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SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

**INVESTIGATION INTO THE INDEX PROPERTIES AND SWELLING
POTENTIAL OF EXPANSIVE SOILS OF SHENO TOWN**

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

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DECLARATION

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

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ABBREVIATIONS

AAiT	Addis Ababa institute of Technology
AAU	Addis Ababa University
a.m.s.l	above mean sea level
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society of Testing and Materials
BS	British Standard
CH	Inorganic Clay of High Plasticity
CL	Inorganic Clay of Low to Medium Plasticity
ML	Inorganic Silt of Low Plasticity
MH	Inorganic Silts of High Plasticity
OH	Organic Clay of Medium of High Plasticity
OL	Organic Silts of Low Plasticity
NMC	Natural Moisture Content
FS	Free Swell
Gs	Specific Gravity
LL	Liquid Limit
PI	Plasticity Index
PL	Plastic Limit

Ps	Swelling Pressure
USCS	Unified Soil Classification System
NGL	Natural Ground Level
TP	Test Pit
EMA	Ethiopian Meteorological Agency

ABSTRACT

In this study the index properties and swelling potential of soils of Sheno town are examined. The study is conducted with the aim of examining the index properties which are relevant in predicting the swelling characteristics of soils of the study area. Expansive soils of Sheno town, both the black soils as well as the light brown soils undergoes considerable swelling during the wet season.

The test results of soils of Sheno town showed that the specific gravity ranges from 2.66 to 2.86. The index property tests showed that the plasticity index ranges from 60% to 78.9% at a depth of 1.5m and 45.2% to 58.2% at a depth of 3.0m. The unconfined compressive strength of soils of the study area ranges from 72kPa to 83kPa at a depth of 1.5m and 82kPa to 93kPa at a depth of 3.0m. The clay content of the soil ranges from 58.47% to 75.0% at a depth of 1.5m and 45.68% to 58.77% at a depth of 3.0m. Free swell tests conducted on the collected samples showed a range from 123% to 165% at a depth of 1.5m and 83% to 120% at a depth of 3.0m. The results of the one-dimensional consolidometer showed that the swelling pressure of the area ranges between 70kPa to 200kPa, the pre-consolidation pressure (P_c) ranges between 150kPa to 290kPa and the compression index (C_c) ranges between 0.285 to 0.389.

Soils of the study area are classified both by the USCS and the AASHTO system. According to the USCS, soils of the study area fall in the CH group and when using the AASHTO system all soils fall in group A-7 which cannot be used as sub grade for highway constructions.

1. INTRODUCTION

1.1. General

Soils are formed by the disintegration of rocks and naturally exist either in the loosest or densest state depending up on the previous loading history. The pore spaces in the soil skeleton are filled with water and air and thus it is a three phase system comprising of solids, liquids and air.

The behavior of soils is affected by the variations in moisture contents. Soils exhibit different responses according to their mineralogical content. Such soils which show an increase in volume or expansion when subjected to moisture and which decrease in volume or shrink when they lose moisture are termed as expansive soils.

Expansive soils are the main causes of failure of light civil engineering structures. Light weight structures (G+0, G+1, G+2, highways etc.) are highly affected by the swelling and shrinking behavior of these soils and cause tremendous loss on the economy of the country. Some studies showed that the annual average loss in United States in 1981 due to failure of structures built on expansive soil was about \$ 9 billion [10].It would be fair to say that more than half of the world is affected by swelling soils [6].Thus, the loss of life and property force engineers to study their properties in detail.

The research is conducted in Sheno town located in North- Shoa. The town is now becoming a commercial center for the surrounding woredas and is proposed as industrial zone. The soil investigation is done as construction of buildings started along the road sides and no previous studies were conducted.

1.2. Objectives and Methodology

1.2.1. Objective

The Specific objectives of this research are:

- a. To investigate the engineering properties of soils found in Sheno town.
- b. To create awareness within the society as how to identify and minimize damages caused by expansive soils.
- c. To get reliable values of swelling pressures of the soils and to make input for economical designs.

1.2.2. Methodology

The methodologies used are:

- a) Identification of the location of expansive soils.
- b) Collection of disturbed and undisturbed samples from six (6) test pits which are believed to be representative of soils of the study area.
- c) Laboratory tests like the Atterberg limit, free swell, specific gravity, hydrometer and swelling pressure determination on disturbed and undisturbed samples as appropriate.

1.3. Structure of the Thesis

The thesis is divided into five Chapters. Chapter one introduces the topic. Chapter two deals with relevant literature review and summarize various aspects related to the research topic. Chapter three introduces the study area, the locations of test pits, the methods of sampling, presents the results of all laboratory tests and soil classification according to the laboratory test results.

Chapter four, discusses on the results obtained. Chapter five, the last chapter mainly focuses on conclusions and recommendations for the future prospect.

2. LITERATURE REVIEW

2.1. Expansive soils in general

Expansive soils are clay soils with high plasticity. They have a peculiar nature of expanding and shrinking when subjected to different moisture contents. They are commonly termed as black clays or in some regions 'black cotton' soils where the name black cotton comes from regions where these soils are suitable for growing cotton [13].

The origin of expansive soils is related to complex combinations and processes that result in formation of clay minerals having a particular make up which when in contact with water will expand. The conditions and processes which determine the clay mineralogy include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected [14].

Parent Material

The constituents of the parent material during the early and intermediate stages of weathering process determine the type of clay formed. The nature of parent material is much more important during these stages than after intense weathering for long periods of time. The parent materials associated with expansive clays can be grouped into two groups where the first group comprises the basic igneous rocks and the second group comprises the sedimentary rocks which contain montmorillonite as a constituent.

The basic igneous rocks are comparatively low in silica, generally about 45% to 52%. Rocks which are rich in metallic bases such as the pyroxenes, amphiboles, biotite and olivine fall within this category. Such rocks include the gabbros, basalts and volcanic glass.

The sedimentary rocks that contain montmorillonite as a constituent include shales and claystones. Limestones and marls rich in magnesium can also weather to clay. These constituents of the shales and claystones contain varying amounts of volcanic ash and glass which were subsequently weathered to montmorillonite. The volcanic eruptions sent up clouds of ash, which fell on the continents and seas. Some of the fine-grained sediments which accumulated to form these rocks undoubtedly contain montmorillonite derived from the weathering of continental igneous rocks and from ash which fell on the continental areas [6].

Weathering

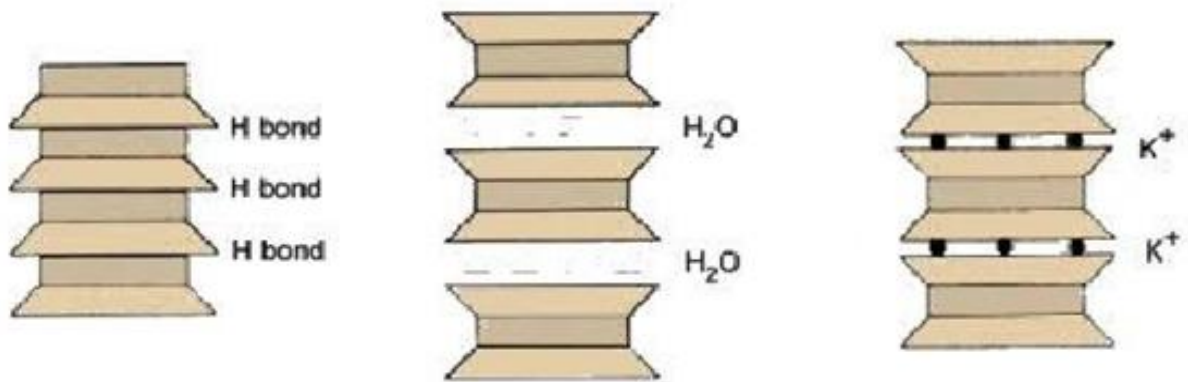
The weathering processes by which clays are formed include physical, biological and chemical processes. Physical weathering changes the particle size and bulk volume of the parent material with no significant change in composition and it includes expansion due to unloading, crystal growth, thermal expansion and contraction, organic activity and colloidal plucking. Chemical weathering causes a complete change in physical and chemical properties. It includes hydration, hydrolysis, oxidation, carbonation and solution where water is the prime source for chemical weathering to take place. Biological weathering is similar to chemical weathering as it changes both the state of aggregate and in chemical composition that occur. The formation of expansive clay or montmorillonite clay is favored by alkaline environment and the absence of leaching, the presence of ferro magnesium minerals in parent materials and the presence of bases. Prolonged leaching under high temperatures or tropical conditions with ferric iron parent rocks favors the formation of minerals of kaolinite group which are non-expansive. The presence of potash in the parent material under these conditions results in the formation of illite [6].

2.2 Mineralogical Structure

The basic building blocks of clays are formed from the silica tetrahedron in which the silicon atom is surrounded tetrahedrally by oxygen ions and the alumina octahedron in which the aluminum atom is surrounded octahedrally by six oxygen ions. The blocks combine into

tetrahedral and octahedral sheets in order to produce various types of clays. The three most important groups of clays are: (Fig. 2.1)

- a) Kaolinite: Is a two-layer mineral having a single tetrahedral sheet joined by a single octahedral sheet where the layers are held together by hydrogen bond and is non-expansive.
- b) Montmorillonite: Is a three layer mineral having a single octahedral sheet sandwiched between two tetrahedral sheets. They are highly expansive and create major engineering Problems as the layers are held together by the weak vanderwaals force which can easily be penetrated by water and causes swelling.
- c) Illite: Has a similar structure with that of montmorillonite but some of the silicon atoms are replaced by aluminum and are held together by potassium ions.



a) Kaolinite

b) Montmorillonite

c) Illite

Figure 2.1 Structure of three main clay types [13]

2.3. Identification

Early identification of expansive soils during the reconnaissance and preliminary stages of the project is essential to allow for appropriate sampling, testing and design in the later stages. Thus, the investigation must actually comprise two important phases. The first is the recognition and identification of soil as expansive soil and the second is sampling and measurement of material properties to be used as the basis for design predictions [12].

2.3.1. Field Identification

Expansive soils in the field can be identified by visual inspections as described below:

- A shiny surface which is easily obtained when a partially dry piece of soil is polished with a smooth object such as top of finger nails.
- The wet sample of soil is sticky.
- Appearance of wide cracks.
- They are mostly black or grey in color.

2.3.2. Laboratory Identification

Expansive soils in the laboratory may be identified using one of the following approaches

- a) Mineralogical identification
- b) Indirect measurement
- c) Direct measurement

Mineralogical identification

Minerals in clay should be identified in order to know the swelling potential of the soils and this can be done in a number of ways. Some of this includes:

- X-ray diffraction
- Differential thermal analysis
- Dye absorption
- Chemical analysis
- Electron microscope resolution

The above methods require expert's interpretation and specialized apparatus which are costly and are not available in most soil testing laboratories [14].

Indirect measurement

These methods include the PVC (potential volume change) test methods and index property tests in order to determine the swelling potential of expansive soils.

Direct measurement

These test measures directly the swelling potential and the swelling pressure of expansive clays in a convenient way using the one dimensional consolidometer where the cantilever consolidometer is common in most soil testing laboratories.

2.4. Mechanics of Swelling

The swelling of expansive soils occurs only if there is a change in the surrounding environment. These changes include pressure release due to excavation, desiccation caused by temperature increase and volume increase because of the introduction of moisture. From the above mentioned changes that occur within the surrounding soil the concern at this stage is the effect of water [12]. There must be a potential gradient which can cause water migration and a continuous passage through which water transfer can take place.

2.4.1 Moisture Migration

The pattern of moisture migration depends on the geological formations, climatic conditions, topographic features, soil types and ground water level. The most common method of moisture transfer is through gravity. The seepage of surface water, precipitation and snow melting are common examples [6].

2.4.2 Depth of moisture fluctuation

In covered area, the moisture profile is shown by curve 1. There is no gain or loss of moisture from the atmosphere. The moisture content of the soil decreases with depth. In uncovered natural conditions shown by curve 2, evaporation cause loss of moisture content in the soil near the ground surface. However, the influence of evaporation decreases with depth and at some depth, H_d , the moisture content equilibrium remains the same as the covered condition and this depth is

termed as depth of desiccation. The value of H_d depends on the climatic conditions, the type of soil and the location of water table. This depth represents the total thickness of the material having the potential to expand. The maximum depth of H_d is equal to the depth of water table and the minimum depth is equal to the depth of seasonal moisture fluctuation.

During wet seasons, with heavier precipitation and higher humidity, the moisture content of near-surface soil increases and the moisture profile represented by curve 2 alters its shape to curve 3. The upper portion of curve 3 can extend beyond curve 1 in very wet seasons and behind curve 1 in dry seasons. The depth of seasonal moisture fluctuation, H_s , depends on the variation of surface moisture, permeability of the soils and climatic conditions.

The watering of lawns, planting of trees and shrubs, discharge of roof drains, formation of drainage channels and swales and the possibility of utility line leakage all increase the value of H_s .

When areas are covered by structures such as buildings, pavements, sidewalks or aprons, evaporation is blocked or partially retarded. The moisture content beneath the covered area increases due to gravitational migration, capillary action, vapor and liquid thermal transfer and in the course of several years the depth of seasonal moisture fluctuation H_s can approach to the depth of desiccation H_d [6].

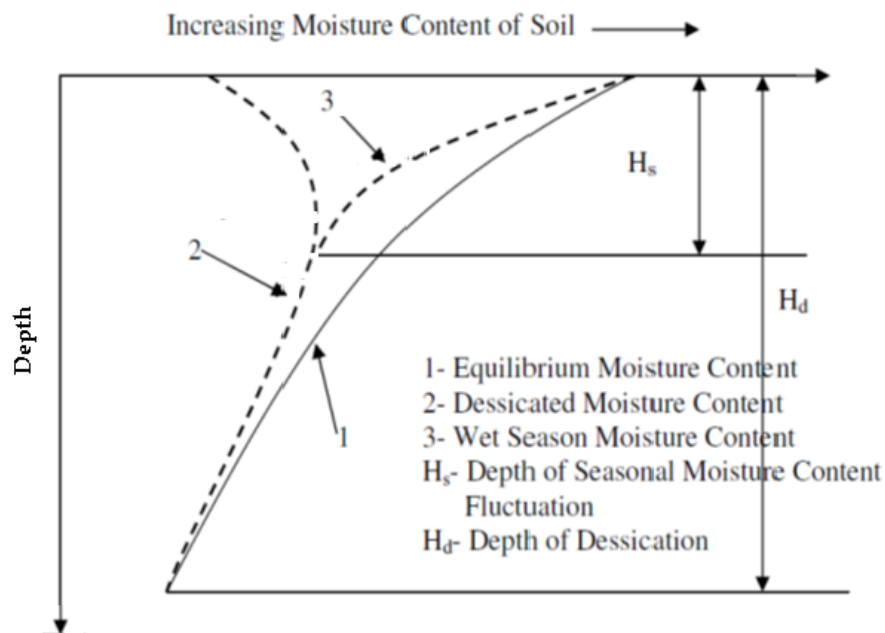


Figure 2.2Moisture content variations with depth below ground surface [6]

2.5. Factors influencing swelling and shrinking of soils

The factors influencing the shrink-swell potential of soil can be considered in three different groups. These are the soil characteristics that influence the basic nature of internal force field, the environmental factors that influence the changes that may occur in the internal force system and the state of stress [12].

2.5.1. Soil Characteristics

Clay mineralogy: Clay minerals which typically cause soil volume changes are montmorillonites, vermaculites and some mixed layer minerals.

Soil water chemistry: Swelling is repressed by increased cation concentration and increased cation valence. E.g. Mg^{2+} cations in soil water would result in less swelling than Na^+ cations.

Plasticity: Soils that exhibit plastic behavior over wide ranges of moisture content and that have high liquid limits have greater potential for swelling and shrinking.

Dry Density: Higher densities usually indicate closer particle spacing which may mean greater repulsive forces between particles and larger swelling potential.

2.5.2. Environmental Conditions

Initial moisture content: A desiccated expansive soil will have a higher affinity to water than the soil at higher water content.

Climate: Amount and variation of precipitation and evapo-transpiration greatly influence the moisture availability and the depth of seasonal moisture fluctuation.

Ground Water: Shallow water tables provide a source of moisture and fluctuating water tables contribute to moisture.

Vegetation: Trees, shrubs and grasses deplete moisture from the soil through transpiration and cause the soil to be differently wetted in areas of varying vegetation.

Permeability: Soils with high permeability allow faster migration of water and promote faster rates of swell.

Temperature: Increasing temperatures cause moisture to diffuse to cooler areas beneath pavements and buildings.

2.5.3. State of stress

Stress History: An over consolidated soil is more expansive than the same soil normally consolidated.

Loading: Magnitude of surcharge load determines the amount of volume change that will occur for a given moisture content and density.

Soil Profile: The thickness and location of potentially expansive layers in the soil profile considerably influence potential movement. Greatest movement will occur in profiles that have expansive clays extending from the surface to depths below the active zone. Less movement will occur if expansive soil is overlain by non-expansive material.

2.6. Classification of expansive soils

The aim of soil classification is to arrange soils having similar properties in the same group. Once the soil is identified as expansive, it has to be classified according to the properties it exhibits.

A reasonable classification involves the use of soil properties and provides one or more of the following ratings [12].

- i) Ranges of values for either probable percentage of volume change or probable swelling pressure.
- ii) A qualitative expansion rating which is low, medium, high and very high expansion potential.

Among the different classification schemes of soils the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) use results obtained from index property tests as their major input to classify soils. The method proposed by Chen also classifies soils using plasticity index and is presented in the Table 2.1.

Table 2.1 Expansive soil classification based on plasticity index [6]

Swelling Potential	PI (Plasticity Index)
Low	0-15
Medium	10-35
High	20-55
Very high	35 & above

3. SITE DESCRIPTION, SAMPLING AND LABORATORY TESTS

3.1. Introduction

Sheno, located between 091928 Latitude and 0391705 Longitude, is 77 kms away from Addis Ababa on the way to Debrebirhan in North Shoa.

The climate of Sheno is temperate as it is on highland region and the mean annual rainfall ranges from 1000mm to 1600mm [8]. The main rainy season falls between June and September and the minor rainfall is observed between February and April. The town is situated in the main highland plateau with an average elevation of 2870m above sea level [8]. The topography of Sheno is variable where most of the areas in the North-East and South-East show hilly terrain mainly covered with rocks while those in the North-West and South-West have flat terrain mostly covered with soils of expansive nature as leaching is restricted. The upper part of the soil is black in color where it is underlain by light brown to brown clay soils.

The map of Sheno town and the location of test pits are presented in Fig. 3.1.

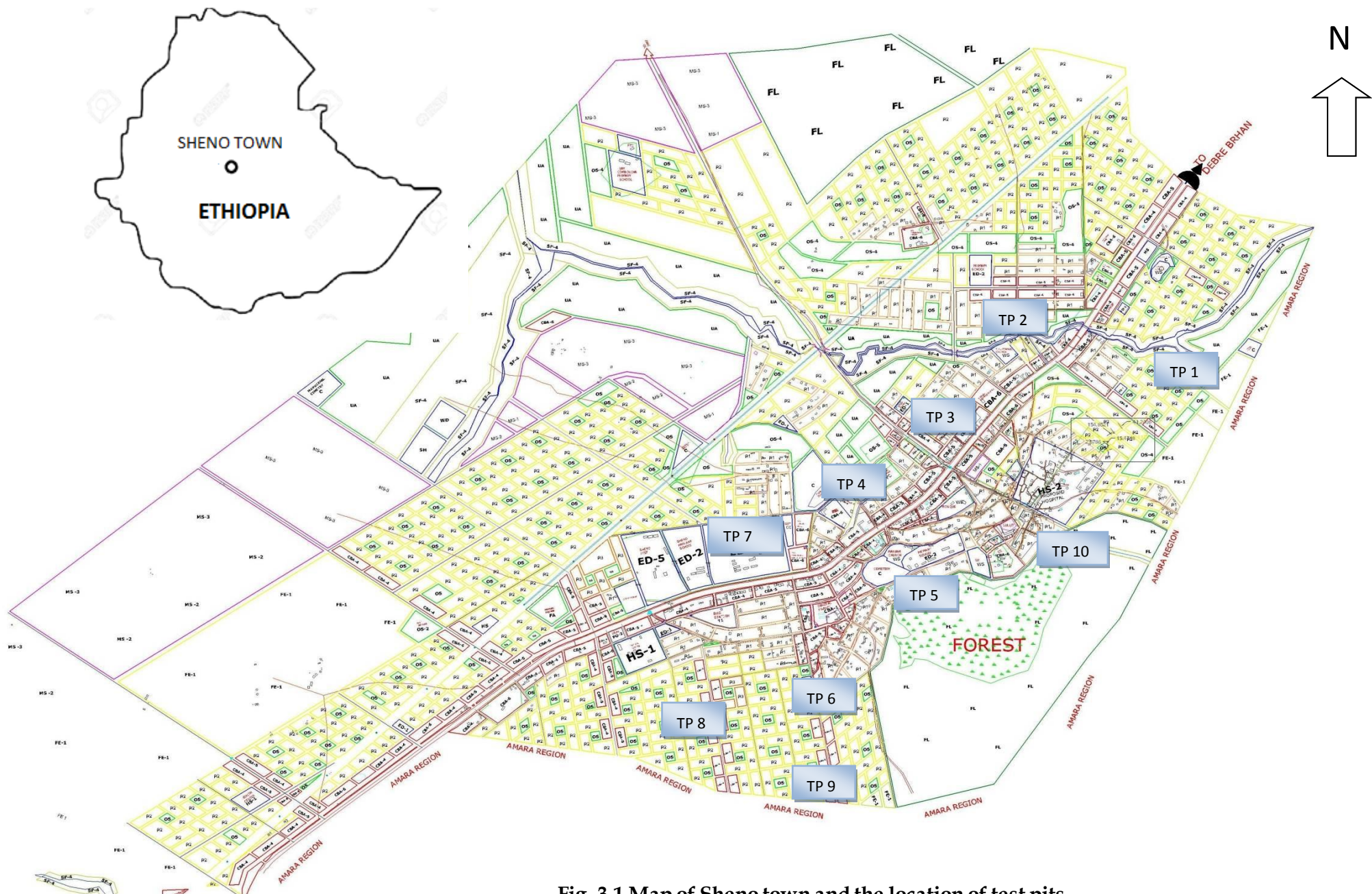


Fig. 3.1 Map of Sheno town and the location of test pits

3.2. Sample Collection

Before fixing the locations of test pits and taking soil samples to the laboratory, field observations were made. During field observation locations assumed favorable for the formation of expansive soils like areas with flat topographies where leaching is restricted are given primary concern and test pits were dug.

A total of ten (10) test pits were envisaged to be opened till a depth of 3m (Fig. 3.1) out of these test pits four (4) test pits encountered rock layer and the desired depth could not be reached. Test pit 6 (TP6) was dug to a depth of 1m, below which rock layer was encountered.

During sampling stage both disturbed and undisturbed soil samples were taken from the test pits. The depths of test pits range from 1.0m to 3m depending up on the existing ground conditions like the locations of ground water table and the locations of rock layers.

