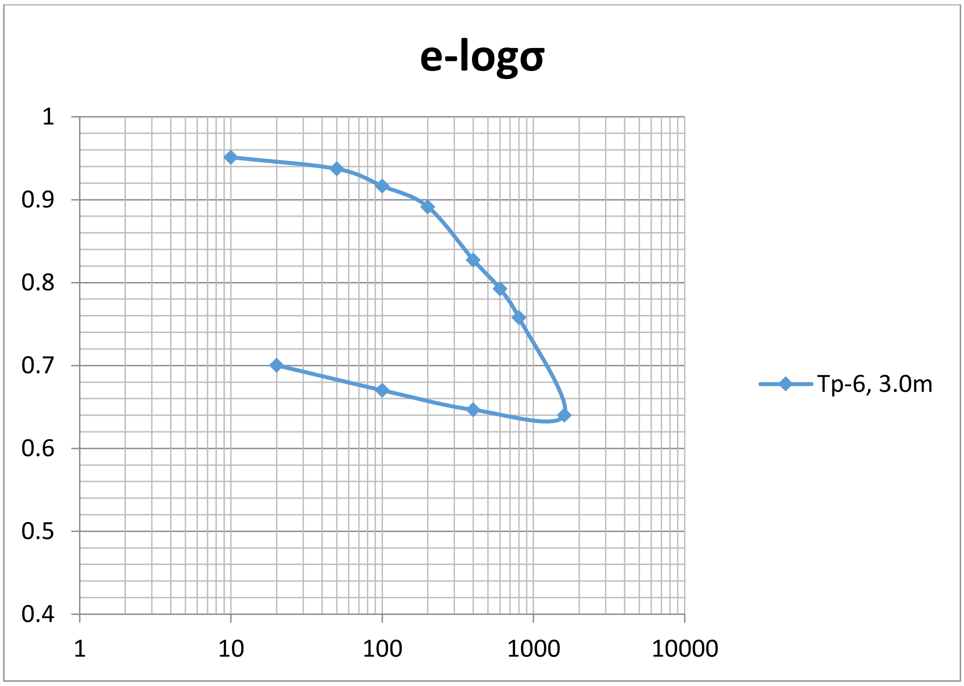
Test pit TP-2@3.0m

Consolidation pressure (kPa)	Change in height of specimen*, ΔH (mm)	Height of specimen ($H=H_i$- ΔH=20.0- ΔH) (mm)	Equivalent height of voids, (=2H - Hs) (mm)	Void ratio, e=(H - Hs)/Hs
0	0	20.000	9.362	0.880
10	0.025	19.975	9.337	0.878
50	0.168	19.832	9.194	0.864
100	0.379	19.621	8.983	0.844
200	0.789	19.211	8.573	0.806
400	1.753	18.247	7.609	0.715
600	2.207	17.793	7.155	0.673
800	2.661	17.339	6.701	0.630
1600	3.733	16.267	5.629	0.529
400	3.643	16.357	5.718	0.538
100	3.326	16.674	6.036	0.567
10	2.92	17.080	6.442	0.606
5	2.71	17.290	6.652	0.625



Test pit TP-6@3.0m

Consolidation pressure (kPa)	Change in height of specimen*, ΔH (mm)	Height of specimen ($H=H_i$- ΔH=20.0- ΔH) (mm)	Equivalent height of voids, (=2H - Hs) (mm)	Void ratio, e=(H - Hs)/Hs
0	0	20.000	9.767	0.954
10	0.034	19.966	9.733	0.951
50	0.176	19.824	9.591	0.937
100	0.388	19.612	9.379	0.917
200	0.644	19.356	9.123	0.892
400	1.300	18.700	8.467	0.827
600	1.656	18.344	8.111	0.793
800	2.012	17.988	7.755	0.758
1600	3.216	16.784	6.551	0.640
400	3.151	16.849	6.616	0.647
100	2.910	17.090	6.857	0.670
10	2.601	17.399	7.166	0.700
5	2.294	17.706	7.473	0.730



Test pit TP-8@3.0m

Consolidation pressure (kPa)	Change in height of specimen*, H (mm)	Height of specimen (2H=2H1-H=20.0- H) (mm)	Equivalent height of voids, (=2H - 2Ho) =2H - 7.277 (mm)	Void ratio, e=(2H - 2Ho)/2Ho
0	0	20.000	9.907	0.982
10	0.030	19.970	9.877	0.979
50	0.172	19.828	9.735	0.965
100	0.384	19.616	9.523	0.944
200	0.811	19.189	9.096	0.901
400	1.733	18.267	8.174	0.810
600	2.232	17.769	7.676	0.760
800	2.730	17.270	7.177	0.711
1600	3.956	16.044	5.951	0.590
400	3.861	16.139	6.046	0.599
100	3.525	16.475	6.382	0.632
10	3.095	16.905	6.812	0.675
5	2.873	17.127	7.034	0.697