While taking disturbed and undisturbed samples, black and light brown to brown soils were encountered. Test pits of size 1.5mx1.5m were dug and disturbed soil samples weighing up to 15kg were taken. Undisturbed soil samples, using sampling tubes, were taken and properly sealed with wax.

3.3. Laboratory Tests

Different laboratory tests have been conducted both on disturbed and undisturbed soil samples which are necessary to meet the required objectives of the research and which completely give full information regarding the engineering properties of expansive soils of the study area.

Laboratory tests both on disturbed and undisturbed samples were conducted following the ASTM standard.

The following laboratory tests are undertaken:

- Atterberg limit tests
- Grain size analysis
- Specific gravity
- Free swell
- Natural moisture content
- Unconfined compression test
- Swelling pressure test

3.4. Laboratory Test Results

3.4.1. Index Properties

Index properties are properties of soils which are indicative of the engineering properties. Tests required for the determination of engineering properties of soils are generally elaborate and time consuming. It is only possible for the geotechnical engineer to have some rough assessment of the engineering properties without conducting the elaborate tests if index properties are determined.

Index properties of soils are bases for distinguishing soils and are divided into two broad categories; namely soil grain properties and soil aggregate properties. Soil grain property indicates the property of individual grain whereas soil mass property indicates the soil mass as a whole [13].

Index property tests include hydrometer analysis, Atterberg limit tests, specific gravity tests and free swell tests.

3.4.2. Grain Size Analysis

Grain size analysis divides soils into two distinctive groups, namely fine-grained and coarse-grained soils. Soil particles coarser than 0.075mm, are generally termed as coarse-grained whereas soil particles finer than 0.075mm like clays and silts are termed as fine-grained.

The particle size distributions can be done by using two methods: sieve analysis for particle sizes larger than 0.075mm (No. 200) in diameter, and the hydrometer analysis for particle sizes smaller than 0.075mm in diameter.

During the hydrometer analysis, sodium hexametaphosphate (NaPO_3) was used as a dispersion agent and the analysis follows the ASTM D 422-63 procedure. The diameter or size range is as follows:

- >4.75mm gravel;
- 4.75mm-0.075mm Sand;
- 0.075-0.005mm Silt and
- <0.005mm Clay.

Using the above classification method the result of the grain size test of the study area is presented in Table 3.1. The details of the tests are presented in Appendix-A.

Table 3.1 Grain Size Analysis test result of soils of the study area

Sample No.	Color	Sample depth (m)	Clay Fraction %	Silt Fraction %	Sand Fraction %	Gravel Fraction %
TP1	Black	1.50	71.82	24.94	3.20	0
TP1	Light Brown	2.70	58.77	37.23	4.0	0
TP2	Black	1.50	60.63	35.67	3.38	0.32
TP2	Light Brown	2.40	55.42	40.88	3.0	0.70
TP3	Black	1.50	71.19	25.99	2.82	0
TP3	Light Brown	3.00	55.0	38.70	6.30	0
TP4	Black	1.20	59.89	36.21	3.90	0
TP4	Light Brown	3.00	53.57	40.43	6.0	0
TP5	Black	1.50	75.0	18.19	4.0	2.10
TP5	Brown	3.00	45.68	54.32	0	0
TP6	Black	1.00	58.47	36.73	3.2	1.60

The grain size distribution curves for the tested samples are presented in Fig. 3.2.

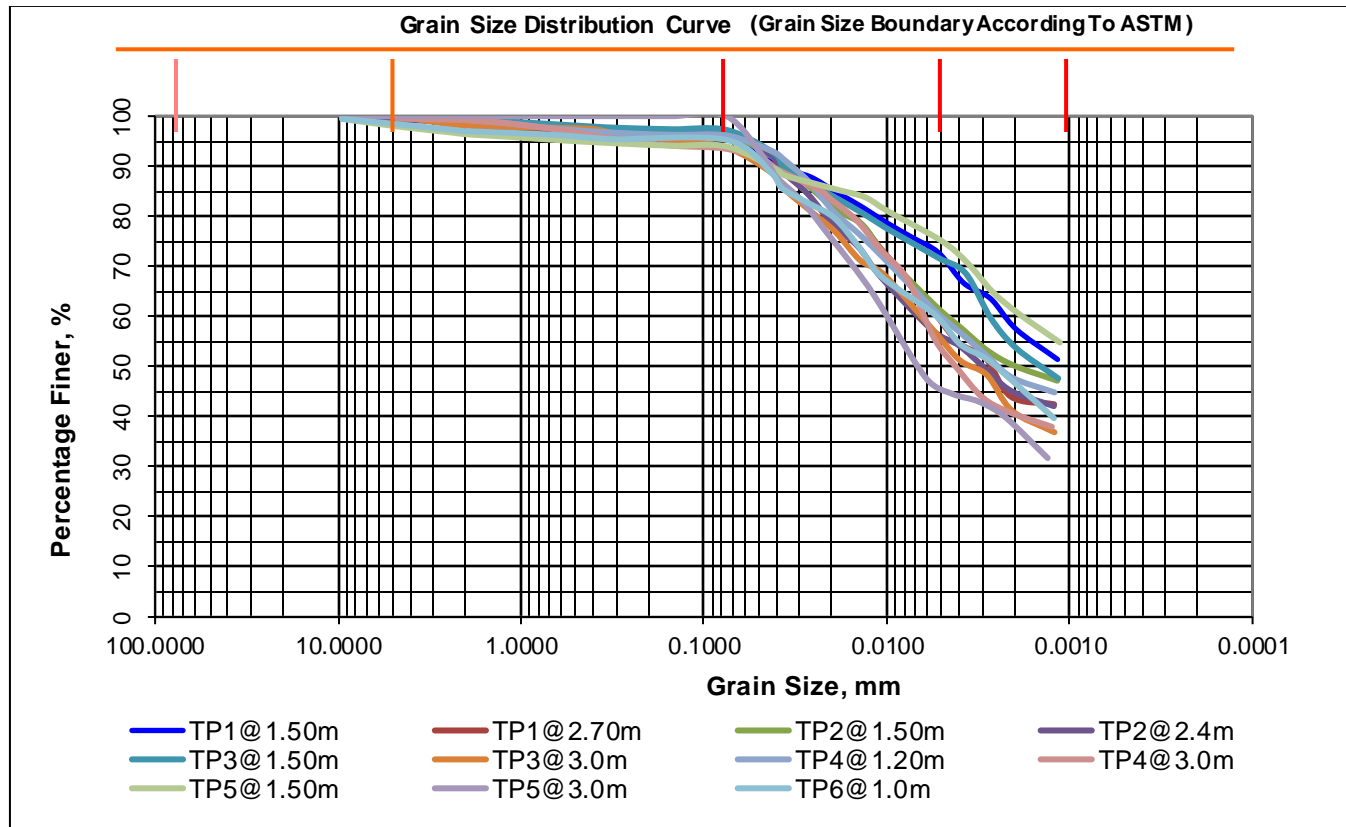


Fig. 3.2 Grain size distribution curve of all test pits

3.4.3. Atterberg Limit Tests

Atterberg limit tests were proposed by a Swedish agricultural engineer, Atterberg and mentioned that the fine grained soil can exist in four states namely liquid, plastic, semi-solid or solid state. The water contents at which the soil changes from one state to the other state is known as consistency limits or Atterberg limits [3].

From the Atterberg limit tests the liquid limit, the plastic limit and finally the plasticity index are determined. Plasticity index is important in classifying fine grained soils. The larger the plasticity index, the greater will be the engineering problems associated when using the soil as an engineering material such as foundation support for residential building and road sub-grades [6].

The liquid limit can be obtained from the plot of moisture content versus number of blows and the moisture content corresponding to the 25th blow is termed as liquid limit.

The results of the liquid limit, plastic limit and plasticity index of the study area are presented in the Table 3.2. The details of the tests are presented in Appendix-B.

Table 3.2 Atterberg Limit test result of the study area

Sample No.	Color	Sample depth(m)	Natural moisture content (%)	Liquid Limit %	Plastic Limit %	Plasticity Index (LL-PL)%
TP1	Black	1.50	51.7	106.0	27.1	78.9
TP1	Light brown	2.70	41.9	90.0	34.0	56.0
TP2	Black	1.50	48.9	98.0	30.9	67.1
TP2	Light brown	2.40	46.2	94.0	35.8	58.2
TP3	Black	1.50	49.2	102.0	29.0	73.0
TP3	Light brown	3.00	43.1	80.0	31.7	48.3
TP4	Black	1.20	47.8	92.0	32.0	60.0
TP4	Light brown	3.00	46.1	87.0	30.3	56.7
TP5	Black	1.50	50.9	108.0	31.2	76.8
TP5	Brown	3.00	40.8	80.0	34.8	45.2
TP6	Black	1.00	48.3	92.0	31.1	60.9

According to Seed, Woodward and Lundgren cited in [9], the plasticity index alone can be used as a preliminary indication of the swelling characteristics of most clays but it should be noted that high index property does not necessarily mean high swelling potential while the converse may be true.

From the results obtained from the study area most of the soils have plasticity index greater than 35 which shows that the soils have high to very high swelling potential.

3.4.4. Specific Gravity Test

The specific gravity of solid particles (G_s) is defined as mass of a given volume of solids to the mass of an equal volume of water at 4°C [3]. It is used in calculating the phase relationships of solids i.e. relative volumes of solids to water and air in a given volume of soil. Determination of specific gravity is useful to determine the diameter of soil grains in the hydrometer analysis. The results of specific gravity of the study area range from 2.66 to 2.86 and is presented in Table 3.3. The details of the tests are presented in Appendix-C.

Table 3.3 Specific Gravity test result of soils of the study area

Sample No.	Color	Sample depth(m)	Specific Gravity
TP1	Black	1.50	2.83
TP1	Light Brown	2.70	2.79
TP2	Black	1.50	2.86
TP2	Light Brown	2.40	2.78
TP3	Black	1.50	2.85
TP3	Light Brown	3.00	2.80
TP4	Black	1.20	2.77
TP4	Light Brown	3.00	2.73
TP5	Black	1.50	2.84
TP5	Brown	3.00	2.66
TP6	Black	1.00	2.80

3.4.5. Free Swell Test

Free swell test is one of the most commonly used simple tests for estimating soil swelling potential. The test is performed by pouring 10cc of dry soil passing through sieve no. 40 (0.425mm) diameter into a 100cc of graduated cylinder. Then the cylinder is filled with distilled water and swelled volume of soil is measured after a material settles for 24hrs without any surcharge.

Free swell is given by:

$$F_s = ((V - V_o) / V_o) * 100 \quad (3.1)$$

Where F_s = Free swell

V = Final Volume

V_o = Initial Volume

According to Holtz and Gibbs (1956) cited in [12], soils having free swell value between 50% to 100% may exhibit considerable expansion in the field when wetted under light loading. Although soils with free swell values below 50% are not considered to exhibit appreciable volume change.

The results of free swell tests of the soil samples range from 83% - 165% and are presented in Table 3.4. The details of the tests are presented in Appendix-D.

Table 3.4 Free Swell test result of soils of the study area

Sample No.	Color	Sample depth(m)	Free Swell (%)
TP1	Black	1.50	133
TP1	Light Brown	2.70	105
TP2	Black	1.50	165
TP2	Light Brown	2.40	120
TP3	Black	1.50	125
TP3	Light Brown	3.00	90
TP4	Black	1.20	143
TP4	Light Brown	3.00	113
TP5	Black	1.50	123
TP5	Brown	3.00	83
TP6	Black	1.00	128

3.4.5. Natural Moisture Content (NMC)

The water content has a significant effect on the behavior of fine grained soils. The swelling and shrinking behaviors of soils are mainly related to natural moisture contents.

Generally, moisture content has an influence on the swelling potential of expansive soils. Dry expansive soil has higher affinity for water and exhibits higher swelling whereas soils with higher initial moisture content has less affinity for water and exhibits less swelling.

The natural moisture content of the soil is affected by climate, vegetation cover of the area and other artificial factor. Thus it varies from season to season and is not constant.

The natural moisture content of the study area ranges from 40.8% to 51.7% and is presented in Table 3.5. The details of the tests are presented in Appendix-E.

Table 3.5 Natural Moisture Content test results of soils of the study area

Sample No.	Color	Sample depth(m)	Natural moisture content (%)
TP1	Black	1.50	51.7
TP1	Light Brown	2.70	41.9
TP2	Black	1.50	48.9
TP2	Light Brown	2.40	46.2
TP3	Black	1.50	49.2
TP3	Light Brown	3.00	43.1
TP4	Black	1.20	47.8
TP4	Light Brown	3.00	46.1
TP5	Black	1.50	50.9
TP5	Brown	3.00	40.8
TP6	Black	1.00	48.3

3.5 Soil Classification

Soil classification scheme tries to group soils into different groups where soils under the same group possess similar properties but the basis of classification depends on many factors. The Unified Soil Classification System (USCS) and the method of American Association of State Highway and Transportation Officials (AASHTO) are widely used.

3.5.1 The Unified Soil Classification System (USCS)

The USCS (Unified Soil Classification System) which was developed by Casagrande uses the liquid limit and plasticity index in order to classify soils. An A-line defined by the equation (i.e. $0.73*(LL-20)$) separates soils into silts and clays. Soils of the study area are classified using the USCS system and are presented in Fig. 3.3 and Table 3.6.

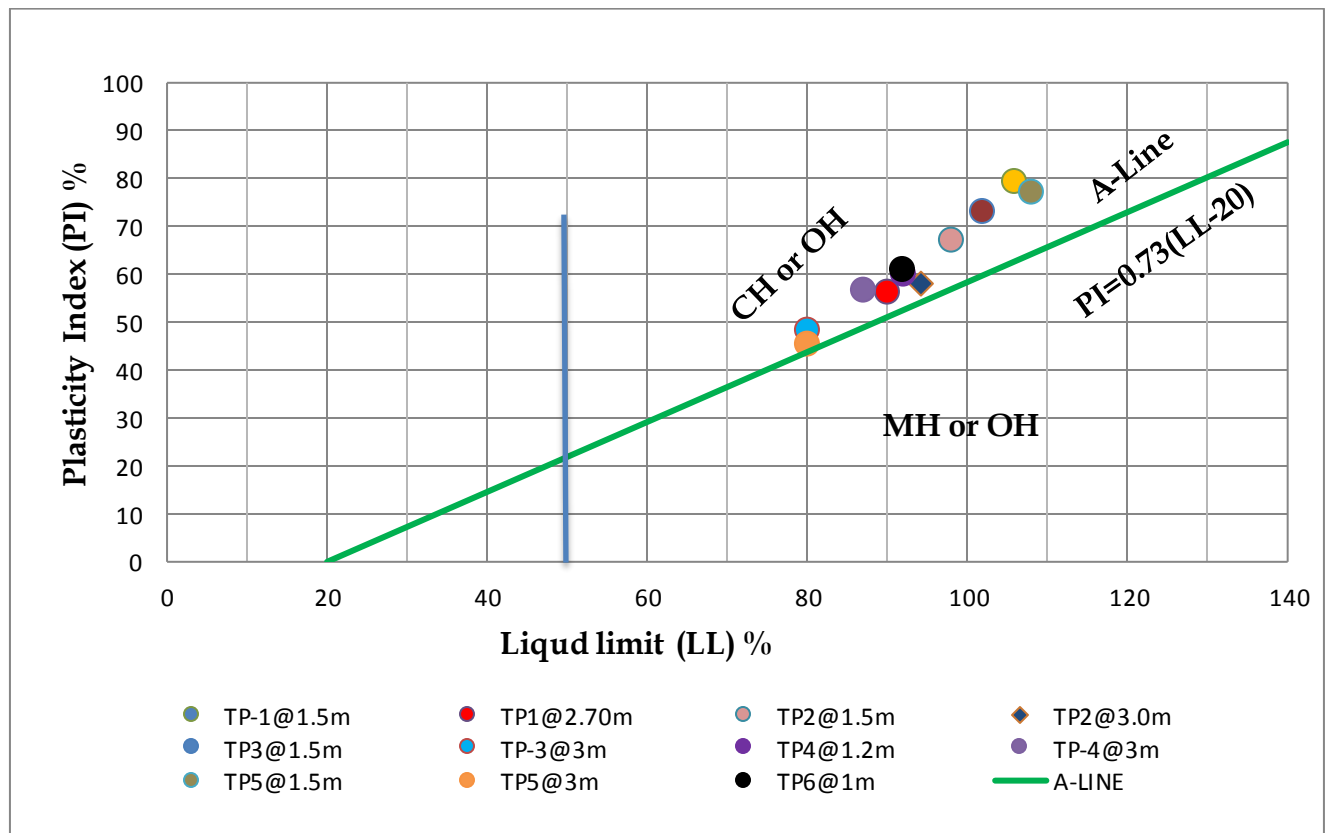


Fig. 3.3 Plasticity chart of soil of the study area according to USCS

Table 3.6 Grain Size Analysis test result and the corresponding group of soils according to USCS

Sample No.	Color	Sample depth (m)	Clay Fraction %	Silt Fraction %	Sand Fraction %	Gravel Fraction %	Classification According to USCS
TP1	Black	1.50	71.82	24.94	3.20	0	CH
TP1	Light Brown	2.70	58.77	37.23	4.0	0	CH
TP2	Black	1.50	60.63	35.67	3.38	0.32	CH
TP2	Light Brown	2.40	55.42	40.88	3.0	0.70	CH
TP3	Black	1.50	71.19	25.99	2.82	0	CH
TP3	Light Brown	3.00	55.0	38.70	6.30	0	CH
TP4	Black	1.20	59.89	36.21	3.90	0	CH
TP4	Light Brown	3.00	53.57	40.43	6.0	0	CH
TP5	Black	1.50	75.0	18.19	4.0	2.1	CH
TP5	Brown	3.00	45.68	54.32	0	0	CH
TP6	Black	1.00	58.47	36.73	3.20	1.6	CH

3.5.2 The AASHTO classification system

The AASHTO system is mainly used for classifying soils for highway purposes and uses the results of sieve analysis, plasticity index and liquid limits to classify soils.

This method classifies soils into seven groups from A-1 to A-7. Groups A-4 to A-7 depends both on the values of plasticity and the amount of soil passing sieve No. 200. A-7 can either be A-7-5 or A-7-6.

The system also uses a group index (GI) to rate a soil qualitatively with in a group. GI is given by the equation

$$GI= (F-35) [0.2+0.005(W_L-40)] + 0.01(F-15) (I_p-10) \quad (3.2)$$

Where F= Percent passing No.200 sieve

If $F < 35$, use $F-35=0$

W_L = Liquid Limit in %

I_p = Plasticity Index in %

The AASHTO system is highly adapted for classifying soils for highways. The maximum values of F-35 and F-15 are taken as 40 and W_L-40 and I_p-10 as 20. The smaller the value of group index, the better the soil as sub grade material.

If plasticity index is equal to or less than $(LL-30)$, the soil is A-7-5 (i.e. $PL > 30\%$) and if plasticity index is greater than $(LL-30)$, the soil is A-7-6 (i.e. $PL < 30\%$). The classification according to AASHTO is presented in Table 3.7.

Table 3.7 AASHTO classification of soils of the study area

Sample No.	Color	Sample depth	Liquid Limit %	Plasticity index %	Soil Classification	Group Index (GI)
TP1	Black	1.50	106.0	79.0	A-7-5	89
TP1	Light Brown	2.70	90.0	56.0	A-7-6	65
TP2	Black	1.50	94.0	67.0	A-7-6	77
TP2	Light Brown	2.40	98.0	58.0	A-7-6	69
TP3	Black	1.50	87.0	73.0	A-7-5	84
TP3	Light Brown	3.00	80.0	48.0	A-7-6	55
TP4	Black	1.20	92.0	60.0	A-7-6	70
TP4	Light Brown	3.00	87.0	57.0	A-7-6	64
TP5	Black	1.50	87.0	77.0	A-7-6	86
TP5	Brown	3.00	80.0	45.0	A-7-6	57
TP6	Black	1.00	92.0	61.0	A-7-6	70

3.5.3 Classification Using Plasticity Index

This classification system uses the method proposed by Chen [6] which uses plasticity index as its bases for classifying soils. The results of soils of the study area are presented in Table 3.8 which shows the swelling behavior.

Table 3.8 Swelling potential of soils of the study area based on the method proposed by Chen (1998).

Sample No.	Color	Sample depth(m)	Plasticity Index %	Swelling Potential
TP1	Black	1.50	78.9	Very high
TP1	Light Brown	2.70	56.0	Very high
TP2	Black	1.50	67.1	Very high
TP2	Light Brown	2.40	58.2	Very high
TP3	Black	1.50	73.0	Very high
TP3	Light Brown	3.00	48.3	High
TP4	Black	1.20	60.0	Very high
TP4	Light Brown	3.00	56.7	Very high
TP5	Black	1.50	76.8	Very high
TP5	Brown	3.00	45.2	High
TP6	Black	1.00	60.9	Very high

3.5.4. Other Classification Systems

This method proposed by Skempton [2] classifies soils according to their activity. He established three degrees of colloidal activity and is presented below in Table 4.4.

$$A = I_p / C \quad (3.3)$$

Where A= Activity

I_p= Plasticity index

C= Percent of clay fraction finer than 2 micron

This classification method is presented in the form of a chart known as activity chart where the clay fraction (as abscissa) and the plasticity index (as ordinate).

Table 3.9 Activity and Degree of Activity

Degree of activity	Activity
Inactive Clay	Less than 0.75
Normal Clay	0.75-1.25
Active Clay	Greater than 1.25

The results of activity of soils of the study area are presented in Table 3.10.

Table 3.10 Result of Degree of Activity of soils of the study area

Sample No.	Color	Sample depth (m)	Clay Fraction %	Plasticity Index %	Activity	Degree of Activity
TP1	Black	1.50	57.51	78.9	1.37	Active
TP1	Light Brown	2.70	43.75	56.0	1.29	Active
TP2	Black	1.50	50.15	67.1	1.34	Active
TP2	Light Brown	2.40	44.77	58.2	1.30	Active
TP3	Black	1.50	54.07	73.0	1.35	Active
TP3	Light Brown	3.00	40.70	48.3	1.19	Normal
TP4	Black	1.20	45.80	60.0	1.31	Active
TP4	Light Brown	3.00	44.65	56.7	1.27	Active
TP5	Black	1.50	56.89	76.8	1.35	Active
TP5	Brown	3.00	38.96	45.2	1.16	Normal
TP6	Black	1.00	46.90	60.9	1.30	Active

The activity of soil of the study area is presented in the form of chart shown in Fig. 3.4.

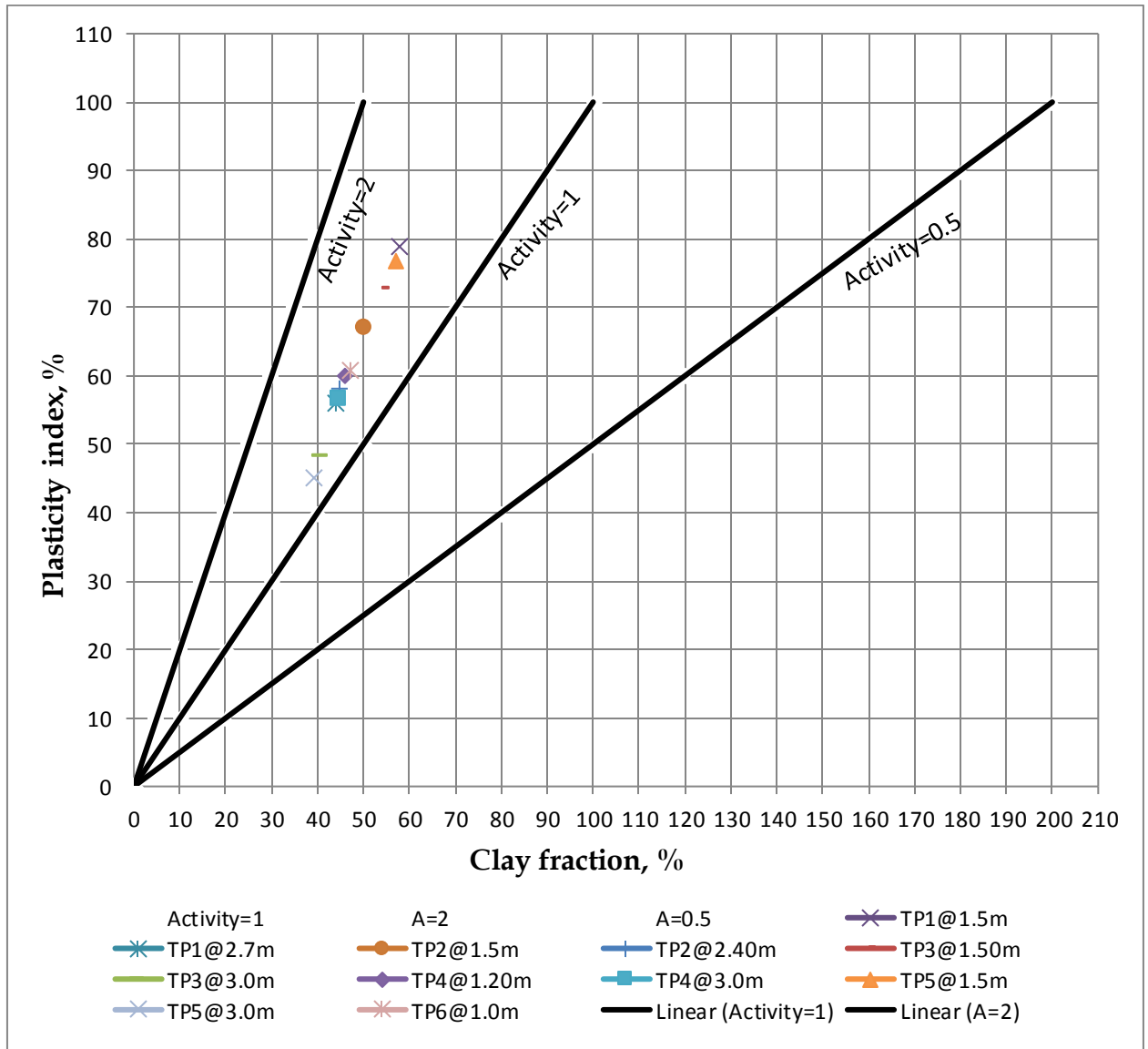


Fig. 3.4 Activity Chart

3.5.5 Soil Map of Sheno town

The types of soil of the study area are identified while digging test pits and taking samples to the laboratory. It was then simple to clearly see the layers i.e. the depths at which the color of soil changes from black to light brown or brown and also the depths at which the rocky layers occur. The observed color of soil beneath the black soils is shown in Fig. 3.5.



Fig. 3.5 Observed soil color (light brown) of the study area beneath the black clay soil

Areas up to a depth of 1.5m are delineated according to the type of soil, the depths at which the rocky layers occur and are shown on the tentative soil map of Sheno town in Fig. 3.6



**TENTATIVE SOIL MAP OF SHENO TOWN
UP TO A DEPTH OF 1.5M**

KEY

ZONE ONE : ROCKY SURFACE

ZONE TWO: BLACK COTTON SOIL

**ZONE THREE : ROCKY LAYER AT
A DEPTH OF 0.4M BELOW NGL**

**ZONE FOUR : ROCKY LAYER AT
A DEPTH OF 1 M BELOW NGL**

Fig. 4.4 TENTATIVE SOIL MAP OF SHENO TOWN

3.6 Unconfined Compressive Strength Test

The unconfined compressive test is a special form of unconsolidated–undrained triaxial compression test in which the confining pressure is zero and is only applicable to clayey soils which do not need any confinement during testing of the specimen.

$$q_u = P/A \quad (3.4)$$

Where q_u = Unconfined compressive strength (kPa)

P = Compressive force (kN)

A = Cross sectional area (m^2)

As the area of the specimen changes throughout the test the average cross sectional area at a particular deformation during the test is calculated using:

$$A = A_o / (1 - \epsilon) \quad (3.5)$$

Where A = Corrected cross sectional area (m^2)

A_o = original cross sectional area (m^2)

ϵ = Axial strain (mm/mm), $\epsilon = \Delta L / L_o$

The graph is plotted and is shown in Fig. 3.7 for all test pits.

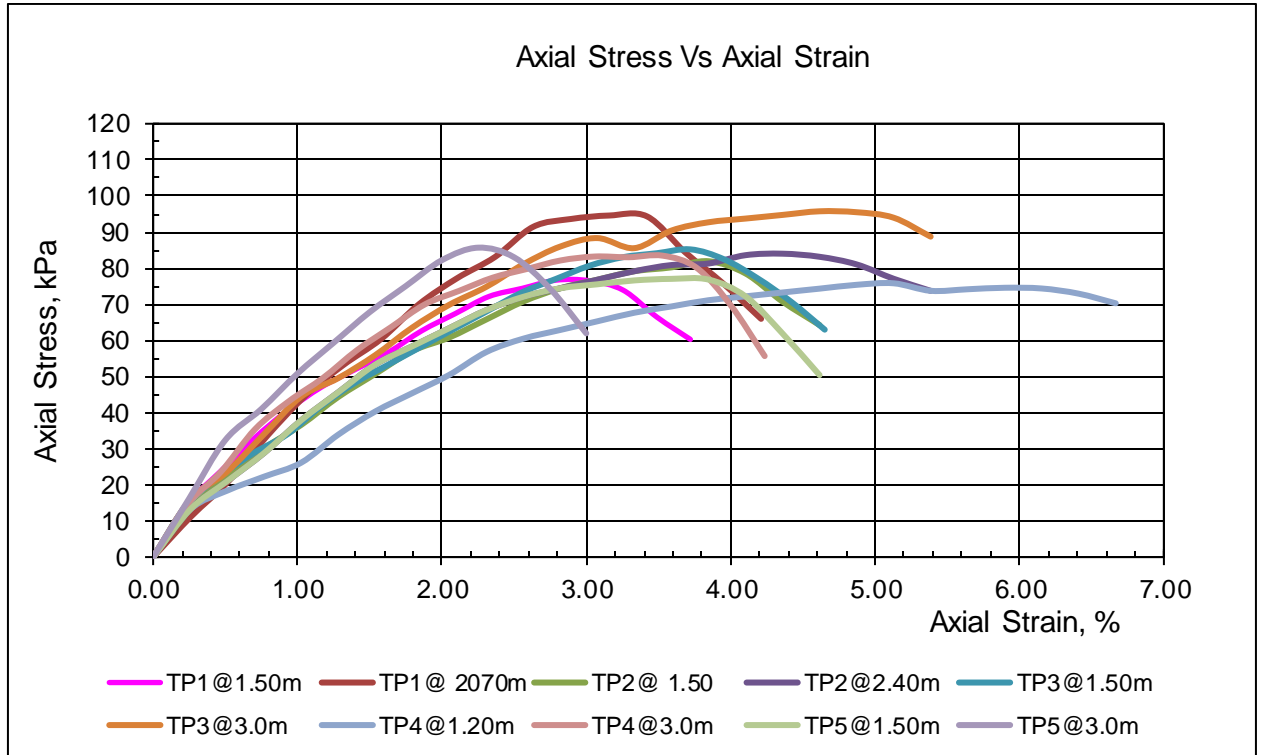


Fig. 3.7 Stress-Strain curve for unconfined compressive strength test of the study area

The results obtained can be used to estimate the bearing capacity of spread footings and other structures founded on the deposits of cohesive soils. The results of unconfined compressive strength of soils of the study area range from 72 kPa to 93 kPa and are presented in Table 3.11. The details of the tests are presented in Appendix-F.

Table 3.11 Unconfined compressive strength test results of soils of the study area

Sample No.	Color	Sample depth(m)	Qu (kPa)
TP1	Black	1.50	78.0
TP1	Light Brown	2.70	91.0
TP2	Black	1.50	76.0
TP2	Light Brown	2.40	90.0
TP3	Black	1.50	83.0
TP3	Light Brown	3.00	93.0
TP4	Black	1.20	72.0
TP4	Light Brown	3.00	82.0
TP5	Black	1.50	76.0
TP5	Brown	3.00	85.0

3.7 Determination of swelling pressure by swell-consolidation method

The available techniques for quantitative measurement of expansive soils can be categorized into three groups, namely, oedometer tests, soil suction tests and empirical methodology. Among these techniques the oedometer tests are capable of simulating some of the factors which affect the swelling characteristics of expansive soils.

ASTM defines swelling pressure as a pressure which prevents the specimen from swelling or that pressure which is required to return the specimen back to its original state after swelling [3]. Swelling pressure can also be defined as the amount of pressure a soil exerts upon swelling.

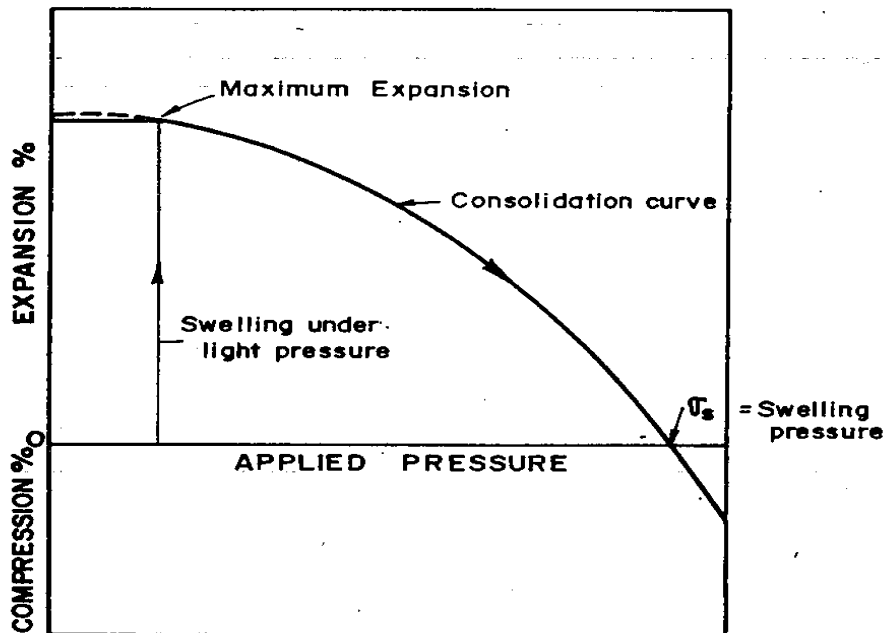


Fig. 3.8 Determination of swelling potential by swell-consolidation method

The results of the test are presented in **e-log p** in graph form where **e** is plotted to the natural scale and **p** is plotted to the logarithmic scale. Finally, the preconsolidation pressure (**P_c**), compression index (**C_c**) and the swelling pressure are obtained from the e-log p curve. The compression index (**C_c**) is numerically equal to the slope of the straight line portion of the e-log p curve and is important to calculate the ultimate settlement of foundations founded on clay layers. From the graph of the e-log p curve the compression index is calculated and is shown in Fig 3.9.

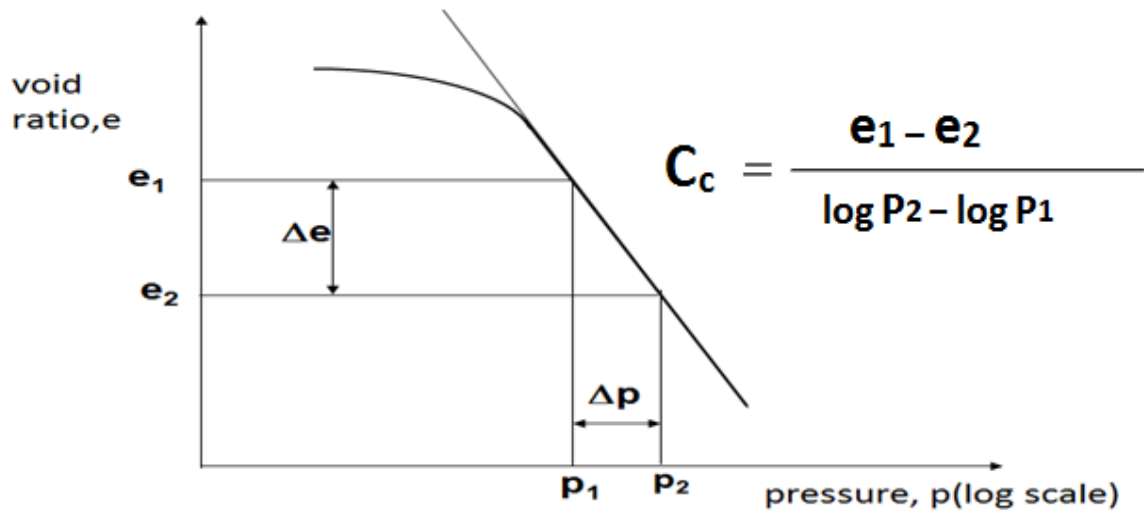


Fig. 3.9 e-log P curve for swelling pressure test

Swell- consolidation tests are conducted for three test pits among the six at a depth of 3m. The results of the tests are presented in table 3.12 and the details are attached in Appendix-G.

Table 3.12 Result of One Dimensional consolidation test of soils of the study area

Sample No.	Depth(m)	Swelling Pressure (kPa)	Pre consolidation Pressure(Pc) kPa	Compression Index(Cc)
TP1	2.7m	200	270	0.346
TP2	2.4m	140	290	0.389
TP5	3.0m	70	150	0.285

From the e-log p graph one can read the pre-consolidation pressure and swelling pressure as shown in the figure below (Fig 3.9 – 3.11).

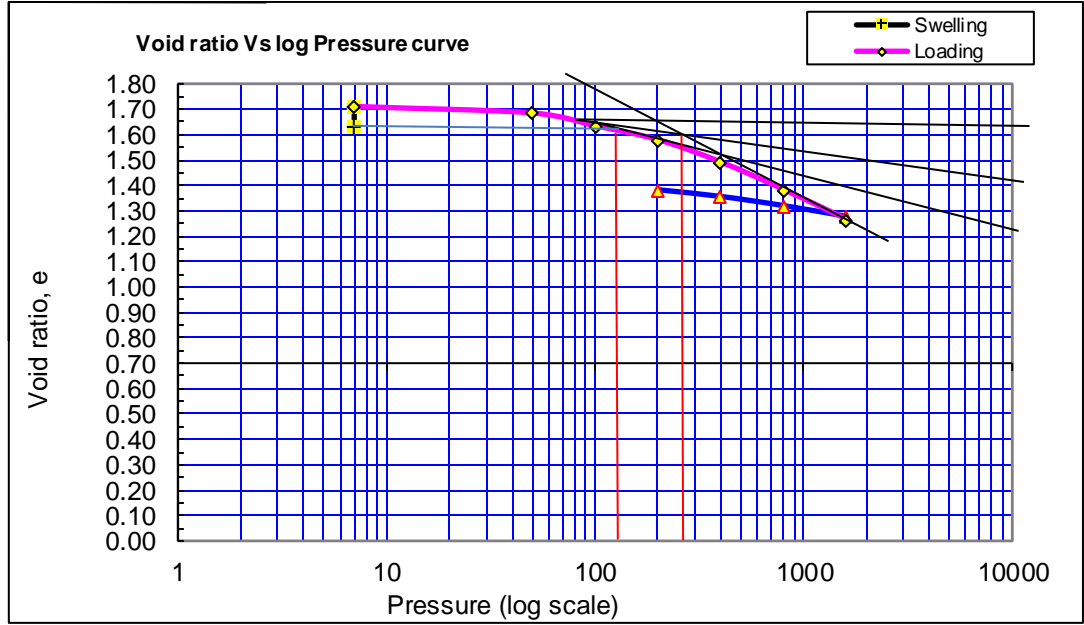


Fig.3.10Plot of void ratio versus log-pressure for TP2 (w=46.20%)

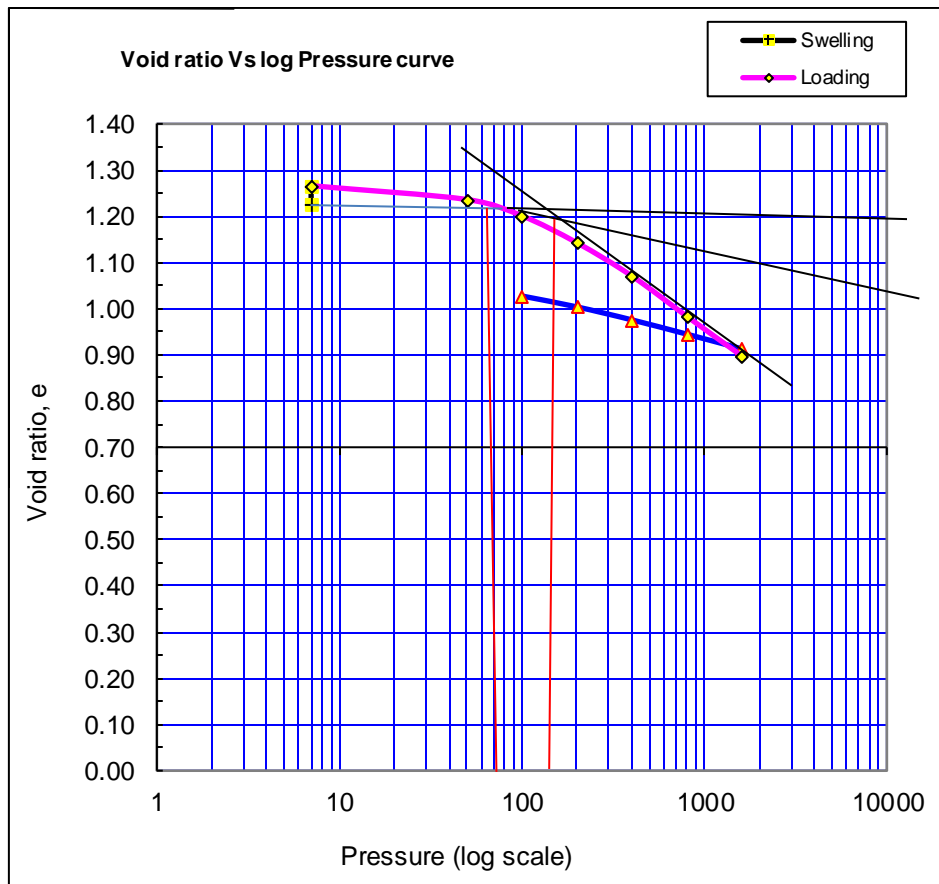


Fig.3.11 Plot of void ratio versus log-pressure for TP5 (w=40.8%)

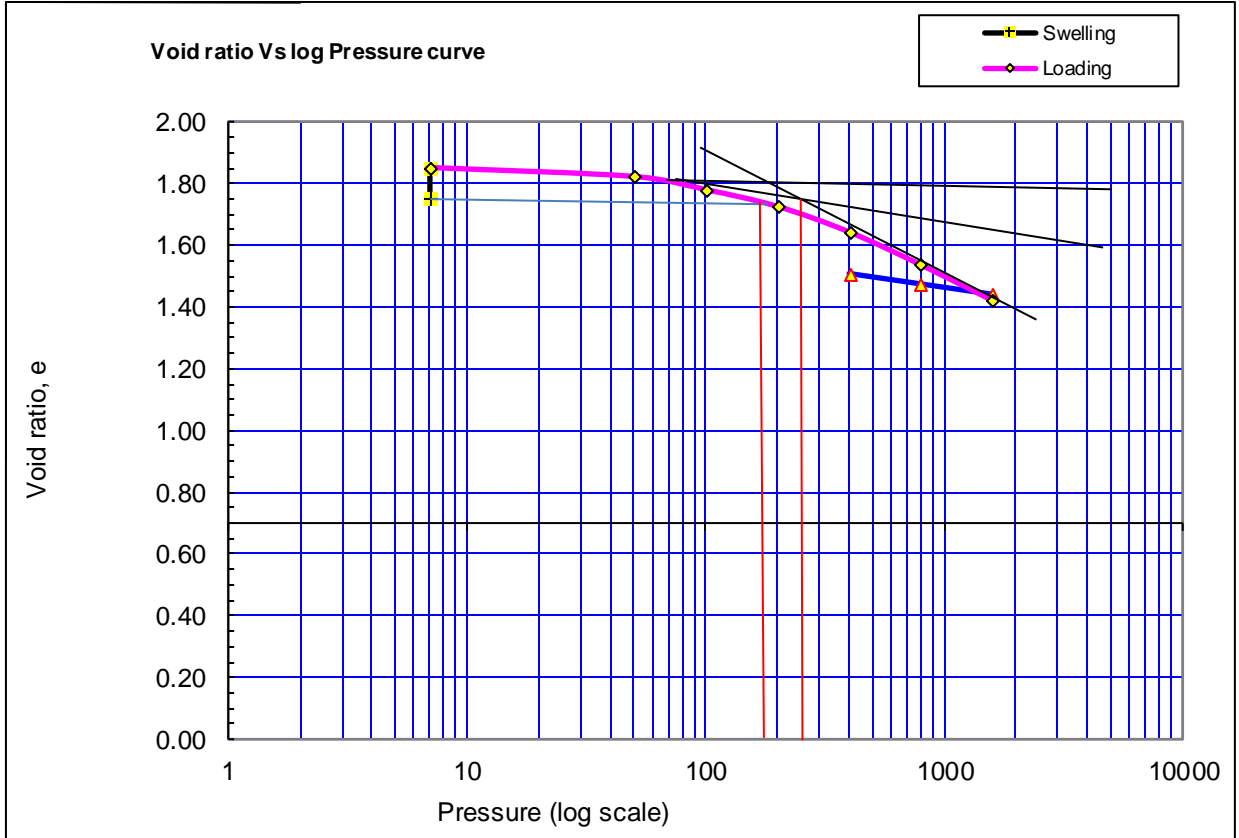


Fig.3.12 Plot of void ratio versus log-pressure for TP1 (w = 41.9%)

4. DISCUSSIONS ON LABORATORY TESTS

The results obtained from the grain size analysis shows that the clay content ranges from 45.68% to 75%, the silt content ranges from 18.19% to 54%, the sand content ranges from 0% to 4% and the gravel content ranges from 0% to 2.1%. According to the results obtained soils of the study area under investigation have higher contents of clays than silts indicating the swelling behavior of soils.

It is also observed that with increasing the clay content the liquid limit increases due strong intermolecular attraction forces.

The results obtained from Atterberg limit tests of soils of the study area, the liquid limit (LL) ranges from 80% to 108%, the plastic limit (PL) ranges from 27.10% to 35.8% and the plasticity index (PI) ranges from 45.2% to 78.9%. According to the results obtained the higher values of plasticity index indicate the very high swelling potential of soils. The higher values of plasticity index also shows the higher content of clays.

The natural moisture content of a soil varies from season to season which means the same soil could have different moisture content values. The natural moisture content depends upon external factors like temperature & topography. The test results shows that the natural moisture content of soils on the top layer is higher than those below due the fact that soil samples were taken immediately after the rainy season stops but the soil on top layer will lose moisture during the dry season indicating the values of natural moisture contents get lesser than the soil below.

The specific gravity of soils of the study area ranges from 2.66% to 2.86%. Accordingly soils with specific gravity > 2.65 are grouped as inorganic clays or inorganic silts but soils of the study area fall above the A-line in the plasticity chart and are inorganic clays. It is also observed that the black soils have higher values than the light brown ones.

The free swell values of soils of the study area ranges from 83% to 165%. According to Chen (1988) soils undergoes higher swelling potential and also from Holtz and Gibbs (1956), soils

having free swell values of 100% can cause considerable damage. It is also observed the black soils of the study area have higher values of free swell the light brown soils.

From the classification tests on soil samples of the study area, soils fall under CH group (Clays with high plasticity) when classifying using the unified soil classification system and under group A-7 when classifying soils with AASHTO system. Soils under group A-7 cannot be used as sub-grade material for highway construction and also as selected material fill for building constructions.

Classifying soils of the study area using activity chart indicate 80% of soils of the study area are active possessing higher swelling.

The results obtained from the unconfined compressive strength tests of soils of the study area ranges from 72% to 93% indicating the consistency of soils as firm.

The natural moisture content has an effect on the swelling pressure of soils. The values of the natural moisture content obtained range from 40.8% to 51.7%. Swelling pressure tests conducted at test pits (TP-1, TP-2 & TP-5) also shows that soils with lower initial moisture content have higher swelling pressures than soils with higher natural moisture contents as these soils are subjected to pre-swelling and further swelling is minimized.

From the swelling pressure tests conducted tests on the soil samples the compression index (C_c) ranges from 0.285 to 0.389. The pre-consolidation pressure of the study area ranges from 150 kPa to 290 kPa.

It is necessary to compare results with the previously conducted researches in order to increase the level of reliability and to get range of values of a specific location. In this research work range of values of expansive soils of Addis Ababa is taken for comparison purposes even though reliability of this research work is measured on researches conducted on the nearby areas.

Range of values of the results of Atterberg limit tests conducted at Addis Ababa and those measured at Sheno are presented in Table 5.1.

Table 5.1 Range of values of index properties of expansive soils of Addis Ababa and the test results of Sheno Town according to this study.

Soil index property	Legesse (2004)	Aynew (2004)	Daniel (2004)	Habtamu (2006)	Jemal (2011)	Sheno Town
LL (%)	96-121	96-121	86-121	90-110	80-99	80-108
PL (%)	24-29	24-37	26-47	29-40	29-40	27-36
PI (%)	70-87	70-84	54-84	60-74	45-63	45-78
FS (%)	75-140			90-105	110-183	83-165
Clay Content					44-78	46-75

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

- The results obtained from the laboratory tests conducted indicate that most parts of the town is covered by expansive soils but the expansive behavior of soils decrease with depth from the natural ground level i.e the black soils are more expansive than the light brown soils.
- Both the black soils as well as the light brown soils are expansive but the degree of expansiveness decrease as the color of soil changes from black to light brown.
- While classifying or grouping based on laboratory test results, soils may fall above the A-line in the plasticity chart even though the percentage of silts is higher than clays. Therefore, one cannot conclude by undertaking the hydrometer analysis only and further tests may be necessary like chemical composition test depending upon the importance of the structure.
- Soils of the town under investigation do not fulfill the criteria to be used as an engineering material either as selected material fill or sub-grade for highway constructions.

5.2 Suggestions and recommendations

- During construction activities it is necessary to replace or remove the upper part of soils with good quality selected material and properly compacting in order to prevent water entering the foundation.
- For light weight structures (G+0 and ware houses) it is necessary to provide reinforced concrete beam beneath the peripheral masonry as it increases the surcharge load and also

prevents differential settlement thus preventing the cracking of masonry itself and also the walls.

- It is necessary to avoid the water entering to the foundation either by providing proper drainage channels or treating walls subjected to moisture by membranes and painting walls by chemicals.
- In order to get reliable values for the laboratory tests conducted, it is better to repeat tests as much as possible in order to avoid test result contradictions that may appear within the same test pit.
- To increase the level of accuracy with respect to the range of values obtained, it is highly recommended to undertake further researches with greater number of test pits in order to make the proposed soil map complete.
- Care should be taken while collecting undisturbed soil samples from the field as well as transporting undisturbed samples to the laboratory as some disturbances due to improper handling may alter laboratory test results.
- During construction activities it is necessary to replace the upper part of soils with good quality soils to a depth of 1.0m or even more depending upon structural units being constructed.

REFERENCES

1. AASHTO, (1993). American Association of State Highway and Transportation Officials.
2. Arora, K.R., Soil Mechanics and Foundation Engineering: Standard Publishers Distributors, New Delhi.
3. ASTM, (1996). American Society for Testing and Material: Annual Book of ASTM Standards.
4. Bowles, J.E., (1996). Foundation Analysis and Design: Fifth Edition, The McGraw-Hill companies Inc.
5. Bowles, J.E., (1984). Engineering properties of soils and their measurement. 4th ed. McGraw-Hill book company, New York.
6. Chen, F.H, (1998). Foundation on Expansive Soils: Elsevier Science Publishers.
7. Das, B.M., (1997). Advanced soil mechanics. Taylor and Francis publishers, Philadelphia.
8. EMA, Ethiopian Meteorological Agency.
9. Gebrekirstos, K.,(2005). Investigation into the Engineering Properties of Mekelle Soils with Emphasis on Expansive Soil. Unpublished M.Sc Thesis, Addis Ababa University.
10. Legesse, M., (2004). Investigation on Index properties of Expansive soils of Ethiopia, M.Sc Thesis, Addis Ababa University, Addis Ababa.
11. Negussie, D.,(2007).In depth Investigation of Relationship between Index Property and Swelling Characteristic of Expansive Soil in Bahir Dar. Unpublished M.Sc. Thesis, Addis Ababa University.
12. Nelson, D.J. and Debora, J.M., (1992). Expansive Soils Problems and Practice in Foundation and Pavement Engineering: John Wiley and sons, Inc., New York.
13. Teferra, A. and Leykun, M., (1999). Soil Mechanics. AAU: Printing Press.
14. Yasin, J., (2011).Relationship between Shrinkage Index and Swelling Pressure for Expansive Soil Found in Addis Ababa. Unpublished M.Sc Thesis, Addis Ababa University.

APPENDIX

Appendix-A

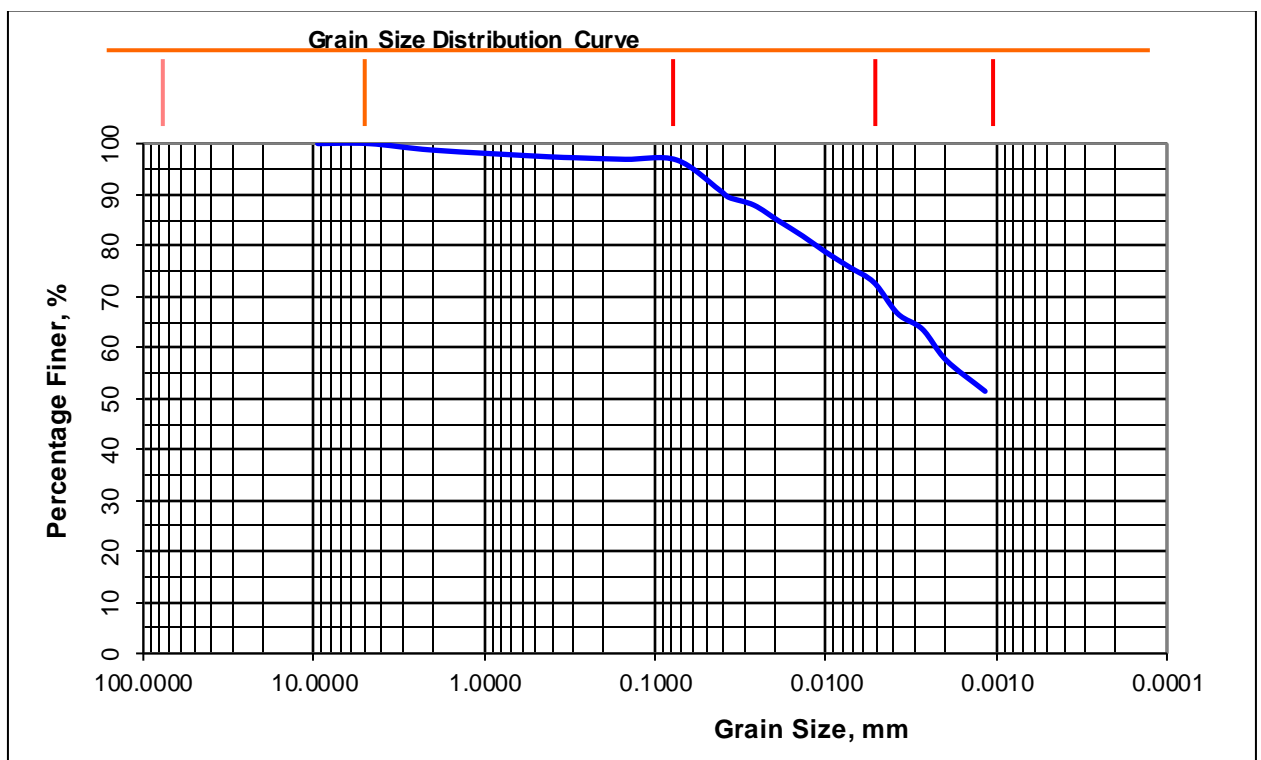
Grain Size Analysis

Test pit no. TP1

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 1.5m



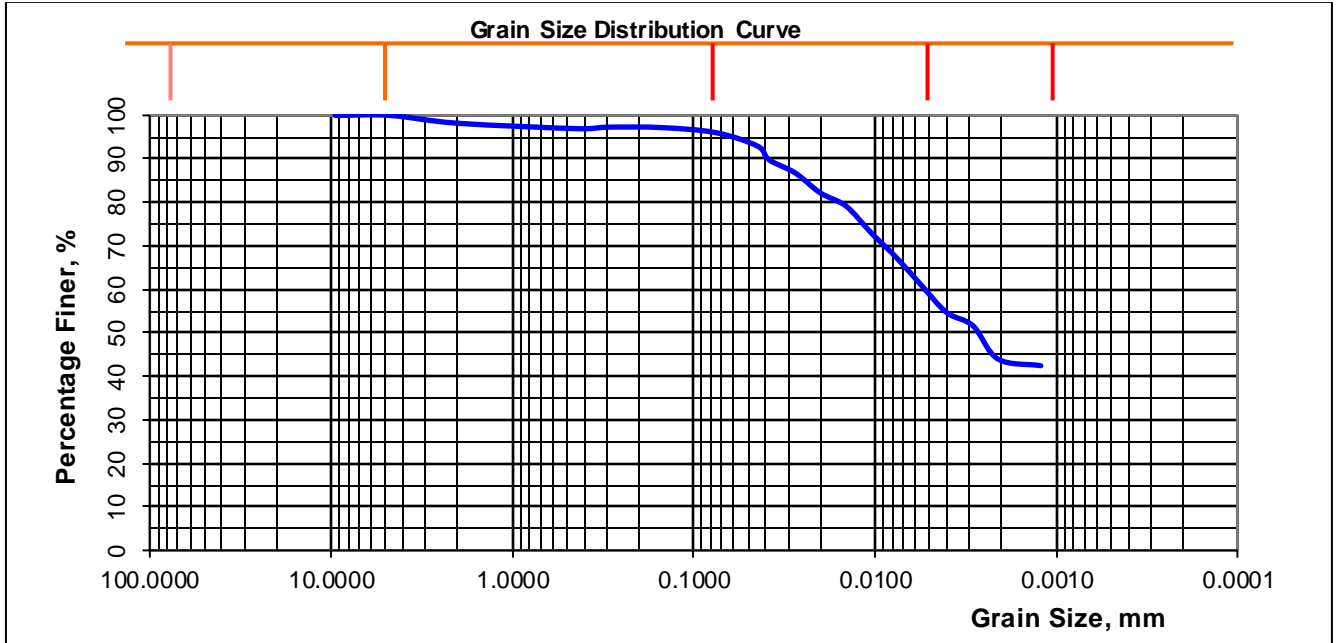
% Clay	% Silt	% Sand	% Gravel
71.82	24.94	3.20	0

Test pit no. TP1

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 2.7m



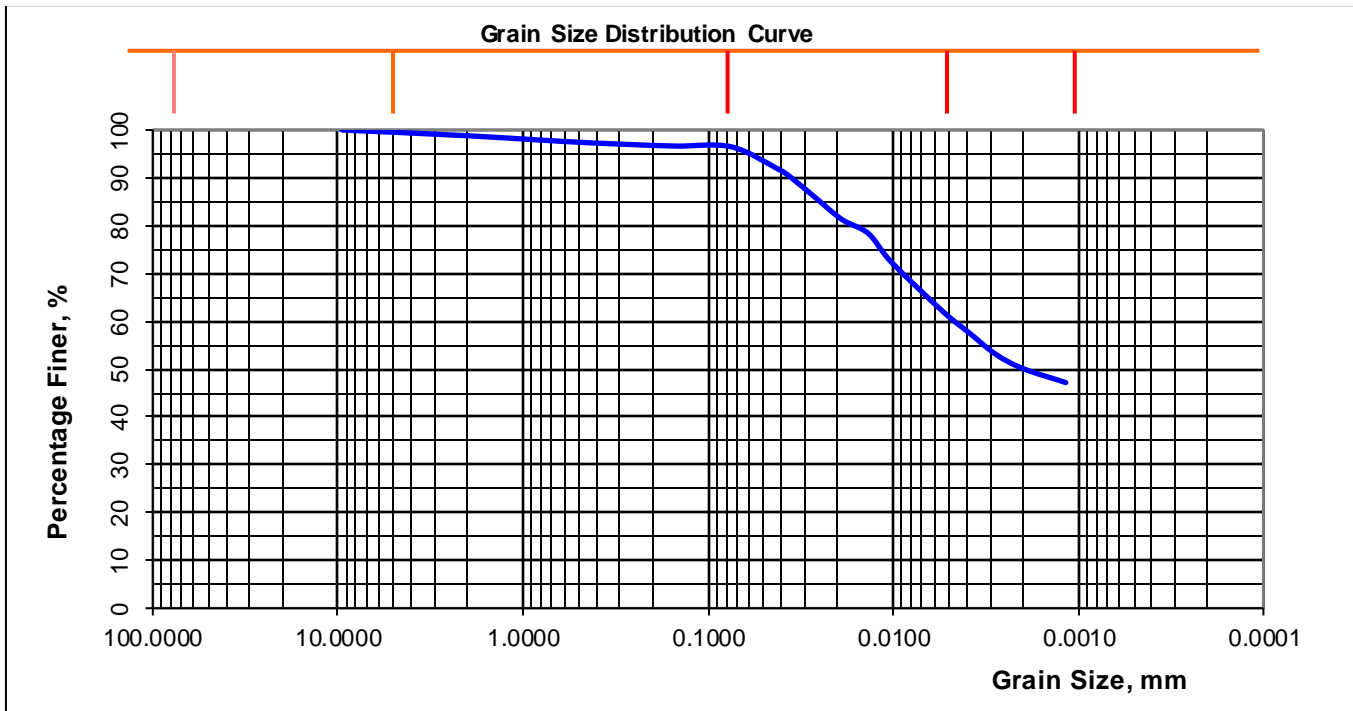
% Clay	% Silt	% Sand	% Gravel
58.77	37.23	4.0	0

Test pit no. TP2

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 1.5m



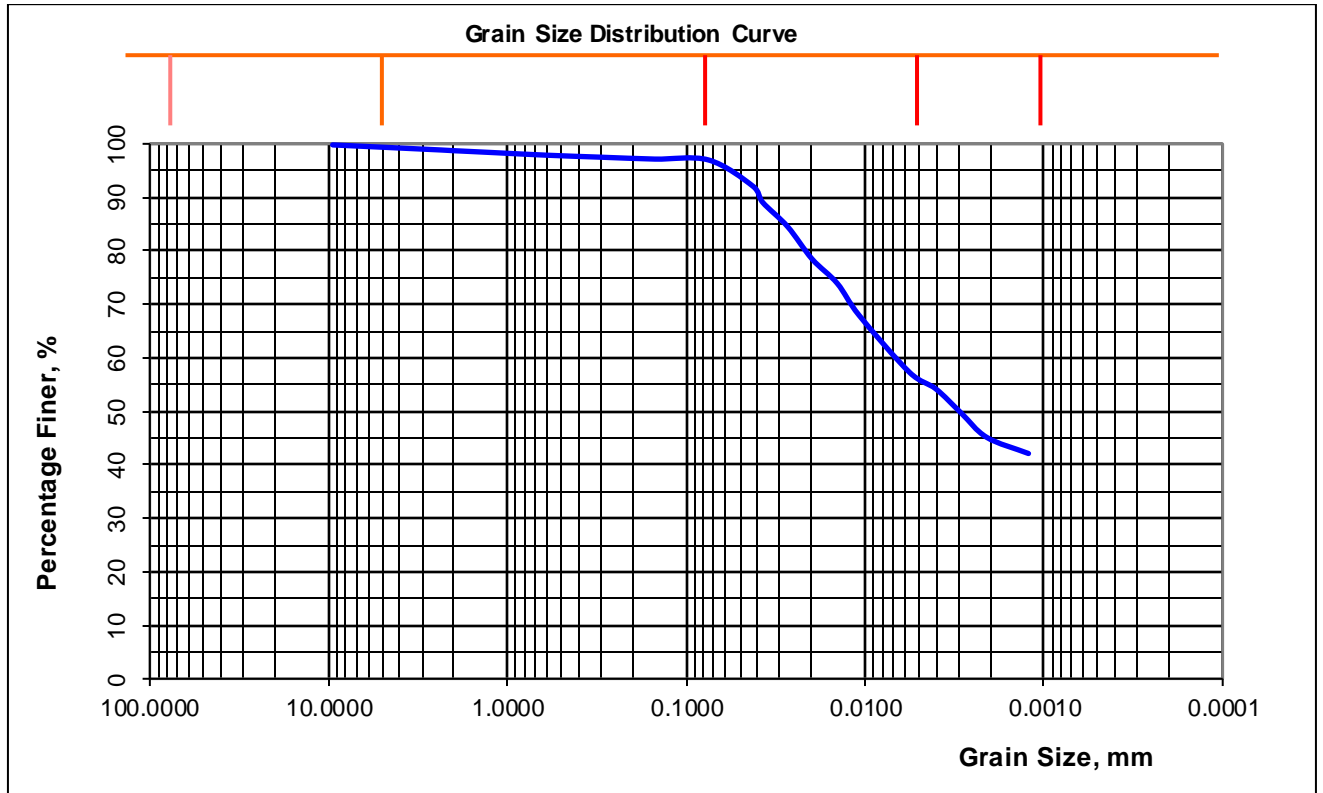
% Clay	% Silt	% Sand	% Gravel
60.63	35.67	3.38	0.32

Test pit no. TP2

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 2.4m



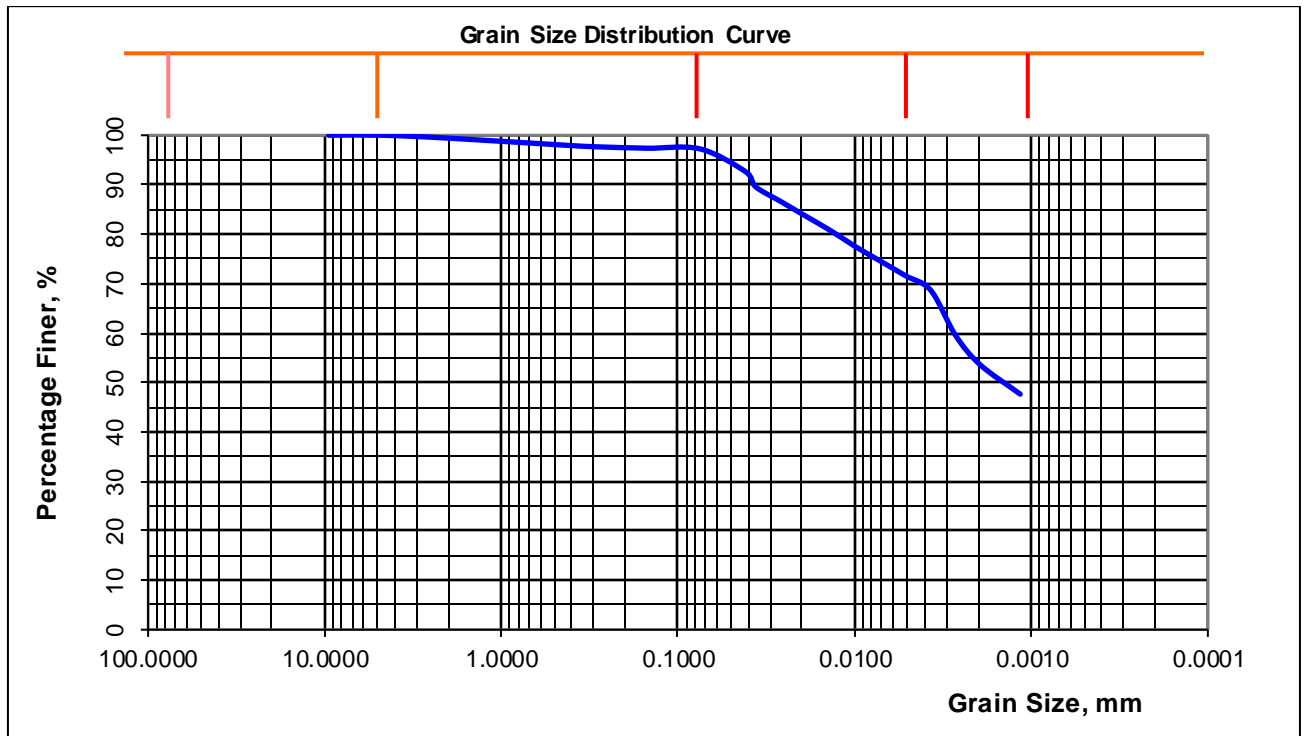
% Clay	% Silt	% Sand	% Gravel
55.42	40.88	3.0	0.7

Test pit no. TP3

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 1.5m



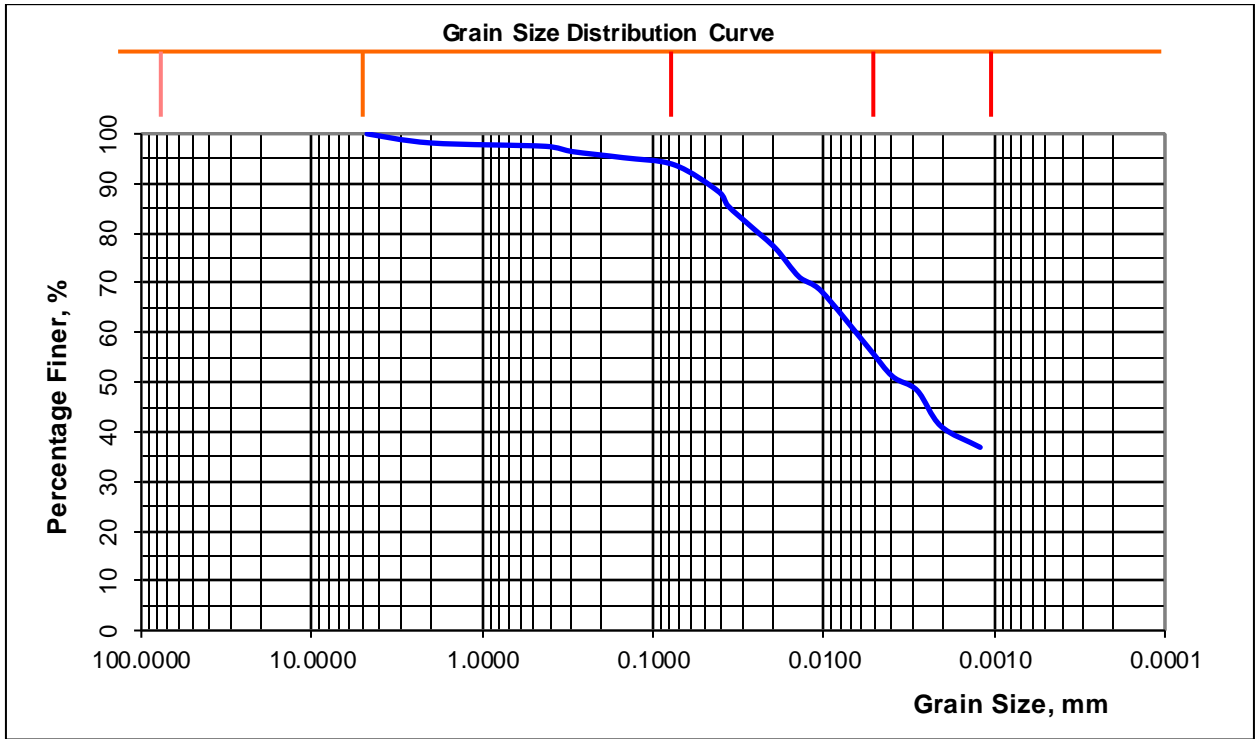
% Clay	% Silt	% Sand	% Gravel
71.19	25.99	2.82	0

Test pit no. TP3

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 3.0m



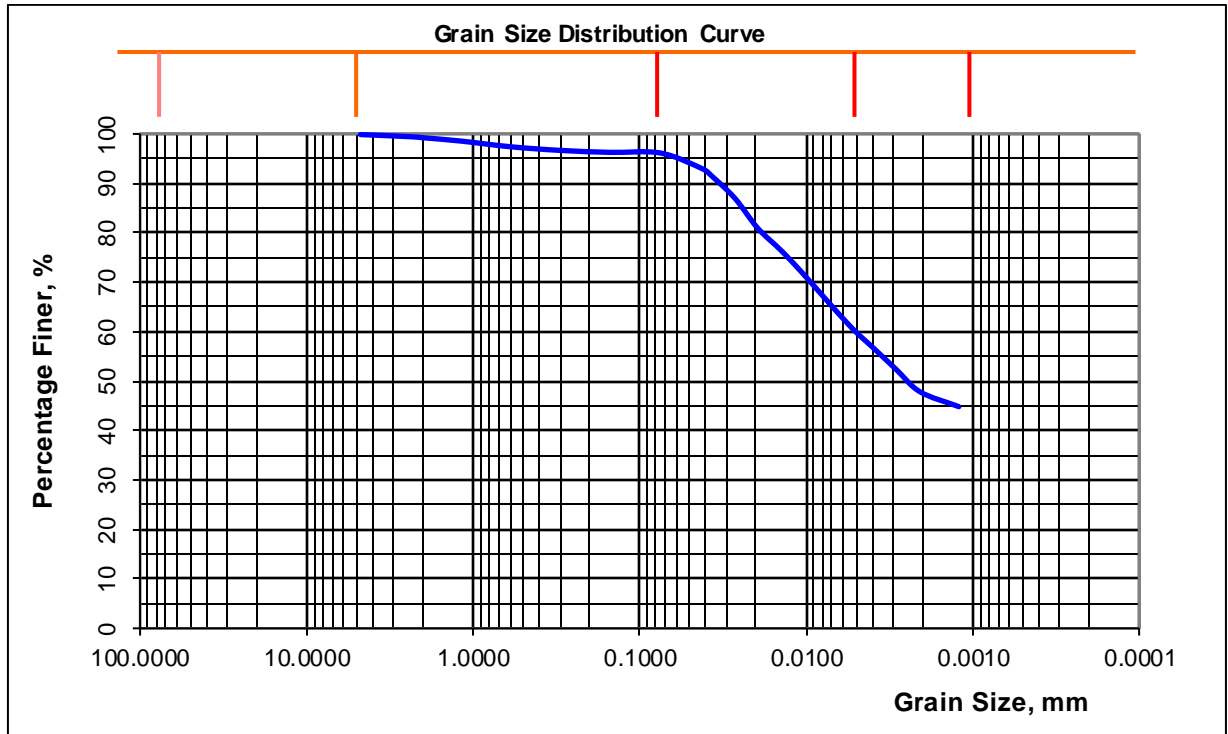
% Clay	% Silt	% Sand	% Gravel
55.00	38.70	6.30	0

Test pit no. TP4

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 1.2m



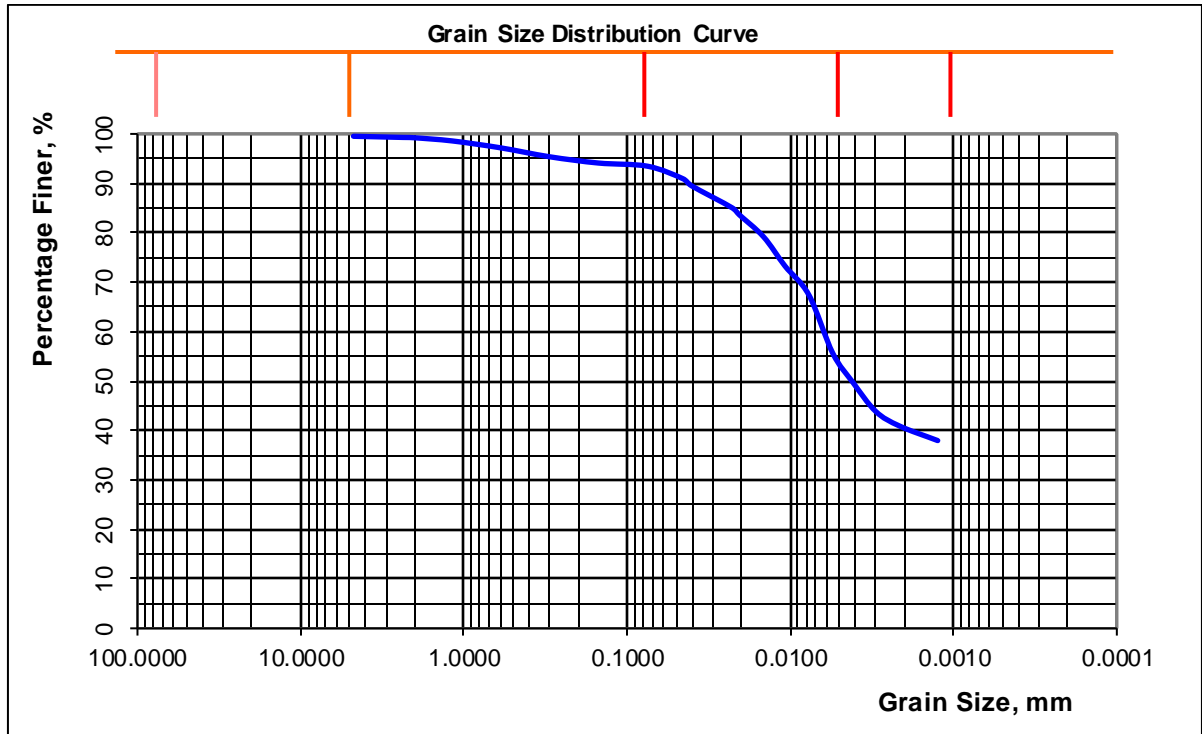
% Clay	% Silt	% Sand	% Gravel
59.89	36.21	3.90	0

Test pit no. TP4

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 3.0m



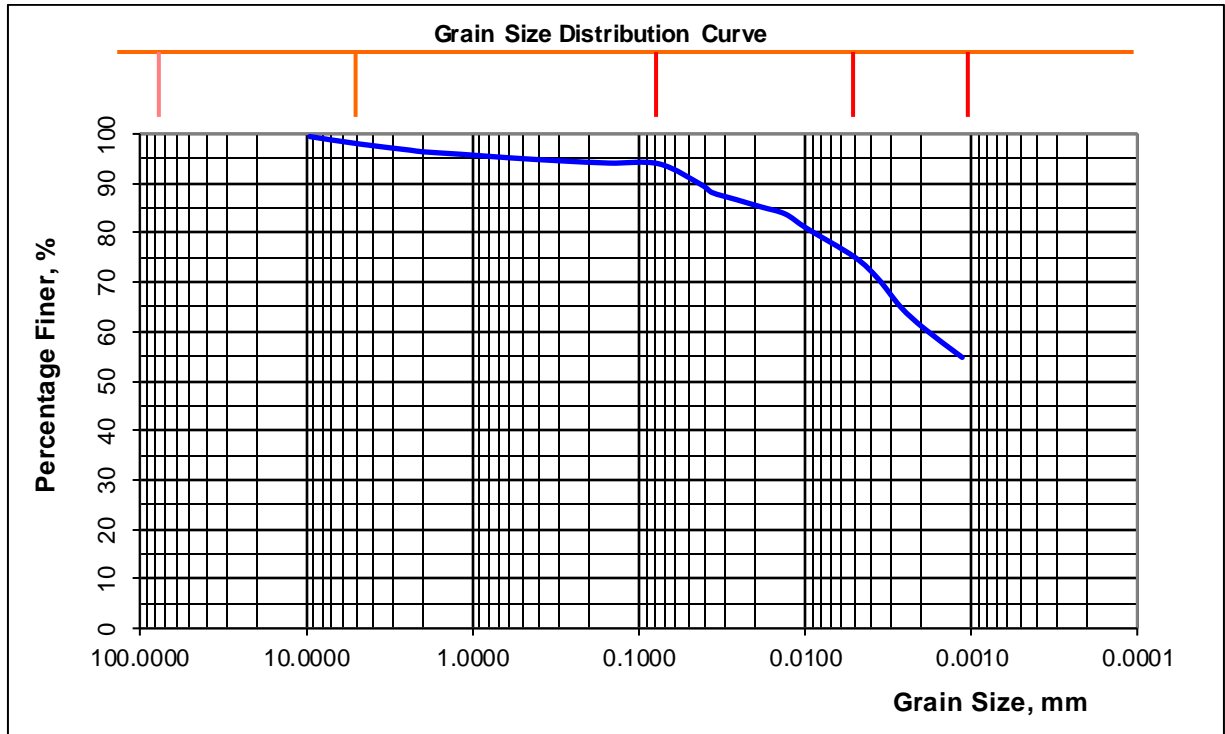
% Clay	% Silt	% Sand	% Gravel
53.57	40.43	6.0	0

Test pit no. TP5

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 1.5m



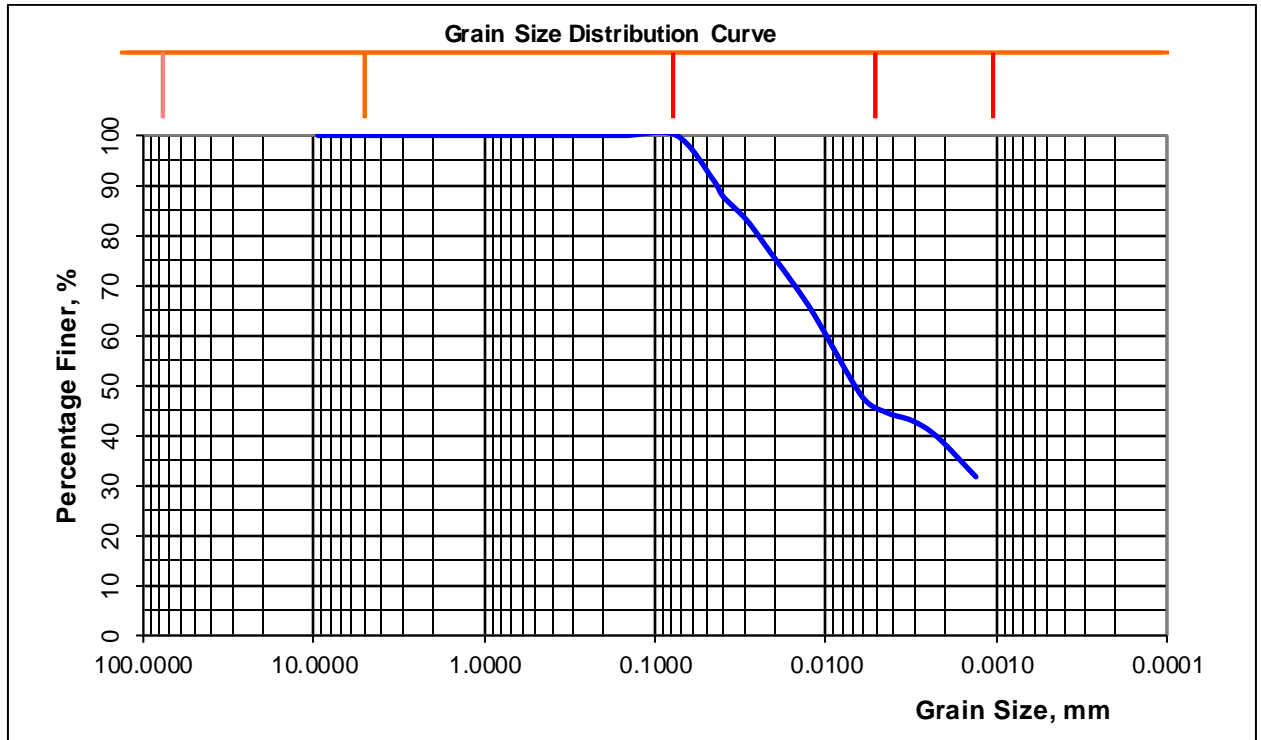
% Clay	% Silt	% Sand	% Gravel
75.00	18.19	0	0

Test pit no. TP5

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 3.0m



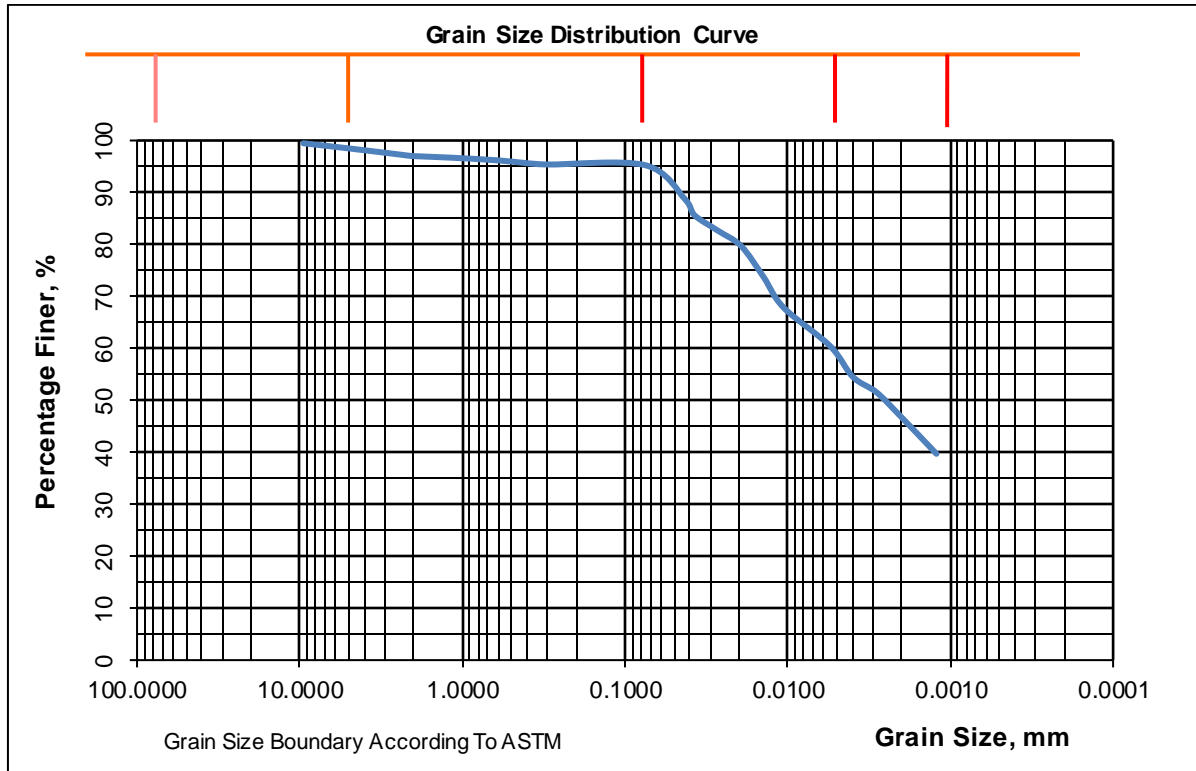
% Clay	% Silt	% Sand	% Gravel
58.97	41.03	0.00	0.00

Test pit no. TP6

Sample Type: disturbed

Test Type: Grain size analysis

Depth: 1.0m



% Clay	% Silt	% Sand	% Gravel
58.47	36.73	3.20	1.6

Appendix-B

Liquid Limit and Plastic Limit Determinations

Test pit no. TP1

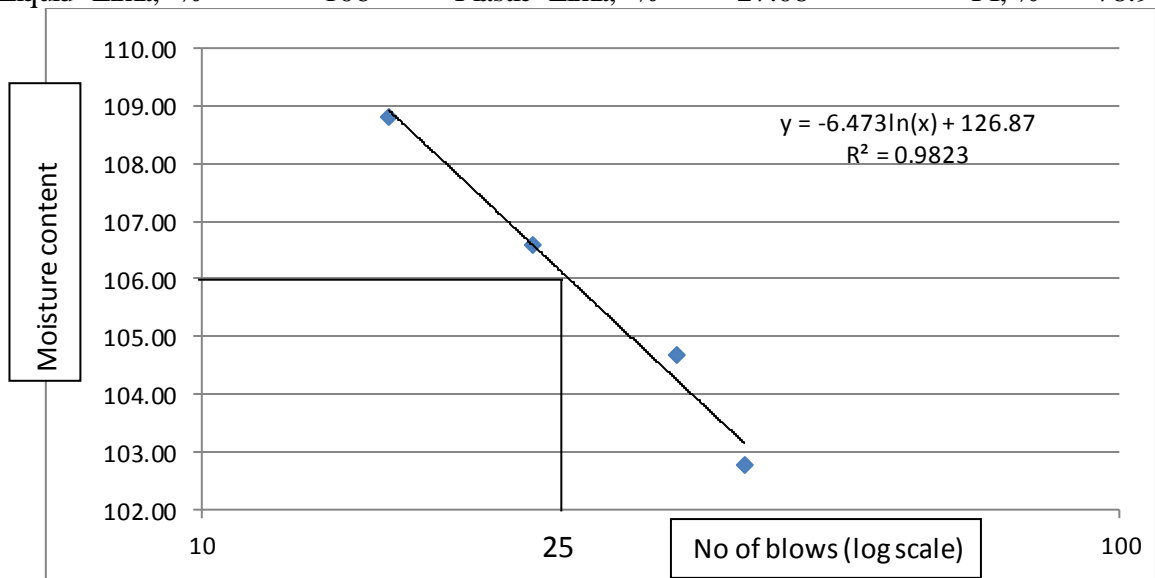
Sample Type: Disturbed

Test Type: Atterberg Limit test

Depth: 1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	b1	b2	b3	b4	M2	M2
M of container, g	17.50	22.10	21.70	22.20	15.80	15.40
M of Container + W soil, g	30.60	36.30	40.50	36.80	34.5	37.0
M of Container + D soil, g	23.90	28.90	30.80	29.40	30.6	32.3
M of water, g	6.70	7.40	9.70	7.40	3.90	4.7
M of d soil, g	6.40	6.80	9.10	7.20	14.80	16.9
Water content, %	104.69	108.82	106.59	102.78	26.35	27.81
No of blows	33	16	23	39	-----	-----

Liquid Limit, % = 106 Plastic Limit, % = 27.08 PI, % = 78.9



Test pit no. TP1

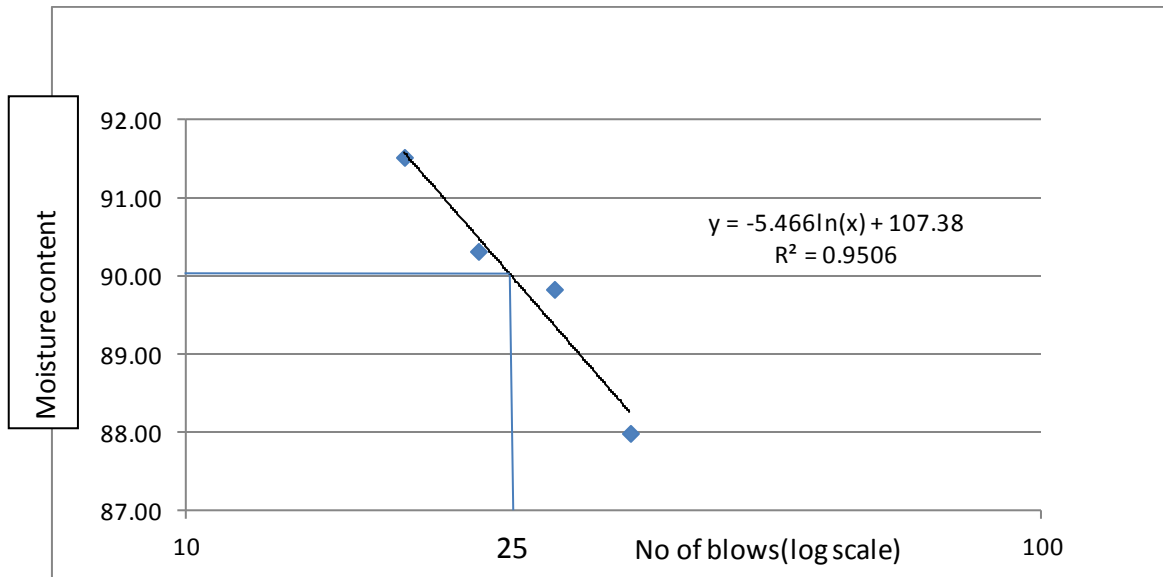
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 2.7m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	B2	C2	C3	c4	B2	C6
M of container, g	15.60	15.60	15.50	15.50	15.80	15.4
M of Container + W soil, g	26.80	25.00	26.80	27.30	30.40	33.10
M of Container + D soil, g	21.50	20.60	21.40	21.70	26.70	28.60
M of water, g	5.30	4.40	5.40	5.60	3.7	4.5
M of d soil, g	5.90	5.00	5.90	6.20	10.9	13.20
Water content, %	89.83	88.00	91.53	90.32	33.94	34.09
No of blows	27	33	18	22	-----	-----

Liquid Limit, % = 90 Plastic Limit% 34.02 PI, %= 55.98



Test pit no. TP2

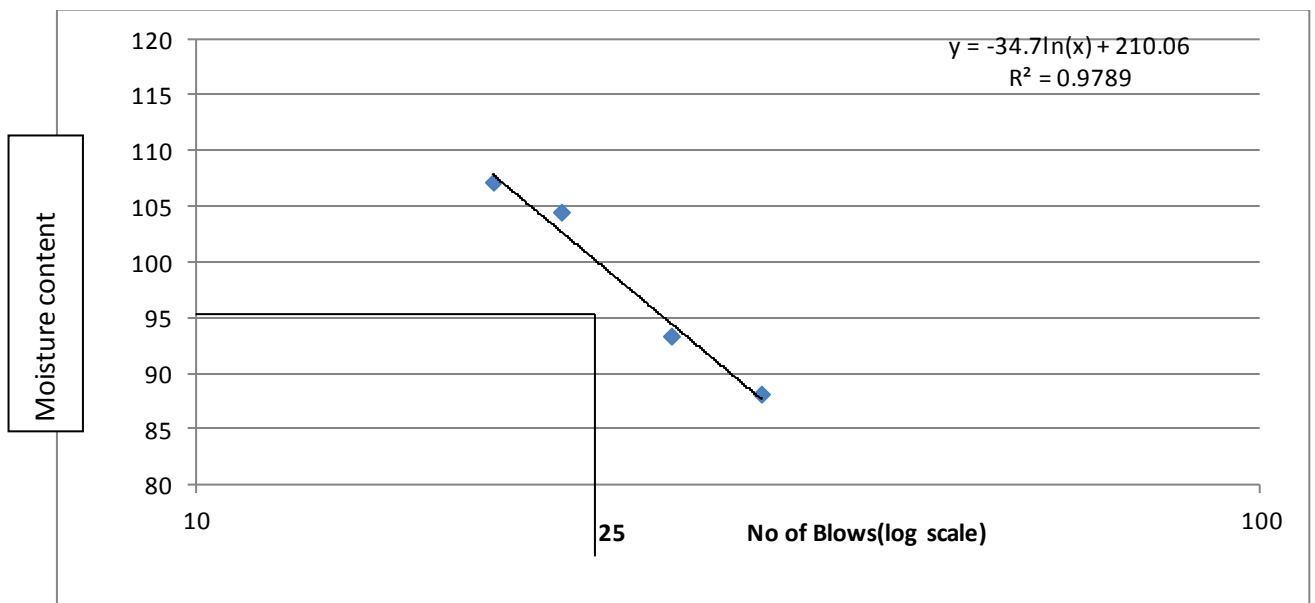
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C1	C4	C3	cc	M2	M2
M of container, g	15.60	15.50	15.70	15.60	15.50	15.80
M of Container + W soil, g	27.40	26.90	29.40	28.20	22.20	23.50
M of Container + D soil, g	21.30	21.40	22.40	22.30	20.60	21.70
M of water, g	6.10	5.50	7.00	5.90	1.60	1.80
M of d soil, g	5.70	5.90	6.70	6.70	5.10	5.90
Water content, %	107.02	93.22	104.48	88.06	31.37	30.51
No of blows	19	28	22	34	-----	-----

Liquid Limit, % = 98 Plastic Limit, % = 30.94 PI, % = 67.06



Test pit no. TP2

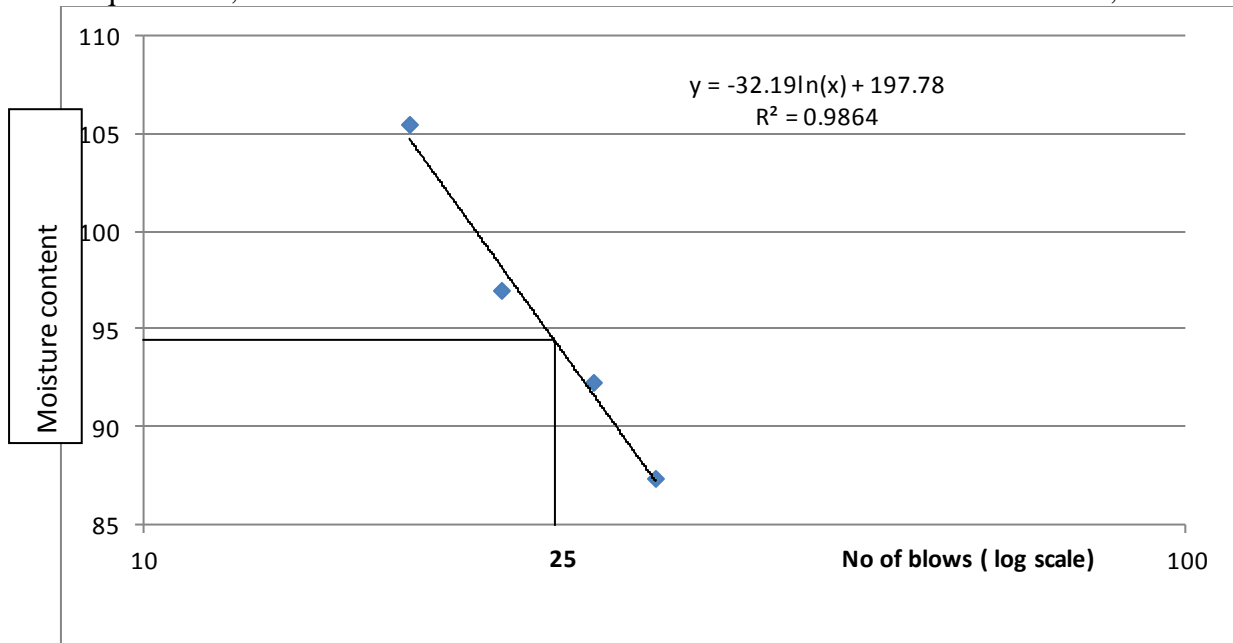
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 2.4m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	B2	C2	C3	cc	B2	C6
M of container, g	15.60	15.10	15.40	15.50	15.50	15.70
M of Container + W soil, g	28.60	26.90	30.60	30.30	22.60	21.50
M of Container + D soil, g	22.20	21.40	22.80	23.20	20.70	20.00
M of water, g	6.40	5.50	7.80	7.10	2.40	1.80
M of d soil, g	6.60	6.30	7.40	7.70	4.10	2.90
Water content, %	96.97	87.30	105.41	92.21	36.54	34.88
No of blows	22	31	18	27	-----	-----

Liquid Limit, % = 94 Plastic Limit% = 35.81 PI, % = 58.19



Test pit no. TP3

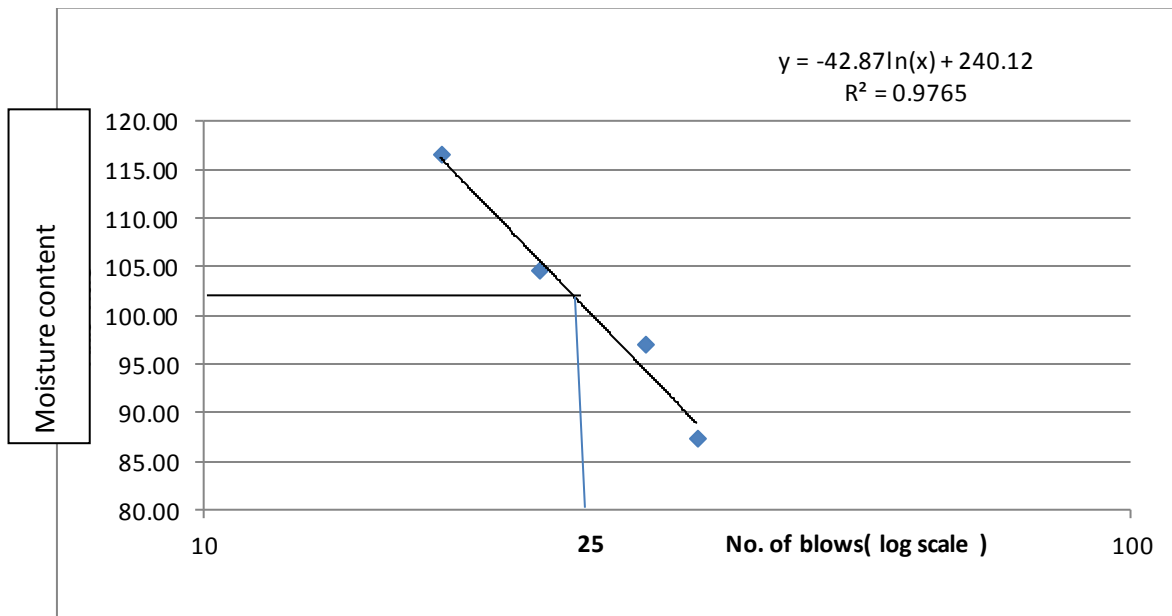
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C1	C4	C3		M2	M2
M of container, g	22.50	22.60	22.10	22.60	15.50	15.80
M of Container + W soil, g	35.70	34.40	34.70	36.10	25.50	25.80
M of Container + D soil, g	28.60	28.90	28.50	29.20	23.20	23.60
M of water, g	7.10	5.50	6.20	6.90	2.30	2.20
M of d soil, g	6.10	6.30	6.40	6.60	7.70	7.80
Water content, %	116.39	87.30	96.88	104.55	29.87	28.21
No of blows	18	34	30	23	-----	-----

Liquid Limit, % = 102 Plastic Limit% = 29.04 PI, % = 72.96



Test pit no. TP3

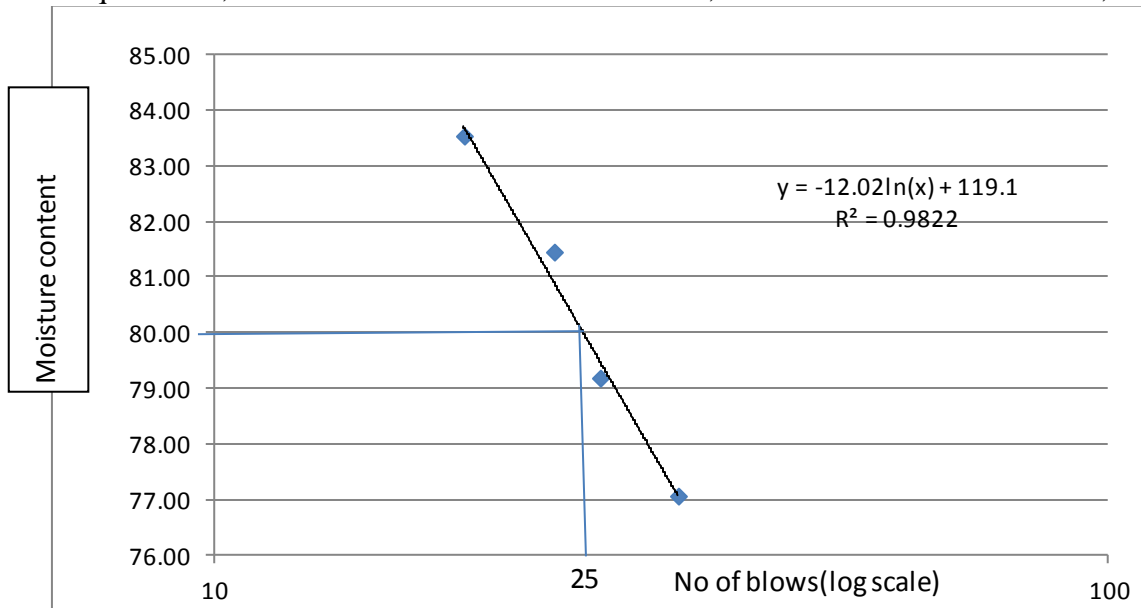
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 3.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	B2	C2	C3	m4	B2	C6
M of container, g	22.10	22.00	22.10	22.10	15.60	15.40
M of Container + W soil, g	32.90	38.70	34.80	30.70	23.5	26.20
M of Container + D soil, g	28.20	31.10	29.10	26.90	21.60	23.60
M of water, g	4.70	7.60	5.70	3.80	1.90	2.60
M of d soil, g	6.10	9.10	7.00	4.80	6.00	8.20
Water content, %	77.05	83.52	81.43	79.17	31.67	31.71
No of blows	33	19	24	27	-----	-----

Liquid Limit, % = 80 Plastic Limit, % = 31.65 PI, % = 48.30



Test pit no. TP4

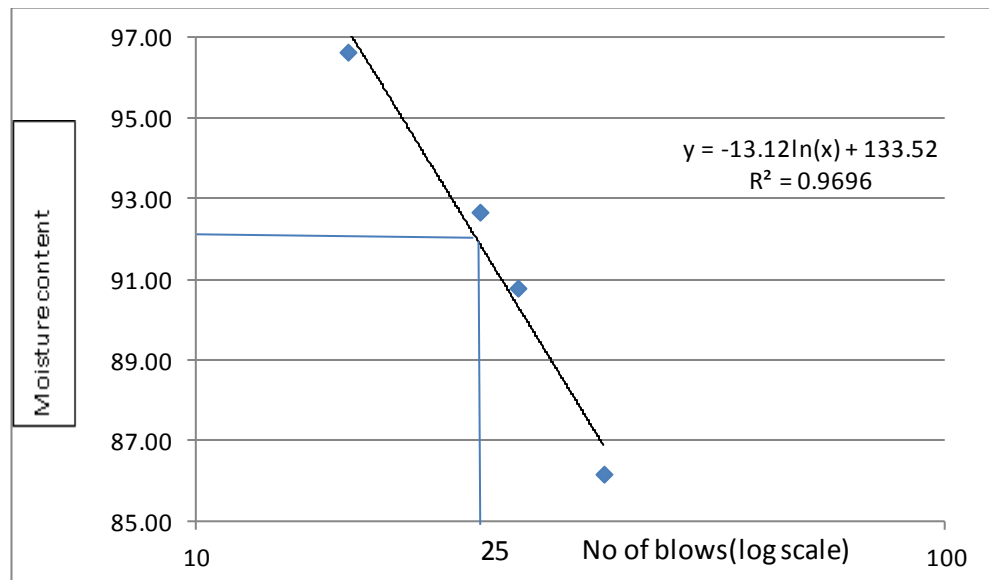
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 1.2m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C1	C4	C3	c12	M2	M2
M of container, g	15.20	15.50	15.40	15.70	15.20	15.60
M of Container + W soil, g	27.30	28.60	27.00	28.10	22.60	24.30
M of Container + D soil, g	21.70	22.30	21.30	22.20	20.80	22.20
M of water, g	5.60	6.30	5.70	5.90	1.80	2.10
M of d soil, g	6.50	6.80	5.90	6.50	5.60	6.60
Water content, %	86.15	92.65	96.61	90.77	32.14	31.82
No of blows	35	24	16	27	-----	-----

Liquid Limit, % = 92 Plastic Limit% = 31.98 PI, % = 60.0



Test pit no. TP4

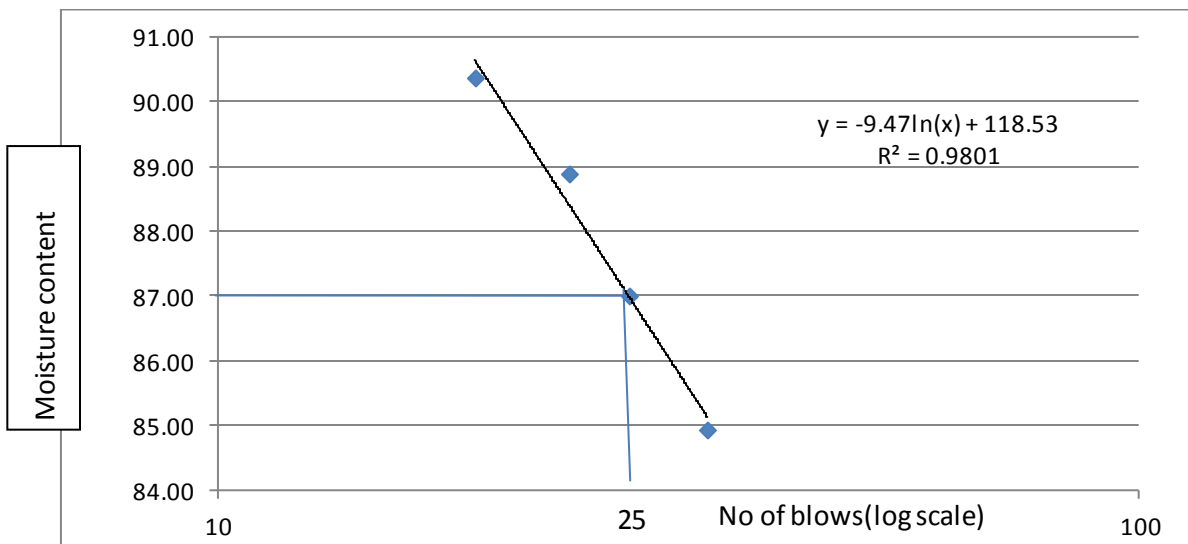
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 3.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	B2	C2	C3	cc	B2	C6
M of container, g	15.60	14.10	15.70	15.50	15.40	15.60
M of Container + W soil, g	31.40	29.40	29.20	34.20	20.60	23.70
M of Container + D soil, g	23.90	22.20	23.00	25.50	19.40	21.80
M of water, g	7.50	7.20	6.20	8.70	1.20	1.90
M of d soil, g	8.30	8.10	7.30	10.00	4.00	6.20
Water content, %	90.36	88.89	84.93	87.00	30.00	30.65
No of blows	19	24	34	28	-----	-----

Liquid Limit, % = 87 Plastic Limit = 30.32 PI,%=56.7



Test pit no. TP5

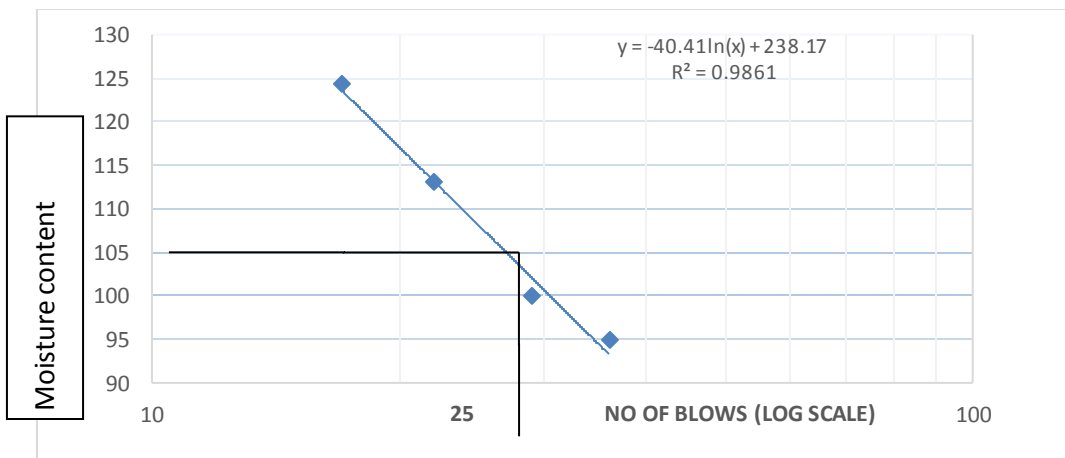
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C1	C4	C3	b2	M2	M2
M of container, g	15.50	15.60	15.60	13.90	15.80	15.40
M of Container + W soil, g	24.70	28.60	27.10	26.80	24.30	22.90
M of Container + D soil, g	19.60	21.70	21.50	20.90	22.30	21.10
M of water, g	5.10	6.90	5.60	4.80	2.00	1.80
M of d soil, g	4.10	6.10	5.90	4.80	6.50	5.70
Water content, %	124.39	113.11	94.92	100.00	30.77	31.58
No of blows	17	22	36	29	-----	-----

Liquid Limit, % = 108 Plastic Limit% 31.17 PI, %= 76.83



Test pit no. TP5

Sample Type: Disturbed

Test Type: Atterberg limit test

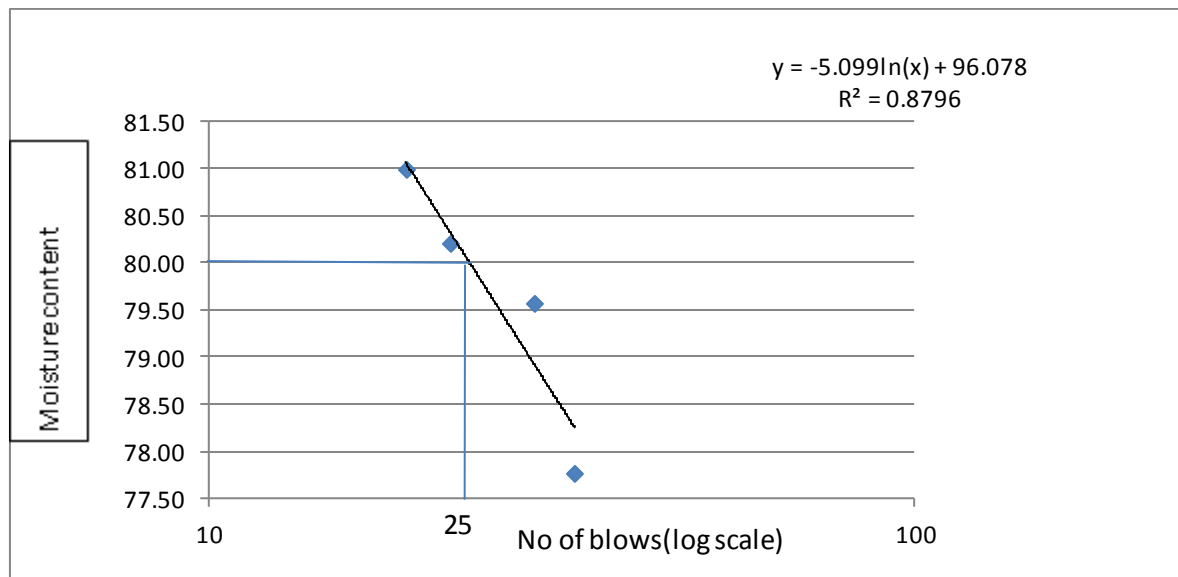
Depth: 3.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	B2	C2	C3	A17	B2	C6
M of container, g	15.60	15.60	14.10	15.30	15.30	15.60
M of Container + W soil, g	28.40	32.30	32.20	33.50	24.90	28.10
M of Container + D soil, g	22.80	24.90	24.10	25.40	22.40	24.90
M of water, g	5.60	7.40	8.10	8.10	2.50	3.20
M of d soil, g	7.20	9.30	10.00	10.10	7.10	9.30
Water content, %	77.78	79.57	81.00	80.20	35.21	34.41
No of blows	33	29	19	22	-----	-----

Liquid Limit, % = 80

Plastic Limit% 34.81

PI, %= 45.2



Test pit no. TP6

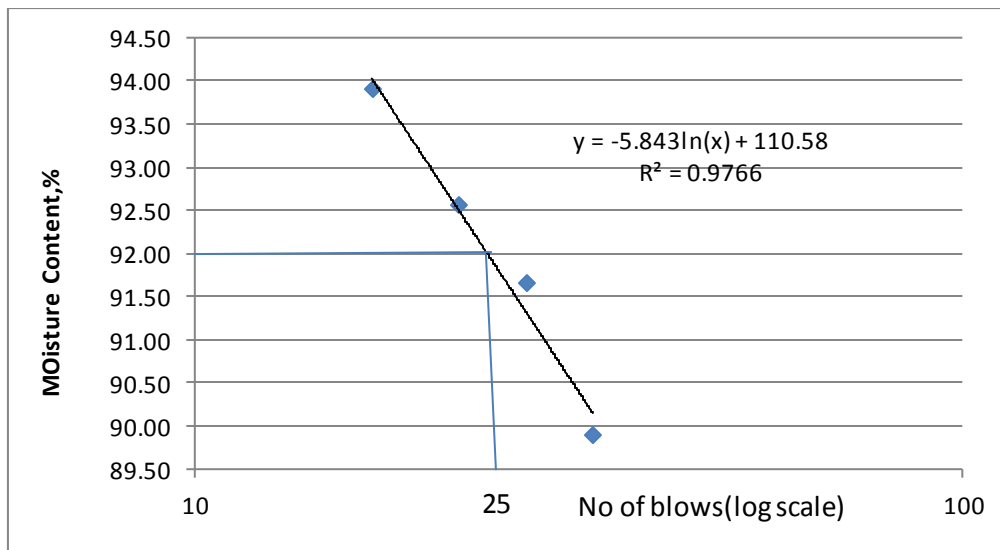
Sample Type: Disturbed

Test Type: Atterberg limit test

Depth: 1m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	C1	C4	C3	cc	M2	M2
M of container, g	15.60	15.70	10.90	15.60	15.40	15.80
M of Container + W soil, g	29.40	33.80	29.70	31.50	23.60	22.80
M of Container + D soil, g	22.80	25.10	20.80	23.80	21.70	21.10
M of water, g	6.60	8.70	8.90	7.70	1.90	1.70
M of d soil, g	7.20	9.40	9.90	8.20	6.30	5.30
Water content, %	91.67	92.55	89.90	93.90	30.16	32.08
No of blows	27	22	33	17	-----	-----

Liquid Limit, % = 92 Plastic Limit, % = 31.12 PI, % = 60.9



Appendix-C

Determination of Specific Gravity

Test pit no. TP1

Sample Type: Disturbed

Test Type: Specific Gravity

Depth: 1.5m

Pycnometer No.	P2	P3
W of dry, clean pycnometer, w_p (g)	48.7	49.8
W of pycnometer + water, w_{pw} (g)	148	149.1
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	164.2	165.2
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	147.98	149.08
W of dry soil , w_s (gm)	25	25
Conversion factor , K	1.0000	0.9998
Gs of soil at 20°c.	2.85	2.82
Average Gs of soil	2.83	

Test pit no. TP1

Sample Type: Disturbed

Test Type: Specific Gravity

Depth: 3.0m

Pycnometer No.	P2	P3
W of dry, clean pycnometer,	48.6	49.8
W of pycnometer + water, w_{pw} (g)	148	149.3
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	164	165.3
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	147.94	149.28
W of dry soil , w_s (gm)	25	25
Conversion factor , K	0.9996	0.9998
Gs of soil at 20°c.	2.80	2.78
Average Gs of soil	2.79	

Test pit no. TP2

Sample Type: Disturbed

Depth: 1.5m

Pycnometer No.	P2	P3
W of dry, clean pycnometer,	49.6	49.6
W of pycnometer + water, w_{pw} (g)	148.7	148.8
Observed temperature of water, T_i (oc)	19	19
W of pycnometer + soil + water, W_{pws} (g)	155.2	155.3
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	148.70	148.80
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0002
Gs of soil at 20°c.	2.86	2.86
Average Gs of soil	2.86	

Test pit no. TP2

Sample Type: Disturbed

Depth: 2.4m

Pycnometer No.	P2	P3
W of dry, clean pycnometer,	49.5	49.6
W of pycnometer + water, w_{pw} (g)	148.9	148.9
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	155.3	155.3
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	148.90	148.90
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0000
Gs of soil at 20°C.	2.78	2.78
Average Gs of soil	2.78	

Test pit no. TP3

Sample Type: Disturbed

Depth: 1.5m

Pycnometer No.	P2	P3
W of dry, clean pycnometer,	48.5	49.7
W of pycnometer + water, w_{pw} (g)	147.9	149.1
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	164	165.3
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	147.79	149.03
W of dry soil , w_s (gm)	25	25
Conversion factor , K	0.9991	0.9993
Gs of soil at 20°c.	2.84	2.86
Average Gs of soil	2.85	

Test pit no. TP3

Sample Type: Disturbed

Depth: 3.0m

Pycnometer No.	P2	P3
W of dry, clean pycnometer,	49.8	49.7
W of pycnometer + water, W_{pw} (g)	149.2	149.3
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	165.3	165.2
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	149.14	149.21
W of dry soil , w_s (gm)	25	25
Conversion factor , K	0.9996	0.9991
Gs of soil at 20°c.	2.83	2.77
Average specific gravity of soil	2.80	

Test pit no. 04

Sample Type: Disturbed

Depth: 1.2m

Pycnometer No.	P2	P3
W of dry, clean pycnometer,	49.5	49.6
W of pycnometer + water, w_{pw} (g)	149	148.9
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	155.4	155.3
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	149.00	148.92
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0002
Gs of soil at 20°c.	2.78	2.76
Average specific gravity of soil	2.77	

Test pit no. TP4

Sample Type: Disturbed

Depth: 3.0m

Pycnometer No.	P2	P3
W of dry, clean pycnometer, w_p (g)	49.5	49.5
W of pycnometer + water, w_{pw} (g)	148.9	148.9
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	155.2	155.3
Temperature, T_x (°c)	19.4	20.1
Wof pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	148.90	148.92
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0002
Gs of soil at 20°c.	2.70	2.76
Average Gs of soil	2.73	

Test pit no. TP5

Sample Type: Disturbed

Depth: 1.5m

Pycnometer No.	P2	P3
W of dry, clean pycnometer, w_p (g)	49.4	49.4
W of pycnometer + water, w_{pw} (g)	148.8	148.8
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	155.3	155.3
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	148.80	148.84
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0004
Gs of soil at 20°c.	2.86	2.83
Average Gs of soil	2.84	

Test pit no. TP5

Sample Type: Disturbed

Depth: 3.0m

Pycnometer No.	P2	P3
W of dry, clean pycnometer, w_p (g)	49.5	49.5
W of pycnometer + water, w_{pw} (g)	148.9	148.9
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	155.2	155.1
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	148.90	148.92
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0002
GS of soil at 20°C.	2.70	2.62
Average Gs of soil	2.66	

Test pit no. TP6

Sample Type: Disturbed

Depth: 1.0m

Pycnometer No.	P2	P3
W of dry, clean pycnometer, w_p (g)	49.4	49.6
W of pycnometer + water, w_{pw} (g)	148.9	149
Observed temperature of water, T_i (oc)	19	20
W of pycnometer + soil + water, W_{pws} (g)	155.3	155.5
Temperature, T_x (°c)	19.4	20.1
W of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	148.90	149.04
W of dry soil , w_s (gm)	10	10
Conversion factor , K	1.0002	1.0004
Gs of soil at 20°c.	2.78	2.83
Average Gs of soil	2.80	

Appendix-D

Determination of Free Swell

Test pit no. TP1

Sample Type: Disturbed

Depth: 1.5m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	23.0	23.5	23.3	133

Test pit no. TP1

Sample Type: Disturbed

Depth: 2.7m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	20.0	21.0	20.5	105

Test pit no. TP2

Sample Type: Disturbed

Depth: 1.5m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	27.0	26.0	26.5	165

Test pit no. TP2

Sample Type: Disturbed

Depth: 2.4m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	21.5	22.5	22.0	120

Test pit no. TP3

Sample Type: Disturbed

Depth: 1.5m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	23.0	22.0	22.5	125

Test pit no. TP3

Sample Type: Disturbed

Depth: 3.0m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	23.0	21.0	22.0	90

Test pit no. TP4

Sample Type: Disturbed

Depth: 1.2m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	25.0	23.5	24.3	143

Test pit no. TP4

Sample Type: Disturbed

Depth: 3.0m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	22.0	20.5	21.3	113

Test pit no. TP5

Sample Type: Disturbed

Depth: 1.5m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	22.5	22.0	22.3	123

Test pit no. TP5

Sample Type: Disturbed

Depth: 3.0m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	17.5	19.0	17.3	83

Test pit no. TP6

Sample Type: Disturbed

Depth: 1.0m

<i>Initial Volume (cc)</i>	<i>Final Volume</i>		<i>Average Final Volume (cc)</i>	<i>Free Swell (%)</i>
	<i>Sample No.1 (cc)</i>	<i>Sample No.2 (cc)</i>		
10.0	23.0	22.5	22.8	128

Appendix-E

Determination of Natural Moisture Content

Test pit no. TP1

Sample Type: Undisturbed

Depth: 1.5m

Trial No	1	2
Container No	12	1
M of container, g	16.20	15.80
M of container + Wet soil, g	45.90	49.70
M of container + Dry soil, g	35.90	38.00
M of water, g	10.00	11.70
M of dry soil	19.70	22.20
Water content,%	50.76	52.70
Ave. moisture content,% =	51.73	

Test pit no. TP1

Sample Type: Undisturbed

Depth: 2.7m

Trial No	1	2
Container No	12	1
M of container, g	15.50	15.50
M of container + Wet soil, g	43.00	55.00
M of container + Dry soil, g	34.90	43.30
M of water, g	8.10	11.70
M of dry soil	19.40	27.80
Water content,%	41.75	42.09
Ave. moisture content,% =	41.92	

Test pit no. TP2

Sample Type: Undisturbed

Depth: 1.5m

Trial No	1	2
Container No	J16	75
M of container, g	15.50	15.80
M of container + Wet soil, g	34.70	35.90
M of container + Dry soil, g	28.30	29.40
M of water, g	6.40	6.50
M of dry soil	12.80	13.60
Water content, %	50.00	47.79
Ave. moisture content,% =	48.90	

Test pit no. TP2

Sample Type: Undisturbed

Depth: 2.4m

Trial No	1	2
Container No	12	1
M of container, g	15.60	15.60
M of container + Wet soil, g	48.20	37.20
M of container + Dry soil, g	38.00	30.30
M of water, g	10.20	6.90
M of dry soil	22.40	14.70
Water content, %	45.54	46.94
Ave. moisture content,% =	46.24	

Test pit no. TP3

Sample Type: Undisturbed

Depth: 1.5m

Trial No	1	2
Container No	T3	A17
M of container, g	15.60	15.90
M of container + Wet soil, g	46.80	49.30
M of container + Dry soil, g	36.40	38.40
M of water, g	10.40	10.90
M of dry soil, g	20.80	22.50
Water content, %	50.00	48.44
Ave. moisture content, % =	49.22	

Test pit no. TP3

Sample Type: Undisturbed

Depth: 3m

Trial No	1	2
Container No	T3	A17
M of container, g	15.60	15.90
M of container + Wet soil, g	45.90	52.00
M of container + Dry soil, g	36.80	41.10
M of water, g	9.10	10.90
M of dry soil, g	21.20	25.20
Water content, %	42.92	43.25
Ave. moisture content, % =	43.09	

Test pit no. TP4

Sample Type: Undisturbed

Depth: 1.2 m

Trial No	1	2
Container No	MA10	LL4
M of container, g	15.60	15.70
M of container + Wet soil, g	41.60	41.00
M of container + Dry soil, g	33.20	32.80
M of water, g	8.40	8.20
M of dry soil, g	17.60	17.10
Water content, %	47.73	47.95
Ave. moisture content,% =	47.84	

Test pit no. TP4

Sample Type: Undisturbed

Depth: 3 m

Trial No	1	2
Container No	T3	T5
M of container, g	15.60	15.60
M of container + Wet soil, g	35.40	48.20
M of container + Dry soil, g	29.10	38.00
M of water, g	6.30	10.20
M of dry soil, g	13.50	22.40
Water content, %	46.67	45.54
Ave. moisture content,% =	46.10	

Test pit no. TP5

Sample Type: Undisturbed

Depth: 1.5m

Trial No	1	2
Container No	12	1
M of container, g	15.50	15.70
M of container + Wet soil, g	29.40	33.00
M of container + Dry soil, g	27.50	25.00
M of water, g	1.90	8.00
M of dry soil, g	12.00	9.30
Water content, %	15.83	86.02
Ave. moisture content,% =	50.93	

Test pit no. TP5

Sample Type: Undisturbed

Depth: 1.5m

Trial No	1	2
Container No	12	1
M of container, g	15.40	15.60
M of container + Wet soil, g	29.90	32.50
M of container + Dry soil, g	25.70	27.60
M of water, g	4.20	4.90
M of dry soil, g	10.30	12.00
Water content, %	40.78	40.83
Ave. moisture content,% =	40.81	

Test pit no. TP6

Sample Type: Undisturbed

Depth: 1.0m

Trial No	1	2
Container No	T3	A17
M of container	15.80	15.80
M of container + Wet soil, g	43.50	48.60
M of container + Dry soil, g	34.50	37.90
M of water,g	9.00	10.70
M of dry soil,g	18.70	22.10
Water content,%	48.13	48.42
Ave. moisture content,% =	48.27	

Appendix-F**Unconfined Compressive Strength determination****Sample Type: Undisturbed****Test pit no. TP1****Depth: 1.5m**

		Ring Calibration Factor, kN/div	0.00142
Diameter of sample , mm	3.8	Moisture content, %	51.73
Length of sample , mm	8.6	Wet unit weight, kN/m ³	16.13

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.23	11	0.0156	0.00108	14.50
0.4	0.47	18	0.0256	0.00108	23.67
0.6	0.70	25	0.0355	0.00108	32.79
0.8	0.93	31	0.0440	0.00109	40.57
1	1.16	36	0.0511	0.00109	47.00
1.2	1.40	42	0.0596	0.00115	51.86
1.4	1.63	46	0.0653	0.00115	56.66
1.6	1.86	51	0.0724	0.00116	62.67
1.8	2.09	55	0.0781	0.00116	67.43
2	2.33	59	0.0838	0.00116	72.16
2.2	2.56	61	0.0866	0.00116	74.43
2.4	2.79	63	0.0895	0.00117	76.69
2.6	3.02	63	0.0895	0.00117	76.50
2.8	3.26	61	0.0866	0.00117	73.90
3	3.49	55	0.0781	0.00117	66.47
3.2	3.72	50	0.0710	0.00118	60.28

			Ring Calibration Factor,	0.00142
			kN/div	
Diameter of sample , mm	3.8		Moisture content, %	51.73
Length of sample , mm	8.7		Wet unit weight, kN/m ³	15.92

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.23	11	0.0156	0.00108	14.50
0.4	0.47	17	0.0241	0.00108	22.35
0.6	0.70	23	0.0327	0.00108	30.17
0.8	0.93	30	0.0426	0.00109	39.26
1	1.16	35	0.0497	0.00109	45.69
1.2	1.40	39	0.0554	0.00109	50.80
1.4	1.63	43	0.0611	0.00109	55.88
1.6	1.86	46	0.0653	0.00110	59.63
1.8	2.09	49	0.0696	0.00110	63.37
2	2.33	52	0.0738	0.00110	67.09
2.2	2.56	55	0.0781	0.00110	70.79
2.4	2.79	58	0.0824	0.00111	74.48
2.6	3.02	61	0.0866	0.00111	78.14
2.8	3.26	62	0.0880	0.00111	79.23
3	3.49	63	0.0895	0.00111	80.32
3.2	3.72	62.5	0.0888	0.00112	79.49
3.4	3.95	61	0.0866	0.00112	77.39
3.6	4.19	58	0.0824	0.00112	73.41
3.8	4.42	53	0.0753	0.00112	66.92

Test pit no. TP1

Depth: 2.7m

Ring Calibration Factor,
kN/div 0.00142

Diameter of sample ,
mm 38

Moisture content, % 41.92

Length of sample ,
mm 76

Wet unit weight, kN/m³ 16.18

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.26	9	0.0128	0.00114	11.24
0.4	0.53	17	0.0241	0.00114	21.18
0.6	0.79	27	0.0383	0.00114	33.54
0.8	1.05	36	0.0511	0.00115	44.60
1	1.32	43	0.0611	0.00115	53.14
1.2	1.58	49	0.0696	0.00115	60.39
1.4	1.84	57	0.0809	0.00116	70.06
1.6	2.11	63	0.0895	0.00116	77.23
1.8	2.37	68	0.0966	0.00116	83.13
2	2.63	75	0.1065	0.00116	91.44
2.2	2.89	77	0.1093	0.00117	93.63
2.4	3.16	78	0.1108	0.00117	94.59
2.6	3.42	78	0.1108	0.00117	94.33
2.8	3.68	70	0.0994	0.00118	84.42
3	3.95	63	0.0895	0.00118	75.77
3.2	4.21	55	0.0781	0.00118	65.97

		Ring Calibration Factor,	
		kN/div	0.00142
Diameter of sample , mm	37	Moisture content, %	41.92
Length of sample , mm	86	Wet unit weight, kN/m³	17.23

Axial Deformation	Axial Strain	Proving Ring Reading	Axial Load	Corrected Area	Axial Stress
[mm]	[%]	[div]	[kN]	[m ²]	[kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.23	10	0.0142	0.00108	13.18
0.4	0.47	18	0.0256	0.00108	23.67
0.6	0.70	25	0.0355	0.00108	32.79
0.8	0.93	33	0.0469	0.00109	43.19
1	1.16	40	0.0568	0.00109	52.22
1.2	1.40	47	0.0667	0.00109	61.22
1.4	1.63	55	0.0781	0.00109	71.47
1.6	1.86	62	0.0880	0.00110	80.37
1.8	2.09	65	0.0923	0.00110	84.06
2	2.33	67	0.0951	0.00110	86.44
2.2	2.56	67.5	0.0959	0.00110	86.88
2.4	2.79	63	0.0895	0.00111	80.90
2.6	3.02	60	0.0852	0.00111	76.86

Test pit no. TP2

Depth: 1.5m

Ring Calibration Factor,
kN/div 0.00142

Diameter of sample ,
mm 38

Moisture content, % 48.90

Length of sample ,
mm 78

Wet unit weight, kN/m³ 17.44

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.26	10	0.0142	0.00108	13.18
0.4	0.51	17	0.0241	0.00108	22.34
0.6	0.77	23	0.0327	0.00108	30.15
0.8	1.03	28	0.0398	0.00109	36.61
1	1.28	34	0.0483	0.00109	44.34
1.2	1.54	39	0.0554	0.00109	50.72
1.4	1.79	44	0.0625	0.00109	57.08
1.6	2.05	47	0.0667	0.00110	60.81
1.8	2.31	51	0.0724	0.00110	65.81
2	2.56	55	0.0781	0.00110	70.79
2.2	2.82	58	0.0824	0.00111	74.45
2.4	3.08	60	0.0852	0.00111	76.82
2.6	3.33	62	0.0880	0.00111	79.17
2.8	3.59	63	0.0895	0.00112	80.23
3	3.85	64.5	0.0916	0.00112	81.92
3.2	4.10	62	0.0880	0.00112	78.54
3.4	4.36	56	0.0795	0.00112	70.75
3.6	4.62	51	0.0724	0.00113	64.26

Ring Calibration Factor, kN/div **0.00142**

Diameter of sample , mm **38** **Moisture content, %** **47.79**

Length of sample , mm **82** **Wet unit weight, kN/m³** **16.59**

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.24	8	0.0114	0.00114	9.99
0.4	0.49	11	0.0156	0.00114	13.71
0.6	0.73	15	0.0213	0.00114	18.65
0.8	0.98	19	0.0270	0.00115	23.56
1	1.22	23	0.0327	0.00115	28.45
1.2	1.46	27	0.0383	0.00115	33.31
1.4	1.71	30	0.0426	0.00115	36.92
1.6	1.95	35	0.0497	0.00116	42.97
1.8	2.20	37	0.0525	0.00116	45.31
2	2.44	40	0.0568	0.00116	48.87
2.2	2.68	43	0.0611	0.00117	52.40
2.4	2.93	47	0.0667	0.00117	57.13
2.6	3.17	51	0.0724	0.00117	61.84
2.8	3.41	54	0.0767	0.00117	65.31
3	3.66	57	0.0809	0.00118	68.76
3.2	3.90	58	0.0824	0.00118	69.79
3.4	4.15	58	0.0824	0.00118	69.62
3.6	4.39	56	0.0795	0.00119	67.04
3.8	4.63	53	0.0753	0.00119	63.29
4	4.88	50	0.0710	0.00119	59.56

Test pit no. TP2
Depth: 2.4m

		Ring Calibration	
		Factor, kN/div	0.00142
Diameter of sample		Moisture content,	
, mm	37	%	46.24
Length of sample ,		Wet unit weight,	
mm	78	kN/m3	18.40

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.26	10	0.0142	0.00108	13.18
0.4	0.51	16	0.0227	0.00108	21.03
0.6	0.77	22	0.0312	0.00108	28.84
0.8	1.03	29	0.0412	0.00109	37.91
1	1.28	35	0.0497	0.00109	45.64
1.2	1.54	41	0.0582	0.00109	53.32
1.4	1.79	45	0.0639	0.00109	58.37
1.6	2.05	49	0.0696	0.00110	63.40
1.8	2.31	53	0.0753	0.00110	68.39
2	2.56	56	0.0795	0.00110	72.08
2.2	2.82	58	0.0824	0.00111	74.45
2.4	3.08	60	0.0852	0.00111	76.82
2.6	3.33	62	0.0880	0.00111	79.17
2.8	3.59	63.5	0.0902	0.00112	80.87
3	3.85	64	0.0909	0.00112	81.29
3.2	4.10	66	0.0937	0.00112	83.60
3.4	4.36	66.5	0.0944	0.00112	84.01
3.6	4.62	66	0.0937	0.00113	83.16
3.8	4.87	64.5	0.0916	0.00113	81.05
4	5.13	61.5	0.0873	0.00113	77.07
4.2	5.38	59	0.0838	0.00114	73.74

Diameter of sample , mm	38	Ring Calibration Factor, kN/div	0.00142
Length of sample , mm	82	Moisture content, %	46.24
		Wet unit weight, kN/m³	16.97

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.24	10	0.0142	0.00114	12.49
0.4	0.49	15	0.0213	0.00114	18.69
0.6	0.73	19	0.0270	0.00114	23.62
0.8	0.98	23	0.0327	0.00115	28.52
1	1.22	27	0.0383	0.00115	33.40
1.2	1.46	31.5	0.0447	0.00115	38.87
1.4	1.71	37	0.0525	0.00115	45.54
1.6	1.95	39	0.0554	0.00116	47.88
1.8	2.20	44	0.0625	0.00116	53.89
2	2.44	50	0.0710	0.00116	61.08
2.2	2.68	55	0.0781	0.00117	67.02
2.4	2.93	59	0.0838	0.00117	71.72
2.6	3.17	63	0.0895	0.00117	76.39
2.8	3.41	67	0.0951	0.00117	81.03
3	3.66	70	0.0994	0.00118	84.45
3.2	3.90	72	0.1022	0.00118	86.64
3.4	4.15	75	0.1065	0.00118	90.02
3.6	4.39	77	0.1093	0.00119	92.19
3.8	4.63	79	0.1122	0.00119	94.34
4	4.88	80.5	0.1143	0.00119	95.89
4.2	5.12	81.5	0.1157	0.00120	96.83
4.4	5.37	83	0.1179	0.00120	98.36
4.6	5.61	83.5	0.1186	0.00120	98.69
4.8	5.85	83	0.1179	0.00120	97.85
5	6.10	82	0.1164	0.00121	96.42

Test pit no. TP3

Depth: 1.5m

		Ring Calibration Factor,	0.00142
		kN/div	
Diameter of sample , mm	3.8	Moisture content, %	49.22
Length of sample , mm	8.4	Wet unit weight, kN/m ³	16.52

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.23	11	0.0156	0.00108	14.50
0.4	0.47	17	0.0241	0.00108	22.35
0.6	0.70	22	0.0312	0.00108	28.86
0.8	0.93	26	0.0369	0.00109	34.02
1	1.16	32	0.0454	0.00109	41.78
1.2	1.40	37	0.0525	0.00109	48.19
1.4	1.63	41	0.0582	0.00109	53.28
1.6	1.86	45	0.0639	0.00110	58.34
1.8	2.09	49	0.0696	0.00110	63.37
2	2.33	53	0.0753	0.00110	68.38
2.2	2.56	57	0.0809	0.00110	73.37
2.4	2.79	60	0.0852	0.00111	77.04
2.6	3.02	63	0.0895	0.00111	80.70
2.8	3.26	65	0.0923	0.00111	83.07
3	3.49	66	0.0937	0.00111	84.14
3.2	3.72	67	0.0951	0.00112	85.21
3.4	3.95	65	0.0923	0.00112	82.47
3.6	4.19	61	0.0866	0.00112	77.20
3.8	4.42	56	0.0795	0.00112	70.70
4	4.65	50	0.0710	0.00113	62.97

Ring Calibration Factor, 0.0014
kN/div

Diameter of sample , mm 38 **Moisture content, % 49.22**
Length of sample , mm 85 **Wet unit weight, kN/m³ 16.51**

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.24	10	0.0142	0.00114	12.49
0.4	0.47	17	0.0241	0.00114	21.19
0.6	0.71	23	0.0327	0.00114	28.60
0.8	0.94	29	0.0412	0.00114	35.97
1	1.18	35	0.0497	0.00115	43.31
1.2	1.41	40	0.0568	0.00115	49.38
1.4	1.65	44	0.0625	0.00115	54.19
1.6	1.88	48	0.0682	0.00116	58.97
1.8	2.12	53	0.0753	0.00116	64.96
2	2.35	56	0.0795	0.00116	68.47
2.2	2.59	59	0.0838	0.00116	71.97
2.4	2.82	62	0.0880	0.00117	75.44
2.6	3.06	65	0.0923	0.00117	78.90
2.8	3.29	68	0.0966	0.00117	82.34
3	3.53	69	0.0980	0.00118	83.35
3.2	3.76	69	0.0980	0.00118	83.15
3.4	4.00	68	0.0966	0.00118	81.74
3.6	4.24	66	0.0937	0.00118	79.15
3.8	4.47	63	0.0895	0.00119	75.36
4	4.71	57	0.0809	0.00119	68.02

Test pit no. TP3

Depth: 3.0m

		Ring Calibration	
Diameter of sample ,		Factor, kN/div	0.00142
mm	38	Moisture content,	
		%	47.84
Length of sample , mm	82	Wet unit weight,	
		kN/m³	17.29

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.26	12	0.0170	0.00108	15.81
0.4	0.51	18	0.0256	0.00108	23.65
0.6	0.77	26	0.0369	0.00108	34.08
0.8	1.03	34	0.0483	0.00109	44.45
1	1.28	38	0.0540	0.00109	49.55
1.2	1.54	43	0.0611	0.00109	55.93
1.4	1.79	49	0.0696	0.00109	63.56
1.6	2.05	54	0.0767	0.00110	69.87
1.8	2.31	58	0.0824	0.00110	74.85
2	2.56	63	0.0895	0.00110	81.08
2.2	2.82	67	0.0951	0.00111	86.01
2.4	3.08	69	0.0980	0.00111	88.34
2.6	3.33	67	0.0951	0.00111	85.55
2.8	3.59	71	0.1008	0.00112	90.42
3	3.85	73	0.1037	0.00112	92.72
3.2	4.10	74	0.1051	0.00112	93.74
3.4	4.36	75	0.1065	0.00112	94.75
3.6	4.62	76	0.1079	0.00113	95.76
3.8	4.87	76	0.1079	0.00113	95.50
4	5.13	75	0.1065	0.00113	93.99
4.2	5.38	71	0.1008	0.00114	88.74

Ring Calibration Factor,
kN/div **0.00142**

Diameter of sample , mm **3.8** **Moisture content, %** **47.84**

Length of sample , mm **83** **Wet unit weight, kN/m³** **17.35**

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.24	9	0.0128	0.00114	11.24
0.4	0.49	16	0.0227	0.00114	19.94
0.6	0.73	22	0.0312	0.00114	27.35
0.8	0.98	27	0.0383	0.00115	33.48
1	1.22	34	0.0483	0.00115	42.06
1.2	1.46	38	0.0540	0.00115	46.89
1.4	1.71	44	0.0625	0.00115	54.16
1.6	1.95	47	0.0667	0.00116	57.71
1.8	2.20	52	0.0738	0.00116	63.69
2	2.44	56	0.0795	0.00116	68.41
2.2	2.68	58	0.0824	0.00117	70.68
2.4	2.93	62	0.0880	0.00117	75.36
2.6	3.17	65	0.0923	0.00117	78.81
2.8	3.41	67	0.0951	0.00117	81.03
3	3.66	69	0.0980	0.00118	83.24
3.2	3.90	71	0.1008	0.00118	85.44
3.4	4.15	72	0.1022	0.00118	86.42
3.6	4.39	73	0.1037	0.00119	87.40
3.8	4.63	74	0.1051	0.00119	88.37
4	4.88	75	0.1065	0.00119	89.33
4.2	5.12	73	0.1037	0.00120	86.73
4.4	5.37	68	0.0966	0.00120	80.58
4.6	5.61	62	0.0880	0.00120	73.28
4.8	5.85	55	0.0781	0.00120	64.84

Test pit no. TP4

Depth: 1.5m

Ring Calibration

Factor, kN/div 0.00142

Diameter of sample ,
mm

38

Moisture content, % 47.73

Length of sample , mm 78

Wet unit weight,
kN/m³ 17.56

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.26	10	0.0142	0.00108	13.18
0.4	0.51	14	0.0199	0.00108	18.40
0.6	0.77	17	0.0241	0.00108	22.28
0.8	1.03	20	0.0284	0.00109	26.15
1	1.28	26	0.0369	0.00109	33.90
1.2	1.54	31	0.0440	0.00109	40.32
1.4	1.79	35	0.0497	0.00109	45.40
1.6	2.05	39	0.0554	0.00110	50.46
1.8	2.31	44	0.0625	0.00110	56.78
2	2.56	47	0.0667	0.00110	60.49
2.2	2.82	49	0.0696	0.00111	62.90
2.4	3.08	51	0.0724	0.00111	65.29
2.6	3.33	53	0.0753	0.00111	67.68
2.8	3.59	54.5	0.0774	0.00112	69.41
3	3.85	56	0.0795	0.00112	71.13
3.2	4.10	57	0.0809	0.00112	72.20
3.4	4.36	58	0.0824	0.00112	73.27
3.6	4.62	59	0.0838	0.00113	74.34
3.8	4.87	60	0.0852	0.00113	75.39
4	5.13	60.5	0.0859	0.00113	75.82
4.2	5.38	59	0.0838	0.00114	73.74
4.4	5.64	59.5	0.0845	0.00114	74.16
4.6	5.90	60	0.0852	0.00114	74.58
4.8	6.15	60	0.0852	0.00115	74.38
5	6.41	59	0.0838	0.00115	72.94
5.2	6.67	57	0.0809	0.00115	70.27

Ring Calibration Factor, kN/div **0.00142**
Diameter of sample , mm **38** **Moisture content, %** **47.95**
Length of sample , mm **82** **Wet unit weight, kN/m³** **16.81**

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.24	9	0.0128	0.00114	11.24
0.4	0.49	20	0.0284	0.00114	24.92
0.6	0.73	24	0.0341	0.00114	29.83
0.8	0.98	27	0.0383	0.00115	33.48
1	1.22	31.5	0.0447	0.00115	38.96
1.2	1.46	35	0.0497	0.00115	43.19
1.4	1.71	37	0.0525	0.00115	45.54
1.6	1.95	40	0.0568	0.00116	49.11
1.8	2.20	42	0.0596	0.00116	51.44
2	2.44	43.5	0.0618	0.00116	53.14
2.2	2.68	47	0.0667	0.00117	57.27
2.4	2.93	48.5	0.0689	0.00117	58.95
2.6	3.17	50	0.0710	0.00117	60.63
2.8	3.41	51	0.0724	0.00117	61.68
3	3.66	52	0.0738	0.00118	62.73
3.2	3.90	53	0.0753	0.00118	63.78
3.4	4.15	54	0.0767	0.00118	64.82
3.6	4.39	55	0.0781	0.00119	65.85
3.8	4.63	56	0.0795	0.00119	66.87
4	4.88	57	0.0809	0.00119	67.89
4.2	5.12	57	0.0809	0.00120	67.72
4.4	5.37	56.6	0.0804	0.00120	67.07
4.6	5.61	54	0.0767	0.00120	63.83
4.8	5.85	51	0.0724	0.00120	60.12

Test pit no. TP4

Depth: 3.0m

Ring Calibration Factor,
kN/div 0.00142

Diameter of sample ,
mm 38

Moisture content, % 43.09

Length of sample , mm 87

Wet unit weight, kN/m³ 16.34

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.24	11	0.0156	0.00108	14.50
0.4	0.47	18	0.0256	0.00108	23.66
0.6	0.71	27	0.0383	0.00108	35.41
0.8	0.94	33	0.0469	0.00109	43.18
1	1.18	38	0.0540	0.00109	49.60
1.2	1.41	44	0.0625	0.00109	57.30
1.4	1.65	49	0.0696	0.00109	63.66
1.6	1.88	54	0.0767	0.00110	69.99
1.8	2.12	57	0.0809	0.00110	73.70
2	2.35	60	0.0852	0.00110	77.39
2.2	2.59	62	0.0880	0.00110	79.78
2.4	2.82	64	0.0909	0.00111	82.15
2.6	3.06	65	0.0923	0.00111	83.23
2.8	3.29	65	0.0923	0.00111	83.03
3	3.53	65.5	0.0930	0.00111	83.47
3.2	3.76	63	0.0895	0.00112	80.09
3.4	4.00	55	0.0781	0.00112	69.75
3.6	4.24	44	0.0625	0.00112	55.66

**Ring Calibration Factor,
kN/div**

0.00142

Diameter of sample , mm 38 Moisture content, % 43.09
Length of sample , mm 84 Wet unit weight, kN/m³ 16.77

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.24	10	0.0142	0.00114	12.49
0.4	0.47	16	0.0227	0.00114	19.94
0.6	0.71	24	0.0341	0.00114	29.84
0.8	0.94	31	0.0440	0.00114	38.45
1	1.18	37	0.0525	0.00115	45.79
1.2	1.41	43	0.0611	0.00115	53.08
1.4	1.65	47	0.0667	0.00115	57.88
1.6	1.88	52	0.0738	0.00116	63.89
1.8	2.12	55	0.0781	0.00116	67.41
2	2.35	58	0.0824	0.00116	70.92
2.2	2.59	60	0.0852	0.00116	73.19
2.4	2.82	62	0.0880	0.00117	75.44
2.6	3.06	63	0.0895	0.00117	76.48
2.8	3.29	64	0.0909	0.00117	77.50
3	3.53	65	0.0923	0.00118	78.52
3.2	3.76	66	0.0937	0.00118	79.53
3.4	4.00	67	0.0951	0.00118	80.54
3.6	4.24	67	0.0951	0.00118	80.34
3.8	4.47	66.5	0.0944	0.00119	79.55
4	4.71	65	0.0923	0.00119	77.56
4.2	4.94	61	0.0866	0.00119	72.61

Test pit no. TP5

Depth: 1.5m

Ring Calibration Factor,
kN/div 0.00142

Diameter of sample ,
mm 37

Moisture content, % 50.93

Length of sample , mm 78

Wet unit weight, kN/m³ 17.55

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00108	0
0.2	0.26	10	0.0142	0.00108	13.18
0.4	0.51	16	0.0227	0.00108	21.03
0.6	0.77	22	0.0312	0.00108	28.84
0.8	1.03	29	0.0412	0.00109	37.91
1	1.28	35	0.0497	0.00109	45.64
1.2	1.54	41	0.0582	0.00109	53.32
1.4	1.79	45	0.0639	0.00109	58.37
1.6	2.05	49	0.0696	0.00110	63.40
1.8	2.31	53	0.0753	0.00110	68.39
2	2.56	56	0.0795	0.00110	72.08
2.2	2.82	58	0.0824	0.00111	74.45
2.4	3.08	59	0.0838	0.00111	75.54
2.6	3.33	60	0.0852	0.00111	76.61
2.8	3.59	60.5	0.0859	0.00112	77.05
3	3.85	60.5	0.0859	0.00112	76.84
3.2	4.10	57	0.0809	0.00112	72.20
3.4	4.36	49	0.0696	0.00112	61.90
3.6	4.62	40	0.0568	0.00113	50.40

Ring Calibration Factor, kN/div **0.00142**
Diameter of sample , mm **38** **Moisture content, %** **50.93**
Length of sample , mm **81** **Wet unit weight, kN/m³** **16.58**

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.25	8	0.0114	0.00114	9.99
0.4	0.50	11	0.0156	0.00114	13.71
0.6	0.75	16	0.0227	0.00114	19.89
0.8	1.00	19.5	0.0277	0.00115	24.17
1	1.25	23	0.0327	0.00115	28.44
1.2	1.50	27	0.0383	0.00115	33.30
1.4	1.75	30	0.0426	0.00115	36.91
1.6	2.00	34	0.0483	0.00116	41.72
1.8	2.25	36	0.0511	0.00116	44.07
2	2.50	38	0.0540	0.00116	46.39
2.2	2.75	40	0.0568	0.00117	48.71
2.4	3.00	41	0.0582	0.00117	49.80
2.6	3.25	43	0.0611	0.00117	52.09
2.8	3.50	45	0.0639	0.00118	54.38
3	3.75	47	0.0667	0.00118	56.65
3.2	4.00	49	0.0696	0.00118	58.90
3.4	4.25	51	0.0724	0.00118	61.15
3.6	4.50	52	0.0738	0.00119	62.18
3.8	4.75	53	0.0753	0.00119	63.21
4	5.00	55	0.0781	0.00119	65.43
4.2	5.25	56	0.0795	0.00120	66.44
4.4	5.50	57	0.0809	0.00120	67.45
4.6	5.75	58	0.0824	0.00120	68.45

4.8	6.00	60	0.0852	0.00121	70.62
5	6.25	61.5	0.0873	0.00121	72.20
5.2	6.50	63	0.0895	0.00121	73.76
5.4	6.75	64	0.0909	0.00122	74.73
5.6	7.00	63.5	0.0902	0.00122	73.95
5.8	7.25	59	0.0838	0.00122	68.52
6	7.50	52	0.0738	0.00123	60.23

Test pit no. TP5

Depth: 3.0m

Ring Calibration Factor, kN/div 0.00142

Diameter of sample , mm

38

Moisture content, % 40.81

Length of sample , mm

80

Wet unit weight, kN/m³ 16.88

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.25	15	0.0213	0.00114	18.74
0.4	0.50	26	0.0369	0.00114	32.39
0.6	0.75	33	0.0469	0.00114	41.01
0.8	1.00	41	0.0582	0.00115	50.83
1	1.25	48	0.0682	0.00115	59.35
1.2	1.50	55	0.0781	0.00115	67.84
1.4	1.75	61	0.0866	0.00115	75.05
1.6	2.00	67	0.0951	0.00116	82.22
1.8	2.25	70	0.0994	0.00116	85.68
2	2.50	68	0.0966	0.00116	83.02
2.2	2.75	61	0.0866	0.00117	74.28
2.4	3.00	51	0.0724	0.00117	61.95

Ring Calibration Factor,
kN/div 0.00142

Diameter of sample , mm 3.8 **Moisture content, % 40.81**

Length of sample , mm 84 **Wet unit weight, kN/m³ 17.76**

Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m ²]	Axial Stress [kPa]
0	0.00	0	0.0000	0.00113	0
0.2	0.25	11	0.0156	0.00114	13.74
0.4	0.50	22	0.0312	0.00114	27.41
0.6	0.75	31	0.0440	0.00114	38.53
0.8	1.00	39	0.0554	0.00115	48.35
1	1.25	45	0.0639	0.00115	55.64
1.2	1.50	51	0.0724	0.00115	62.90
1.4	1.75	54	0.0767	0.00115	66.44
1.6	2.00	59	0.0838	0.00116	72.40
1.8	2.25	62	0.0880	0.00116	75.89
2	2.50	65	0.0923	0.00116	79.36
2.2	2.75	68	0.0966	0.00117	82.81
2.4	3.00	69	0.0980	0.00117	83.81
2.6	3.25	69	0.0980	0.00117	83.59
2.8	3.50	65	0.0923	0.00118	78.54
3	3.75	61	0.0866	0.00118	73.52
3.2	4.00	57	0.0809	0.00118	68.52

Appendix-G

One Dimensional Consolidation test results

Dial gauge readings

Test pit no. TP5

Sample Type: Undisturbed

Test Type: One dimensional consolidation

Depth: 3.0m

		Dial Gauge Reading, mm						
		7	50	100	200	400	800	1600
Time(min.)	□time	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	2.60	2.230	2.499	2.816	3.340	3.986	4.770
0.1	0.32		2.360	2.630	2.840	3.602	4.184	4.862
0.25	0.50	-	2.374	2.642	2.868	3.626	4.202	4.874
0.50	0.71	-	2.388	2.654	2.886	3.644	4.218	4.888
1	1.00	-	2.402	2.668	2.908	3.664	4.238	4.902
2	1.41	-	2.416	2.686	2.924	3.686	4.262	4.922
4	2.00	-	2.434	2.702	2.962	3.712	4.292	4.950
8	2.83	-	2.444	2.724	2.990	3.750	4.328	4.984
15	3.87	-	2.452	2.738	3.216	3.784	4.374	5.038
30	5.48	-	2.462	2.755	3.244	3.824	4.439	5.112
60	7.75	-	2.472	2.768	3.270	3.871	4.514	5.206
120	10.95	-	2.486	2.800	3.294	3.915	4.600	5.322
240	15.49	-	2.490	2.802	3.314	3.950	4.682	5.466
480	21.91	-	2.496	2.808	3.324	3.972	4.732	5.524
1440	37.95	2.230	2.499	2.816	3.340	3.986	4.770	5.540

Cumulative Dial Gauge Reading At The End Of Each Consecutive Unloading

Dial Gauge Reading, mm						
1600	800	400	200	100	50	7
[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
5.403	5.118	4.840	4.588	4.376		

Test pit no. TP5

Sample Type: Undisturbed

Test Type: One dimensional consolidation

Depth: 2.4m

Cumulative dial gauge reading at the end of each consecutive loading

		Dial Gauge Reading, mm						
		7	50	100	200	400	800	1600
Time(min.)	□time	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	0.00	0.428	0.622	1.004	1.420	2.084	2.904
0.1	0.32		0.504	0.882	1.118	1.517	2.216	2.986
0.25	0.50	-	0.512	0.886	1.126	1.590	2.240	3.000
0.50	0.71	-	0.520	0.890	1.136	1.602	2.256	3.012
1	1.00	-	0.526	0.896	1.148	1.628	2.276	3.028
2	1.41	-	0.534	0.906	1.170	1.654	2.306	3.050
4	2.00	-	0.552	0.912	1.186	1.692	2.344	3.082
8	2.83	-	0.568	0.924	1.214	1.764	2.394	3.129
15	3.87	-	0.582	0.938	1.246	1.790	2.452	3.186
30	5.48	-	0.596	0.954	1.284	1.858	2.540	3.280
60	7.75	-	0.608	0.968	1.319	1.920	2.642	3.408
120	10.95	-	0.611	0.984	1.350	1.982	2.746	3.524
240	15.49	-	0.614	0.990	1.380	2.038	2.830	3.654
480	21.91	-	0.622	1.000	1.392	2.054	2.872	3.742
1440	37.95	0.428	0.622	1.004	1.420	2.084	2.904	3.792

Cumulative dial gauge reading at the end of each consecutive unloading

Dial Gauge Reading, mm						
1600	800	400	200	100	50	7
[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
3.710	3.390	3.116	2.916			

Test pit no. TP1

Sample Type: Undisturbed

Test Type: One dimensional consolidation

Depth: 2.7m

Time(min.)	□time	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	4.00	3.270	3.482	3.790	4.187	4.789	5.565
0.1	0.32		3.352	3.548	3.840	4.290	4.812	5.590
0.25	0.50	-	3.396	3.564	3.866	4.328	4.892	5.612
0.50	0.71	-	3.414	3.582	3.886	4.356	4.982	5.674
1	1.00	-	3.426	3.618	3.912	4.384	5.072	5.736
2	1.41	-	3.438	3.626	3.936	4.422	5.142	5.814
4	2.00	-	3.450	3.632	3.948	4.472	5.222	5.884
8	2.83	-	3.458	3.642	3.960	4.506	5.308	5.938
15	3.87	-	3.466	3.650	3.984	4.544	5.394	6.006
30	5.48	-	3.470	3.666	4.022	4.572	5.438	6.114
60	7.75	-	3.474	3.692	4.060	4.598	5.484	6.172
120	10.95	-	3.476	3.724	4.084	4.626	5.516	6.224
240	15.49	-	3.478	3.642	4.122	4.672	5.536	6.298
480	21.91	-	3.478	3.668	4.154	4.722	5.552	6.356
1440	37.95	3.270	3.482	3.790	4.187	4.789	5.565	6.409

Cumulative Dial Gauge Reading At The End Of Each Consecutive Unloading

Dial Gauge Reading, mm						
1600 [kPa]	800 [kPa]	400 [kPa]	200 [kPa]	100 [kPa]	50 [kPa]	7 [kPa]
6.257	6.013	5.767				